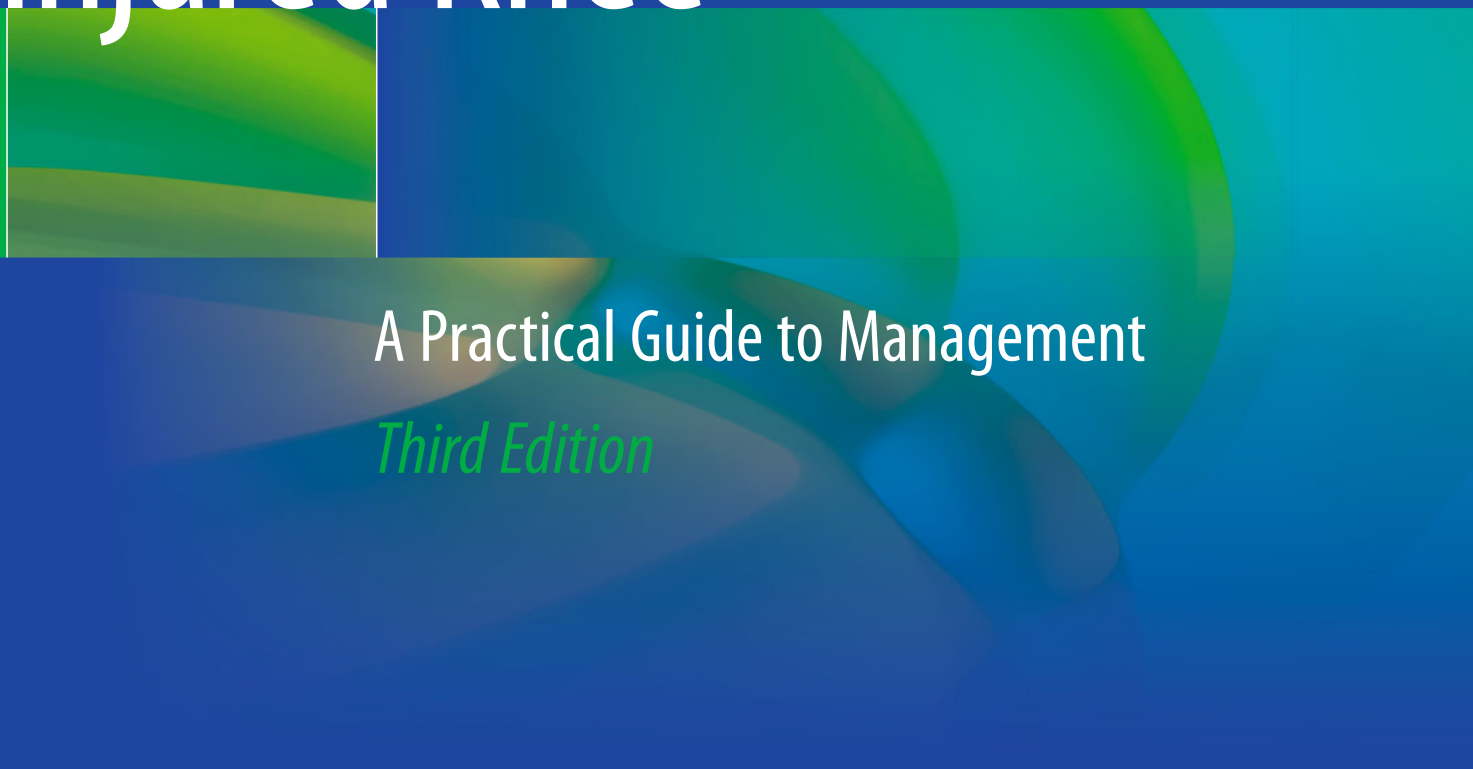
Gregory C. Fanelli
Editor

The Multiple Ligament Injured Knee

A Practical Guide to Management

Third Edition



Springer

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To my wife Lori, and my children Matthew, David, and Megan who all have a tireless work ethic, and are a never ending source of inspiration to me, and to Jesus Christ, Our Lord and Savior.

Preface

Our practice environment largely determines the pathways that our individual orthopedic careers take. It has been a blessing to be in a position that enabled me to expand my surgical techniques and research interest in the evaluation and treatment of the multiple ligament injured knee. I believe the same situation exists for other contributors to this book. We all share a passion and a commitment to the treatment of these complex instabilities of the knee. The purpose of this book is to provide experienced knee surgeons, general orthopedic surgeons, fellows, residents, medical students, and other healthcare professionals with an interest in the multiple ligament injured knee, a useful tool for the management of the complex injuries.

The Multiple Ligament Injured Knee: A Practical Guide To Management, Third Edition, is expanded from 35 chapters in the *Second Edition* to 42 chapters in the *Third Edition*. The *Third Edition* is compiled of 11 functional segments with each segment having a number of chapters. New chapters in the *Third Edition* include direct nerve transfer for peroneal nerve injury, management of extensor mechanism disruption and patellar instability, multiple ligament knee injuries in professional athletes, internal bracing in multiple ligament knee reconstruction, multiple ligament knee injuries in the United States active duty military population, knee dislocations in the morbidly obese, multiple ligament knee injuries in patients 18 years of age and younger, and anterolateral ligament reconstruction in the multiple ligament injured knee. The chapters were organized and written so that they build upon each other, and also so that they are able to stand alone. This will enable the reader to leisurely explore the topic of the multiple ligament injured knee, or to use the text as a quick, practical reference when the need arises.

Chapter 1 presents the editor's 28 years experience in evaluation and treatment of the multiple ligament injured knee. Chapters 2 and 3 address anatomy and biomechanics of the knee, while Chaps. 4 through 8 address diagnosis, initial assessment, classification, and nonsurgical management of the acutely dislocated knee. Chapters 9 through 20 provide multiple authors' techniques and opinions in the surgical treatment of the ACL-based and PCL-based multiple ligament injured knee. Chapters 21 through 40 present methods to evaluate and manage associated complex conditions that occur in treating the multiple ligament injured knee. These include mechanical graft tensioning, vascular injuries, nerve injuries, tendon transfers, fixed posterior tibial subluxation, revision surgery, the role of osteotomy, fracture dislocations, articular cartilage restoration, meniscus transplantation, extensor mechanism disruption, multiple ligament knee injuries in professional athletes and active duty military patients, internal bracing in multiple ligament reconstruction, knee dislocations in the morbidly obese, multiple ligament injuries in patients 18 years of age and younger, the anterolateral ligament, postoperative rehabilitation, special aspects of functional bracing, and complications. Chapter 41 presents the results of treatment of the multiple ligament injured knee from an outcomes data perspective. The final chapter, Chap. 42, presents 16 case studies in the management of the multiple ligament injured knee. Each case study presents a different knee instability problem, and then takes the reader through the decision-making process, the surgical treatment, and the final outcome.

The multiple ligament injured knee is an extremely complex pathologic entity. I believe that through research, improved surgical techniques, the use of allograft tissue, advancement in surgical equipment, careful documentation, and experience, we are progressively improving our outcomes in treating this devastating knee injury. It is my personal hope that this book will serve as a catalyst for new ideas to further develop treatment plans and surgical techniques for posterior cruciate ligament and related injuries, and that God and His Son Jesus Christ will continue to guide us in the care and treatment of these patients.

Danville, PA, USA Gregory C. Fanelli, M.D.

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Danville, PA, USA Gregory C. Fanelli, M.D.

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Part I

Editor’s Experience

1

PCL Based Multiple Ligament Knee Injuries: What I Have Learned in 28 Years

Gregory C. Fanelli

1.1 Introduction

Welcome to the third edition of *Practical Management of the Multiple Ligament Injured knee*. This chapter is a compilation of my experience treating the multiple ligament knee injuries over the past twenty eight years. I have written this chapter in the first person which is a departure from most text books. I want this chapter to be a conversation between the reader and myself about one of the most complex and interesting topics in orthopaedic surgery; the multiple ligament injured knee. This chapter could also be titled "Avoiding Complications and Staying Out of Trouble Treating the Multiple Ligament Injured Knee" since the goal of this chapter is to maximize success, avoid complications, and help the surgeon stay out of trouble treating these complex and difficult cases. Topics addressed include injury incidence, anatomy, vascular assessment, external fixation, surgical timing, repair and/or reconstruction, graft preparation, arthroscopic or open surgical procedures, surgical technique highlights, mechanical graft tensioning, postoperative rehabilitation, multiple ligament knee injuries in patients under 18 years of age, total knee replacement following multiple knee ligament reconstruction, and results of treatment. Specific surgical procedures are discussed in various chapters throughout this text book. This chapter is organized to present brief sections of information that will help the orthopaedic surgeon and other health care professionals to make treatment decisions in multiple ligament knee injury cases.

I live in rural central Pennsylvania in the United States. This is both a farming and industrial area located among multiple interstate high way systems, and I work in a level one trauma hospital. This combination of location, patient population, and hospital facility creates an environment where multiple ligament knee injuries occur with some frequency. Posterior cruciate ligament injuries in trauma patients with acute knee injuries range between 38 and 44% in our hospital [1, 2]. These injuries are related to higher energy trauma in approximately 56%, and to sports related injuries in approximately 32%. Isolated posterior cruciate ligament tears occur 3.5% of the time in this population, while posterior cruciate ligament tears combined with other ligaments (the PCL based multiple ligament injured knee) occur in 96.5% of posterior cruciate ligament injuries in our series. The combined posterior and anterior cruciate ligament tears, 45.9%, and combined posterior cruciate ligament posterolateral instability, 41.2%, are the most common posterior cruciate based combined injuries that seen in our series [2]. The purpose of reviewing this data is to emphasize the point that posterior cruciate ligament tears that occur in a higher energy trauma population will most likely be PCL based multiple ligament knee injuries. It is also important to realize that posterior cruciate ligament injuries in high energy sports are also at risk of being a combined ligament injury [1, 2].

1.2 Respect the Anatomy

As orthopaedic knee surgeons we focus on the knee ligaments, menisci, articular cartilage, and extensor mechanism. In multiple ligament knee injuries, it is critically important to be aware of arterial and venous injuries, skin trauma, and peroneal and tibial nerve injuries. Bony injuries to the tibia, femur, patella, pelvis, and spine may also occur in patient with multiple knee ligament injuries. Head injuries also occur in this patient population placing these patients at risk for heterotopic ossification and lower extremity spasticity complicating the treatment and postoperative course in these patients with multiple knee ligament injuries. Multiple system injuries can affect the outcomes of treatment in multiple ligament knee injuries, and must be considered in the treatment plans in these complex knee injuries.

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Articular surface fractures in the multiple ligament injured (dislocated) knee must be anatomically reduced and internal fixation achieved before the knee ligament instability pattern can be determined since the intact femur or tibia will fall into the fracture, and potentially hinder an accurate knee ligament injury diagnosis. Tibial plateau depression fractures that meet non surgical criteria with intact knee ligaments should be anatomically reduced and secured since the tendency will be for the femoral condyle to fall into the fracture site, perpetuate the instability, and compromise knee ligament repair or reconstruction.

Femur or tibia fractures requiring reduction and fixation may require that multiple ligament reconstruction be performed after fracture healing has occurred. When varus or valgus alignment with resultant varus or valgus thrust during the stance phase of gait is present after fracture healing, consideration should be given to fracture fixation hardware removal (stage 1) followed by corrective osteotomy (stage 2) to restore normal alignment and gait pattern, followed by knee ligament reconstruction (stage 3) when the osteotomy has healed and osteotomy hardware has been removed if necessary. A normal gait pattern with the absence of a varus or valgus thrust will improve the chance for successful knee ligament reconstruction.

1.3 Vascular Assessment

The incidence of vascular injuries in multiple knee ligament injuries may occur in 32–50% of cases with bicruciate tears having the same incidence as frank tibio-femoral dislocations [3–5]. Hyperextension mechanisms of injury may result in anterior tibial displacement with subsequent popliteal artery stretch and rupture, while a direct impact to the proximal tibia in the ninety degree flexed knee leads to posterior tibial displacement with potential arterial contusion and intimal damage [6]. Post traumatic deep venous thrombosis also occurs in these severe knee injuries, so a high index of suspicion must be maintained for this clinical entity.

Evaluation of the acute multiple ligament injured knee includes careful physical examination of the injured and uninjured lower extremities, and an ankle brachial index measurement. If there are abnormal or asymmetric pulses or an ankle brachial index of less than 0.9, more advanced vascular evaluation and vascular surgical consultation is indicated [7]. The absence of pulses distal to the knee requires prompt vascular surgical intervention. It is very important to evaluate the popliteal artery for intimal flap tears which could potentially cause delayed vascular occlusion. Clinical examination suggesting deep venous thrombosis indicates the need for further vascular evaluation.

Up to 12% of popliteal arteries may have abnormal branching patterns, and this may be important for planning surgical reconstruction in the multiple ligament injured knee [8–11]. In addition, a certain number of multiple knee ligament injury patients will have had arterial repair or reconstruction. It is important to know about potential abnormal branching patterns of the popliteal artery, and the location of arterial reconstructions, to avoid injury to these structures during multiple knee ligament reconstruction surgical procedures.

1.4 Peroneal Nerve Injury

Peroneal nerve injuries can occur with multiple knee ligament injuries and knee dislocations, and may influence the outcomes of multiple ligament knee reconstruction surgery. Treatment options for the nerve injury include nerve repair, nerve grafting, and direct nerve transfer. Our preferred treatment includes peroneal nerve decompression at the time of the initial knee ligament surgery. When the nerve is in continuity, serial electromyograms are obtained. When no nerve recovery is demonstrated, posterior tibial tendon transfer is performed [12]. It is important to maintain a plantigrade foot with flexible ankle motion, and to avoid an equinis deformity. If equinis develops, this will cause hyperextension at the knee during the stance phase of gait and compromise knee ligament reconstruction.

1.5 Correct Diagnosis

Identifying the multiple planes of instability in these complex knee ligament injuries is essential for successful treatment of the multiple ligament injured knee. The posterior and anterior cruciate ligament disruptions will lead to increased posterior and anterior laxity at ninety and thirty degrees of knee flexion. The difficulty arises in recognizing the medial and lateral side instability patterns in the multiple ligament injured knee. Recognition and correction of the medial and lateral side instability is the key to successful posterior and anterior cruciate ligament surgery.

There are three different types of instability patterns that I have observed in medial and lateral side knee injuries [13–15]. These are, Type A (axial rotation instability only), Type B (axial rotation instability combined with varus and/or valgus laxity with a soft endpoint), and Type C (axial rotation instability combined with varus and/or valgus laxity with little or no endpoint). In my experience, the axial rotation instability (Type A) medial or lateral side is most frequently overlooked. It is also critical to understand that combined medial and lateral side instability of different types occur with bicruciate and unicruciate multiple ligament knee injuries. Examples include PCL, ACL, lateral side type C, and medial side type A, or PCL, medial side type B, and lateral side type A instability patterns.

A combination of careful clinical examination, radiographs, and MRI studies aide in determining the correct diagnosis of multiple ligament knee injuries. Knee examination under anesthesia combined with fluoroscopy, stress radiography, and diagnostic arthroscopy also contribute to accurately diagnosing the multiple planes of instability [16, 17]. Recognition and correction of the medial and lateral side instability is the key to successful posterior and anterior cruciate ligament surgery.

1.6 Arthroscopic Evaluation of the Posterior Cruciate Ligament

Arthroscopic evaluation of the posterior cruciate ligament has been reported by Lysholm and Guillquist and by Fanelli et al. [16, 18, 19]. Arthroscopic evaluation of the PCL is a very helpful adjunct to physical examination and imaging studies especially with respect to surgical planning. We have developed and published the three zone concept of arthroscopic posterior cruciate ligament evaluation, and use this method in our treatment of posterior cruciate ligament injuries [16, 19]. In this concept, the PCL is divided into three distinct zones. Zone 1 extends from the femoral insertion of the posterior cruciate ligament to where the PCL disappears behind the anterior cruciate ligament (ACL). Zone 2 of the PCL is where the posterior cruciate ligament lies behind the ACL which is the middle section of the posterior cruciate ligament. Zone 3 is the posterior cruciate ligament tibial insertion site.

Arthroscopic posterior cruciate ligament evaluation is performed with the surgical leg draped free using a lateral post for extremity control. A 25° or 30° arthroscope is used through the anterior inferior lateral patellar portal to visualize zone 1 of the posterior cruciate ligament. The posterior medial portal is used to visualize zone 2 and zone 3 also using the 25° or 30° arthroscope. This two portal viewing combination enables complete visualization of the posterior cruciate ligament.

Arthroscopic findings in the PCL injured knee are either direct or indirect [16, 19]. Direct findings include damage to the posterior cruciate ligament itself such as mid-substance tears, interstitial tears with ligament stretching, hemorrhage within the synovial sheath, and avulsion of bony insertions. Indirect arthroscopic findings occur as a result of the posterior cruciate ligament injury and include the sloppy ACL sign, altered contact points, and degenerative changes of the patellofemoral joint and medial compartment.

The sloppy ACL sign demonstrates relative laxity of the anterior cruciate ligament secondary to posterior tibial drop back with the knee at 90° of knee flexion because of the PCL insufficiency. When the tibia is reduced, the normal anterior cruciate ligament tension is restored. Altered contact points occur secondary to tibial drop back with the knee flexed 90°. Clinically, this is the posterior sag sign [20]. Placing the arthroscope in the anterolateral inferior patellar portal shows closer proximity of the anterior horn of the medial and lateral menisci to the distal femoral condyle articular surfaces. This altered tibiofemoral relationship allows abnormal stress distribution in the tibiofemoral and patellofemoral compartments, and may promote degenerative joint disease [21, 22].

Arthroscopic visualization of the posterolateral and posteromedial corners of the knee is helpful in diagnosis and surgical planning in these complex knee ligament injuries. Posterolateral and posteromedial instability will often result in widening of the affected compartment with the respective varus or valgus stress. The widening indicates damage to the posteromedial or posterolateral structures, and the position of the menisci relative to the femur and tibia indicates the location of the capsular injury. In my experience, when the meniscus stays with the tibia, the capsular damage is on the femoral side, and when the meniscus stays with the femur, the capsular damage is on the tibial side. When the meniscus is floating in the middle of the affected compartment gap, there is structural damage on both the femoral and tibial sides. Axial rotation instability can occur without medial or lateral compartment widening which is seen with posterolateral and posteromedial instability Type A [13, 15]. Arthroscopic visualization is helpful to make the diagnosis by seeing the tibia rotate under the medial or lateral meniscus with the knee at 90° of knee flexion and internal and external axial rotation applied to the tibia.

Arthroscopic evaluation of the posterior cruciate ligament and related structures in the PCL injured knee is a useful adjunct to the history, physical examination, arthrometer testing, and imaging studies. Arthroscopic posterior cruciate ligament evaluation aids in surgical decision making and planning of reparative or reconstructive surgical procedures. A standard 25° or 30° arthroscope placed in the inferior lateral patellar and posteromedial arthroscopic portals provides excellent visualization of all three zones of the posterior cruciate ligament, and the posterolateral and posteromedial corners of the knee.

1.7 External Fixation

External fixation is a useful tool in the management of the multiple ligament injured knee. Preoperative indications for the use of spanning external fixation include open dislocations, vascular repair, and inability to maintain reduction [23]. The advantages of using spanning external fixation include skin assessment, compartment pressure observation, and monitoring the neurovascular status of the affected limb. Preoperative use of external fixation compared to brace immobilization may lead to less terminal flexion postoperatively; however, this may be more dependent on injury severity of the involved extremity than the use of the spanning external fixation device [24]. According to some clinicians, postoperative protection of multiple knee ligament reconstructions in a hinged external fixation device has led to more favorable static stability than postoperative brace immobilization [25]. My opinion regarding the use of spanning external fixation in treatment of the multiple ligament injured knee preoperatively and postoperatively is that if I can control the knee in a brace, I use a brace. If I cannot control the knee in a brace, I use an external fixation device. Occasionally, I have used a spanning external fixator for treatment of the multiple ligament injured knee in patients who are not surgical candidates.

1.8 Surgical Treatment

Over the past three decades, technical advancements in the use of allograft tissue, arthroscopic surgical instruments, graft fixation methods, improved surgical techniques and postoperative rehabilitation programs, and an improved understanding of knee ligament structure and biomechanics have, in my experience, led to more predictable and successful results with multiple knee ligament reconstructions documented with physical examination, arthrometer measurements, knee ligament rating scales, stress radiography, and return to function [26–39].

1.9 Surgical Timing

Surgical timing in the acute multiple ligament injured knee is dependent on the vascular status of the extremity, collateral ligament injury severity, and the degree of reduction stability. My experience and that of others demonstrates that a delayed or staged reconstruction of two to three weeks has resulted in less motion loss and arthrofibrosis [26–34, 40–46]. My preferred surgical approach is a single stage arthroscopic posterior and anterior cruciate ligament reconstruction using allograft tissue, and medial and/or lateral side primary repair combined with allograft augmentation reconstruction within two to four weeks of the initial injury. Some medial side injuries may be successfully treated with bracing [27, 28].

There are surgical timing modifiers or considerations that may occur in the evaluation and treatment of the acute multiple ligament injured knee. These modifiers may adversely affect the timing of surgery creating a situation where the surgical procedure may need to be performed earlier or later than desired by the surgeon. These modifiers include vascular status of the extremity, open injuries, reduction stability of the knee, severe medial or lateral side injuries, skin conditions, multiple system injuries, other orthopaedic injuries, and meniscus and articular surface injuries. It is important to recognize and understand that in complex multiple knee ligament injuries, ideal surgical timing is not always possible. When ideal surgical timing is not possible, staged surgical reconstruction may be required, and to use external fixation when acute stabilization is required until the definitive treatment can be performed. When staged reconstruction is employed, the knee must be protected between stages so the initial stage reconstruction is not compromised with over aggressive physical activity.

1.10 The Chronic Multiple Ligament Injured Knee

Chronic multiple knee ligament injuries typically present to my clinic with progressive functional instability. These patients may or may not have some degree of post traumatic arthrosis depending upon their time from injury. It is important to identify both the structural injuries, and the planes of instability in these chronic knee ligament injuries. The structural injuries may include meniscus damage, malalignment, articular surface defects, and gait abnormalities in addition to the chronic knee ligament instability. Surgical options under consideration include osteotomies to correct malalignment and gait abnormalities, ligament reconstruction, meniscus surgery (repair, resection, transplantation), and osteochondral grafting. My preference is to perform staged surgeries in these complex injury patterns beginning with correction of malalignment.

1.10.1 Repair or Reconstruction

Since beginning my treatment of multiple knee ligament injuries, my preference has been to reconstruct the cruciate ligaments, and to perform a combined repair and reconstruction of the medial and lateral side injuries. Allograft tissue is preferred for these surgeries, however, we have had successful results with both allograft and autograft tissue [26–34, 38–41, 47]. Large posterior cruciate ligament tibial bony avulsions are treated with reduction and fixation of the bony fragment. Small posterior cruciate ligament tibial bony avulsions are evaluated with the arthroscopic three zone posterior cruciate ligament surgical technique to determine the condition of the posterior cruciate ligament before proceeding with fixation of the small bony fragment [16]. Several studies have shown high rates of medial and lateral side surgical failures with primary repair alone [47–49]. We have had consistently successful results with combined primary repair and reconstruction with allograft or autograft tissue for medial and lateral side injuries [26–34, 39–41, 47]. The important point is that medial and lateral side combined primary repair and reconstruction is more successful than primary repair alone in our experience, and in the recent literature. Allograft and autograft tissue both provide successful results.

1.10.2 Multiple Knee Ligament Reconstruction Surgery

1.10.2.1 Graft Preparation

Intraoperative graft preparation is a very important part of the surgical procedure, and can enhance or destroy the flow of the operation. I have always prepared my allograft and autograft tissue personally with the help of an assistant. When allograft tissue is used, this tissue is prepared in the sterile operating room prior to bringing the patient into the operating room to minimize general anesthesia time for the patient. Cases where autograft tissue is used, the autografts are harvested, and then I personally prepare them with an assistant. During the graft preparation, the surgeon “gets a feel for the graft” which provides insight into optimal tunnel size, and how the graft will behave during graft passage. This attention to detail facilitates the flow of the surgical procedure by maximizing the probability of uneventful graft passage leading to successful tensioning and final graft fixation. It is not recommended to delegate graft preparation responsibility to the lowest ranking member of the surgical team.

1.10.2.2 Arthroscopic or Open Surgical Procedure

How do I decide to perform an open or arthroscopic combined posterior and anterior cruciate ligament reconstruction in these multiple ligament injured knees, and whether or not to do a single stage or two stage procedures? My preference is to perform a single stage arthroscopic posterior and anterior cruciate ligament reconstruction using allograft tissue combined with medial and or lateral side combined primary repair and reconstruction with allograft tissue within two to four weeks of the initial injury. Severe medial and or lateral side injuries with significant capsular damage that does not allow arthroscopic fluid to be maintained safely in the knee joint are treated as two stage surgical procedures. The medial and or lateral side surgery will be performed within the first week following the injury. The knee will be immobilized in full extension, and the arthroscopic combined posterior and anterior cruciate ligament reconstruction will be performed approximately four to five weeks after the initial medial or lateral side surgery. When staged reconstruction is employed, the knee must be protected between stages so the initial stage reconstruction is not compromised with over aggressive physical activity. As always, surgical timing modifiers such as skin condition, vascular status, reduction stability, fractures, and other systemic injuries may alter the course of treatment.

1.10.2.3 Surgical Technique

The patient is positioned on the fully extended operating room table [50–54]. A lateral post is used and the well leg is supported by the fully extended operating room table. The Biomet Sports Medicine PCL/ACL System (Biomet Sports Medicine, Warsaw, Indiana) are the surgical instruments used for this surgical procedure. Intraoperative radiography and C-arm image intensifier are not routinely used for this surgical procedure.

My preferred surgical technique is an arthroscopic posterior cruciate ligament reconstruction using an Achilles tendon allograft to reconstruct the anterolateral bundle of the PCL. When I perform a double bundle PCL reconstruction, an Achilles tendon allograft is used to reconstruct the anterolateral bundle of the posterior cruciate ligament, and a tibialis anterior allograft for the posteromedial bundle of the posterior cruciate ligament reconstruction. The anterior cruciate ligament is reconstructed using an Achilles tendon allograft. Lateral side surgery is a combined primary repair and fibular head based figure of eight reconstruction using a semitendinosus or other soft tissue allograft. The addition of a tibialis anterior allograft through a drill hole in the proximal tibia is added for knees with severe hyperextension external rotation recurvatum deformity and revision posterolateral reconstruction when needed. Lateral side surgeries also have a posterolateral capsular shift or capsular reattachment performed as indicated. Medial side injuries are treated with primary repair combined with allograft augmentation/reconstruction, and posteromedial capsular shift as indicated.

The allograft tissue used is from the same tissue bank with the same methods of tissue procurement and preservation that provides a consistent graft of high quality. It is very important for the surgeon to “know the tissue bank”, and to obtain high quality allograft tissue that will maximize the probability of surgical success. These multiple knee ligament reconstruction procedures are routinely performed in an outpatient setting unless specific circumstances indicate the necessity of an inpatient environment using general anesthesia combined with peripheral nerve blocks. The same experienced surgical teams are assembled for these complex surgical procedures. Experienced and familiar teams provide for a smoother operation, shorter surgical times, enhanced patient care, and a greater probability of success in these difficult surgical procedures. Preoperative and postoperative prophylactic antibiotics are routinely used in these complex and time consuming surgical procedures to decrease the probability of infection. The specific details of my surgical procedure, including intraoperative photographs and diagrams, are presented in Chaps. 20, 22 and 36 of this text book. The following sections in this chapter will address specific points that contribute to the success of this complex surgical procedure.

1.11 Posteromedial Safety Incision

Three factors that contribute to posterior cruciate ligament reconstruction surgical failures are failure to address associated ligamentous instabilities, varus osseous malalignment, and incorrect tunnel placement [51]. My posterior cruciate ligament reconstruction principles are to identify and treat all pathology, protect the neurovascular structures, accurately place tunnels to approximate the posterior cruciate ligament anatomic insertion sites, use strong graft material, minimize graft bending, restore the anatomic tibial step off, utilize a mechanical graft tensioning device, use secure fixation, and to use a slow and deliberate postoperative rehabilitation program [13–16, 24, 30–41, 45, 46, 50–66].

My posterior cruciate ligament reconstruction surgical technique since 1990 has been an arthroscopic transtibial tunnel posterior cruciate ligament reconstruction using a posteromedial safety incision to protect the neurovascular structures, confirm the accuracy of the tibial tunnel placement, and to facilitate the flow of the surgical procedure [16, 50, 52–56]. An extra capsular extraarticular posteromedial safety incision is made by creating an incision approximately 2–3 cm long at the posteromedial border of the tibia near the diaphyseal metaphyseal junction of the proximal medial aspect of tibia. Dissection is carried down to the crural fascia, which is incised longitudinally, and as always, the neurovascular structures are protected. An interval is developed between the medial head of the gastrocnemius muscle and the nerves and vessels posterior to the surgeons finger, and the capsule of the knee joint anterior to the surgeon's finger. The posteromedial safety incision enables the surgeon to protect the neurovascular structures, confirm the accuracy of the PCL tibial tunnel, and to facilitate the flow of the surgical procedure. The neurovascular structures of the popliteal fossa are in close proximity to the posterior capsule of the knee joint, and are at risk during transtibial posterior cruciate ligament reconstruction. The posteromedial safety incision is very important for the protection of these structures.

1.12 PCL Tibial Tunnel Creation

The arm of the PCL/ACL guide (Biomet Sports Medicine, Warsaw, Indiana) is inserted through the inferior medial patellar portal. The tip of the guide is positioned at the inferior lateral aspect of the PCL anatomic insertion site. This is below the tibial ridge posterior and in the lateral aspect of the PCL anatomic insertion site. The bullet portion of the guide contacts the anteromedial surface of the proximal tibia at a point midway between the posteromedial border of the tibia, and the tibial crest anterior at or just below the level of the tibial tubercle. This will provide a relatively vertically oriented posterior cruciate ligament tibial tunnel and an angle of graft orientation such that the graft will turn two very smooth 45° angles on the posterior aspect of the tibia. The tip of the guide, in the posterior aspect of the tibia is confirmed with the surgeon's finger through the extra capsular extra-articular posteromedial safety incision. Intraoperative AP and lateral X-ray may also be used; however, I do not routinely use intraoperative X-ray. When the PCL/ACL guide is positioned in the desired area, a blunt spade-tipped guide wire is drilled from anterior to posterior. The surgeon's finger confirms the position of the guide wire through the posterior medial safety incision. The critical posteromedial safety incision protects the neurovascular structures, confirms the accuracy of the posterior cruciate ligament tibial tunnel placement, and enhances the flow of the surgical procedure.

The appropriately sized standard cannulated reamer is used to create the tibial tunnel. The surgeon's finger through the extra capsular extra-articular posteromedial incision is monitoring the position of the guide wire. When the drill is engaged in bone, the guide wire is reversed, blunt end pointing posterior, for additional patient safety. The drill is advanced until it comes to the posterior cortex of the tibia. The chuck is disengaged from the drill, and completion of the tibial tunnel is performed by hand. The position and orientation of the posterior cruciate ligament reconstruction transtibial tunnel creates a trough in the back of the tibia that mimics the tibial inlay technique, and provides a very smooth transition for the PCL grafts from the back of the tibia into the joint.

1.13 PCL Femoral Tunnel Creation

The PCL single bundle or double bundle femoral tunnels are made from inside out using the double bundle aimers, or an endoscopic reamer can be used as an aiming device (Biomet Sports Medicine, Warsaw, Indiana). With the knee in approximately 100°–110° of flexion, the appropriately sized double bundle aimer or endoscopic reamer is inserted through a low anterior lateral patellar arthroscopic portal to create the posterior cruciate ligament anterior lateral bundle femoral tunnel. The double bundle aimer or endoscopic reamer is positioned directly on the footprint of the femoral anterior lateral bundle posterior cruciate ligament insertion site. The appropriately sized guide wire is drilled through the aimer or endoscopic reamer, through the bone, and out a small skin incision. Care is taken to prevent any compromise of the articular surface. The double bundle aimer is removed, and the endoscopic reamer is used to drill the anterior lateral posterior cruciate ligament femoral tunnel from inside to outside. When the surgeon chooses to perform a double bundle double femoral tunnel PCL reconstruction, the same process is repeated for the posterior medial bundle of the PCL. Care must be taken to ensure that there will be an adequate bone bridge (approximately 5 mm) between the two femoral tunnels prior to drilling. This is accomplished using the calibrated probe, and direct arthroscopic visualization of the posterior cruciate ligament femoral anatomic insertion sites.

I have evolved from outside to inside PCL femoral tunnel creation to inside to outside PCL femoral tunnel creation for two reasons. There is a greater distance and margin of safety between the posterior cruciate ligament femoral tunnels and the medial femoral condyle articular surface using the inside to outside method. Additionally, a more accurate placement of the posterior cruciate ligament femoral tunnel(s) is possible because I can place the double bundle aimer or endoscopic reamer on the anatomic foot print of the anterior lateral and posterior medial posterior cruciate ligament insertion sites under direct visualization.

1.14 ACL Reconstruction

With the knee in approximately 90° of flexion, the anterior cruciate ligament tibial tunnel is created using a drill guide. My preferred method of anterior cruciate ligament reconstruction is the transtibial femoral tunnel endoscopic surgical technique. The arm of the drill guide enters the knee joint through the inferior medial patellar portal. The bullet of the drill guide contacts the anterior medial proximal tibia externally at a point midway between the posterior medial border of the tibia, and the anterior tibial crest just above the level of the tibial tubercle. A one centimeter bone bridge or greater exists between the PCL and ACL tibial tunnels. This will reduce the possibility of tibial fracture. The guide wire is drilled through the guide and positioned so that after creating the anterior cruciate ligament tibial tunnel, the graft will approximate the tibial anatomic insertion site of the anterior cruciate ligament. A standard cannulated reamer is used to create the tibial tunnel.

With the knee in approximately ninety to one hundred degrees of flexion, an over the top femoral aimer is introduced through the tibial tunnel, and used to position a guide wire on the medial wall of the lateral femoral condyle to create a femoral tunnel approximating the anatomic insertion site of the anterior cruciate ligament. The anterior cruciate ligament graft is positioned, and fixation achieved on the femoral side using two stacked polyethylene ligament fixation buttons for cortical suspensory fixation. The endoscopic transtibial femoral tunnel anterior cruciate ligament reconstruction surgical technique enables reliable tunnel creation which allows the ACL graft tissue to approximate the tibial and femoral anatomic insertion sites of the anterior cruciate ligament. Proper tunnel position increases the probability of successful results.

1.15 Mechanical Graft Tensioning and Fixation

The cyclic dynamic method of graft tensioning using the Biomet graft tensioning boot (Biomet Sports Medicine, Warsaw, Indiana) is used to tension the posterior and anterior cruciate ligament grafts [55, 56]. During this surgical technique, the posterior and/or anterior cruciate ligament grafts are secured on the femoral side first with the surgeon's preferred fixation method. The technique described is a tibial sided tensioning method. I routinely use polyethylene ligament fixation buttons for cortical suspensory fixation on the femoral side, and aperture opening interference fixation with bioabsorbable interference screws for tibial side posterior and anterior cruciate ligament fixation combined with polyethylene ligament fixation buttons or screw and washer for cortical suspensory back up fixation. In combined PCL ACL reconstructions, the posterior cruciate ligament graft is tensioned first, followed by final PCL graft(s) tibial fixation. The anterior cruciate ligament graft tensioning and fixation follows that of the PCL.

The tensioning boot is applied to the foot and leg of the surgical extremity, and tension is placed on the PCL graft(s) distally using the Biomet graft-tensioning boot (Biomet Sports Medicine, Warsaw, Indiana). Tension is gradually applied with the knee in zero degrees of flexion (full extension) reducing the tibia on the femur. This restores the anatomic tibial step off. Although there are numbers on the torque wrench dial, these numbers are not used to set the tension. The numbers on the torque wrench serve as a reference point during the cycling process, and readjustment process, and are not indicators of final tension in the graft. The tension is determined by reduction of the tibia on the femur in zero degrees of knee flexion (full extension), the restoration of the anatomic tibial step offs, a negative posterior drawer on intra-operative examination of the knee, and full range of motion of the knee. The knee is cycled through a full range of motion multiple times to allow pre-tensioning and settling of the graft. The process is repeated until there is no further change on the torque setting on the graft tensioner with the knee at zero degrees of flexion (full extension). When there are no further changes or adjustments necessary in the tension applied to the graft, the knee is placed in 70°–90° of flexion, and fixation is achieved on the tibial side of the PCL graft with a bioabsorbable interference screw for interference fit fixation, and back up cortical suspensory fixation with a bicortical screw and spiked ligament washer or polyethylene ligament fixation button.

The cyclic dynamic method of tensioning of the anterior cruciate ligament graft is performed using the Biomet graft-tensioning boot (Biomet Sports Medicine, Warsaw, Indiana) after tensioning and final fixation of the posterior cruciate ligament graft(s) has been performed. Traction is placed on the anterior cruciate ligament graft sutures with the knee in zero degrees of flexion (full extension), and tension is gradually applied reducing the tibia on the femur. The knee is then cycled through multiple full flexion and extension cycles to allow settling of the graft. The Lachman and pivot shift tests are performed. The process is repeated until there is no further change in the torque setting on the graft tensioner at full extension (zero degrees of knee flexion), and the Lachman and pivot shift tests are negative. Although there are numbers on the torque wrench dial, these numbers are not used to set the tension. The numbers on the torque wrench serve as a reference point during the cycling process, and readjustment process, and are not indicators of final tension in the graft. Final anterior cruciate ligament graft tension is determined by the Lachman and pivot shifts becoming negative, and achieving full range of motion of the knee. The knee is placed in approximately thirty degrees of flexion, and fixation is achieved on the tibial side of the anterior cruciate ligament graft with a bioabsorbable interference screw, and back up fixation with a polyethylene ligament fixation button or screw and washer cortical suspensory back up fixation.

Secure fixation is critical to the success of this surgical procedure. Mechanical tensioning of the cruciates at zero degrees of knee flexion (full extension), and restoration of the normal anatomic tibial step-off at 70°–90° of flexion has provided the most reproducible method of establishing the neutral point of the tibia-femoral relationship in my experience. Full range of motion is confirmed on the operating table to assure the knee is not “captured” by the reconstruction.

1.16 Posterolateral Reconstruction

My most commonly utilized surgical technique for posterolateral reconstruction is the fibular head based figure of eight technique utilizing semitendinosus allograft, or other soft tissue allograft material. This procedure requires an intact proximal tibiofibular joint, and the absence of a severe hyperextension external rotation recurvatum deformity. This technique combined with capsular repair and posterolateral capsular shift procedures, mimics the function of the popliteofibular ligament and lateral collateral ligament, tightens the posterolateral capsule, and provides a post of strong allograft tissue to reinforce the posterolateral corner. When there is a disrupted proximal tibiofibular joint, or severe hyperextension external rotation recurvatum deformity, a two-tailed (fibular head, proximal tibia) posterior lateral reconstruction is performed in addition to the posterolateral capsular shift procedure [50, 52, 54, 57–59].

In acute cases, primary repair of all lateral side injured structures is performed with suture anchors, screws and washers, and permanent sutures through drill holes as indicated. The primary repair is then augmented with an allograft tissue reconstruction. Posterolateral reconstruction with the free graft figure of eight technique utilizes semitentinosus or other soft tissue allograft. A curvilinear incision is made in the lateral aspect of the knee extending from the interval between Gerdy’s tubercle and the fibular head to the lateral epicondyle and then proximal following the course of the iliotibial band. A peroneal nerve neurolysis is performed, and the peroneal nerve is protected throughout the procedure. The fibular head is identified and a tunnel is created in an anterior lateral to posterior medial direction at the area of maximal fibular head diameter. The tunnel is created by passing a guide pin followed by a standard cannulated drill 7 mm in diameter. The peroneal nerve is protected during tunnel creation, and throughout the procedure. The free tendon graft is passed through the fibular head drill hole. An incision is made in the iliotibial band in line with the fibers exposing the lateral femoral epicondyle area of the distal femur. The graft material is passed medial to the iliotibial band for the fibular collateral ligament limb, and medial to the common biceps tendon and iliotibial band for the popliteus tendon popliteofibular ligament limb. The limbs of the graft are crossed to form a figure of eight with the fibular collateral ligament component being lateral to the popliteus tendon component. A 3.2 mm drill hole is made to accommodate a 6.5 mm diameter fully threaded cancellous screw that is approximately 40–45 mm in length. The drill hole is positioned in the lateral epicondylar region of the distal lateral femur so that after seating a 17–20 mm spiked ligament fixation washer with the above mentioned screw, the spiked ligament fixation washer will precisely secure the two limbs of the allograft tissue at the respective anatomic insertion sites of the fibular collateral ligament and popliteus tendon on the distal lateral femoral condyle. This drill hole is approximately 1 cm anatomically anterior to the fibular collateral ligament femoral insertion. A longitudinal incision is made in the lateral capsule just posterior to the fibular collateral ligament in the interval between the mid lateral and posterolateral capsule, and the posterolateral capsular shift is performed with number 2 Ethibond suture, with the knee in

90° of knee flexion to correct posterolateral capsular redundancy. The graft is tensioned at approximately 30°–40° of knee flexion, secured to the lateral femoral epicondylar region with a screw and spiked ligament washer at the above mentioned point. Number two ethibond suture is used to sew the tails of the graft together proximal to the washer to prevent slipping, and also to sew the allograft to the deep capsular layers for additional reinforcement. The anterior and posterior limbs of the figure of eight graft material are sewn to each other and to the deep capsular layer to reinforce and tighten the construct. The final graft tensioning position is approximately 30°–40° of knee flexion with a slight valgus force applied to the knee, and slight internal tibial rotation, while the posterior lateral capsular shift and reinforcing suture placement is performed at 90° of knee flexion. The iliotibial band incision is closed. The procedures described are designed to eliminate pathologic posterolateral axial rotation and varus rotational instability.

When there is a disrupted proximal tibiofibular joint, or hyperextension external rotation recurvatum deformity, a two-tailed (fibular head, proximal tibia) posterior lateral reconstruction is utilized combined with a posterolateral capsular shift. A seven or eight millimeter drill hole is made over a guide wire approximately two centimeters below the lateral tibial plateau. A tibialis anterior or other soft tissue allograft is passed through this tibial drill hole and follows the course of the popliteus tendon to its anatomic insertion site on the lateral femoral epicondylar region. Nerves and blood vessels must be protected. The tibialis anterior or other soft tissue allograft is secured with a suture anchor, and multiple number two braided non absorbable sutures at the popliteus tendon anatomic femoral insertion site. The knee is cycled through multiple sets of full flexion and extension cycles, placed in ninety degrees of flexion, the tibia slightly internally rotated, slight valgus force applied to the knee, and the graft tensioned, and secured in the tibial tunnel with a bioabsorbable interference screw, and polyethylene ligament fixation button. The fibular head based reconstruction and posterolateral capsular shift procedures are then carried out as described above.

When local autogenous tissue is preferred for posterolateral reconstruction, we have had successful results controlling posterolateral instability types A and B using the split biceps tendon transfer [26–29, 57–59]. I have found that the split biceps tendon transfer is not as effective at controlling posterolateral instability type C as a fibular head based free graft [57–59].

1.17 Posteromedial Reconstruction

The surgical leg positioned on the extended operating room table in a supported flexed knee position. Posteromedial and medial reconstructions are performed through a medial curved incision taking care to maintain adequate skin bridges between incisions [14, 15, 50, 52, 54, 60]. In acute cases, primary repair of all medial side injured structures is performed with suture anchors, screws and washers, and permanent sutures through drill holes as indicated. The primary repair is then augmented with an allograft tissue reconstruction. In chronic cases of posteromedial reconstruction, the Sartorius fascia is incised and retracted exposing the superficial medial collateral ligament and the posterior medial capsule. Nerves and blood vessels are protected throughout the procedure. A longitudinal incision is made just posterior and parallel to the posterior border of the superficial medial collateral ligament. Care is taken not to damage the medial meniscus during the capsular incision. Avulsed capsular structures are primarily repaired using bioabsorbable suture anchors and permanent braided number two ethibond sutures. The interval between the posteromedial capsule and medial meniscus is developed. The posteromedial capsule is shifted in an anterior and superior direction. The medial meniscus is repaired to the new capsular position, and the shifted capsule is sewn into the medial collateral ligament using three number two permanent braided ethibond sutures in horizontal mattress fashion, and that suture line is reinforced using a running number two ethibond suture.

When superficial medial collateral ligament reconstruction is indicated, this is performed using allograft tissue after completion of the primary capsular repair, and posteromedial capsular shift procedures are performed as outlined above. This graft material is attached at the anatomic insertion sites of the superficial medial collateral ligament on the femur and tibia using a screw and spiked ligament washer, suture anchors, or looped around the adductor magnus tendon on the femoral side and sewn back on itself. The final graft tensioning position is approximately 30–40° of knee flexion. It is my preference to secure the tibial insertion site first, and to perform the final tensioning and fixation of the allograft tissue on the femoral side. Number two Ethibond suture is used to sew the tails of the graft together proximal to the washer to prevent slipping, and also to sew the allograft to the deep capsular layers for additional reinforcement.

1.18 Postoperative Rehabilitation

The knee is maintained in full extension for three to five weeks non-weight bearing. This initial period of immobilization is followed by progressive range of motion and progressive weight bearing. Progressive closed kinetic chain strength training, proprioceptive training, and continued motion exercises are initiated very slowly beginning at postoperative week eleven. The long leg range of motion brace is discontinued after the tenth week and the patient may wear a global laxity functional brace for all activities for additional protection if necessary. Return to sports and heavy labor occurs after the ninth to twelfth post-operative month when sufficient strength, range of motion, and proprioceptive skills have returned [61–64]. It is very important to carefully observe these complex knee ligament injury patients, and get a feel for the "personality of the knee". The surgeon may need to make adjustments and individualize the postoperative rehabilitation program as necessary. Careful and gentle range of motion under general anesthesia is a very useful tool in the treatment of these complex cases, and is utilized as necessary. Our postoperative rehabilitation program is discussed in more detail in Chap. 39 of this book.

1.19 Posterior Cruciate Ligament Injuries in Patients 18 Years of Age and Younger

My experience with PCL injuries and multiple ligament knee injuries in children ranges from ages six to eighteen years of age. These patients have varying degrees of open growth plates, and their injury mechanisms include trampoline, motorcycle, gymnastics, soccer, automobile, and farming accidents. The principles of reconstruction in the posterior cruciate ligament injured knee and the multiple ligament injured knee are to identify and treat all pathology, accurate tunnel placement, anatomic graft insertion sites, utilize strong graft material, mechanical graft tensioning, secure graft fixation, and a deliberate postoperative rehabilitation program. The concern in the 18 years of age and younger patient population with open growth plates is the potential for growth arrest and resultant angular deformity about the knee after surgical intervention. This risk can be decreased by insuring that no fixation devices or bone blocks cross or damage the physis during ligament reconstruction. Therefore, in patients with open physes, soft tissue allografts without the bone plugs are used, and no fixation devices cross the physis. Patients with closed or nearly closed growth plates may be treated with the same surgical techniques as adults. Our preference is to perform single bundle posterior cruciate ligament reconstruction in patients with open growth plates, while single bundle or double bundle PCL reconstruction have both been successful in patients with closed or nearly closed growth plates. Medial and lateral side reconstructions have been performed with combined primary repair, capsular shift, and allograft augmentation as indicated. The goal of each surgical technique is growth plate preservation. Results evaluated with arthrometer measurements, stress radiography, and knee ligament rating scales demonstrate results similar to those we have achieved in adult patient populations. I have had no patients with growth arrest and resultant angular deformity about the knee after surgical intervention. These severe knee injuries do occur in children, and can be a source of significant instability. Surgical reconstruction of the posterior cruciate ligament injured and the multiple ligament injured knee in children using surgical techniques to preserve the growth plates results in functionally stable knees, and no growth plate arrest in my experience [38, 39, 65].

1.20 Outcomes and Results of Treatment

1.20.1 Combined PCL Posterolateral Reconstruction

Fanelli and Edson, in 2004, published the 2–10 year (24–120 month) results of 41 chronic arthroscopically assisted combined PCL/posterolateral reconstructions evaluated pre and postoperatively using Lysholm, Tegner, and Hospital for Special Surgery knee ligament rating scales, KT 1000 arthrometer testing, stress radiography, and physical examination [29]. Posterior cruciate ligament reconstructions were performed using the arthroscopically assisted single femoral tunnel-single bundle transtibial tunnel posterior cruciate ligament reconstruction technique using fresh frozen Achilles tendon allografts in all 41 cases. In all 41 cases, posterolateral instability reconstruction was performed with combined biceps femoris tendon tenodesis, and posterolateral capsular shift procedures. Postoperative physical exam revealed normal posterior drawer/tibial step off for the overall study group in 29/41 (70%) of knees. Normal posterior drawer and tibial step offs were achieved in 91.7% of the knees tensioned with the Biomet Sports Medicine mechanical graft tensioner. Posterolateral stability was restored to normal in 11/41 (27%) of knees, and tighter than the normal knee in 29/41 (71%) of knees evaluated with the external rotation thigh foot angle test. 30′ varus stress testing was normal in 40/41 (97%) of knees, and grade 1 laxity in 1/41 (3%) of knees. Postoperative KT 1000 arthrometer testing mean side to side difference measurements were 1.80 mm (PCL screen), 2.11 mm (corrected posterior), and 0.63 mm (corrected anterior) measurements. This is a statistically significant improvement from preoperative status for the PCL screen and the corrected posterior measurements ($p = 0.001$). The postoperative stress radiographic mean side to side difference measurement measured at 90′ of knee flexion, and 32 lb of posterior directed force applied to the proximal tibia using the Telos device was 2.26 mm. This is a statistically significant improvement from preoperative measurements ($p = 0.001$). Postoperative Lysholm, Tegner, and Hospital for Special Surgery knee ligament rating scale mean values were 91.7, 4.92, and 88.7, respectively, demonstrating a statistically significant improvement from preoperative status ($p = 0.001$). The authors concluded that chronic combined PCL/posterolateral instabilities can be successfully treated with arthroscopic posterior cruciate ligament reconstruction using fresh frozen Achilles tendon allograft combined with posterolateral corner reconstruction using biceps tendon tenodesis combined with posterolateral capsular shift procedure. Statistically significant improvement is noted ($p = 0.001$) from the preoperative condition at 2–10 year follow-up using objective parameters of knee ligament rating scales, arthrometer testing, stress radiography, and physical examination.

1.20.2 Combined PCL ACL Reconstruction Without Mechanical Graft Tensioning

Our results of multiple ligament injured knee treatment without mechanical graft tensioning are outlined below [28, 30]. This study presented the 2–10 year (24–120 month) results of 35 arthroscopically assisted combined ACL/PCL reconstructions evaluated pre and postoperatively using Lysholm, Tegner, and Hospital for Special Surgery knee ligament rating scales, KT 1000 arthrometer testing, stress radiography, and physical examination.

This study population included 26 males, 9 females, 19 acute, and 16 chronic knee injuries. Ligament injuries included 19 ACL/PCL/posterolateral instabilities, 9 ACL/PCL/MCL instabilities, 6 ACL/PCL/posterolateral/MCL instabilities, and 1 ACL/PCL instability. All knees had grade III preoperative ACL/PCL laxity, and were assessed pre and postoperatively with arthrometer testing, 3 different knee ligament rating scales, stress radiography, and physical examination. Arthroscopically assisted combined ACL/PCL reconstructions were performed using the single incision endoscopic ACL technique, and the single femoral tunnel-single bundle transtibial tunnel PCL technique. PCL's were reconstructed with allograft Achilles tendon (26 knees), autograft BTB (7 knees), and autograft semitendinosus/gracilis (2 knees). ACL's were reconstructed with autograft BTB (16 knees), allograft BTB (12 knees), Achilles tendon allograft (6 knees), and autograft semitendinosus/gracilis (1 knee). MCL injuries were treated with bracing or open reconstruction. Posterolateral instability was treated with biceps femoris tendon transfer, with or without primary repair, and posterolateral capsular shift procedures as indicated. No Biomet Sports Medicine graft tensioning boot was used in this series of patients (Biomet Sports Medicine, Warsaw, Indiana).

Postoperative physical examination results revealed normal posterior drawer/tibial step off in 16/35 (46%) of knees. Normal Lackman and pivot shift tests in 33/35 (94%) of knees. Posterolateral stability was restored to normal in 6/25 (24%) of knees, and tighter than the normal knee in 19/25 (76%) of knees evaluated with the external rotation thigh foot angle test. 30° varus stress testing was normal in 22/25 (88%) of knees, and grade 1 laxity in 3/25 (12%) of knees. 30° valgus stress testing was normal in 7/7 (100%) of surgically treated MCL tears, and normal in 7/8 (87.5%) of brace treated knees. Postoperative KT 1000 arthrometer testing mean side-to-side difference measurements were 2.7 mm (PCL screen), 2.6 mm (corrected posterior), and 1.0 mm (corrected anterior) measurements, a statistically significant improvement from preoperative status ($p = 0.001$). Postoperative stress radiographic side-to-side difference measurements measured at 90° of knee flexion, and 32 lb of posteriorly-directed proximal force were 0–3 mm in 11/21 (52.3%), 4–5 mm in 5/21 (23.8%), and 6–10 mm in 4/21 (19%) of knees. Postoperative Lysholm, Tegner, and HSS knee ligament rating scale mean values were 91.2, 5.3, and 86.8 respectively demonstrating a statistically significant improvement from preoperative status ($p = 0.001$). No Biomet graft tensioning boot was used in this series of patients.

The conclusions drawn from the study were that combined ACL/PCL instabilities could be successfully treated with arthroscopic reconstruction and the appropriate collateral ligament surgery. Statistically significant improvement was noted from the preoperative condition at 2–10 year follow-up using objective parameters of knee ligament rating scales, arthrometer testing, stress radiography, and physical examination.

1.20.3 Combined PCL ACL Reconstruction with Mechanical Graft Tensioning

Our results of multiple ligament injured knee treatment using mechanical graft tensioning are outlined below [28, 30]. This data presents the 2-year follow up of 15 arthroscopic assisted ACL PCL reconstructions using the Biomet graft tensioning boot (Biomet Sports Medicine, Warsaw, Indiana). This study group consists of 11 chronic and 4 acute injuries. These injury patterns included 6 ACL PCL PLC injuries, 4 ACL PCL MCL injuries, and 5 ACL PCL PLC MCL injuries. The Biomet graft tensioning boot was used during the procedures as in the surgical technique described above. All knees had grade III preoperative ACL/PCL laxity, and were assessed pre and postoperatively using Lysholm, Tegner, and Hospital for Special Surgery knee ligament rating scales, KT 1000 arthrometer testing, stress radiography, and physical examination.

Arthroscopically assisted combined ACL/PCL reconstructions were performed using the single incision endoscopic ACL technique, and the single femoral tunnel-single bundle transtibial tunnel PCL technique. PCL's were reconstructed with allograft Achilles tendon in all 15 knees. ACL's were reconstructed with Achilles tendon allograft in all 15 knees. MCL injuries were treated surgically using primary repair, posteromedial capsular shift, and allograft augmentation as indicated. Posterolateral instability was treated with allograft semitendinosus free graft, with or without primary repair, and posterolateral capsular shift procedures as indicated. The Biomet graft tensioning boot was used in this series of patients.

Post-reconstruction physical examination results revealed normal posterior drawer/tibial step off in 13/15 (86.6%) of knees. Normal Lackman test in 13/15 (86.6%) knees, and normal pivot shift tests in 14/15 (93.3%) knees. Posterolateral stability was restored to normal in all knees with posterolateral instability when evaluated with the external rotation thigh foot angle test (9 knees equal to the normal knee, and 2 knees tighter than the normal knee). Thirty degree varus stress testing was restored to normal in all 11 knees with posterolateral lateral instability. Thirty and zero degree valgus stress testing was restored to normal in all 9 knees with medial side laxity. Postoperative KT-1000 arthrometer testing mean side-to-side difference measurements were 1.6 mm (range −3 to 7 mm) for the PCL screen, 1.6 mm (range −4.5 to 9 mm) for the corrected posterior, and 0.5 mm (range −2.5 to 6 mm) for the corrected anterior measurements, a significant improvement from preoperative status. Postoperative stress radiographic side-to-side difference measurements measured at 90° of knee flexion, and 32 lb of posteriorly-directed proximal force using the Telos stress radiography device were 0–3 mm in 10/15 knees (66.7%), 0–4 mm in 14/15 (93.3%), 4 mm in 4/15 knees (26.7%), and 7 mm in 1/15 knees (6.67%). Postoperative Lysholm, Tegner, and HSS knee ligament rating scale mean values were 86.7 (range 69–95), 4.5 (range 2–7), and 85.3 (range 65–93) respectively, demonstrating a significant improvement from preoperative status. The study group demonstrates the efficacy and success of using a mechanical graft-tensioning device in posterior and anterior cruciate ligament reconstruction procedures.

1.20.4 Double Bundle Compared to Single Bundle PCL Reconstruction

Our comparison of single bundle and double bundle posterior cruciate ligament reconstruction in the PCL based multiple ligament injured knee using allograft tissue revealed the following [32]. Ninety consecutive arthroscopic transtibial PCL reconstructions were performed by a single surgeon (GCF). Forty five single bundle and 45 double bundle reconstructions were performed using fresh frozen Achilles tendon allograft for the anterolateral bundle, and tibialis anterior allograft for the posteromedial bundle. Postoperative comparative results were assessed using Telos stress radiography, KT 1000, Lysholm, Tegner, and HSS knee ligament rating scales. Postoperative period ranged from 15 to 72 months.

Three groups of data were analyzed: Single and double bundle all; single bundle PCL-collateral and PCL double bundle-collateral; and single bundle PCL-ACL-collateral and double bundle PCL-ACL-collateral.

Mean postoperative side to side difference values for Telos, KT PCL screen, KT corrected posterior, and KT corrected anterior measurements for the overall single bundle group in millimeters were 2.56, 1.91, 2.11, and 0.23, respectively. Mean postoperative side to side difference values for Telos, KT PCL screen, KT corrected posterior, and KT corrected anterior measurements for the overall double bundle group in millimeters were 2.36, 2.46, 2.94, and 0.15, respectively. Mean postoperative values for Tegner, Lysholm, and Hospital for Special Surgery (HSS) knee ligament rating scales for the single bundle group was 5.0, 90.3, and 86.2, respectively. Mean postoperative values for Tegner, Lysholm, and Hospital for Special Surgery (HSS) knee ligament rating scales for the double bundle group was 4.6, 87.6, and 83.3, respectively.

Mean postoperative side to side difference values for Telos, KT PCL screen, KT corrected posterior, and KT corrected anterior measurements for the PCL-collateral single bundle group in millimeters were 2.59, 1.63, 2.03, and 0.25, respectively. Mean postoperative side to side difference values for Telos, KT PCL screen, KT corrected posterior, and KT corrected anterior measurements for the PCL-collateral double bundle group in millimeters were 1.85, 2.03, 2.83, and −0.17, respectively. Mean postoperative values for Tegner, Lysholm, and Hospital for Special Surgery (HSS) knee ligament rating scales for the single bundle PCL-collateral group was 5.4, 90.9, and 87.7, respectively. Mean postoperative values for Tegner, Lysholm, and Hospital for Special Surgery (HSS) knee ligament rating scales for the double bundle PCL-collateral group was 4.9, 89.0, and 86.5, respectively.

Mean postoperative side to side difference values for Telos, KT PCL screen, KT corrected posterior, and KT corrected anterior measurements for the PCL-ACL-collateral single bundle group in millimeters were 2.53, 2.19, 2.19, and 0.22, respectively. Mean postoperative side to side difference values for Telos, KT PCL screen, KT corrected posterior, and KT corrected anterior measurements for the PCL-ACL-collateral double bundle group in millimeters were 3.16, 2.86, 3.09, and 0.41, respectively. Mean postoperative values for Tegner, Lysholm, and Hospital for Special Surgery (HSS) knee ligament rating scales for the PCL-ACL-collateral single bundle group was 4.7, 89.6, and 84.6, respectively. Mean postoperative values for Tegner, Lysholm, and Hospital for Special Surgery (HSS) knee ligament rating scales for the PCL-ACL-collateral double bundle group was 4.3, 86.0, and 79.4, respectively. There was no statistically significant difference between the single bundle and the double bundle PCL reconstruction in any of the groups compared ($p > 0.05$).

Return to pre-injury level of activity was evaluated between the single and double bundle posterior cruciate ligament reconstruction groups. The bicruciate single bundle reconstruction group return to pre-injury level of activity was 73.3%, and the bicruciate double bundle reconstruction group return to pre-injury level of activity was 84.0%. There was no statistically significant difference ($p = 0.572$) between the single bundle and double bundle group in the posterior cruciate ligament based multiple ligament injured knee. Both single bundle and double bundle arthroscopic transtibial tunnel posterior cruciate ligament reconstructions provide excellent results in these complex multiple ligament injured knee instability patterns. Our results did not indicate that one posterior cruciate ligament reconstruction surgical procedure was clearly superior to the other.

1.20.5 Combined PCL, ACL, Medial Posteromedial Reconstruction

My experience with 27 PCL ACL medial posteromedial reconstructions performed with the surgical techniques outlined in this chapter include 2–25 year (mean 5.7 years) postoperative outcomes evaluated with KT 1000, stress X-ray, Lysholm, Tegner, and Hospital for Special Surgery knee ligament rating scales. Mean side to side difference in millimeters KT 1000 knee ligament arthrometer demonstrate PCL Screen: 2.0 mm (range −3 to 5.5 mm), corrected posterior: 2.3 mm (range −1 to 5.5 mm), corrected anterior: 0.3 mm (range −3 to 4 mm), 30° knee flexion anterior displacement: 1.8 mm (range −1 to 8 mm). Stress X-ray mean side to side difference at 90° knee flexion with posterior displacement force applied to the proximal tibia: 1.5 mm (range −8.6 to 7.7 mm). Postoperative mean knee ligament rating scale scores: Lysholm: 88.7/100 (range 63–100), Hospital for Special Surgery: 85.2/100 (range 60–100), Tegner: 4.9 (range 2–8). 53.8% of patients achieved their preinjury level of Tegner function post surgical reconstruction, and 77.0% of patients achieved their preinjury or one grade lower level of Tegner function post reconstruction.

1.20.6 Combined PCL, ACL, Posterolateral, Posteromedial (Global Laxity) Reconstruction with 2–18 Year Follow up

Our 2–18 year postsurgical results in combined PCL, ACL, medial and lateral side knee injuries (global laxity) revealed the following information [33]. Forty combined PCL-ACL-lateral-medial side (global laxity reconstructions were performed by a single surgeon (GCF). 28 of 40 were available for 2–18 year follow up (70% follow up rate). The patients were evaluated postoperatively with three different knee ligament rating scales for physical examination and functional capacity (Hospital for Special Surgery, Lysholm, Tegner). Static stability was assessed postoperatively comparing the normal to the injured knee using the KT 1000 knee ligament arthrometer (PCL screen, corrected posterior, corrected anterior, and 30° posterior to anterior translation), and stress radiography at 90° of flexion to assess PCL static stability using the Telos device. All measurements are reported as a side to side difference in millimeters comparing the normal to the injured knee. Range of motion, varus and valgus stability, and axial rotation stability of the tibia relative to the femur using the dial test are reported comparing the injured to the normal knee. Incidence of degenerative joint disease, and return to pre injury level of function are also reported.

Knee ligament rating scale mean scores were: Hospital for Special Surgery 79.3/100 (range 56–95), Lysholm 83.8/100 (range 58–100), and Tegner 4/10 (range 2–9). KT 1000 mean side to side difference measurements in millimeters were: PCL screen at 90° of knee flexion 2.02 mm (range 0–7 mm), corrected posterior at 70° of knee flexion 2.48 mm (range 0–9 mm), corrected anterior at 70° of knee flexion 0.28 mm (range −3 to 7 mm), and the 30° of knee flexion posterior to anterior translation 1.0 mm (range −6 to 6 mm). Telos stress radiography at 90° of knee flexion with a posterior displacement force applied to the area of the tibial tubercle mean side to side difference measurements in millimeters were 2.35 mm (range −2 to 8 mm).

Range of motion side to side difference mean flexion loss comparing the normal to the injured knee was 14.0° (range 0°–38°). There were no flexion contractures. Varus and valgus stability were evaluated on physical examination at hyperextension, zero, and 30° of knee flexion comparing the injured to the normal knee. Symmetrical varus stability was achieved in 93.3% of knees, and symmetrical valgus stability was achieved in 92.6% of knees. The dial test performed at 30° of knee flexion to evaluate axial rotation posterolateral stability comparing the injured to the normal knee was symmetrical in 85.2%, tighter than the normal knee (less external rotation) in 11.1%, and more lax (greater external rotation) in 3.7% of knees. Thus, posterior lateral axial rotation instability was corrected or over corrected in 96.3% of knees.

Radiographic post traumatic degenerative joint disease occurred in 29.6% of injured knees. No degenerative joint disease was found in 70.4% of the injured knees. Postoperatively, patients were able to return to their pre injury level of activity in 59.3% of cases, and returned to decreased level of postoperative activity in 40.7% of cases.

1.20.7 Knee Dislocations with 5–22 Year Postoperative Results

Our experience with the results of surgical treatment of knee dislocations with 5–22 year follow up in 44 patients when evaluated with arthrometer testing, stress radiography, physical examination, and knee ligament rating scales is as follows [34]. KT 1000 arthrometer mean side to side difference measured in millimeters are: PCL screen 1.9 mm (range 0–6), corrected posterior 2.4 mm (range 0–6), corrected anterior 0.8 mm (range −3 to 7), and the anterior displacement at 30° of knee flexion 1.7 mm (−6 to 6). The combined mean side to side difference measurement for all parameters was 1.7 mm. Stress radiographic measurements at 90° of knee flexion with a posterior displacement force applied to the proximal tibia to evaluate the PCL reconstruction revealed a mean 1.9 mm side to side difference (range −8.6 to 12.7). 84.6% of knees were in the range of 0–5 mm side to side difference. Mean Lysholm knee ligament score was 84.4/100 (range 44–88). Mean Hospital for Special Surgery score was 82.8/100 (range 51–97).

Post reconstruction physical examination for the PCL revealed symmetrical tibial step off in 29 knees (65.9%). 97.8% of knees had symmetrical or less than grade one posterior drawer (43 of 44 knees). Post ACL reconstruction, 39 knees had symmetrical Lachman test (86.6%) and 40 knees had symmetrical (negative) pivot shift (90.9%). Symmetrical varus was present in 41 knees (93.2%), and symmetrical valgus was present in 43 knees (97.7%). Axial rotation was symmetrical to the normal knee in 38 knees (86.4%) and tighter than the normal knee in 6 (13.6%).

Mean Tegner score was 4.1/9 (range 0–6). 65.1% of patients returned to their pre-injury level of activity, and 92.8% of postoperative patients returned to their pre-injury level of activity or one Tegner grade lower level of function. There were 10 of the 44 knees that developed degenerative joint disease (22.7%), and 3 of the 44 knees required total knee replacement (6.8%). There was no loss of terminal extension in any of the knees (no flexion contractures); however, the mean flexion loss was 12.5° compared to the normal knee (range 0°–43°).

There are several important points that have been learned from this study. 74.1% of these patients are 21–50 years of age, and are members of the working population, not the student or professional athlete population. The combined PCL ACL lateral side is the most common injury pattern (50.0%). The most common injury mechanisms are motor vehicle, motor cycle, all terrain vehicles, and snowmobile accidents (59.1%). This is a trauma patient population, not an athletic injury population. These knees are not normal, but they are functionally stable in the industrial athlete population. It is not possible to extrapolate these results to the elite athletic population.

Patients requiring total knee replacements in this post multiple ligament injured knee surgical reconstruction population did not require constrained components. All total knee replacements in this group of patients were performed using standard posterior stabilized total knee components.

1.20.8 Posterior Cruciate Ligament Injuries in Patients 18 Years of Age and Younger

We present the results of treatment of 58 patients in the combined PCL-collateral ligament group, and 25 patients in the combined PCL-ACL-collateral ligament (knee dislocation) group for a total of 83 patients [38, 39, 65]. Mechanisms of injury in the PCL-collateral ligament group are sports related in 72%, motor vehicle accident related in 25%, and trampoline accidents in 3%. Mechanisms of injury in the PCL-ACL-collateral ligament (knee dislocation) group are sports related in 39%, motor vehicle accident related in 57%, and trampoline related accidents in 4%.

The diagnosis of the posterior cruciate ligament based multiple ligament knee injuries in this 18 years of age and under patient population broken down by percentages are PCL-lateral side 39%, PCL-medial side 1%, PCL-medial-lateral sides 28%, PCL-ACL-lateral side 17%, PCL-ACL-medial side 12%, and PCL-ACL-medial-lateral sides 3%. Ninety seven percent of the PCL-collateral group were chronic injuries, while 3% were acute injuries. In contrast, 57% of the PCL-ACL-collateral ligament injured knees were chronic, while 43% of these knee injuries were acute. Forty nine percent of the PCL-collateral ligament reconstruction group was right knees, and 51% were left knees. Fifty eight percent of the PCL-ACL-collateral ligament reconstruction group was right knees, and 42% were left knees.

The mean age at the time of surgery in the PCL-collateral ligament reconstruction group was 16.3 years (range 6–18 years). Three percent of the patients in this group were less than 10 years old, 9% were 10–14 years old, and 88% were 15–18 years old. Sixty seven percent of the PCL-collateral ligament reconstruction group was boys, and 33% of this group was girls. The age group of boys less than 10 years old was 0%, 10–14 years old 8%, and 15–18 years old 92%. The age groups of the girls who were less than 10 years old were 11%, 10–14 years old 11%, and 15–18 years old 78%.

The mean age at the time of surgery in the PCL-ACL-collateral ligament (knee dislocation) reconstruction group was 16.7 years (range 13–18 years). Zero percent of the patients in this group were less than 10 years old, 4% were 10–14 years old, and 96% were 15–18 years old. Seventy six percent of the PCL-ACL-collateral ligament reconstruction group were boys, and 24% of this group were girls. The age groups of the boys who were less than 10 years old were 0%, 10–14 years old 0%, and 15–18 years old 100%. The age groups of the girls who were less than 10 years old were 0%, 10–14 years old 17%, and 15–18 years old 83%. All patients in this series received the surgical techniques they required as described above.

It is very important for the reader to understand that the majority of patients in our series were in the 15–18 year old age group, and that our surgical technique was adjusted to accommodate to the stage of development of the growth plate at the time of surgery as described in the surgical technique section of this article. Postoperatively, the patients were evaluated with range of knee motion, KT 1000 arthrometer, 90° knee flexion posterior tibial displacement stress radiography, Lysholm, Tegner, and Hospital for Special Surgery knee ligament rating scales, X-ray, and physical examination.

1.20.8.1 PCL + Collateral Ligament Group

The results of our combined posterior cruciate ligament and collateral ligament reconstruction group (PCL + collateral ligament) are as follows. Fifty one percent of the patients in this group (29/57) had single bundle PCL reconstruction, while 49% (28/57) of the PCL collateral ligament group received a double bundle PCL reconstruction. The mean follow up for this group of 58 patients was 3.5 years with a range of 1–17 years. The postoperative mean range of motion difference between the surgical knee and the non-surgical normal knee was a 9.6° loss of terminal flexion with a range of 0°–32° of terminal flexion loss. There were no flexion contractures in this series of patients.

Tibiofemoral displacement measurements were performed using the KT 1000 knee arthrometer (Medmetric Corporation, San Diego, California, USA) and the Telos stress radiography device (Austin Associates, Baltimore, Maryland, USA). Postoperative mean KT 1000 side to side difference measurements in millimeters (mm) for the PCL screen, corrected posterior, and corrected anterior were 2.5 mm (range −0.5 to 6.0 mm), 3.3 mm (range −1.0 to 7.0 mm), and 0.1 mm (range −1.5 to 3.0 mm), respectively. The KT 1000 arthrometer 30 lb anterior displacement mean side to side difference measurement at 30° of knee flexion was 1.6 mm (range −2.0 to 5.0 mm). Ninety degree knee flexion stress radiography with a posterior directed force applied to the proximal tibia using the Telos device mean side to side difference measurement was 2.5 mm (range −0.4 to 18.1 mm).

Lysholm, Hospital for Special Surgery, and Tegner knee ligament rating scales were used to evaluate the patient outcomes postoperatively. The Lysholm, Hospital for Special Surgery, and Tegner mean postoperative values were 93/100 (range 83–100), 90/100 (range 75–100), and 6/10 (range 3–9), respectively. Sixty seven percent (32/48) of patients returned to their preinjury Tegner level of function, while 15% (7/48), 6% (3/48), 4% (2/48), and 8% (4/48) of the patients were 1, 2, 3, and 4 Tegner levels below their preinjury Tegner level of function, respectively.

Physical examination tests used to evaluate the postoperative outcomes of the combined PCL collateral ligament group included the posterior drawer, Lachman, pivot shift, varus stress, valgus stress, and the axial rotation dial tests. All physical examination tests compared the postoperative surgical knee to the normal uninjured non-surgical knee. The posterior drawer test was normal in 63% (34/54), grade ½ laxity in 9% (5/54), grade 1 laxity in 26% (14/54), and grade 3 laxity in 2% (2/54). The Lachman and pivot shift tests were 100% normal in this intact anterior cruciate ligament group of patients as expected. The varus stress test at 0° and 30° of knee flexion were symmetrical to the normal knee in all patients tested (54/54). The valgus stress test at 0° and 30° of knee flexion were symmetrical to the normal knee in 98% (53/54), and grade 1 laxity in 2% (1/54). The axial rotation dial test at 30° and 90° of knee flexion was symmetrical to the contralateral normal knee in 87% (47/54) of patients, and less external rotation than the contralateral normal knee in 13% (7/54). There were no patients with growth arrest or resultant angular deformity about the knee after surgical intervention in any age group.

1.20.8.2 PCL + ACL + Collateral Ligament (Knee Dislocation) Group

The results of our combined posterior cruciate ligament, anterior cruciate ligament, and collateral ligament (PCL + ACL + collateral ligament) reconstruction group are presented here. Fifty nine percent of the patients in this group (13/22) had single bundle PCL reconstruction, while 41% (9/22) of the PCL collateral ligament group received a double bundle PCL reconstruction. The mean follow up for this group of 22 patients was 4.5 years with a range of 1–10 years. The postoperative mean range of motion difference between the surgical knee and the non-surgical normal knee was an 11.3° loss of terminal flexion with a range of 0° to 43° of terminal flexion loss. There were no flexion contractures in this series of patients.

Tibiofemoral displacement measurements were performed using the KT 1000 knee arthrometer (Medmetric Corporation, San Diego, California, USA) and the Telos stress radiography device (Austin Associates, Baltimore, Maryland, USA). Postoperative mean KT 1000 side to side difference measurements in millimeters (mm) for the PCL screen, corrected posterior, and corrected anterior were 1.7 mm (range 0.0–3.0 mm), 2.0 mm (range −1.0 to 5.0 mm), and 0.6 mm (range −1.5 to 4.0 mm), respectively.

The KT 1000 arthrometer 30 lb anterior displacement mean side to side difference measurement at 30° of knee flexion was 2.2 mm (range −1.0 to 5.0 mm). Ninety degree knee flexion stress radiography with a posterior directed force applied to the proximal tibia using the Telos device mean side to side difference measurement was 2.9 mm (range 0.0–12.7 mm).

Lysholm, Hospital for Special Surgery, and Tegner knee ligament rating scales were used to evaluate the patient outcomes postoperatively. The Lysholm, Hospital for Special Surgery, and Tegner mean postoperative values were 93/100 (range 69–100), 89/100 (range 76–96), and 5/10 (range 3–9), respectively. Fifty five percent (11/20) of patients returned to their preinjury Tegner level of function, while 20% (4/20), 10% (2/20), and 15% (3/20) of the patients were 1, 2, and 3 Tegner levels below their preinjury Tegner level of function, respectively.

Physical examination tests used to evaluate the postoperative outcomes of the combined PCL collateral ligament group included the posterior drawer, Lachman, pivot shift, varus stress, valgus stress, and the axial rotation dial tests. All physical examination tests compared the postoperative surgical knee to the normal uninjured non-surgical knee. The posterior drawer test was normal in 65% (13/20), grade 1 laxity in 30% (6/20), and grade 2 laxity in 5% (1/20). The Lachman and pivot shift tests were symmetrical to the normal knee in 95% (19/20), and grade 1 laxity in 5% (1/20). The varus stress test at 0° and 30° of knee flexion was symmetrical to the normal knee in all patients tested (20/20). The valgus stress test at 0° and 30° of knee flexion was symmetrical to the normal knee in all patients tested (20/20). The axial rotation dial test at 30° and 90° of knee flexion was symmetrical to the contralateral normal knee in 100% (20/20) of patients in the PCL + ACL + collateral ligament group. There were no patients with growth arrest or resultant angular deformity about the knee after surgical intervention in any age group.

1.20.9 Revision PCL Based Multiple Knee Ligament Reconstruction

My experience with revision PCL reconstruction in the multiple ligament injured knee with mean 6.5 years follow up (range 2–11 years) evaluated with stress radiography, arthrometer measurements, and knee ligament rating scales is as follows [66]. Mean side to side difference measurements at 90° knee flexion stress radiography is 2.7 mm (range 0.9–4.0 mm). Mean side to side difference KT 1000 arthrometer measurements on the PCL screen, corrected posterior, corrected anterior, and the anterior displacement measurement at 30° of knee flexion are 2.9, 5.1, 1.6, and 1.0 mm respectively. Mean Hospital for Special Surgery and Lysholm knee ligament rating scale scores are 81.5 and 87.3 out of 100 respectively. Seventy five percent of patients returned to their pre-injury Tegner activity scale level of function following PCL revision reconstruction.

Successful revision posterior cruciate ligament based multiple knee ligament reconstruction surgery results from identification and treatment of associated pathology such as posterolateral instability, posteromedial instability, and lower extremity malalignment. The use of strong graft material, properly placed tunnels to as closely as possible approximate the posterior cruciate ligament insertion sites, and minimization of graft bending also enhance the probability of PCL reconstruction success. Mechanical graft tensioning, primary and back up posterior cruciate ligament graft fixation, and the appropriate postoperative rehabilitation program are also necessary ingredients for posterior cruciate ligament reconstruction success. Both single bundle and double bundle posterior cruciate ligament reconstruction surgical techniques are successful. Posterior cruciate ligament reconstruction failure may result when any or all of these surgical principles are violated. Revision PCL reconstruction demonstrates improvements in pain, function, and stability.

1.21 Summary

The multiple ligament injured knee is a severe injury that may also involve neurovascular injuries, fractures, skin compromise, and other systemic injuries. Abnormal pulses and/or an ankle brachial index less than 0.9 indicate the need for more advanced vascular evaluation or intervention. Correct diagnosis of the multiple planes of instability is essential to maximize successful surgical results. Articular surface fractures in the multiple ligament injured (dislocated) knee must be anatomically reduced and internal fixation achieved before the knee ligament instability pattern can be determined since the intact femur or tibia will fall into the fracture, and potentially hinder an accurate knee ligament injury diagnosis. Tibial plateau depression fractures that meet non surgical criteria with intact knee ligaments should be anatomically reduced and secured since the tendency will be for the femoral condyle to fall into the fracture site, perpetuate the instability, and compromise knee ligament repair or reconstruction. The severity of the medial and lateral side injuries determines whether the procedure will be done arthroscopically, open, single stage, or in two stages. Selective external fixation for preoperative and postoperative control of the injured extremity may be used if control of the injured knee cannot be maintained with bracing. Surgical timing in acute multiple ligament injured knee cases depends upon the ligaments injured, injured extremity vascular status, skin condition of the extremity, degree of instability, and the patients overall health. Delayed reconstruction of 2–3 weeks may decrease the incidence of arthrofibrosis. It is important to address all components of the instability. Surgical treatment, in my experience, offers good functional results documented in the literature by physical examination, arthrometer testing, stress radiography, and knee ligament rating scales. Some low grade medial collateral ligament complex injuries may be amenable to brace treatment, while high grade medial side injuries require repair-reconstruction. Lateral posterolateral injuries are most successfully treated with surgical repair-reconstruction. Allograft tissue is my preference for these complex surgical procedures. The mechanical graft tensioning boot (Biomet Sports Medicine, Warsaw, Indiana) is very important in cruciate ligament graft tensioning, demonstrating improved posterior cruciate ligament reconstruction results in our series. Anatomic insertion sites, strong graft material, and secure fixation also contribute to successful results. A slow, deliberately progressive postoperative rehabilitation program is utilized to avoid overloading healing tissues. Both single and double bundle posterior cruciate ligament reconstruction provide successful results in PCL based multiple ligament knee reconstruction. These severe injuries also occur in children with open growth plates, and these pediatric injuries, in my experience, are also successfully treated with surgical intervention. Approximately 30% of multiple ligament knee injuries will develop degenerative joint disease. Patients requiring total knee replacements in this post multiple ligament injured knee surgical reconstruction population did not require constrained components. All total knee replacements in our patients were performed using standard posterior stabilized total knee components.

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Part II

Anatomy and Biomechanics

2

Anatomy and Biomechanics of the Cruciate Ligaments and Their Surgical Implications

Jeffrey D. Hassebrock, David E. Hartigan, Justin L. Makovicka, and Anikar Chhabra

2.1 Introduction

Multiple ligament knee injuries, although rare, are severe injuries that often result in the loss of the passive and active knee stabilizers as well as often being associated with the compromise of neurovascular structures. Treatment of these injuries is controversial, and results after surgery are often poor. After sustaining injuries to multiple ligaments, the knee is at a biomechanical disadvantage which poses a reconstructive and rehabilitative challenge to even the most experienced orthopedic surgeon. Surgeons performing reconstructions in patients with these injuries must have a complete understanding of the normal anatomy and biomechanics of the knee to optimize the timing of surgery, surgical approach, tunnel preparation, and the anatomic placement of grafts. This chapter outlines the anatomy and biomechanics of the cruciate ligaments and their surgical implications. The structure and form of the anterior and posterior cruciate ligaments, patterns of injury, structural properties of the cruciate ligaments and graft substitutes, functional biomechanics and interplay between the cruciate ligaments, and the surgical implications related to anatomic reconstruction of the anterior and posterior cruciate ligaments are all reviewed in detail.

2.2 Anatomy of the Cruciates

2.2.1 Anterior Cruciate Ligament Anatomy

The anterior cruciate ligament (ACL) extends from a broad area anterior to and between the intercondylar eminences of the tibia to a semicircular area on the posteromedial portion of the lateral femoral condyle. It not only prevents anterior translation of the tibia on the femur but also allows for normal helicoid knee action, thus preventing the chance for meniscal pathology. It is compiled of two bundles that are named based on their relative attachments from the tibia to the femur: an anteromedial bundle, which is tight in flexion, and a posterolateral bundle, which is more convex and tight in extension (Fig. 2.1) [1, 2]. While there are reports in the literature that suggest up to 26% of knees have microscopic single-bundle ACLs as well as knees that have a third intermediate bundle, it is now generally accepted that the native ACL consists of two discrete bundles [3, 4]. Anatomic studies have shown that the ACL ranges from 31 to 38 mm in length and 10–12 mm in width [5]. The anteromedial bundle on average measures 6–7 mm in width, while the posterolateral bundle measures 5–6 mm [3, 4].

Recently, the study of the ACL along with its osseous footprint and associated topographical anatomical landmarks has clarified the understanding of ACL anatomy. On the femur, the lateral intercondylar ridge (sometimes referred to as resident's ridge) and the lateral bifurcate ridge (also known as the cruciate ridge) are utilized to identify the discrete attachment points of the anteromedial and posterolateral bundles of the ACL on the lateral femoral condyle [6]. The attachment of the two ACL bundles is separated by the lateral bifurcate ridge just posterior to the lateral intercondylar ridge (Fig. 2.2). On the tibia, the medial and lateral intercondylar tubercles have been described in relation to the distal attachment sites for both bundles of the ACL (Fig. 2.3) [6, 7]. These osseous landmarks have become increasingly important reference points during arthroscopy and cruciate ligament reconstruction.

The ACL is intra-articular; however, it is encased in its own synovial membrane. The vascular supply of the ACL is derived from the middle genicular artery, as well as from

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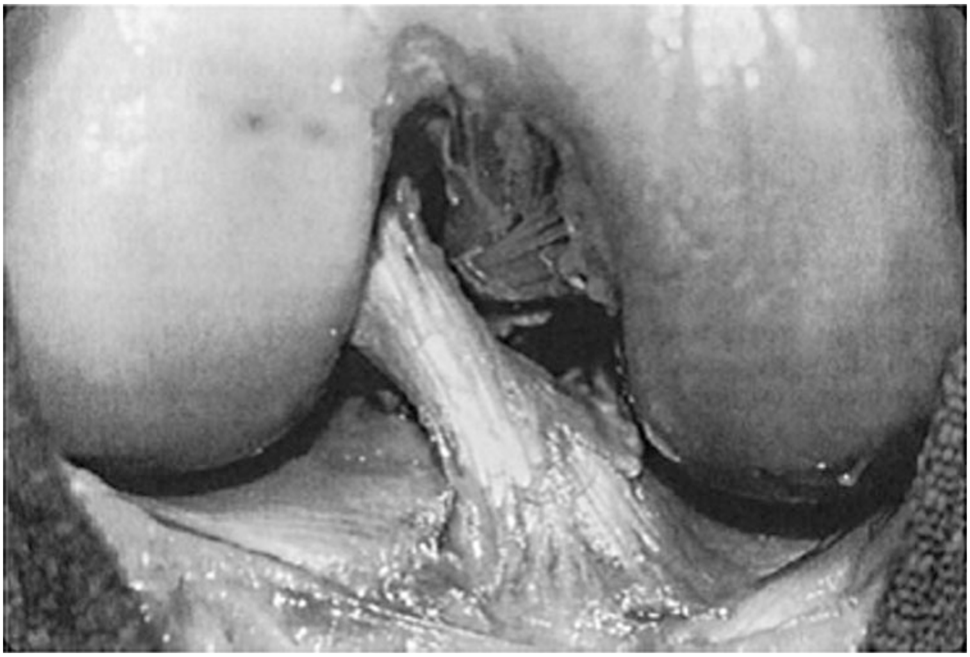


Fig. 2.1 Human anatomic specimen showing the complex helical arrangement of the ACL and its broad attachment

diffusion through its synovial sheath [8, 9]. The innervation of the ACL consists of mechanoreceptors derived from the tibial nerve and contributes to its proprioceptive role [10, 11]. Pain fibers in the ACL are virtually nonexistent, which explains why there is minimal pain after an acute ACL rupture prior to development of a painful hemarthrosis [9, 12].

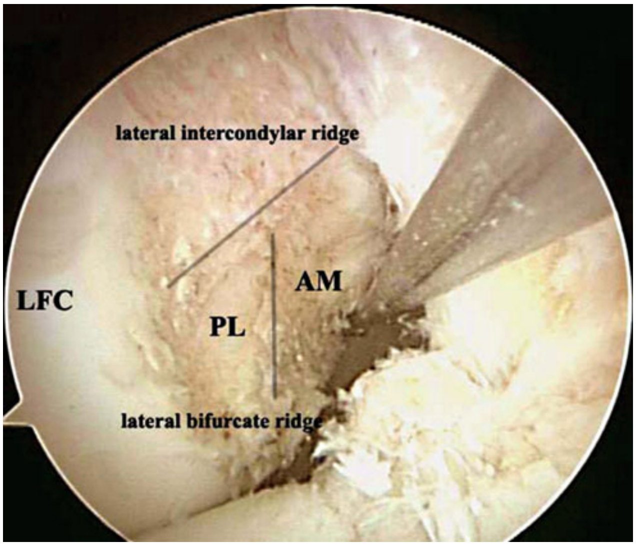


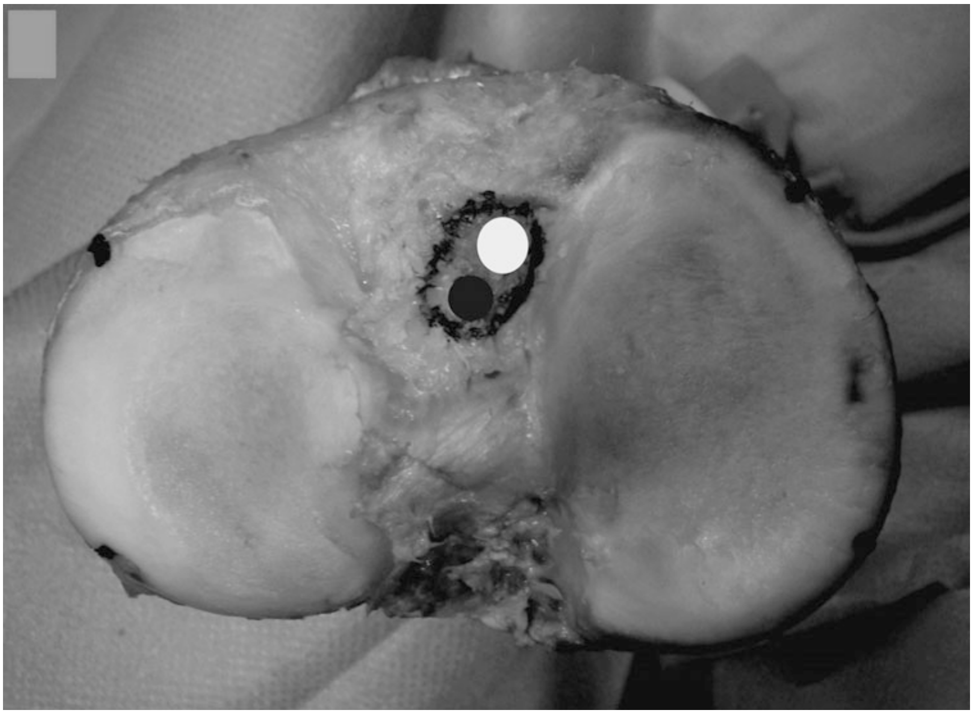
Fig. 2.2 Arthroscopic view of the lateral notch demonstrating the femoral attachment sites of the anteromedial (AM) and posterolateral (PL) bundles of the ACL in relation to cruciate ridge and resident's ridge

2.2.2 Posterior Cruciate Ligament Anatomy

The posterior cruciate ligament (PCL), like the ACL, is intra-articular and extrasynovial, with a much larger part existing extrasynovially. It extends from a broad semicircular area on the lateral aspect of the medial femoral condyle and projects to a sulcus that is posterior and inferior to the articular plateau of the tibia. The PCL consists of two bundles: a larger anterolateral bundle, which is tight in flexion, and a smaller posteromedial unit, which is tight in extension (Fig. 2.4) [13–15]. Its average length and width at its midportion, as reported by Girgis et al., are 38 and 13 mm, respectively [15, 16]. The PCL cross-sectional area is 50% greater than the ACL at the femur and 20% greater at the tibia. In contrast to the ACL, the PCL is larger at its femoral insertion than at its tibial insertion [13]. Two intra-articular accessory ligaments, the meniscofemoral ligaments, extend from the posterior horn of the lateral meniscus and insert anterior and posterior to the PCL onto the medial femoral condyle. These are termed the ligaments of Humphrey and Wrisberg, respectively, and are not present in all knees. They average approximately 22% of the entire cross-sectional area of the PCL and serve as secondary stabilizers to posterior tibial translation (Fig. 2.5) [13, 15].

As with the ACL, PCL attachments on the femur and tibia are more complex than originally understood, and there exists some variance between individuals. The femoral footprint for the PCL on average measures 209 mm^2 with

Fig. 2.3 Cadaveric specimen showing the attachment points of each bundle of the ACL onto the tibia



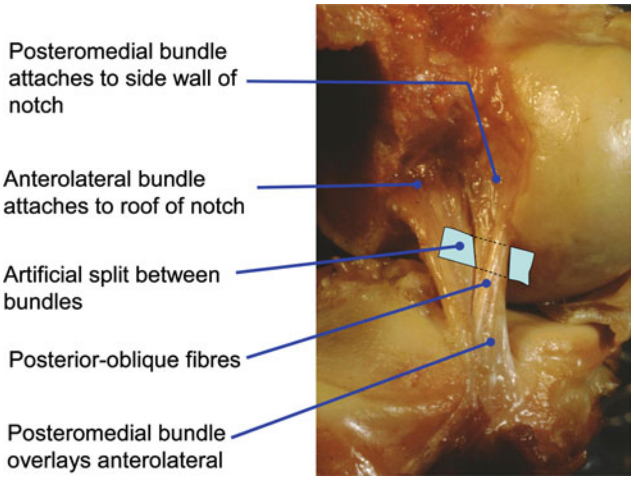


Fig. 2.4 Anterior view of cadaveric specimen showing the two bundles of the PCL and the attachment sites on the femur

the anterolateral portion measuring 118 mm^2 and posteromedial insertion measuring 90 mm^2 [17]. The medial intercondylar wall and medial bifurcate ridge have been described as osseous landmarks on the femur in relation to the site of attachment of the PCL. On the tibia, the surface area for the PCL attachment is 244 mm^2 on the posterior intercondylar fossa between the tibial plateaus one centimeter distal to the joint surface with the anterolateral and posteromedial insertions measuring 93 and 151 mm^2, respectively [18].

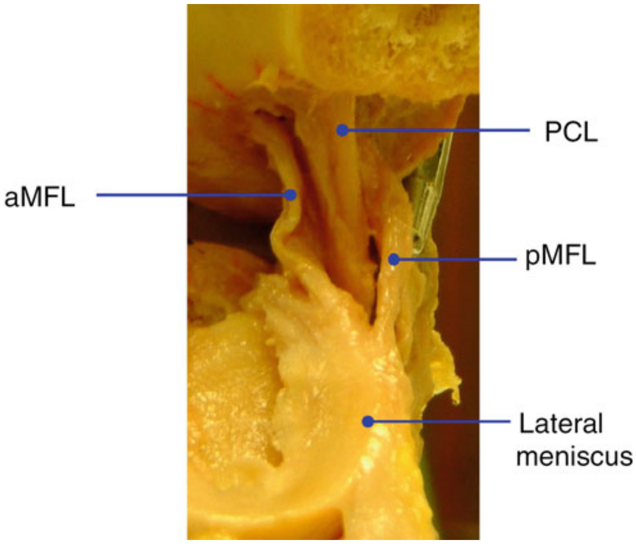


Fig. 2.5 Posterior view of knee showing the PCL attachment on the tibia and accessory ligaments located posteriorly

The vascular supply of the PCL is similar to that of the ACL since both are derived from the middle genicular artery. The vascular supply is mainly soft tissue-based, not osseous-based [19]. The innervation of the PCL is from the tibial and obturator nerves. As with the ACL, this serves primarily as a proprioceptive function [10].

2.2.3 Vasculature of the Knee

Branches of the femoral and popliteal arteries supply the knee and its structures. The descending geniculate artery is a branch of the femoral artery proximal to Hunter's canal and supplies the vastus medialis at the anterior border of the intermuscular septum. The medial and lateral geniculate arteries wrap around the distal femoral condyles and supply the menisci, while the middle geniculate artery supplies the cruciate ligaments [19]. The superior lateral geniculate artery is often injured during lateral release procedures, while the inferior lateral geniculate artery is often injured during posterolateral corner reconstructions (Fig. 2.6) [15, 20].

2.2.4 Injury Patterns of the Cruciate Ligaments

The injury pattern of both the cruciate ligaments and their discrete bundles has not been well studied. While the classic presentation and mechanism of injury leading to isolated ACL and PCL injuries are well described, combined multi-ligament injuries are often due to higher energy injuries. The anteromedial bundle of the ACL is more commonly torn from its femoral attachment site, whereas the posterolateral bundle is often torn at its midsubstance. While the majority of ACL injuries involve complete rupture of both bundles, 12% have a completely intact posterolateral bundle [21]. Injury patterns of the PCL are not as well described in the literature but can consist of injury to the posteromedial, anterolateral, or both bundles. As our understanding of the cruciate anatomy has increased, surgical implications of double-versus single-bundle repairs also increased in importance. However, recent reviews suggest that single- versus double-bundle ACL repairs demonstrate equivalent outcomes.

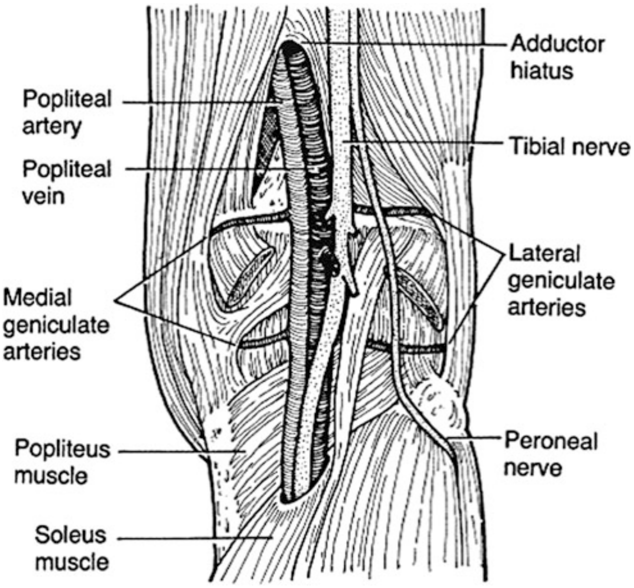


Fig. 2.6 The vasculature of the knee viewed posteriorly. The geniculate arteries, the descending branch of the lateral circumflex femoral artery, and the recurrent branches of the anterior tibial artery form the anastomosis around the knee that connects the femoral, popliteal, and anterior tibial arteries

2.3 Biomechanics of the Cruciates

2.3.1 Biomechanics and Kinematics of the Knee Joint

The goal of all joints is to allow for motion of the bony segments surrounding the joint, while withstanding the loads against gravity imposed by these movements. Biomechanics is defined as the science of the action of forces on the living body. The complex interaction of femur, tibia, and patella allows the knee joint to withstand tremendous forces during normal phases of ambulation. Kinematics is defined as the study of body motion without regard for the cause of that motion [20]. Six planes of motion exist for the knee: anterior/posterior translation, medial/lateral translation, cephalad/caudad translation, flexion/extension, internal/external rotation, and varus/valgus angulation [22]. The knee joint must provide a normal amount of motion without sacrificing stability during static activities such as standing to more dynamic functions such as walking, jogging, running, pivoting, and ascending or descending stairs. These goals are achieved by the interaction of the osseous anatomy, articular surface, ligaments, menisci, and surrounding musculature about the knee [23]. Changes in any of these components can alter the biomechanics of the knee joint, greatly increasing the loads and functional demands placed on the remaining structures. Understanding the normal interactions of these structures is necessary prior to attempting any reconstructive procedures.

2.3.2 Passive Motion of the Knee

The primary motion of the knee is flexion and extension. The knee joint averages from 0° to 135° of flexion in the sagittal plane [2]. The passive motion of the knee joint is dictated by the anatomy of the articular surfaces and the surrounding soft-tissue capsule and ligaments [24]. As a result of the distal asymmetry between the medial and lateral femoral condyles, motion between full extension and 20° of flexion is accompanied by rolling of the lateral femoral condyle posteriorly more than the medial femoral condyle. This allows the femur and tibia to unlock from full extension and occurs without the assistance of any dynamic muscle involvement [23]. After 20° of flexion, passive flexion of the knee joint occurs by a sliding motion, with relative tibial movement on the femur [2].

2.3.3 The Functional Biomechanics of the Cruciate Ligaments

Of the knee ligaments, the cruciates are the most important in providing passive restraint to anterior/posterior knee motion. If one or both of the cruciates are disrupted, the biomechanics during ambulatory activities may be disrupted. The interplay between the cruciate ligaments, the collateral ligaments, and the other static and dynamic stabilizers of the knee is complex, and an appreciation for the osseous, articular, meniscal, tendinous, and other soft-tissue components that contribute to overall knee motion and stability is important.

2.3.4 Biomechanics of the ACL

The primary function of the ACL is to prevent anterior translation of the tibia. It acts as a secondary stabilizer against internal rotation of the tibia and valgus angulation at the knee [25, 26]. In full extension, the ACL absorbs 75% of the anterior translation load and 85% between 30° and 90° of flexion [27]. Loss of the ACL leads to a decreased magnitude of this coupled rotation during flexion and an unstable knee. Many studies have been performed to determine the biomechanical properties of the ACL. However, uniform testing with regard to strain rates and orientation is impossible. Several recent studies have demonstrated that the anteromedial bundle has a higher maximum stress and strain than the posterolateral bundle [28]. The tensile strength of the ACL is approximately 2200 N, but is altered with age and repetitive loads [20, 29, 30]. As the magnitude of the anterior drawer force increases, the in situ force of the ACL also increases [5].

2.3.5 Biomechanics of the PCL

The primary function of the PCL is to resist posterior translation of the tibia on the femur at all positions of knee flexion [31, 32]. It is a secondary stabilizer against external rotation of the tibia and excessive varus or valgus angulation at the knee [33]. The anterolateral band is tight in flexion and is most important in resisting posterior displacement of the tibia in 70°–90° of flexion. The posteromedial portion is tight in extension; thus, it resists posterior displacement of the tibia in this position. While the PCL is the primary restraint to posterior translation of the tibia, this function is greatly enhanced by other structures [32, 34]. Recent cadaveric studies have suggested that excessive posterior translation of the tibia requires injury to one or more secondary structures in addition to the PCL [35].

Isolated PCL ruptures may cause a mild increased in external rotation at 90° of knee flexion; however, they do not greatly alter tibial rotation or varus/valgus angulation because of the intact extracapsular tissues and ligaments. With both PCL and posterolateral corner injuries, there is a marked increase in tibia external rotation because of the lack of supporting restraints [36]. Harner et al. demonstrated that the anterolateral component had a greater stiffness and tensile strength than the posteromedial bundle and the meniscofemoral ligaments [13, 37]. Furthermore, Fox et al. demonstrated that at varying degrees of knee flexion, different in situ forces existed. At 0°, the PCL had an average tensile strength of 6.1 N, while at 90°, it had a tensile strength of 112.3 N. The posteromedial bundle attained a maximum force of 67.9 N at 90° of knee flexion, while the anterolateral bundle reached a maximal force of 47.8 N at 60° [38]. Understanding these relationships is critical in reconstructive surgery to ensure that the grafts are tensioned properly.

In addition to its known role in the sagittal plane, the PCL influences knee motion in the frontal plane. This occurs because the PCL inserts onto the lateral aspect of the medial femoral condyle and is oriented obliquely. This orientation of the PCL aids in the articular asymmetry between the medial and lateral femoral condyles and permits adequate tensioning of the PCL during the rolling of the lateral femoral condyle posteriorly in early flexion.

The popliteus muscle aids the PCL in resisting posterior tibial translation and enhancing stability. Harner et al. demonstrated that in a PCL-deficient knee, the popliteus muscle reduced posterior translation of the tibia by 36% [39].

2.3.6 The Interplay of the Cruciate Ligaments

The complex interaction between ACL and PCL at varying degrees of flexion and extension helps account for the dynamic stability of the knee joint. The length and tension of the ACL and the PCL change during flexion and extension owing to their asymmetric insertion sites. In full extension, the ACL is taut, while the PCL is relatively lax. When a person is standing with the knee in hyperextension, the joint is passively stable, with little need for muscular support. As the knee flexes, the posterolateral portion of the ACL becomes lax, while the PCL tightens, especially the anterolateral bundle. Stability is more tenuous between 20° and 50° of flexion since neither cruciate ligament is very taut. The change in the orientation of the ACL and PCL fibers during knee flexion allows for dynamic stability in the sagittal plane. With increasing flexion, the ACL changes from a vertical position to a more horizontal orientation in relation to the joint line. The PCL's orientation is opposite to the ACL's during flexion and extension.

Consequently, as the knee reaches higher degrees of flexion, the PCL becomes more important in preventing distraction of the joint [23, 40]. This interplay between ACL and PCL is often referred to as the four-bar cruciate linkage system (Fig. 2.7) [41]. The intersection of these ligaments demonstrates that the center of joint rotation moves posterior with knee flexion. This allows for both sliding and rolling movements of the femur during flexion and prevents the femur from rolling off the tibial plateau at extremes of flexion [2].

During the different phases of the gait cycle, the force vectors about the knee in the sagittal plane change. The mechanical loads across the knee joint are altered by changes in foot position as well as by the intensity and type of ambulatory activity. During normal ambulation, a joint reactive force of two to five times the body weight is produced; this force is up to 24 times the body weight during running. Dynamic muscle forces help to balance these functional loads and joint reactive forces, especially as the knee flexes and the weight-bearing axis shifts from a position anterior to the knee joint to one posterior [24, 42]. If a ligamentous, muscular, and/or bony injury occurs that alters this delicate balance of forces, the joint is not as effective at withstanding these loads, hastening the degenerative process of the knee [23].

The dynamic actions of the surrounding muscles are restrained by the cruciate ligaments during knee flexion and extension. The quadriceps muscles, by way of the patellar tendon, ultimately insert onto the anterior tibia, and, consequently, the tibia is translated anteriorly by the extensor mechanism and constrained by the pull of the ACL. The biomechanical advantage is maximized when the center of rotation of the knee joint is perpendicular to the joint line. If anterior translation occurs in the sagittal plane during ambulation, as with ACL deficiency, the center of rotation is altered, and the resultant increase in forces across the knee joint places increased stress upon the secondary restraints. The moment arm of the knee extensor apparatus is decreased, causing an increase in the muscle forces necessary to maintain balance across the knee joint. This leads to an increase in joint reactive forces and, ultimately, stressed or injured supporting structures [43]. In an ACL-deficient knee, increased stress is placed on the secondary restraints of anterior translation, including the menisci and the surrounding soft-tissue capsule. When the quadriceps becomes atrophied after an ACL rupture, the extensor pull on the tibia lessens, decreasing the stresses placed on the secondary stabilizers.

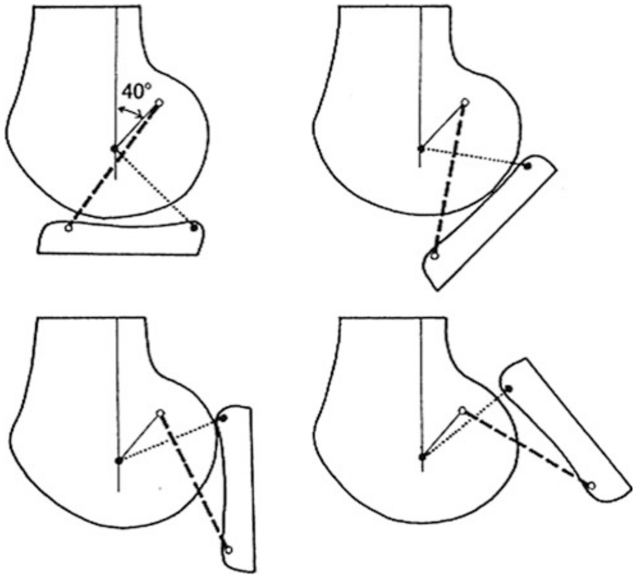


Fig. 2.7 The four-bar cruciate linkage system

The screw-home mechanism again demonstrates the importance of the dynamic muscles in knee motion. As the lateral femoral condyle rolls posteriorly in early flexion, the moment arm of the extensor apparatus increases (Fig. 2.8). This gives a mechanical advantage to the knee in stair climbing and running, when there is maximal demand on the knee joint [40].

2.4 Surgical Implications of Cruciate Anatomy and Biomechanics

2.4.1 The Biomechanics of Ligament Reconstruction

As the incidence of multiple ligament knee injuries increases, the order and necessity of the reconstruction of the ACL, PCL, and the posterolateral corner in combined injuries have become controversial. Harner et al. demonstrated that in isolated PCL injuries, reconstruction led to an average posterior tibial translation of 1.5 and 2.4 mm at 30° and 90°, respectively. These numbers increased to 6.0 and 4.6 mm if the only PCL was reconstructed in a combined PCL–posterolateral corner injury. In addition, external rotation and varus angulation increased 14° and 7°, respectively. This study supports the reconstruction of both ligaments at the same setting in combined PCL–posterolateral corner injuries [38, 39]. If the ACL is also disrupted, it should be reconstructed either primarily or in a staged procedure, but the PCL and posterolateral corner should be considered to be a higher priority [29]. The specific surgical treatments of ACL- and PCL-based multiple ligament injured knees and treatment approaches are reviewed in following chapters.

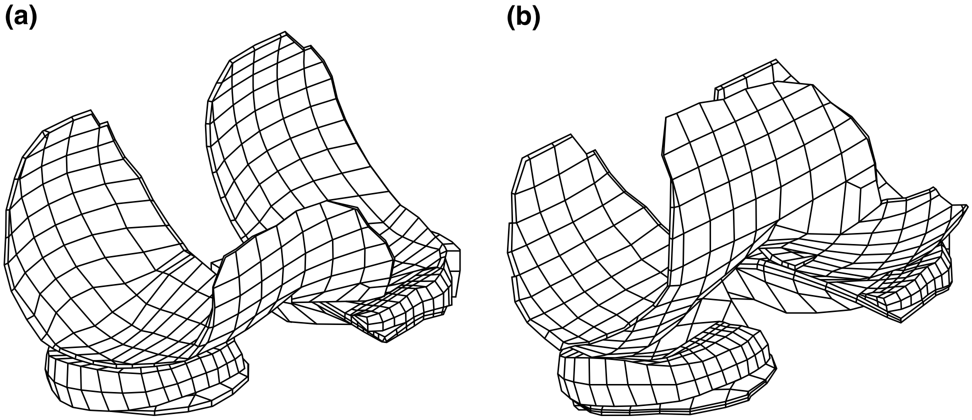


Fig. 2.8 Depiction of the knee in 0 (**a**) and 30 (**b**) degrees of flexion illustrating femoral rotation related to the tibia in early flexion

2.4.2 Structural Properties of Ligaments and Commonly Used Grafts

The maximal stress that a ligament or graft can withstand prior to failure has been studied extensively. The ACL has been reported to have an average maximal tensile stress to failure of between 1725 and 2500 N. Many studies have found the PCL to have significantly more tensile strength than the ACL, but this is controversial [29, 44].

Cooper et al. have shown that the tensile strength of grafts taken from the central third of the patellar tendon average 4389 N for grafts 15 mm wide and 2977 N for grafts 10 mm wide. Twisting the graft 90° increased its strength approximately 30%. This study advocates using 10-mm central-third patellar tendon grafts for ACL reconstruction to avoid the risks of notch impingement and patellar fracture encountered with larger grafts [45]. See Table 2.1 for comparison of mechanical strength of native cruciates and commonly utilized autografts (Table 2.1) [46].

Over time, wear and degeneration cause ligaments and grafts to decrease in strength. This has been demonstrated in multiple studies by means of ACL and graft tensile tests. The biologic effects of aging, maturation, and immobilization may also affect the viscoelastic properties of a ligament or graft, leading to a decrease in biomechanical strength [22, 47]. Recent reviews of graft properties have demonstrated superior outcomes of autograft when compared to allograft for primary ACL reconstruction and minimal difference between soft tissue and BTB autografts [48–50].

2.4.3 Graft Tensioning

Cruciate anatomy has many surgical implications related to graft tensioning during ACL and PCL reconstruction. High amounts of tension through the graft can result in poor results after surgery due to excessive wear through the tunnels, impaired vascularity, and restricted range of motion [51–57]. Too little tension may result in continued postoperative laxity of the knee. Generally, most surgeons will statically precondition the graft on the back table and/or cyclically precondition the graft in the knee prior to final fixation. Graft tensioning during cruciate reconstruction is also heavily dependent on tunnel placement. The importance of accurate tunnel placement in single- or double-bundle reconstructions or in revision reconstruction situations of the ACL and PCL cannot be understated [48].

Table 2.1 Tensile strength comparison

Material	Maximum load (N)
Anterior cruciate ligament	2000
Posterior cruciate ligament	4000
Bone–patellar tendon–bone (10 mm)	2900
Semitendinosus and gracilis (2-strand)	1900
Semitendinosus and gracilis (4-strand)	2800
Quadriceps (10 mm)	2100

Table comparing tensile strength of the native ACL, PCL, patella tendon autograft, doubled hamstring, quadrupled hamstring autografts, and quadriceps autograft

2.4.4 Tunnel Placement for Cruciate Reconstruction

Cadaver and computed tomography studies have led to a different understanding of cruciate ligament anatomy and relationships, osseous landmarks, and anatomical reference points for accurate placement of grafts and tunnels during ACL and PCL reconstructions [6, 17, 18]. The existence of two discrete attachment points for each bundle of both the ACL and PCL is now well understood. This has prompted increased focus on the surgical implications of reconstructing injured cruciate ligaments anatomically, placing emphasis on proper tunnel placement even in single-bundle repairs [9, 48, 49].

An abundance of studies have demonstrated the varying effects that tunnel placement and orientation or the addition of a second tunnel has on ACL or PCL graft tension [48, 58–60]. Historically, the most common technical mistake has been to place both femoral and tibial tunnels too far anteriorly. With newer cadaveric and radiologic studies that have clarified the anatomic relationships between the ACL, PCL, and their corresponding bony sites of attachment, the subtleties of accurate tunnel placement during reconstruction are clearer.

Efforts have been made recently to reconstruct both cruciates more anatomically utilizing double-bundle techniques and creating multiple tunnels when reconstructing multiple ligament injured knees. However, drilling of multiple tunnels for double-bundle reconstruction is technically demanding and requires good patient selection and technical skill to avoid complications related to its use. While these techniques have gained popularity, studies have failed to show clinical superiority with a double-bundle compared to tradition single-bundle ACL reconstruction. The outcomes of double-bundle PCL reconstruction are currently still under investigation [7, 9].

2.5 Conclusion

Knee dislocations are severe injuries because they may result in disruption of multiple ligaments, surrounding musculature, and neurovascular structures [61]. Diagnosis and acute treatment can be difficult, and the varying techniques that are utilized to reconstruct the cruciates can be controversial. These injuries, owing to ligamentous disruption and surrounding soft-tissue damage, may lead to a biomechanical disadvantage of the knee joint prior to or after reconstruction attempts are made. To prevent abnormal translation and angulation in the reconstructed knee, surgeons performing reconstructions in patients with multiple ligament injuries must have a complete understanding of the normal anatomy and biomechanics of the ACL and PCL, as well as the entire knee. This knowledge should help optimize the timing of surgery, the order of ligamentous reconstruction, the anatomic placement of grafts, and the rehabilitation of the surrounding musculature.

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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.

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

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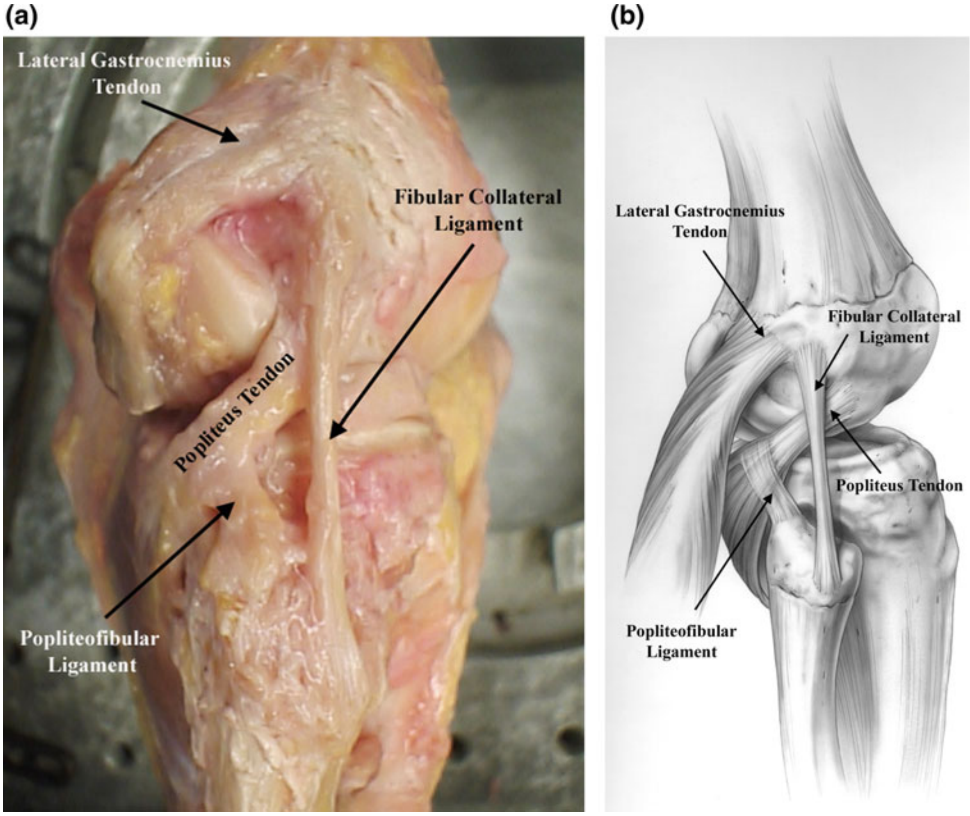

Fig. 3.1 *Right knee* **a** dissection and **b** illustration demonstrating the fibular collateral ligament, popliteofibular ligament, popliteus tendon, and lateral gastrocnemius tendon. Figure used with permission from LaPrade et al. [7], SAGE Publications

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

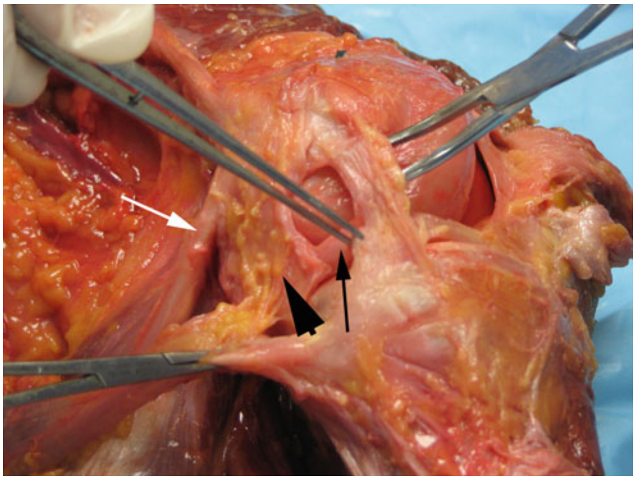

Fig. 3.2 A photograph of a dissection of the medial aspect of the *left knee* is shown. The meniscofemoral portion of the deep medial collateral ligament is seen elevated by the curved hemostat, and the meniscotibial portion is grasped by the forceps. The central arm of the posterior oblique ligament (*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*)

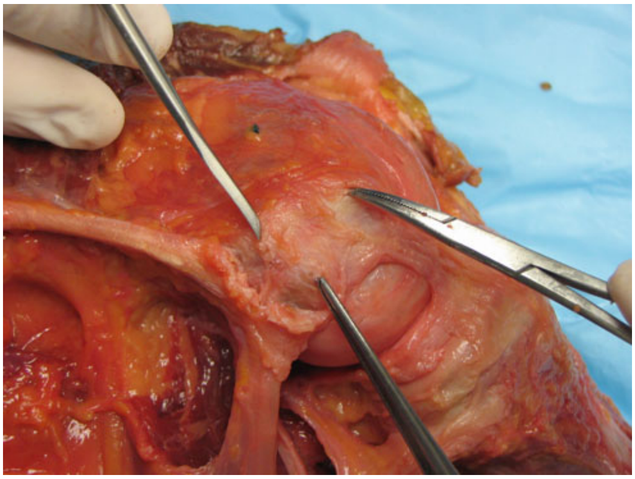

Fig. 3.3 A photograph of a dissection of the medial *left knee* demonstrating three main bony landmarks. The adductor tubercle is located posterosuperiorly (chisel), the gastrocnemius tubercle posteroinferiorly (Kocher), and the medial epicondyle anteriorly (curved hemostat)

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.

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).

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

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

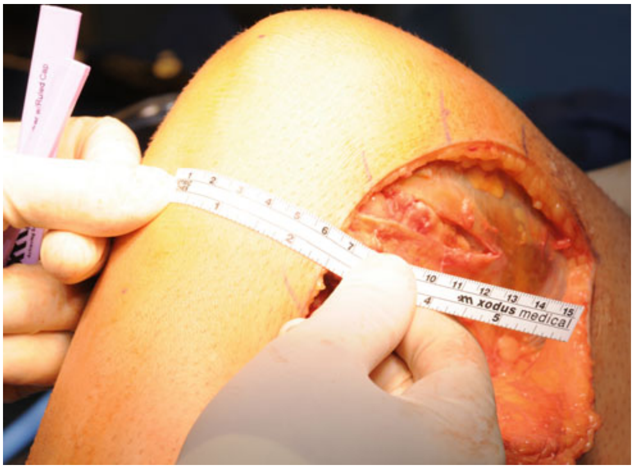

Fig. 3.5 An intraoperative photograph demonstrating a planned 6-cm skin bridge is shown. This technique is utilized for patients with a planned patellar tendon autograft harvest for anterior cruciate ligament reconstruction

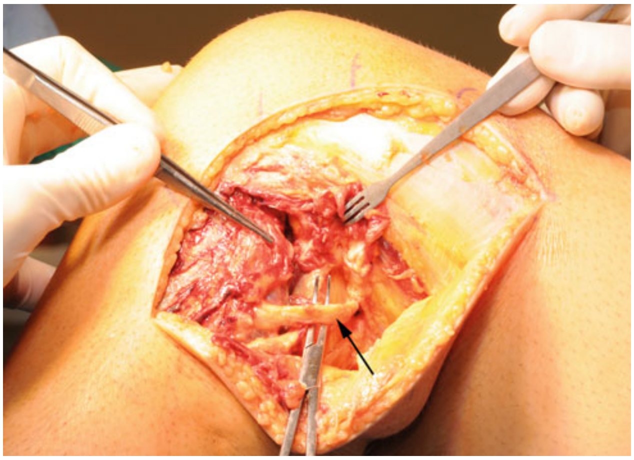

Fig. 3.6 An intraoperative photograph of the lateral side *left knee* is shown. The common peroneal nerve (*arrow*) is visualized following neurolysis

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

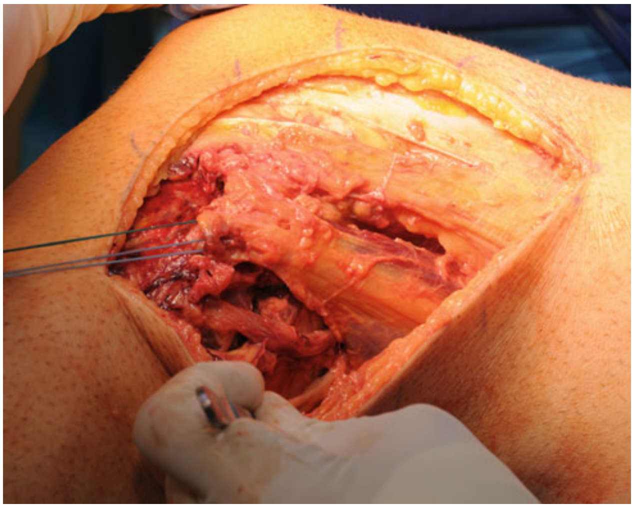

Fig. 3.7 An intraoperative photograph of the lateral side of the *left knee* is shown in a patient with an avulsion of the biceps femoris tendon. A tag stitch was placed in the distal aspect of the tendon to allow a proximal release and reapproximation to its distal attachment

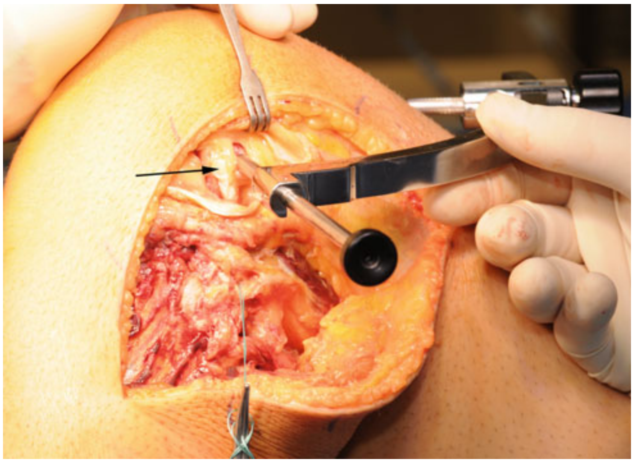

Fig. 3.8 An intraoperative photograph of the lateral side of the *left knee* is shown. A tag stitch was placed in the distal aspect of the fibular collateral ligament (FCL); the free end is wrapped around a curve hemostat, and traction is used to allow visualization of the femoral attachment of the FCL. 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

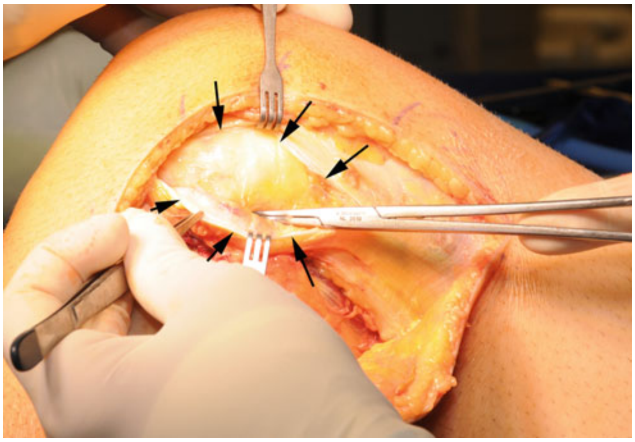

Fig. 3.9 An intraoperative photograph of a splitting incision of the iliotibial band is shown. The anterior and posterior borders (*arrows*) of the iliotibial band incision are retracted with surgical rakes

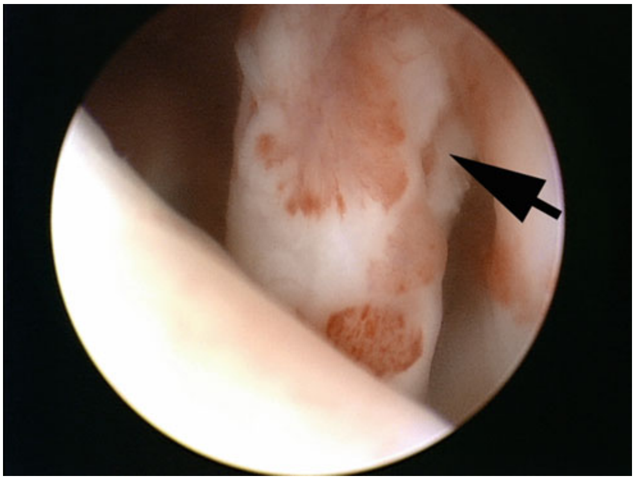

Fig. 3.10 An arthroscopic photograph of a torn popliteus tendon (*arrowhead*) is demonstrated

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

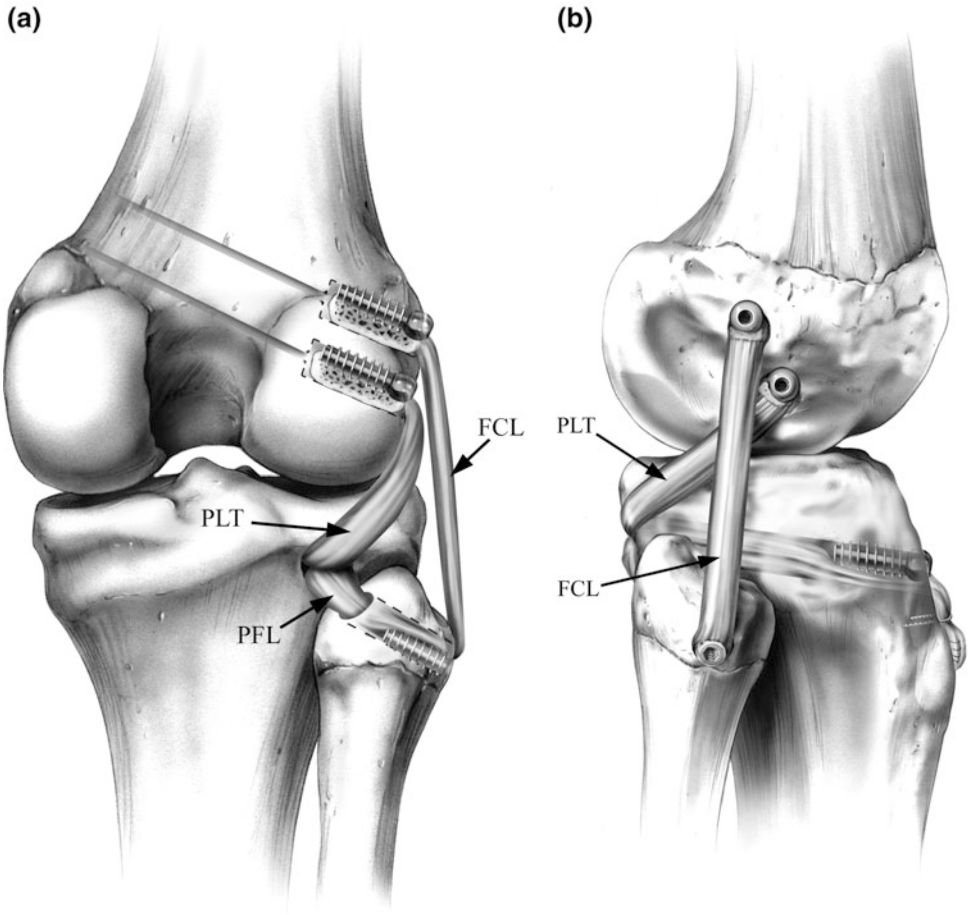

Fig. 3.11 An illustration of a **a** posterior view and **b** lateral view of an anatomic posterolateral corner reconstruction is shown. The two femoral tunnels with the fibular collateral ligament (FCL) and popliteus tendon (PLT) grafts with bone blocks and the interference screws are demonstrated. 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

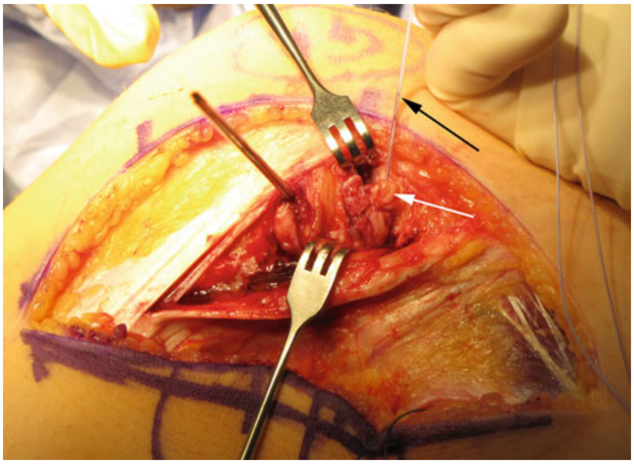

Fig. 3.12 An intraoperative *right knee* photograph is shown with a splitting incision of the iliotibial band for exposure of the femoral attachments of the fibular collateral ligament and popliteus tendon. The avulsed popliteus tendon (*white arrow*) and passing sutures (*black arrow*) are demonstrated.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

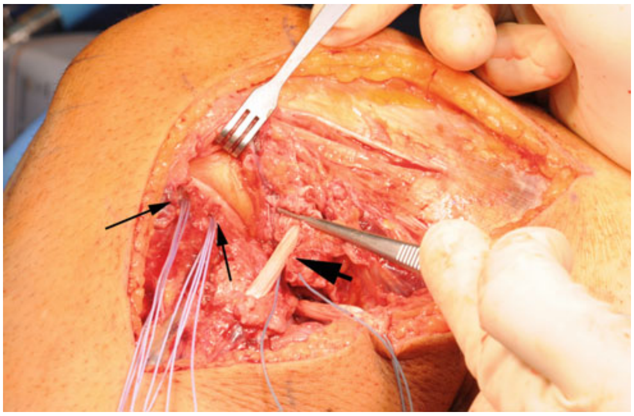

Fig. 3.13 An intraoperative photograph of a suture anchor repair (*arrows*) of a lateral capsule tear off tibia is shown. A fibular collateral ligament reconstruction graft is also visualized (*arrowhead*)

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

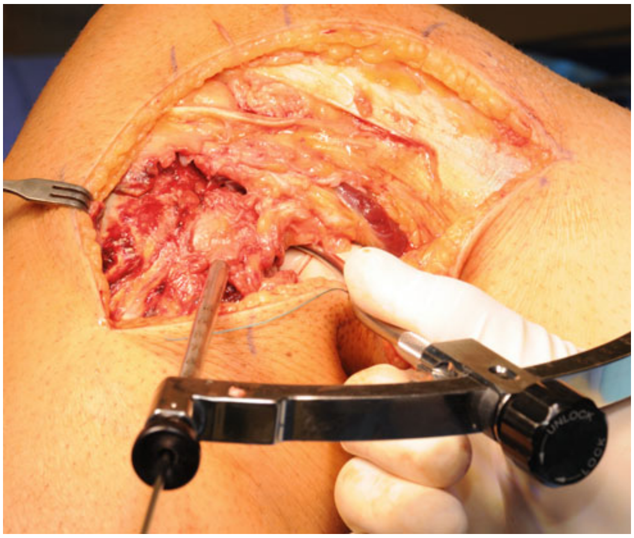

Fig. 3.15 An intraoperative photograph of a *left knee* is shown. A cannulated cruciate ligament tunnel-aiming device is used for placement of a K-wire through the fibular head

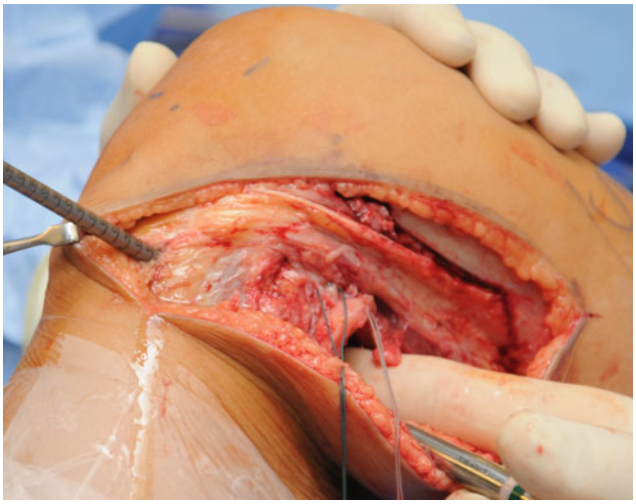

Fig. 3.16 An intraoperative photograph of a *left knee* is shown. A 9-mm reamer is used to create the tibial tunnel for a posterolateral corner reconstruction. Posteriorly, the neurovascular bundle is protected

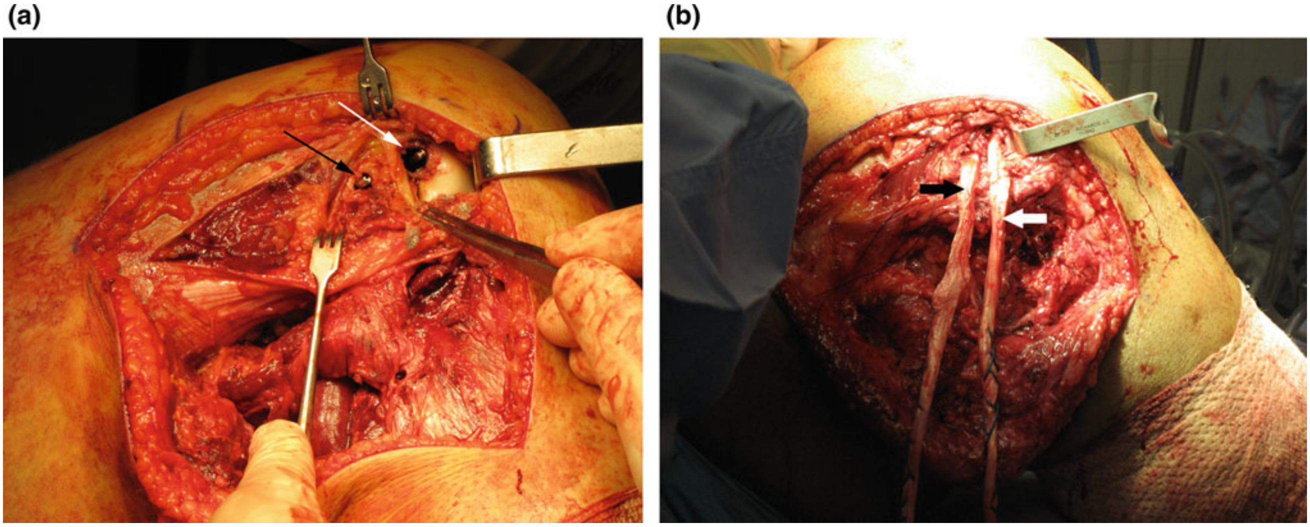

Fig. 3.17 Intraoperative photographs of a *right knee* posterolateral corner reconstruction are shown. **a** Eyelet pins are shown in the femoral attachment sites of the popliteus tendon (*white arrow*, reamed) and fibular collateral ligament (*black arrow*, not yet reamed). **b** The popliteus tendon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

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

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).

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

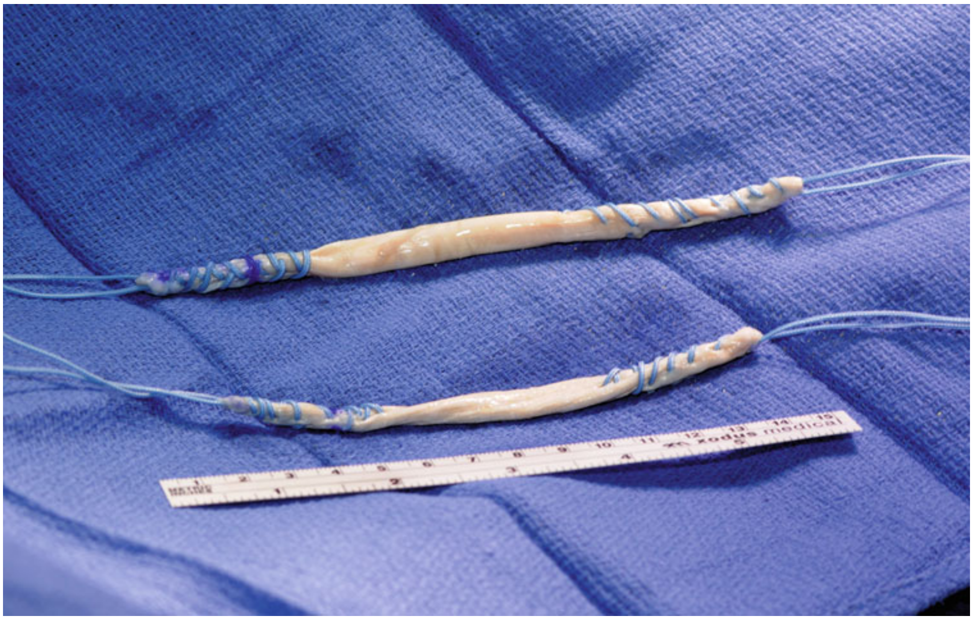

Fig. 3.19 A photograph of the 16- and 12-cm grafts for reconstruction of the superficial medial collateral ligament and posterior oblique ligament, respectively, is shown. The tendons are sized for 7-mm tunnels and tubularized with nonabsorbable suture at each end

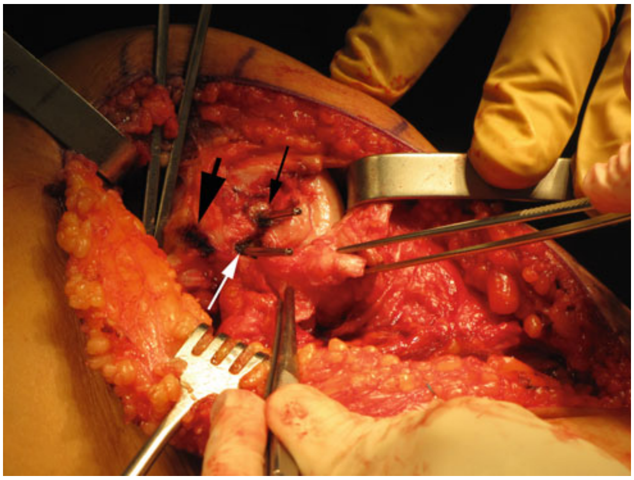

Fig. 3.20 An intraoperative photograph of the medial aspect of *left knee* is shown. The pins placed in the planned locations for the superficial medial collateral ligament (*black arrow*) and posterior oblique ligament (*white arrow*) tunnels are visible. Also, the location of the adductor tubercle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

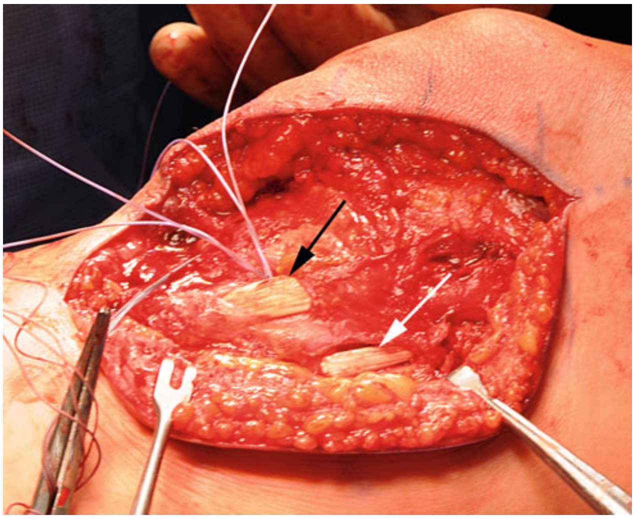

Fig. 3.21 An intraoperative photograph of the medial aspect of the *right knee* is shown. The superficial medial collateral ligament (*black arrow*) and posterior oblique ligament (*white arrow*) grafts are demonstrated

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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Part III

Diagnosis and Evaluation of the Multiple Ligament Injured Knee

4

Initial Assessment in the Acute and Chronic Multiple-Ligament-Injured Knee

Graeme Hoit, Ujash Sheth, and Daniel B. Whelan

4.1 Physical Examination

4.1.1 Acute Presentation

Multi-ligament knee injuries (MLKIs) typically occur as a result of supraphysiologic force passing through the knee joint, which may or may not be associated with a knee dislocation [1, 2]. Accordingly, prompt examination of patients with a suspected MLKI is essential to rule out associated serious neurovascular injury, joint malposition or an open dislocation. These patients routinely have concomitant multisystem traumatic injuries and should be triaged using the Advanced Trauma and Life Support protocol [3, 4]. Following initial stabilization and required resuscitation of the trauma patient with suspected knee dislocation, prompt determination of the limb viability is of utmost importance. Thereafter, examination of the knee can proceed.

As with other musculoskeletal examination, a framework of inspection, palpation, the range of motion, neurovascular assessment and special testing should be followed to ensure an organized and comprehensive approach to the injured joint.

Beginning with inspection, a thorough visual examination of the affected leg should rule out any obvious evidence of active bleeding, gross malalignment, open injury, ecchymosis, skin mottling or blisters. Despite the high energy mechanism, knee dislocations can occasionally present as a relatively benign looking limb. Spontaneous reduction of the dislocated knee is thought to happen 50% of the time prior to ER presentation [5, 6]. Additionally, compromise of the joint capsule can allow synovial fluid and hemarthrosis to leak into the surrounding tissues, resulting in the absence of an effusion [7]. In those whose injury is due to a posteriorly directed force on the tibia, such as from a dashboard-type mechanism, bruising and hematoma over the anterior aspect of the tibia may be seen and is commonly associated with a PCL and posterolateral corner (PLC) injury [8]. Open knee dislocations occur with an incidence of between 5 and 17% and require surgical washout on an urgent basis to prevent associated infection and complications [9]. In cases with an open joint, appropriate systemic antibiotic therapy should be initiated as soon as possible. Another important physical exam finding is the presence of a 'dimple sign' (Fig. 4.1), which can indicate a potentially irreducible knee dislocation that may require an open reduction. This results from a posterolateral rotary-type mechanism that has caused the MCL and joint capsule to become incarcerated in the joint, providing a pinched appearance to the medial skin and a potential soft tissue block to reduction (Fig. 4.2).

Moving on to palpation, a standard assessment for points of tenderness and evaluation of a potential effusion can help identify the possibility of knee or ligamentous injury. Tenderness or presence of crepitus over the fibular head can indicate an LCL avulsion fracture and lateral sided injury. Crepitus on the medial side may indicate a medial-sided tibial plateau fracture, often associated with knee dislocation. The prominence of the femoral condyles posteriorly can indicate an anterior knee dislocation and associated ACL injury. Conversely, a tibial sag can indicate a posterior knee dislocation and associated PCL injury, also particularly worrisome for neurovascular injury.

The range of motion testing can be difficult in the acute setting of an MLKI. It often requires several weeks of physiotherapy before flexion can be restored to 90°, which is required for proper evaluation of PCL integrity. Another important part of the initial examination is to assess for intact

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Fig. 4.1 Dimple sign in an irreducible knee dislocation

extensor mechanism. Although associated extensor mechanism injuries are rare, the morbidity of extensor mechanism compromise necessitates early diagnosis and treatment.

Vascular assessment of the leg is of critical importance in the setting of an MLKI given the associated risk to limb viability. A recent systematic review of knee dislocations concluded 18% of patients had a vascular injury, of which 80% required surgery and 12% required amputation [10]. Should the knee be found to be dislocated, vascular assessment should be performed and documented before and after reduction. Hard signs of vascular injury, such as active haemorrhage, distal ischemia and expanding hematoma are clear indications to urgently involve a vascular surgeon and obtain vascular imaging in the form of a CT angiogram. Softer signs of vascular injury can also be used to guide clinical decision making and include limb colour, warmth and capillary refill. Palpation of both the dorsalis pedis and posterior tibial pulse should be documented and compared to the contralateral side. Despite some evidence that the presence of palpable distal pulses can be used to rule out vascular injury in the setting of a knee dislocation [11, 12], many surgeons advocate for further investigation in the form of arterial–brachial indices (ABIs) for all patients [13]. They may refer to contradictory evidence that suggests the presence of collateral circulation may be enough to provide normal pulses in the setting of a vascular injury [14–16]. There is some evidence to suggest that non-occlusive intimal tears of the popliteal artery can initially present with a normal physical exam but go on to cause an occlusive thrombus 48–72 h after the time of injury [17, 18]. We would strongly suggest that in the presence of a knee with a suspected multi-ligament injury an ABI be performed as a screening tool if ANY physical sign of vascular compromise is encountered at ANY time during the assessment. For this test, a Doppler ultrasound is used to measure the systolic pressure in the affected leg at either the dorsalis pedis or posterior tibial artery by placing and inflating blood pressure cuff proximal to the ankle. This value is then divided by the systolic pressure of the ipsilateral arm. A value of >0.9 is a reliable marker for normal arterial flow [12, 19]. This value can be falsely inflated in individuals with peripheral arterial disease [20]. In the setting of an abnormal or inconclusive ABI, a CT angiogram should be performed.

Neurologic examination in the setting of an MLKI can be difficult in trauma patients with associated head injuries or those sedated or intoxicated during their initial assessment. Peroneal nerve injury is a frequent complication of MLKI (14–25% incidence), especially in the setting of a posterior

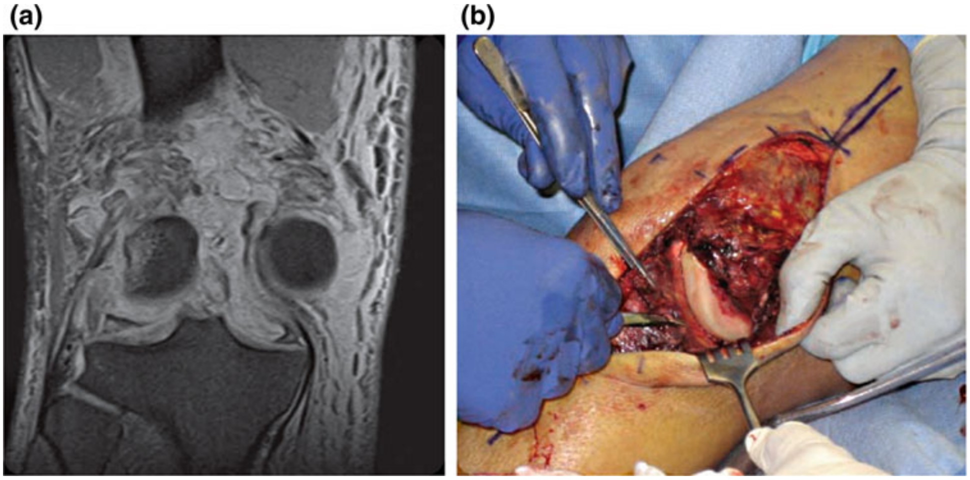

Fig. 4.2 (**a**) Coronal MRI and (**b**) Intraoperative photo demonstrating 'button-holing' of the medial femoral condyle through the medial capsule with the incarceration of the MCL and medial capsule in the joint preventing reduction. Courtesy of Robert G. Marx, MD, with permission

dislocation with damage to other posterolateral structures (45% incidence) [7, 21–23]. The tibial nerve is less frequently injured [24]. Motor and sensory functions of both nerves should be examined and documented, and findings from this exam can help prognosticate chance of recovery. Favourable prognostic features for peroneal nerve recovery are younger age and the absence of associated fracture [25]. A systematic review demonstrated that 87% of partial common peroneal nerve injuries fully recovered compared to 38% of complete injuries [26]. Repeat examination should occur and be documented if a reduction maneuver is required in the setting of a dislocation to rule out iatrogenic injury. In some patients, recovery can take up to a year following injury.

Finally, special tests of the knee should be performed to assess knee stability and ligamentous structures including the ACL, PCL, MCL, LCL, PLC and posteromedial corner (PMC). The Lachman and posterior drawer tests have proven to be the most sensitive for isolated ACL and PCL injuries, respectively [27]. However, in the setting of an MLKI, drawer tests may be difficult to interpret. Step-off between the medial tibial plateau and medial femoral condyle, or tibial sag, can be an important marker of PCL injury [28] (Fig. 4.3). In the setting of a PCL injury, one might appear to have a positive anterior drawer test due to posterior subluxation of the tibia as a start point. Therefore a combination of step-off, drawer and Lachman testing can be combined to assess the cruciate ligaments.

Assessment of the MCL and LCL are performed with controlled valgus and varus forces, respectively. This is best performed at full extension and then again 30° of flexion and should be compared with the contralateral side to rule out pre-existing symmetric laxity. A valgus stress that produces a significant medial opening in an extended position indicates an MCL, PMC combined injury; whereas a normal exam in an extended position with an opening at 30° of flexion indicates an isolated MCL injury [29]. Similarly lateral opening with varus stress in an extended position indicates injuries to the LCL, lateral capsule and PCL; whereas a normal extended exam with an opening at 30° of flexion indicates and isolated LCL injury [7].

The Slocum test is a modification of the anterior drawer that can help evaluate anteromedial and anterolateral rotational instability. The test involves applying an anterior force on the tibia with a 90° flexed knee and the leg in both external and internal rotational positions to assess the integrity of the PMC and PLC, respectively [8, 29, 30].

Further examination of the PLC can be completed with a dial test and an external rotation recurvatum test. The dial test helps to differentiate between isolated PLC injures and combined PCL/PLC injuries. With the patient prone, an external rotation force is applied to the tibia at 30° and 90° of flexion to both extremities. A > 10° discrepancy in external rotation at 30° of flexion only indicates an isolated PLC injury, whereas if a > 10° discrepancy exists at both 30° and 90° of flexion indicate a combined PCL, PLC injury [7, 8]. An external rotation recurvatum test is likely not appropriate in the acute setting, particularly when worried about a knee dislocation, as the hyperextended position can cause the knee to re-dislocate. This test can be useful in the chronic setting and is described below [31].

Fig. 4.3 Tibial posterior sag evident on patient's left side, demonstrating PCL insufficiency

4.1.2 Chronic Presentation

The approach to a chronic MLKI exam differs than the acute presentation. At times, patients with MLKIs present to specialists weeks or months after their initial injury either due to difficulties posed by geographic proximity, misdiagnosed injury or choice to trial non-operative management prior to obtaining a surgical opinion. In this setting, while it is still important to complete a peripheral vascular exam, the concern for urgent vascular compromise has usually passed. An assessment of the peripheral nerves should be completed and compared to the records from the initial assessment to determine if there has been any change or recovery in neurologic function. Additionally, particular attention should be

Fig. 4.4 Grossly positive ERRT during examination under anaesthesia with significant hyperextension

paid to range of motion. We believe strongly that, in the sub-acute or chronic setting, patients should be able to obtain 90° of flexion before consideration of operative management. This allows for a more complete assessment of injury and likely minimizes the risk of arthrofibrosis post operatively. Additionally in the chronic setting gait analysis is essential to assess for any dynamic instability such as a varus thrust. In that case, a bone realignment procedure may have to be considered—either prior to or concomitant with ligamentous reconstruction. The assessment of the ACL, PCL, LCL and MCL should be performed in similar fashion to the acute setting as described above. In the chronic setting, however, an external rotation recurvatum test can be performed to assess for possible PLC injury. For this test, with the patient supine, grasp the great toe of each foot and allow the knees to fall towards the bed. The test is positive if the knee takes on the position of hyperextension, varus angulation and external rotation of the tibia compared to the contralateral side (Fig. 4.4) [8, 32]. Additionally, the dial test and Slocum test should be applied to patients presenting in a chronic setting as described above.

4.2 Imaging Studies

In the acute setting, AP and lateral radiographs should be obtained to rule out knee dislocation or subluxation in addition to fracture. Tibial plateau and less commonly femoral condyle fractures can be associated with MLKIs. More commonly, the fractures are avulsion type injuries such as the fibular head, tibial spine and PCL tibial insertion. In obvious dislocations, reduction should not be delayed for imaging. Cross-sectional imaging in the form of CT angiography is essential in cases of possible vascular compromise, as mentioned above. CT scan can also be helpful to assess bone injury and associated avulsion fractures that may be difficult to visualize on plain X-rays especially if obscured by splint material.

The gold-standard imaging for assessment of ligamentous injury remains MRI and is the most useful imaging modality in planning surgical treatment of MLKI [33]. However, given the prolonged acquisition time, the patient may need to be stabilized prior to the study. In the event of an injury requiring urgent operative management such as a vascular injury, irreducible dislocation or open dislocation, it may be most appropriate to perform the MRI after initial stabilization of the knee with an external fixator, which will be addressed in the coming section of this chapter. Studies have demonstrated MRI ability to detect ligamentous and meniscal injury in the setting of knee dislocation is in the realm of 85–100%, exceeding that of physical examination [34]. Coronal cuts are particularly helpful in assessing the medial and lateral collateral ligaments (Fig. 4.5), whereas sagittal cuts are most helpful in assessing the cruciates [35]. The advent of MRI compatible fixator materials has made this investigation safe and likely even more accurate. For an approach to interpreting MRI findings in the setting of an MLKI, please refer to the appropriate chapter in this textbook.

In the sub-acute or chronic setting, stress radiographs can be very useful to determine objective, measurable laxity. For

Fig. 4.5 Coronal MRI cut showing tibial-sided MCL avulsion

assessment of the MCL, a valgus stress is applied to both knees individually and compared to an AP radiograph. The difference in the opening of the medial joint space with and without stress is compared between the affected and contralateral side. Similarly, the LCL is evaluated with a varus stress. In general, valgus and/or varus opening of greater than 3 mm is considered pathologic. An opening greater than 5 mm that is associated with symptomatic instability should likely be considered for reconstruction [36, 37] (Fig. 4.6). Kneeling stress radiographs can be useful to determine PCL incompetence by comparing femoral condyle translation from the affected side to the contralateral side [35]. Additionally, bilateral skyline X-rays can be used to objectively grade posterior sag by comparing the position of the tibial plateau in relation to the anterior femur (Fig. 4.7) [38].

4.3 Surgical Timing

Historically, MLKIs were treated with prolonged immobilization in a splint or hinged brace [39]. According to modern surgical practice, however, operative management is often required with aims to restore a functional, stable and pain-free knee. A systematic review by Peskun et al. in 2011 and a meta-analysis by Dedmond and Almekinders in 2001 provide clear evidence that patients with MLKIs managed operatively have improved functional outcomes in comparison to those managed conservatively [39, 40]. The timing of surgery is influenced by the anatomic nature of the injury, the overall clinical status of the patient and surgeon preference. The presence of vascular injury, open injury, compartment syndrome, irreducible dislocation or grossly unstable dislocation is an indication for emergent surgical management.

Popliteal artery injury in association with a knee dislocation requires emergent diagnosis and treatment with involvement from the vascular surgery team to avoid distal limb ischemia. Often the arterial disruption is due to a traction-type injury in the setting of anterior knee dislocation, and thus end-to-end repair of the artery is rarely feasible. The standard of treatment is contralateral saphenous vein bypass grafting. The vascular surgery team should be involved in the planning of surgery and provide guidance for the draping of the contralateral limb so the graft can be harvested. Providing a stable framework for arterial bypass in the setting of a knee dislocation can be helpful, and as such it is in the opinions of these authors and other experts that a spanning external fixator should be applied first while the saphenous vein is harvested from the contralateral limb [41]. This will also prevent future injury to the delicate graft site. Previous studies have found that a delay beyond 8 h for revascularization results in drastically increased complication and amputation rates [42–45]. In the event that the revascularization has occurred more than 6 h after the injury, four compartment fasciotomies should be performed to prevent reperfusion compartment syndrome.

An open knee dislocation also demands urgent surgical management in the form of irrigation and debridement of contaminated wounds which communicate with an injured joint. Prompt antibiotic treatment, irrigation and debridement and definitive soft tissue closure help reduce risk of associated infection and decrease complications especially if allograft reconstruction is to be considered. Should there be significant soft tissue injury preventing primary closure, a spanning external fixator can provide temporary stability without significant soft tissue compromise when vacuum dressings or soft tissue flap reconstruction are required. Additionally, irreducible knee dislocations should be taken to the operating room urgently for an open reduction to prevent point loading of the articular cartilage and further tension and injury to neurovascular structures.

In the absence of an indication for urgent operative management, the timing of surgery is a topic that remains controversial amongst experts who treat MLKIs. Those who advocate for early surgery, often within 3 weeks of injury, state the importance of returning the knee to its normal anatomic state and axis of rotation before scarring and tissue necrosis [46–50]. If repair of any damaged ligaments or capsule is to be considered, it is optimally done before tissues can retract and when individual structures can still be easily identified. Most experts agree that the optimal window of opportunity for such repair is within 3 weeks from injury.

An unpublished dataset from Moatshe et al. of 303 patients with knee dislocations claims a significantly lower

Fig. 4.6 **a, b** Valgus stress X-rays with medial opening on the left knee (**b**). (**c, d**) Varus stress X-rays with lateral opening on the right knee (**c**)

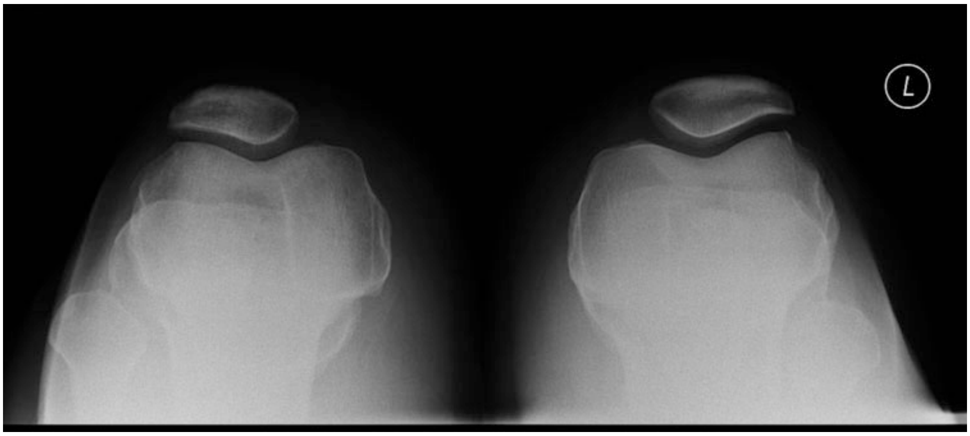

Fig. 4.7 Bilateral skyline views with tibial sag on the right knee

rate of arthrofibrosis in a delayed surgery cohort (3.8% within 6 weeks of injury vs. 15.2% after 6 weeks) [35]. Fanelli et al. found similar results in combined ACL, PCL repair and PCL, PLC repair [49, 51]. Early surgery is generally agreed upon as appropriate in the case of bony avulsion injuries, though even with that some would argue for a staged approach to later 'augment' such a repair with a secondary reconstruction. Proponents of delayed surgery argue the importance of establishing a functional preoperative range of motion, allowing the swelling and soft tissues to improve and giving the collateral ligaments and other extraarticular structures the opportunity to heal [51–55]. A staged approach is also preferred by some experts, whereby extraarticular structures are repaired acutely with a delayed reconstruction of the cruciate ligaments [51–61].

As with most MLKI controversies, no RCTs have been performed to provide level 1 evidence guiding the decision of surgical timing. In 2009 and 2015, two systematic reviews were published with relatively contradictory results, further illustrating the ongoing controversy. Mook et al. suggested early surgery may lead to more significant complications in compared with delayed surgery [62]. In contrast, Jiang et al.'s review found that the best results were accomplished by staged surgery [63]. However, a more recent systematic review (pending publication) by Sheth et al. examining 11 studies with 320 total patients found overall functional outcomes were superior in those who received early surgery in comparison with delayed surgery. This study also confirmed earlier findings that those who underwent early surgery were at a greater risk of arthrofibrosis requiring manipulation under anaesthesia or arthrolysis [64]. Overall, higher quality evidence will be required to change the wide variance in the practice of MLKI experts with respect to surgical timing.

Our current preference is to repair injured extra-articular structures—wherever possible—within the recommended 3-week window. Such repairs are always augmented with concomitant reconstructions and combined with cruciate reconstructions. The risk of such an approach is arthrofibrosis and every effort should be made to mitigate that via the restoration of a functional range of joint motion prior to surgery. The latter demands an experienced therapist and orthoptist to help maintain joint congruity during therapy.

4.4 External Fixation

A knee-spanning external fixator is rarely required in the treatment of MLKIs, although it can be helpful in providing immediate stable fixation when required. Pin site infections, quadriceps muscle damage, joint stiffness and patient discomfort make the use of an external fixator less desirable [65]. However, in the setting of a knee dislocation with a vascular injury requiring repair, an open injury with significant soft tissue compromise or a grossly unstable knee, a rigid external fixator can provide the necessary stability before definitive surgery [66]. A further advantage of an external fixator is the ability to monitor skin and compartments with serial examinations more easily when compared with splints or knee immobilizers. Additionally, some may choose to use external fixators in those where a hinged brace may not provide enough stability, such as in morbidly obese patients [2]. There is the competing disadvantage here, however, of a larger soft tissue envelope through which pins must pass—thereby increasing both the difficulty of application and the risk of pin tract infection. We prefer not to use fixators in obese patients for the latter reasons.

Application of a spanning external fixator is technically straightforward and involves placement of pins in both the femur and the tibia. The joint must be concentrically reduced prior. Optimally, pin placement should avoid the intra-articular space, areas of obvious soft tissue injury and potential sites of future incisions. The femoral pins should be placed at a level at least 5 cm (or one handsbreadth) above the patella, and the tibial pins 5 cm below the tibial tubercle, to avoid the joint recesses and extensions thereof. Furthermore, femoral pins may be placed directly anterior or anterolateral, with each approach having its own advantages and disadvantages. Anteriorly placed pins are technically straightforward to insert, but place the quadriceps muscle at risk for tethering or defunctioning. Anterolaterally based pins spare the quadriceps but are thought to be less stable. A popular approach is to place anterolateral pins in the femur and anteromedial pins in the tibia (Fig. 4.8). This configuration provides a stable construct with limited soft tissue violation, thus minimizing subsequent loosening and

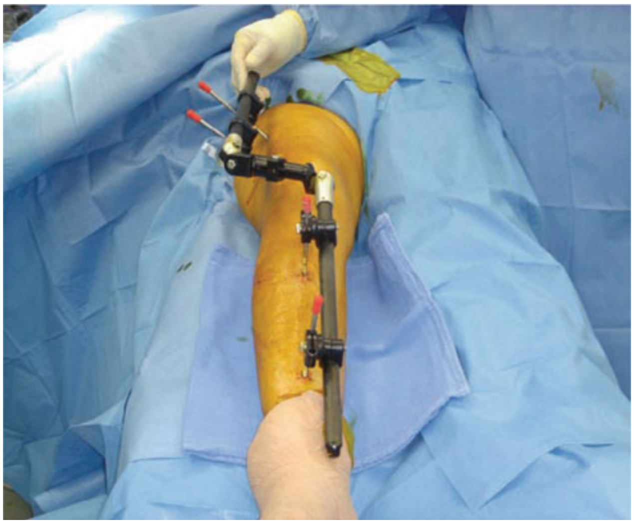

Fig. 4.8 Knee-spanning external fixator with anterolateral femoral pins and anteromedial tibial pins

infection. A warning, however: pins placed in grossly different planes can make the reduction (and maintenance thereof) difficult. If a fixator is applied to aid in the stability in the setting of a vascular repair, the knee should be fixed in a small amount of flexion to de-tension the graft construct. Regardless of the configuration, the fixator should be applied to an adequately reduced knee, confirmed by fluoroscopy imaging. The external fixator is traditionally left on for a period of 6–8 weeks and removed for definitive fixation. In the setting of vascular surgery, the timing of removal should be discussed with the entire surgical team.

4.5 Arthroscopic Versus Open

The selection of an open versus an arthroscopic approach to multi-ligament knee reconstruction depends primarily on the characteristics of the injury. The MCL, LCL, PLC and PMC require open approaches for reconstruction. The debate lies in the cruciate repair, with the majority of surgeons currently choosing an arthroscopic approach for reconstruction or repair [67]. There are, however, certain injury characteristics where an open cruciate repair can be considered. For example, an irreducible knee dislocation may require an open approach to remove the incarcerated medial soft tissues [68, 69]. An open knee dislocation requiring extensive irrigation and debridement would also likely necessitate an open approach for any means of early reconstruction [56–58]. Additionally, avulsion fractures of either the tibial spines or the PCL insertion that can be addressed with fixation can be performed open.

The primary advantage of an arthroscopic approach is improved visualization of associated intra-articular pathology including cartilage damage and meniscal tears. It has also been proposed that an arthroscopic approach decreases infection risk, though this has not been proven in direct comparison for MLKI reconstruction [55]. Additionally, the avoidance of a large midline arthrotomy provides freedom for placement of incisions for either lateral- or medial-sided collateral repair without fear of skin bridge compromise. The potential disadvantage is compartment syndrome via extravasation of arthroscopic fluid through capsular rents. This risk is likely increased with the use of arthroscopic pumps. If an arthroscopic approach is chosen, serial assessments of compartment pliability are essential.

There are no head-to-head trials examining open vs arthroscopic cruciate repair in MLKIs. Several case series studies examining functional outcomes have been published for each technique with similar results [51, 67, 70]. At present, the choice between an open, arthroscopic or combined approach is almost entirely based on the experience and preference of the surgeon.

4.6 Transtibial Tunnel Versus Tibial Inlay

In isolation, PCL injuries are most often managed non-operatively with success [71–74]. Symptomatic-grade III PCL injuries, or those that have failed conservative management, can be considered for reconstruction. Repair may be performed for high-grade avulsions. While the decision to operate for isolated PCL injury remains somewhat controversial, most experts would agree that in the setting of MLKIs or bi-cruciate tears the PCL should be reconstructed or repaired.

The choice of surgical technique for PCL reconstruction and graft selection, remain sources of debate. The two main PCL reconstruction techniques are the transtibial tunnel and the tibial inlay technique [75]. The transtibial tunnel consists of drilling an anterior to posterior proximally directed tunnel from the anterior tibia to the PCL insertion site and passing a graft from this tunnel through the femoral sided tunnel. This technique is performed in the supine position, allowing for reconstruction of the other ligaments without any repositioning necessary. Additionally, it can be performed arthroscopically with no need for open exploration of the PCL insertion. Studies evaluating the effectiveness of transtibial tunnel PCL reconstruction have found it to be a technique with low morbidity and satisfactory outcomes [76, 77]. The criticism of this technique is the variance in angles between the tibial and femoral tunnels, causing the graft to curve sharply around the posterior aspect of the proximal tibia. This is known as the ‘killer turn’ and has been cited as a reason for graft wear, residual laxity and possible graft failure [75, 78–81] (Fig. 4.9). A recent meta-analysis by Lee et al. found that biomechanical studies have shown this technique causes greater in situ force on the graft in comparison with the tibial inlay technique [82]. Due to these concerns, many surgeons have transitioned to the tibial inlay technique.

The tibial inlay technique was first described by Berg et al. [83]. It involves securing a graft with a bone block to the native PCL insertion site on the posterior proximal tibia and passing the graft through the femoral tunnel. The main advantage of this technique includes lower in situ forces on the graft due to the absence of a killer turn [82]. It also can be used in the setting of a revision procedure with an inappropriately placed tibial tunnel or in the setting of previous fracture or osteotomy of the proximal tibia [84]. A disadvantage of this technique, however, is that it necessitates an open posterior or posteromedial approach to the knee, endangering neurovascular structures, requiring alternate positioning and complicating a combined arthroscopic approach [85, 86]. The meta-analysis by Lee et al. gives a strong recommendation to warn patients about the risk of serious neurovascular complications with the tibial inlay

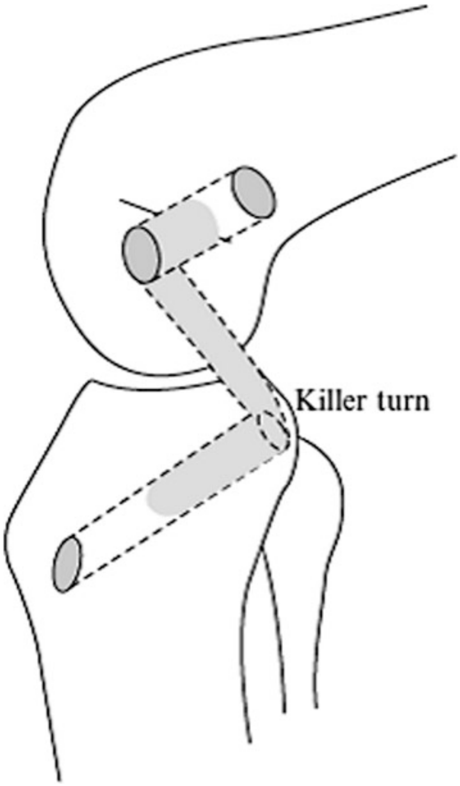

Fig. 4.9 Killer turn phenomenon as demonstrated by the acute turn of the graft from the proximal tibia. Courtesy of Don Johnson MD, Sports Medicine Clinic, Carleton University, Ottawa, ON, Canada. Reprinted with permission

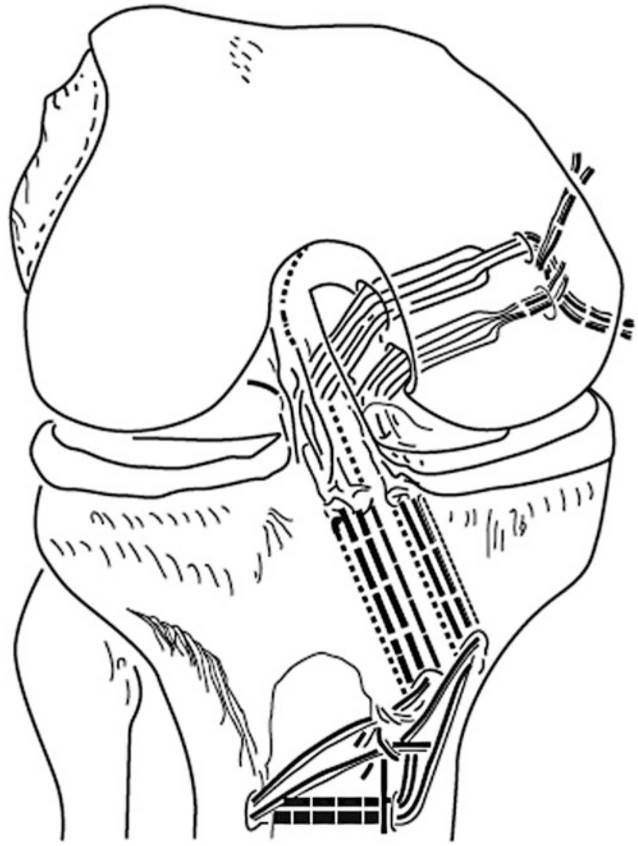

Fig. 4.10 Double-bundle PCL reconstruction. From [102] Reprinted with permission from Elsevier

technique due to a higher complication rate in the clinical studies they analyzed [82].

Like most debated treatment options discussed previously, there are no RCTs comparing tibial graft fixation techniques in the setting of MLKIs. However, those completed on isolated PCL reconstructions have not found any significant clinical difference in functional outcomes or failure rates between the transtibial tunnel and tibial inlay options. Factors such as proximal tibial anatomy, patient positioning and desired arthroscopic versus open approach can be used to guide decision-making between these two techniques.

4.7 Single- or Double-Bundle Cruciate Reconstruction

Anatomically, the ACL and PCL are individually made up of two bundles: the larger anteromedial bundle and smaller posterolateral bundle for the ACL, and the larger anterolateral bundle and smaller posteromedial bundle for the PCL. These bundles individually contribute to the stability of the knee in various degrees of flexion and extension [87, 88]. Historically, both the ACL and PCL have been addressed with single-bundle graft constructs in both individual and multi-ligament reconstructions, however, over the past 15 years interest in double-bundle reconstruction has increased as surgeons pursue more anatomically accurate reconstruction options (Fig. 4.10) [89, 90].

Those who advocate for double-bundle ACL reconstruction cite biomechanical evidence of better rotational and sagittal plane stability when compared with single-bundle reconstruction [91, 92]. A meta-analysis by Chen et al. of 8 RCTs looking at individual ACL reconstruction with double versus single bundle found better clinical stability and subjective function in the post-operative period for patients who received double-bundle reconstruction; however, results at 2 years post-op were equivalent between the two groups [93]. These results contradict an earlier meta-analysis on the same topic by Branch et al. where no difference was demonstrated [94]. We strongly prefer a single-bundle approach for the ACL in MLKI. Multiple ACL constructs have not been clearly demonstrated to be superior and—especially in the setting of multiple ligament reconstruction—can further complicate and lengthen an already complex procedure.

With regards to the PCL, a biomechanical study by Kennedy et al. [95] demonstrated a codominant relationship between the two PCL bundles, which contradicted earlier accepted dogma that the anterolateral bundle was more important [96, 97]. Additionally, more recent biomechanical studies have demonstrated that double-bundle reconstructions restore native knee kinematics with superiority and greater reliability than single bundle grafts [95, 98]. Two recent meta-analyses demonstrated similar results between double- and single-bundle-isolated PCL reconstruction, with one showing superior objective posterior tibial stability amongst the double-bundle group, though no patient reported differences [99, 100]. Although clinical evidence for double-bundle PCL constructs is weak, the biomechanical data is persuasive. For this reason, we prefer—wherever possible—the creation of two femoral-sided tunnels (Anterolateral and posteromedial)—to more accurately restore kinematics.

We recognize double-bundle procedures are not without their drawbacks. The need for additional graft material, operative time and increased cost are not minor considerations. Additionally, the requirement of individual bone tunnels for each graft on the femur makes an already technically challenging operation more difficult and can for tunnel collision or compromise structural integrity [101]. This is particularly germane when concomitant MCL reconstructive procedures are being performed. Overall the decision for double versus single-bundle reconstruction should be based on individual patient factors, resource availability and the technical comfort of the surgeon. Like most controversies in MLKIs, more high-level evidence specific to these complex patients is needed.

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5

Classification of Knee Dislocations and the Surgical Implications

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5.1 Introduction

The concept of knee dislocations (KD) has evolved significantly over the past three decades. Once thought to be such a rare occurrence that it would be unusual for an orthopedic surgeon to see more than one knee dislocation in an entire career, knee dislocations are now occurring much more frequently than in the past [1]. For reference, multiligamentous knee injuries can occur as frequently as 1 for every 60 ACLs [2]. While still rare occurrences with an incidence of 0.02–0.2% of all orthopedic injuries, knee dislocations are seen with increasing frequency [3]. Causes are related to higher exposures to trauma, newer safety measures that have decreased mortality from trauma, an increase in extreme activities and sports, and better recognition by clinicians. The rise in obesity has also contributed to the increasing trend of ultralow-velocity knee dislocations [4]. Another factor that has led to the increased numbers is the recognition of the spontaneously reduced knee dislocation. Wascher et al. showed that up to 50% of knee dislocations present with the tibiofemoral joint in a reduced position [5]. In reality, this number of spontaneously reduced knee dislocation may be greater. The recognition of the spontaneously reduced knee dislocation has led to a greater awareness by physicians for neurovascular injuries. In effect, multiligament knee injuries (MLIs) must be treated as knee dislocations with the well-known attendant risk of neurovascular injury. Although the position classification is useful to understand reduction maneuvers, the concept of spontaneous dislocations makes over 50% of knee dislocations by definition, unclassifiable. Because of the complex presentations of knee dislocations, a classification system for all knee dislocations was necessary in order to help orthopedic surgeons with the diagnosis, treatment, and communication.

Classification systems serve many purposes, and there are many factors that make them useful. A classification system must be simple and reproducible and in turn will aid in both communication between providers and overall acceptance of its use. A system should also help in the decision-making process, especially in surgical management. Furthermore, a good classification system will also reflect the severity of the injury. Knee dislocations can be classified either by position, energy of injury, pathophysiology, or the injured anatomic structures. We will review each of these classification systems in this chapter.

5.2 Initial Evaluation

A thorough physical examination should be performed upon initial presentation. Because knee dislocations frequently occur in multitrauma patients, the physical examination should include a general assessment of the patient's head, chest, abdomen, and extremities. The initial examination should include inspection of the knee for penetrating wounds, the presence of deformity, range of motion, and if possible, the ability to perform a straight leg raise. The ligament examination must include a Lachman's examination at 20°, anterior and posterior drawer tests at 90°, varus and valgus stress at 0° and 30°, and a dial test as pain allows. Examination of the dislocated knee with a stabilized Lachman (examiner's thigh under affected knee) will often allow for a relatively painless and accurate examination. Palpation can often identify extensor mechanism or hamstring tendon ruptures. Having the patient perform a straight leg raise, when possible, is very useful to determine the status of the extensor mechanism, as concomitant extensor mechanism injuries and KD have been described [6, 7].

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A careful neurovascular assessment must be performed and is critical in the management of KDs. The rate of vascular injuries varies widely in the literature from 3.3 to 64% [4, 8–12], though the largest population study of 8050 knee dislocations in North America revealed an incidence 3.3% [10]. The decreasing incidence of arterial injury with MLIs is related to the presence of spontaneously reduced knee dislocations and improved surveillance/recognition for such bicruciate injuries. Nonetheless, a delayed diagnosis of a vascular injury can result in a compartment syndrome or amputation in up to 20% of patients [13]. Earlier studies from wartime injuries noted an 80% chance of amputation if vascular repair is delayed past 8 h. At a minimum, vascular assessment should include palpation of the posterior tibial and dorsalis pedis pulses, which has been shown to have near 100% sensitivity for vascular injury [12]. Depending on the initial examination, further investigation should be directed by an evidence-based protocol that can include measurement of the ankle–brachial index (ABI), duplex ultrasonography, angiography, CT angiography, on table angiography, or emergent exploration of the popliteal artery [14–17]. Vascular interventions may be necessary depending on the results of these investigations (Figs. 5.1 and 5.2). Peroneal nerve injury is common in KD [18], though function can be difficult to assess in patients who are unresponsive or have multiple trauma issues. It is important to assess both tibial and peroneal nerve function as best possible. Identifying nerve injuries preoperatively is important in predicting patient morbidity and in turn can help in planning treatment [19–23]. It is especially important to recognize the partial from the complete nerve injuries because a partial injury is prognostic for nerve recovery and function [24].

Following a thorough physical examination, AP and lateral radiographs should be obtained to identify fractures and assess tibiofemoral displacement. It is customary and appropriate to repeat radiographs should a reduction maneuver be required to ensure satisfactory alignment of the joint and the potential for an irreducible knee dislocation. Special attention should also be given to the proximal tibiofibular joint, which has been shown to be unstable in up to 9% of KD [25]. Lastly, radiographic evidence of knee joint distraction is often seen even after successful reduction maneuvers. Magnetic resonance imaging (MRI) is extremely useful in identifying the structures injured, the degree of injury, and the location of the injury [26–28]. Although MRI is helpful in surgical decision-making and planning, it does not replace a thorough physical examination. It should be noted that spontaneously reduced knee dislocations require a high level of suspicion and if picked up first on MRI or CT, plain radiographs are still needed to look for subluxation, rim or joint surface fractures and evidence of avulsions seen with PCL, ACL, Iliotibial band, and Segond type injuries. Lastly, the use of stress radiography is often helpful when evaluating posterolateral or posteromedial corner injuries. MRI can suggest injury, but examination and stress radiography may reveal functionally intact ligaments (Fig. 5.3). LaPrade and others have identified normal joint line opening parameters when comparing side-to-side differences on stress radiography, and we recommend this approach (Table 5.1) [29].

Fig. 5.1 AP radiograph of a patient who suffered an open knee dislocation. A Gelpi retractor is imaged facilitating exploration of the disrupted popliteal artery see on angiography

A critical step in assessing the injured knee is a comfortable ligamentous examination. Because of the severe injury of the knee and patient discomfort, this frequently is only accomplished by an examination under anesthesia (EUA). A thorough EUA with side-to-side comparison gives the clinician an idea of the functionality of the injured structures, especially the possibility of an injured corner. In many cases, structures identified as injured on MRI may be functionally intact at the time of EUA and not require repair or reconstruction. Additionally, even severely injured capsular and cruciate ligaments may heal if surgery is delayed; the only way to assess the functional integrity of injured structures is the EUA at the time of surgery [30, 31]. Occasionally, it is difficult to determine the neutral position of the knee when assessing varus and valgus laxity; in these

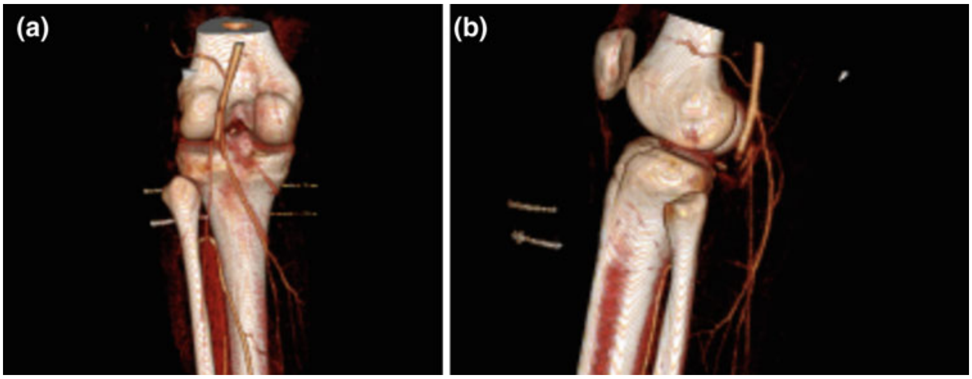

Fig. 5.2 Coronal (**a**) and sagittal (**b**) reconstructions of a CT angiogram demonstrating popliteal artery injury in the setting of a KD IIIL knee dislocation

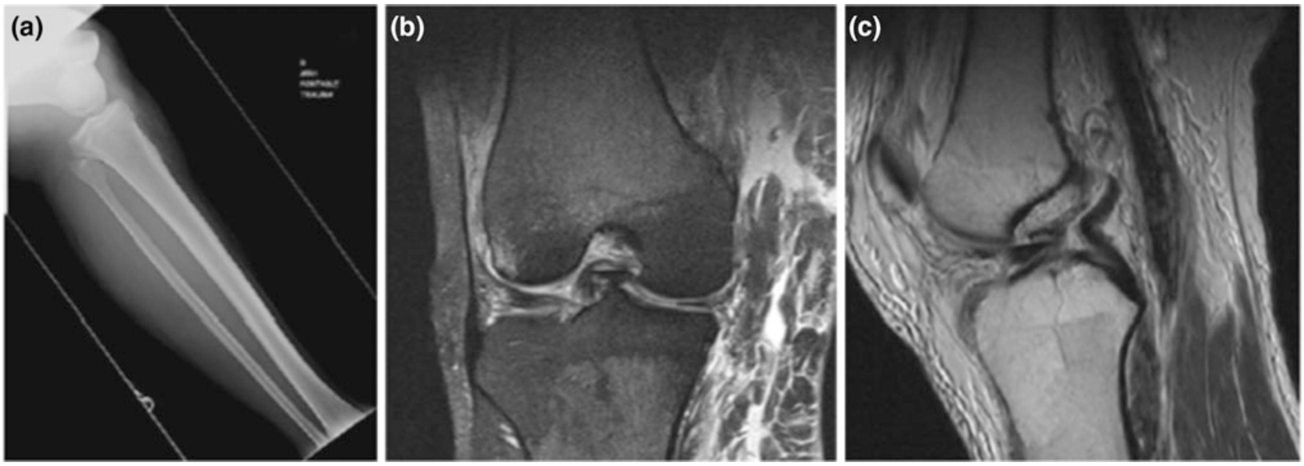

Fig. 5.3 Spot radiograph of a knee dislocation (**a**). Coronal (**b**) and sagittal (**c**) intermediate-weight MRI images, of the same patient, showing torn ACL, PCL, and bucket handle meniscal tear. Coronal section shows injury to MCL as well

Table 5.1 Normal joint line opening distances with stress radiography

Normal joint line opening (mm)	
Lateral (LCL)	2.7
Posterolateral corner	4.0
Medial (superficial MCL)	3.0
Posteromedial	9.8

instances, the examiner should obtain bilateral comparison stress radiographs.

5.3 Position Classification System

The position classification system, described by Kennedy, is based on the position of the tibia in relation to the femur at the time of dislocation [32]. This classification requires clinical or radiographic evidence of a knee dislocation. With this system, five types of dislocations are described: anterior, posterior, medial, lateral, and rotatory. Rotatory dislocations are further subclassified as anteromedial, anterolateral, posteromedial, and posterolateral.

The position system has been utilized for many years, but it does have some limitations. Classifying by tibiofemoral position is useful in identifying possible coexisting injuries such as vascular or nerve injuries. The anterior and posterior dislocations have been associated with a higher likelihood of coexisting popliteal artery injury [1, 32, 33]. However, because all types of dislocations can have a concomitant vascular injury, the physician must maintain a high index of suspicion for vascular injury in any dislocation, regardless of tibiofemoral position. The Kennedy or position system can also help with planning of a reduction maneuver, but again many dislocations reduce easily with longitudinal traction and are often performed by first responders without benefit of a radiograph. The position system is very useful when the physician identifies a posterolateral knee dislocation

(Fig. 5.4). These dislocations are often irreducible with closed means as the medial femoral condyle buttonholes through the medial joint capsule or vastus medialis, forcing the medial collateral ligament or other medial structures to invaginate into the joint [30, 31, 34–38]. The hallmark sign of the posterolateral KD is a "Pucker Sign" or more classically "furrowing" along the medial aspect of the knee at the joint line, often showing an outline of the articular surface of the distal femoral condyle [39]. Prompt open reduction is necessary because if left unreduced the pressure from the medial femoral condyle can lead to necrosis of the skin and/or medial knee structures including the MCL [40]. Identifying a posterolateral knee dislocation alerts the orthopedic surgeon to the high likelihood of irreducibility by closed means [41, 42]. Peroneal nerve injuries are also frequently associated with posterolateral dislocations as the nerve is stretched across its fixed points [30, 43, 44].

The major limitation of the position system is that it is unable to classify over half of all knee dislocations (i.e., >50% spontaneously reduce). Because such injuries cannot be classified by the position system, a clinician might fail to recognize that a multiligament knee injury is a knee dislocation which requires careful assessment and monitoring of the vascular status. If a neurovascular injury in a reduced knee dislocation is not recognized, this can have devastating consequences.

There are other deficiencies in the position classification system which we have found. The position system does not help with planning surgical treatment. No information is conveyed that would assist in the placement of surgical incision, the number and type of grafts required, or the need for bony fixation. Additionally, the position classification system does not allow for easy or thorough communication between physicians of what needs to be reconstructed. While of historical importance, we have found this system lacking in providing modern care to patients with knee dislocations, except in discussing the posterolateral KD where the position system remains useful.

5.4 Energy of Injury Classification System

Knee dislocations have also been classified by the energy or velocity of injury (Table 5.2). Dislocations were previously categorized as either high energy or low energy based on mechanism [45–47]. However, in the last decade, the description of the ultralow-velocity KD in obese patients by Azar and others has made it a critical advancement [48]. High-energy KDs are those seen in patients involved in motor vehicle collisions, industrial accidents, or falls from a great height. Low-energy KDs are classically described in high-level athletes during sporting activities. Ultralow-velocity KDs typically occur in the morbidly obese [48, 49].

Most KDs are high energy and are the result of major trauma, typically motor vehicle crashes or pedestrian vs motor vehicle injuries. The patients who sustain a high-energy KD often have associated traumatic injuries to multiple systems including head, chest, abdominal, and other

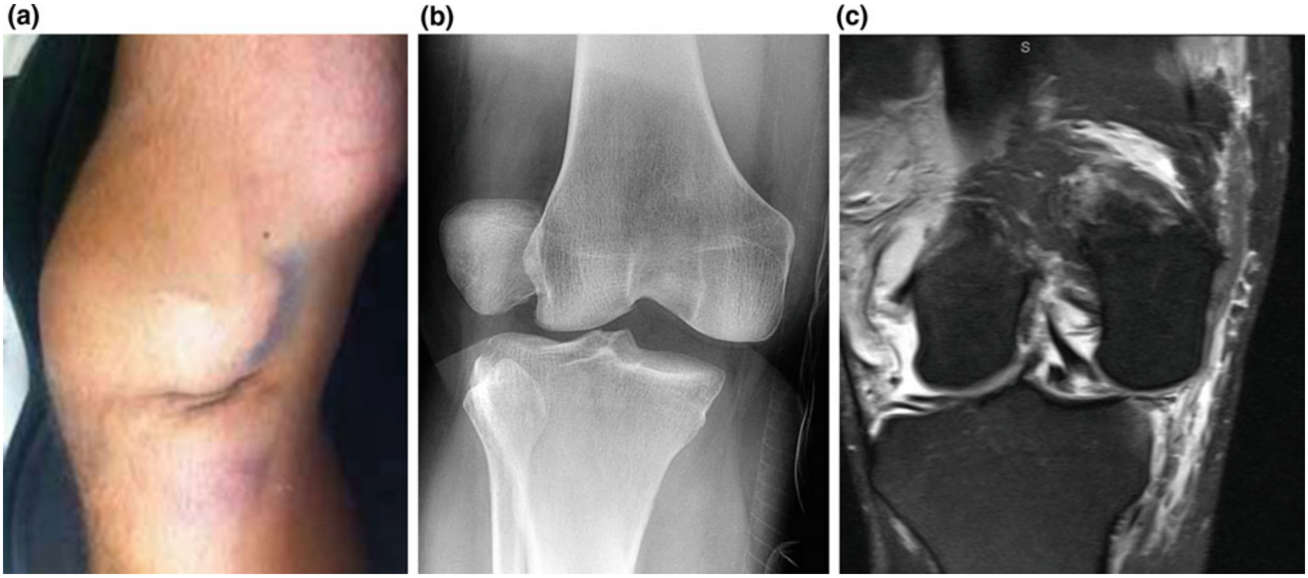

Fig. 5.4 Clinical image of a posterolateral knee dislocation demonstrating classic "pucker sign" or "medial furrowing" (**a**). Radiograph of a posterolateral dislocation (**b**). This KD was irreducible and required an open reduction where the MCL was interposed into the joint. MRI of posterolateral knee dislocation demonstrating interposition of the MCL in the joint (**c**)

Table 5.2 Energy of injury classification

Classification	
High-energy KD	MVC, falls from height, polytraumatized patients
Low-energy KD	Sporting activities, falls, often isolated injury
Ultralow-velocity KD	Morbidly obese, high incidence of nerve and vessel injury

extremity injuries. These injuries can be life-threatening and often take precedence over the ligamentous aspects of the KD. KDs occurring in multitrauma patients require a coordinated team approach that includes emergency physicians, trauma surgeons, and orthopedic surgeons to ensure the patient receives appropriate care and attention to all injuries. A knee dislocation should not take precedence over a life-threatening intrathoracic or abdominal injury, nor should a reduced knee dislocation with vascular injury be overlooked, as a delay in revascularization of 6–8 h has a high likelihood of limb loss [13, 33]. Furthermore, the presence of a closed head injury may delay surgical treatment because the patient is unable to participate in postoperative rehabilitation. Stannard et al. have noted that closed head injuries increase the possibility of heterotopic ossification around the injured knee [50].

To some extent, the level of energy does dictate the course of treatment of a KD. High-energy KDs most often have other associated injuries, which may lead to delay in definitive treatment. Although a well-padded brace can be utilized in a high-energy KD, we have often found it useful for treating high-energy KDs with an external fixator (Fig. 5.5). External fixation provides easy access to the soft tissues of the leg, allows for mobilization of the trauma patient, and is extremely useful in unstable high-energy KD. In some patients with severe associated injuries, immobilization in the fixator for 6–8 weeks can serve as definitive treatment. However, the use of an external fixator carries the risk of pin-track infections and may interfere with incisions used for ligament reconstruction. Conversely, patients who sustain low-energy, isolated, or sporting KDs often are suitable for early repair and/or reconstruction if there is no vascular injury. Although low-energy knee dislocations have a lower incidence of vascular injury, a complete popliteal artery injury can occur in any patient with a knee dislocation and requires immediate evaluation [15, 45]. Early treatment of low-energy KD minimizes the disability period for the patient and may allow for repair of some of the injured structures.

The clinician should recognize that ultralow KD in a morbidly obese patient can present as a seemingly innocuous event, such as stepping off a curb or even a fall when walking. These injuries have become more prevalent and are associated with a high rate of neurovascular injury, up to 40% in some studies. Interestingly, in our experience, these patients often are seen with a radiographically defined KD with evidence the femur driven down in an anterior dislocation pattern. These injuries are commonly associated with a BMI >48, increased peri-operative complications, and lower functional scores after surgery. We commonly use an external fixator to maintain reduction in the obese patient

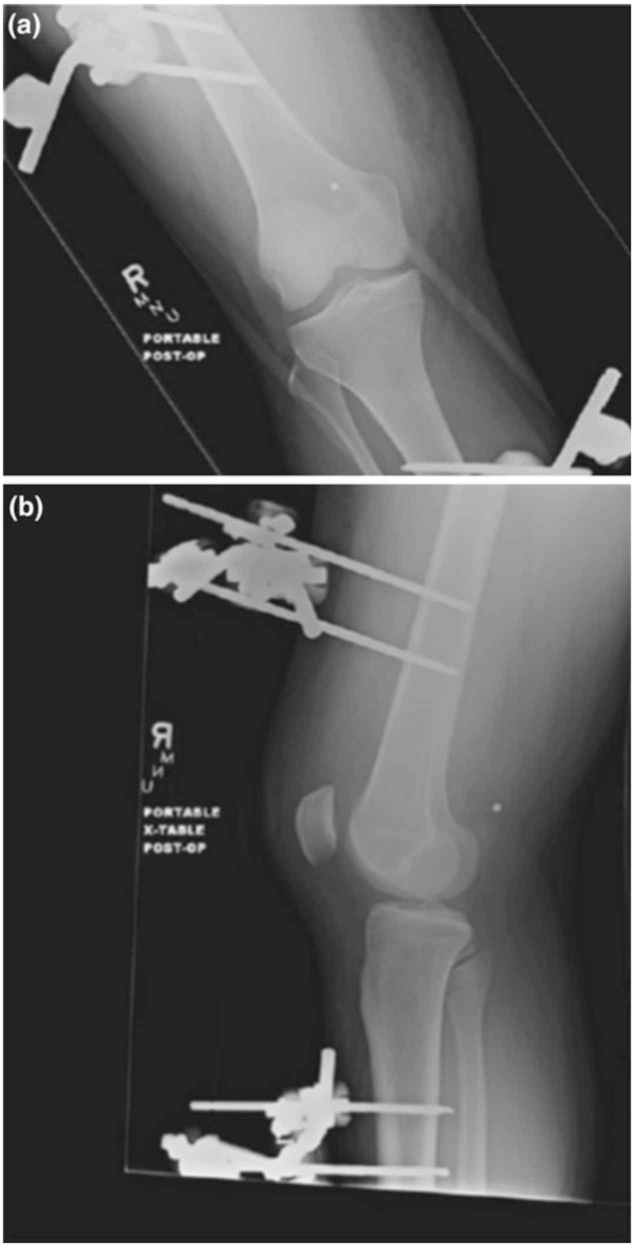

Fig. 5.5 AP (**a**) and lateral (**b**) radiographs of a spanning external fixator placed for an unstable knee dislocation. Note the proper tibiofemoral reduction after ex-fix placement

because the large soft tissue envelope around the knee is not always amenable to bracing. However, nonoperative management has a high rate of failure and once neurovascular compromise is ruled out treatment involves ligament repair, reconstruction, or prolonged use of an external fixator [4, 48, 49, 51, 52].

Classifying KDs by energy of injury does have considerable limitations. First, the energy of injury is often arbitrary. Many sporting activities could be classified as either high or low energy, take, for example, the patient who dislocates his/her knee skiing. This could be the result of a ground level fall at low speed or a high-speed collision with a tree. The initial and definitive management could be different for each of these individuals. Second, this classification does not identify the injured structures nor help in surgical planning. Vascular injuries can be seen with any amount of energy. Lastly, since the classification is arbitrary and does not identify injured anatomic structures, it does not allow quick and accurate communication between physicians of what is actually torn.

5.5 The French Society of Orthopedic Surgery and Traumatology (SOFCOT) Classification

The SOFCOT classification was initially devised in 2008 as a pathophysiological descriptor of bicruciate knee injuries. It is a continuation of the European Society for Sports Traumatology, Knee Surgery and Arthroscopy (ESSKA) classification by Neyret and Rongerias in 1998 [53]. The SOFCOT classification adapts the same principles of the ESSKA, but incorporates single cruciate KD [54]. The SOFCOT classification separates cruciate injuries into four patterns based on presence of dislocation and integrity of collateral ligaments, termed "peripheral tear". This classification takes into account clinical examination findings in addition to dynamic radiographs in assessing KD (Table 5.3). The authors consider "simple gaping" on imaging as indicative of bicruciate knee injury without dislocation, whereas "simple translation" indicates bicruciate injury with dislocation. A combination of gaping and translation corresponds to bicruciate injury with associated collateral ligament dysfunction [54].

The SOFCOT classification is helpful in classifying bicruciate injuries that occur without dislocation. It also more clearly defines single cruciate ligament injury. Although the SOFCOT classification claims to provide more qualitative data, it fails to define gaping and translation in quantifiable measures and the descriptions can appear confusing. Furthermore, combined gaping and translation of the knee can still occur in the presence of bicruciate injury with intact collateral ligaments. The most concerning limitation is the potential neglect of KDs that spontaneously reduced, as roughly 50% of KD can present in such a way to a tertiary center. Thus what may be considered an SOFCOT "type 1", or bicruciate lesion without dislocation, may in fact be a dislocation unbeknownst to the clinician as a dislocation with spontaneous reduction. An unidentified KD could have devastating consequences as described previously.

5.6 The Anatomic Classification (Schenck Classification)

The anatomic classification is based on the ligamentous anatomy of the knee and what structures have been torn [55]. To describe the pattern of injury, the ligaments of the knee are divided into four anatomic groups that have unique but overlapping functions. They consist of (1) the anterior cruciate ligament (ACL), (2) the posterior cruciate ligament (PCL), (3) the medial structures, and (4) the posterolateral structures. The medial structures include the medial collateral ligament (MCL), both superficial and deep, and the posteromedial capsule, or posterior oblique ligament (POL). The posterolateral structures consist of the lateral collateral ligament (LCL), popliteofibular ligament, popliteus tendon, and the posterolateral capsule.

Table 5.3 SOFCOT classification

SOFCOT classification	
Type 1—"Simple" bicruciate lesion w/o dislocation	(a) Medial (b) Lateral (c) Posterior
Type 2—Pure dislocation w/o peripheral tear	(a) Anterior (b) Posterior
Type 3—Dislocation w/single cruciate injury	(a) ACL (b) PCL
Type 4—Combined lesions associating peripheral tear and dislocation	(a) Medial (lateral dislocation) (b) Lateral (medial dislocation) (c) Complex (rotational, medial, and lateral tear)

Table 5.4 The anatomic classification system based on injured structures

Anatomic classification	
KDI	Cruciate intact KD; only one cruciate injured. Most common: ACL, PLC torn
KDII	ACL and PCL torn, collaterals intact
KDIII	ACL, PCL, and collateral structure torn; L = lateral involvement and M = medial involvement
KDIV	All four ligaments torn
KDV	Fracture dislocation

C arterial injury
N nerve injury

The anatomic classification system is relatively simple and reproducible because it is based on what structures have been torn. In order to classify a knee dislocation by the anatomic system, a thorough evaluation of the injured knee must be performed as described above. After evaluation, the KD can be categorized into one of five different major injury patterns that may occur (Table 5.4). Injuries are classified by Roman numerals that generally indicate increasing severity of injury with the higher the number. A KD I is a radiographically or clinically dislocated knee with only one cruciate ligament torn, either the ACL or PCL. These have been reported but are relatively rare injuries [56]. A KD II is a bicruciate injury with functional integrity of both collateral structures, also a rare injury pattern. A KD III is a bicruciate injury with an associated collateral injury. KD IIIs are subclassified by M for injuries involving the medial structures and L for injuries involving the lateral structures. A KD IV indicates injury to both cruciates and both the medial and lateral sides of the knee (i.e., both corners). Fracture dislocations of the knee can occur where the displacement occurs through a fracture fragment rather than through a torn ligament. Therefore, a fifth category, a KD V, was added [5]. A KD V is a knee dislocation with an associated periarticular fracture and can be subclassified by other systems such as Moore, Stannard, and Hohl [16, 57]. Stannard further classified KD V based on the injured ligamentous structures [16]. In Stannard's classification, a KD V1 is a single cruciate injury, in KD V2 both cruciates are involved, in KD V3 both cruciates and a collateral structure are injured, and in KD V4 both cruciates and both collaterals are involved. Small avulsion fractures such as tibial spine fractures are not classified as KD Vs but as ligamentous injuries. Finally, those KDs with neurovascular injuries are subclassified using C for vascular injury and N for nerve injury, as is used with classifying open tibia fractures [58]. An example of using this system would be a knee dislocation with ACL, PCL, and PLC injuries with a normal vascular examination but absent peroneal nerve motor function. Using the anatomic classification system, this injury would be described as a "KD III-L-N." Furthermore, a KDIIIM is a knee injury where there is complete tearing of the ACL, PCL, and MCL/PMC. Interestingly the clinician must be concerned for an injury of the medial patellofemoral ligament (MPFL) as a widely subluxed KDIIIM could result in a patellar femoral dislocation (Fig. 5.6). Of note, the anatomic system is based on what is functionally torn on examination or EUA. MRI will frequently show a partial ligamentous injury that is functionally intact, such as a KDIIIM with a torn ACL, PCL, and MCL but increased signal in a functionally intact PLC.

The anatomic classification has several notable advantages over older classification systems. First, virtually all KDs can be classified using this system, including multi-ligament injured knees that present reduced. Second, this system identifies the severity of the injury and may be predictive of outcome. Generally speaking, the higher the Roman numeral, the more severe the injury to the knee and

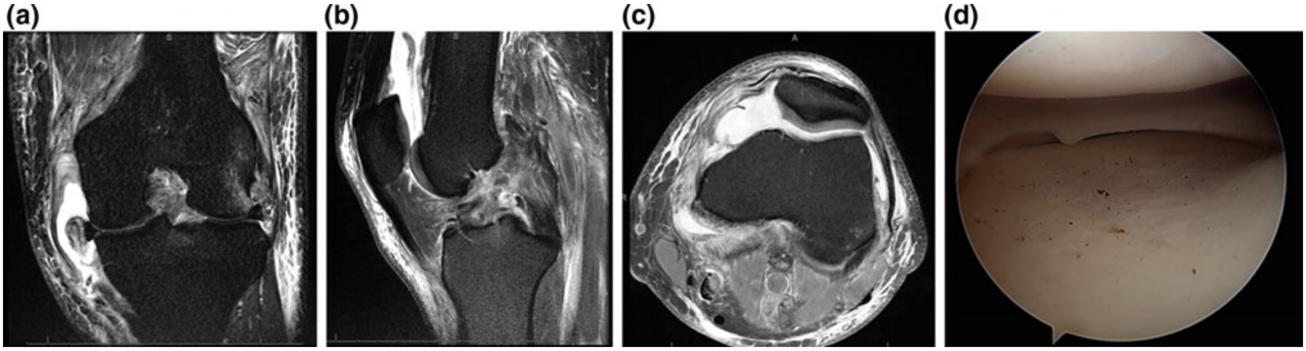

Fig. 5.6 Coronal (**a**), sagittal (**b**), and axial (**c**) MRI images of a KDIIIM with a torn MPFL requiring reconstruction of ACL, PCL, MCL, and MPFL. Notice the evidence of partial lateral corner injury that was structurally intact on EUA, stress radiographs, and stress arthroscopy (**d**)

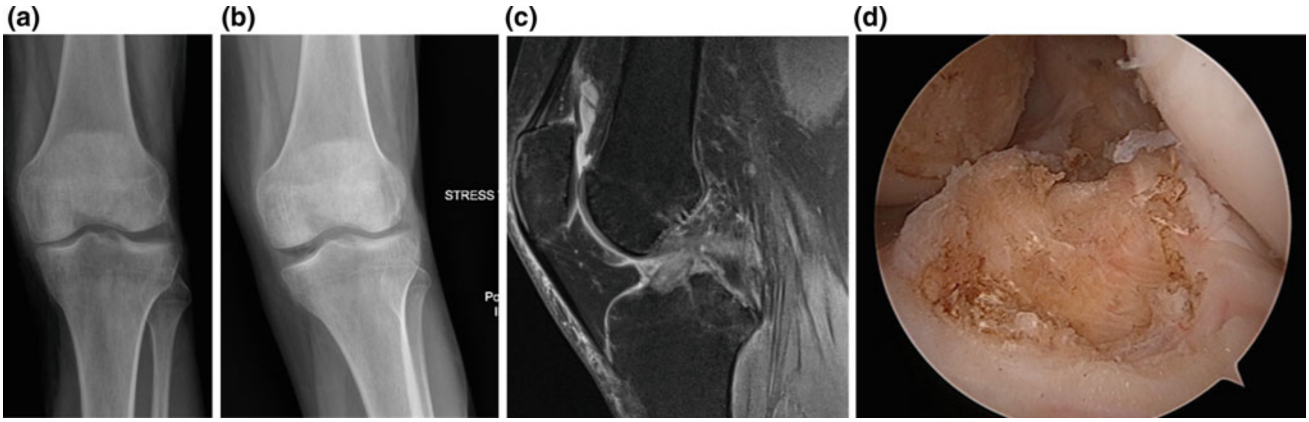

Fig. 5.7 AP (**a**) and AP stress (**b**) radiographs of patient RB presents with what was recognized as a KDIV but had some evidence of ACL function. Stress views document both corners injured, MRI (**c**) with injury to the ACL and reconstruction required of all ligaments (**d**)

the worse the prognosis. KD IVs have been shown to have a higher incidence of vascular injuries because the tibiofemoral joint has lost all ligamentous structures functionality [14, 16]. Third, the anatomic classification helps to guide treatment because the injured structures that will need reconstruction/repair are identified. Finally, the anatomic classification allows for easy communication between providers and allows accurate comparison of outcomes. A recent systematic review showed that the anatomic classification system was predictive of return to work after treatment of a KD [59].

Some confusion has arisen regarding that application of the anatomic classification system in single cruciate ligament injuries. In Merritt et al.'s excellent review of 138 KD, they were unable to classify single cruciate KD based on MRI findings [44]. To clarify, a multiligament injury with clinically insufficient PCL, LCL, and MCL would be considered a KDI ML by the anatomic classification. Furthermore, the anatomic classification is based on clinical examination rather than imaging findings alone as was done in their study. To contrast, Moatshe et al. were able to classify all but 4 of their 303 KD. Of the 4 that were not classified, 1 left the country for definitive surgery, 1 underwent above knee amputation, and 2 were elderly and treated nonoperatively [43]. In the senior author's experience, a KDI ML is an exceedingly rare injury and may likely represent a KDIV with what appears to be one remaining normal cruciate (Fig. 5.7).

5.7 Congenital Knee Dislocation

Over the past decade, a body of literature has developed regarding pediatric congenital knee dislocation (CKD). Briefly, CKD is commonly the result of pathologic knee hyperextension and is often associated with arthrogryposis, myelomeningocele, and Larsen's syndrome [60]. Classification schemes have been put forth but are beyond the scope of this chapter. It is worth noting that CKD is described in the literature but is a distinct clinical entity from traumatic KD in terms of neurovascular risk and surgical treatment [61].

5.8 Conclusion

Knee dislocations are increasing in frequency and are more common than previously thought. Because KDs are complex and often difficult to manage, it is essential that the injury be recognized early and classified appropriately. Position, energy, and pathophysiologic classifications are not able to fully characterize each dislocation, and they are not able to aid in planning treatment. The anatomic classification is simple yet comprehensive, helpful in directing treatment, reflective of the severity of injury, and allows for easy communication between providers when managing such ligamentous injuries about the knee. We recommend that all knee dislocations be classified using this system (Appendix 1).

Appendix 1: "The Story" of the Anatomic Classification System

New ideas take approximately 7 years to gain scientific consensus and the KD classification had a similar path [62]. I am of late asked the origination of the system, and it was a relatively easy concept after caring for a patient I couldn't classify by the Kennedy system. In the early 1990s, I was preparing for an ACL reconstruction when I was asked by a trauma surgery colleague to come to his room for help with a knee injury. The surgeons were re-vascularizing patient MS after a pedestrian motor vehicle accident in a 22-year-old college student hit by a tractor trailer. In that operating room, I saw two images: a single lateral knee radiograph (knee

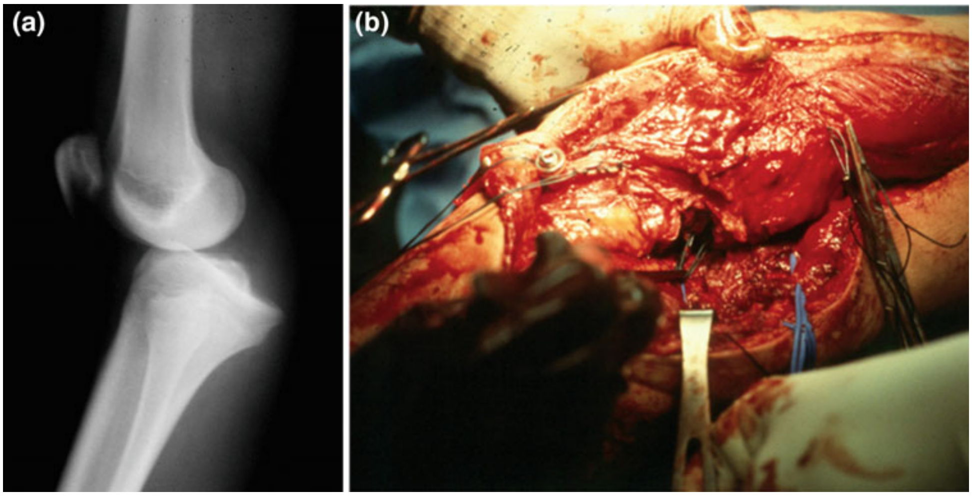

Fig. 5.8 Lateral and only radiograph (**a**) available for patient with a KDIIIMC that lead to the anatomic knee dislocation classification. The radiograph was not classifiable by the position system and appeared "perched". Open exploration for the vascular injury related to the knee dislocation seen in (**b**). Immediate repair of the MCL and PCL "peel-off" from the femur with delayed reconstruction of the ACL provided long-term stability and good knee function at 20-year follow-up

reduced before an AP could be obtained) and a knee open from a posteromedial approach, Fig. 5.8.

Because of the perfect timing of presentation (I was rested, had a sports team available, MCL sleeve avulsion, PCL peel off from the femur, and I was comfortable with the management planned) I was able to reattach the MCL and PCL ligaments quickly and create a stable knee with a tibiofemoral pin through the notch in the alignment of the ACL. The Steinmann pin was removed at day 10, motion was established, and I performed an ACL hamstring autograft reconstruction at 8 weeks post injury with a matured reverse saphenous vein graft reconstruction. The patient underwent a third surgery 5 years post injury in 1997 for meniscal injury. In 2013, MS was seen with a thorough examination at 22-year follow-up [63].

That afternoon, however, in 1991, I reflected on the "perched" appearance of the tibiofemoral joint and I realized MS wasn't classifiable with available systems. Understanding the controversy of instability patterns (position or Kennedy system) and the concept of individual ligaments torn, I came up with the KD concept. I wanted to include spontaneously reduced dislocations, PCL intact dislocations (KDI), and the variety of injuries that could be realistically included with increasing numbers having increasing energy of injury. The original classification was published in 1994 and was modified to add a fifth category when gratefully collaborating with Dr. Daniel C. Wascher in New Mexico. The acceptance of the system in the literature was slow but has been used regularly in the United States when Dr. William Clancy advocated for using the system at an AOSSM meeting in the late 1990s (Robert C. Schenck, Jr.).

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6

Instrumented Measurement of the Multiple-Ligament Injured Knee: Arthrometers, Stress Radiography, and Laxiometer

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List of Abbreviations

ACL	Anterior cruciate ligament
AP	Anterior–posterior
BAT	Blumensaat's line-anterior tibia
CAS	Computer-assisted surgery
GNRB	Genourob
KiRA	Kinematic Rapid Assessment
LARS	Ligament augmentation and reconstruction system
LCL	Lateral collateral ligament
MCL	Medial collateral ligament
MRI	Magnetic resonance imaging
N	Newton
PCL	Posterior cruciate ligament
PCL	Posterolateral corner
PKTD	Porto Knee Testing Device
SSD	Side-to-side difference
VKLD	Vermont Knee Laxity Device

6.1 Introduction

Knee stability is comprised of dynamic and static stabilizers, working synchronously to resist physiologic forces. Pathologic laxity occurs with injury to one or more of these supporting structures [1]. Assessment of knee laxity is imperative for the diagnosis of acute traumatic or chronic ligamentous injuries, as well as postoperative monitoring and outcome data reporting. The morbidity of untreated or undiagnosed ligamentous injuries of the knee contributing to symptomatic instability, gait disturbance, and accelerated degenerative changes of articular cartilage. Thus, the importance of a conclusive, reliable, and accurate diagnosis of these ligamentous injuries particularly in multi-ligamentous injuries cannot be overstated.

There are numerous established means of diagnosing ligamentous knee injuries, including physical examination, advanced imaging studies, stress radiography, and arthrometry. Each of these modalities has their own benefits and limitations. For example, the physical exam is a quick, inexpensive diagnostic test, but also has been labeled as subjective, imprecise, and non-reproducible. Whereas magnetic resonance imaging (MRI) allows for assessment of bony and soft tissue structures about the knee, but is expensive, time-consuming, and does not allow for dynamic examination of knee structures. Thus, it is important to understand the pros and cons of these diagnostic tests for diagnosing laxity when utilizing them in practice.

By definition, laxity is "the measured amplitude of joint movement within the constraints of its ligaments." Within this parameter, both physiologic and pathologic laxity exist. The process of differentiating these two can be aided by laxiometry, which is the measurement of movement within a joint. The objective of laxiometry is to assign an objectively measured value on the amount of movement within a joint, and then determine whether that motion is associated with a pathologic process [1].

In this chapter, we will discuss historical methods of laxiometry, primarily stress radiography or arthrometry. In addition to these conventional techniques, newer technologies are being utilized in order to obtain more reliable measurements with the use of motion sensors and visual recognition. Furthermore, we will itemize ligament-specific technique recommendations based on the current literature.

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6.2 Stress Radiography

In general terms, stress radiography is the visual measurement of resultant joint translation as captured on X-ray in the presence of a directionally applied force. There are many considerations that need to be addressed when performing stress radiography to obtain reproducible and reliable measurements. These consist of patient positioning, designation of local anatomical reference points, how to apply different forces, and what measurements will constitute significant values to suggest pathologic laxity [2].

6.2.1 Reference Points

With stress radiography, ideal reference points on the proximal tibia and distal femur should be selected, in close proximity to the joint line or axis of rotation, and the translational difference of these points after an applied force could be measured and recorded. Unfortunately, plain radiographs are two-dimensional images, and thus, reproducibility is susceptible to deviations in patient positioning, extremity posture, and X-ray cassette placement. These distortions can be minimized through the use of meticulous exam technique and by selecting reference points that are less susceptible to flexion and rotational errors.

When assessing for anterior–posterior instability of the knee, laxity is best assessed on a lateral film. The two basic reference point principles are as follows:

(1) Rotational error decreases as points are selected closer to the center of the knee.
(2) Flexion error decreases as points are selected closer to the posterior tibial cortex.

The balance of these two principles will provide the most reliable anterior to posterior translational measurements despite small changes in flexion and rotation of the extremity [3, 4].

Historically, the reliable radiographic landmarks of the femur include the posterior aspect of the medial or lateral femoral condyle, midpoints between the femoral condyles, axis of the femoral shaft, and tangential lines to the Blumensaat's line. Landmarks of the tibia include the posterior aspect of the medial and lateral tibial condyle, midpoints between the tibial condyles, axis of the tibial shaft, the tibial eminence, and the fibular head [3].

Anterior Tibial Translation: Lee et al. demonstrate the most reliable and reproducible measurement for anterior tibial translation was obtained from the Blumensaat's line-anterior tibia method (BAT). The BAT method consists of drawing perpendicular lines tangentially to the posterior point of the Blumensaat's line, then a line along the anterior cortex of the tibia proximal to the tibial tubercle as seen in Fig. 6.1. The distance between these points would be the reference value. The measurements are then recalculated after an anteriorly directed force is placed on the tibia [4].

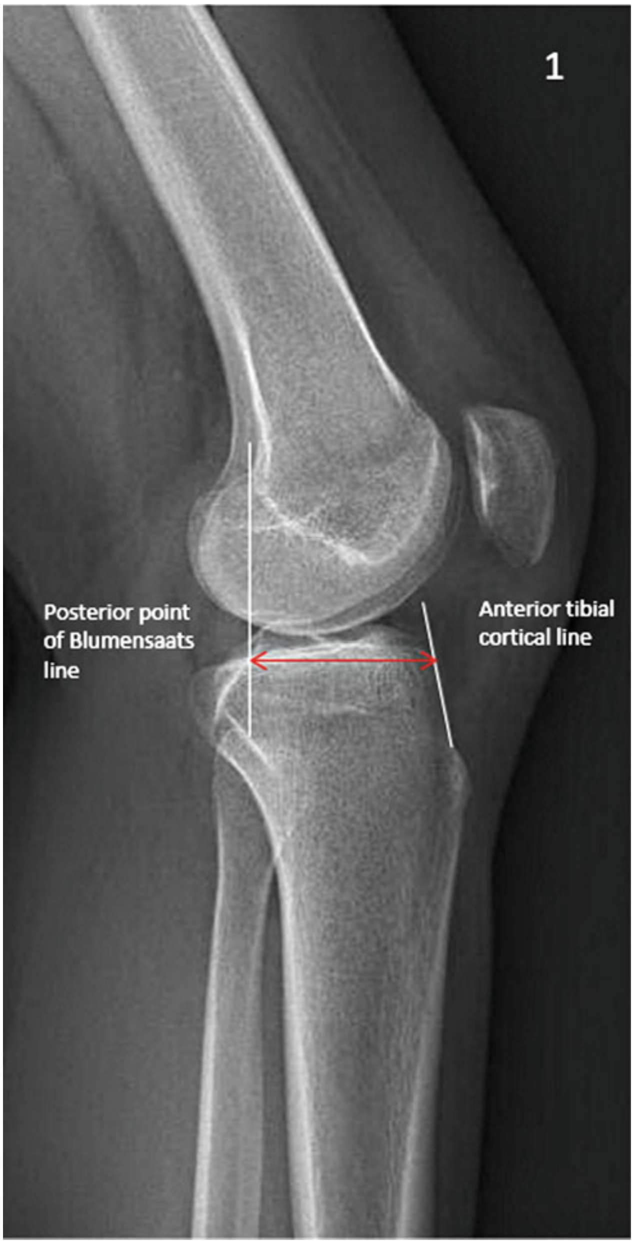

Fig. 6.1 Lateral XR of the knee demonstrating BAT technique with tangential line drawn at the posterior aspect of Blumensaat's line and along the anterior tibial cortex, proximal to the tibial tubercle

Posterior Tibial Translation: The previously described BAT and the central–peripheral method were found to be most reliable and reproducible in assessing posterior tibial translation. The central–peripheral method consists of drawing perpendicular lines tangentially to the midpoint

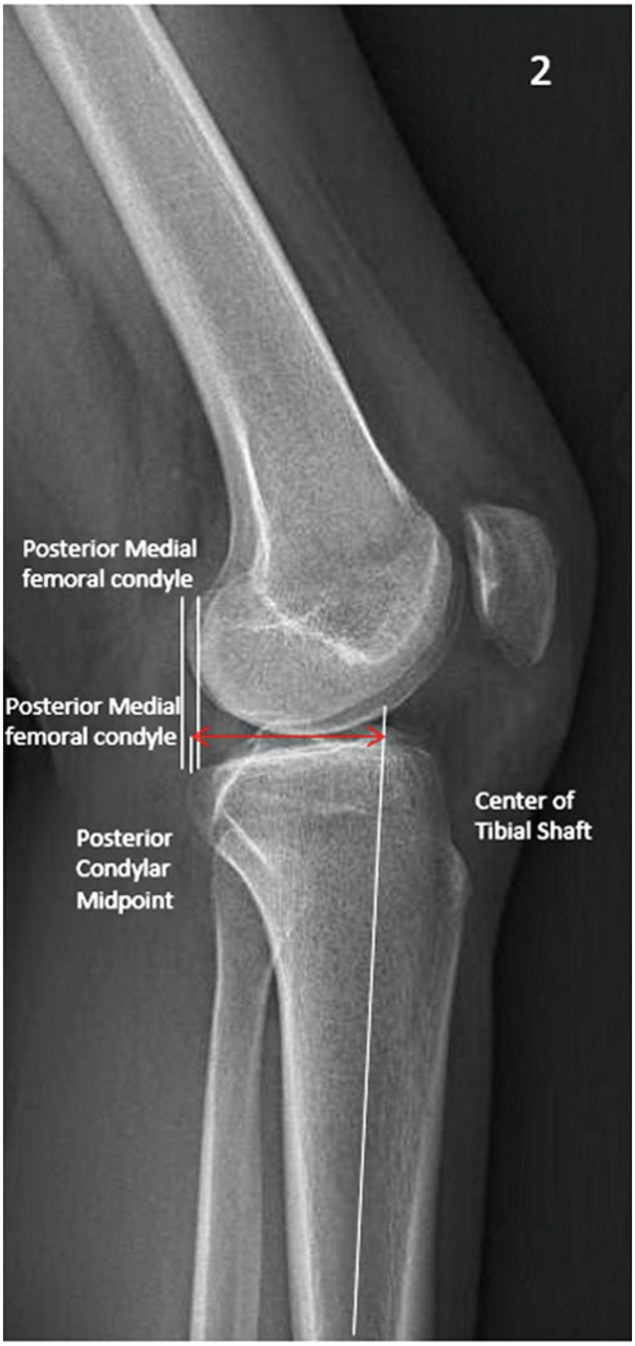

Fig. 6.2 Lateral XR of the knee demonstrating central–peripheral method with a line drawn midway between the posterior aspect of the medial and lateral condyles, then a second line drawn down the center of the tibial shaft

between the posterior contour of the medial and lateral femoral condyles, then a line directly parallel to the center of the tibial shaft as depicted in Fig. 6.2. Similarly, the translation was measured between these two lines with and without a posteriorly directed force upon the tibia [3, 4].

Varus/Valgus Laxity: This is best assessed on anterior–posterior (AP) radiographs. There are no studies comparing which reference points provide the most reliable measurements. However, landmarks that have been described by investigators in the literature on valgus stress testing include distance from the midpoint of the medial femoral condyle and a perpendicular line to the corresponding medial femoral condyle [5], or a tangent line drawn to the subchondral bone of the femoral condyles, then a perpendicular line down to the most medial point of the medial tibial plateau [6]. Similar measurements were used for varus stress, including the distance between the subchondral bone at the most distal point on the lateral femoral condyle and a perpendicular point on the lateral tibial plateau (Fig. 6.3) [7].

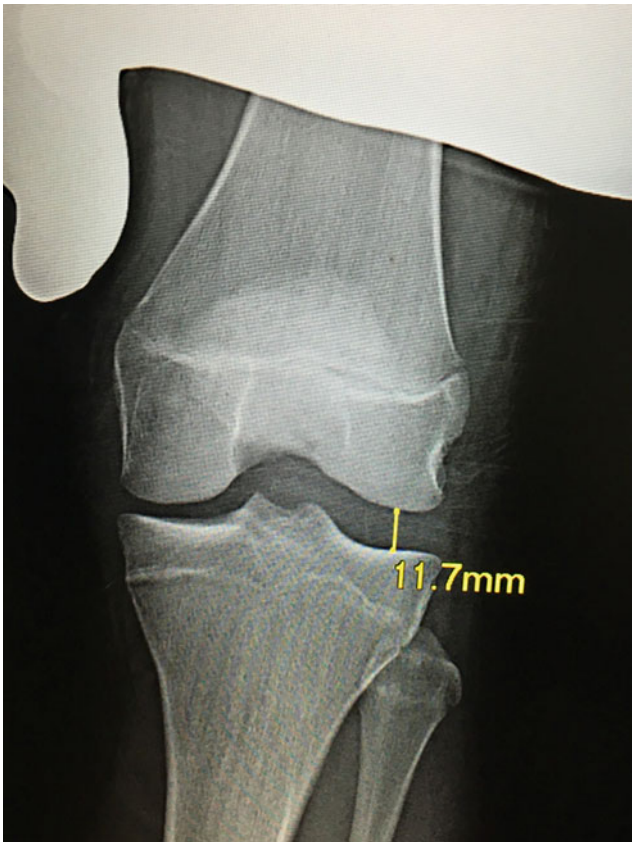

Fig. 6.3 AP radiograph of the knee with an applied varus stress. The depicted measurement demonstrates the lateral compartment gapping by drawing a line from the subchondral bone of the lateral femoral condyle and the subchondral bone of the lateral tibial plateau. Image courtesy of Patrick Kane, MD

6.2.2 Positioning

Positioning of the patient is determined by the anatomical structures being evaluated. Varying degrees of flexion will engage different anatomic stabilizers throughout the arc of motion. The goal in patient position is to isolate specific structures the examiner is trying to assess from other stabilizers.

Anterior Cruciate Ligament (ACL): The predominant and most commonly accepted position for assessing the ACL is with the knee resting in 20° of flexion. This is consistent with position of the Lachman examination, which is thought to best isolate the ACL's contribution to anterior stability from other structures of the knee [2, 8].

Posterior Cruciate Ligament (PCL): Protocols for assessing the PCL have ranged from positioning the knee in 10° of flexion up to 100° [8]. However, the most prevalent position places the knee in 90° of flexion, as this best isolates the PCL [8].

Varus/Valgus: The most common protocols place the knee in 20° of flexion alone or with repeated examinations at 0° and 20° [2, 8].

6.2.3 Application of Force

The utility of a stress exam is in dynamic nature, achieved through the variable application of force about the knee. There are numerous means of applying and varying force amplitude, including the three most commonly used methods: Manual, Active, and Telos device (Telos GmbH, Laubscher, Holstein, Switzerland) [2].

Manual: The manual method of force application involves an examiner applying force upon the knee joint. At the point of greatest translation, radiographs would be obtained in order to capture a quantitative degree of laxity within the knee. The inherent limitations are dependent upon consistency of the examiner.

Active Stress: In this method, the force application is generated by loading the knee joint with gravity or through the use of weights. For ACL assessment, DeJour et al. described a method in which the patient is lying supine with the knee draped over a triangle. Once positioned, the patient performs isolated quadriceps activation to extend the leg in the air using only gravity as resistance. The resultant action of the quadriceps contracting while extending the leg will cause anterior translation of the tibia [2]. In another example, Beldame et al. report using a 7-kg ankle weight while the knee is supported at 20° of flexion, the patient then extends the knee against the weight to exert anterior tibial translation [9].

Telos Device: The most commonly used technique for force application is the Telos device [8]. This device delivers a consistent and measurable amount of force to the knee in a linear plane. It is comprised of a pressure plate that exerts force in the direction of testing, while two "counter bearings" provide restraints proximal and distal to axis of rotation. When testing the ACL, the pressure plate is placed on the posterior calf (to apply an anteriorly directed force to the tibia), the proximal counter bearing is placed 5 cm above the patella to resist femoral translation, and the distal counter bearing is placed at the anterior ankle joint to fix the distal tibia (Fig. 6.4). The knee can then be placed in a desired position, stress can be applied, and radiographs are obtained.

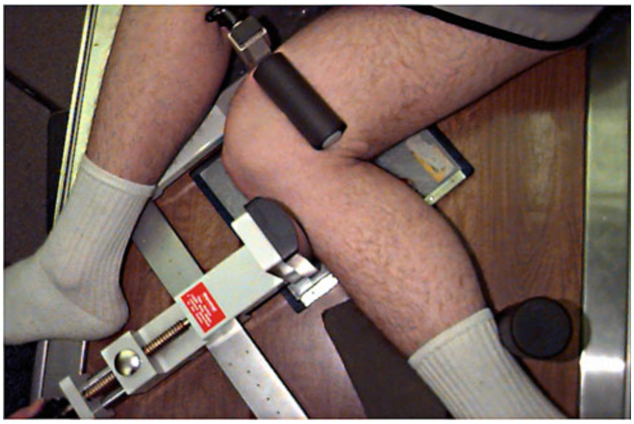

Fig. 6.4 Clinical photo of the Telos device exerting a posteriorly directed force on the proximal tibia

Other described methods of force application have been described in the literature, but are not as widely studied. The Genucom Knee Analysis System (FARO Medical Technologies Inc, Montreal, Canada) is a computer-assisted device that measures the degree of laxity based on surface translation during a manual stress exam [10]. Another example is the S-type load cells, which are electronic measurements of a manually applied force based on strain readings, typically used for varus/valgus stress [5, 7].

In addition to means of force application, the magnitude of the force is equally important. Manual force application, such as in the Lachman maneuver, does not have an objectively measured quantity of force. For reference, however, a study by Beldame et al. suggests that the average amount of force applied in the manual Lachman exam is 154.8 ± 28.5 Newton (N) [11]. In terms of objective measures, the Telos device is the most reliable and reproducible method for applying a constant force. Often applied force values of 67, 89 134, 150, 178 and 250 N have been described in Telos protocols for ACL assessment [9, 12, 13]. Beldame et al. have data that suggests increasing the force to 250 N during Telos testing will increase the sensitivity and specificity of diagnosing ACL tears [9]. However, the trade-off for increasing force is patient discomfort and guarding [14].

6.2.4 Measurement Thresholds and Comparisons

Once a reliable and quantifiable stress examination has been performed, the next step is to understand the clinical significance of these measurements and their application in the context of ligamentous injuries. There are three commonly reported ways to utilize these values: side-to-side differences (SSD), absolute values, and ratios [2, 6, 8].

Side-to-Side Differences (SSD): This is the most common means to deduce the clinical significance of stress radiographs is to perform a side-to-side comparison. This strategy consists of performing the same stress test, regardless of method, to both the injured and the non-injured side with secondary comparison. There are many different reported values in the literature as to what constitutes a meaningful threshold that would suggest a ligamentous injury. When assessing the ACL with the use of Telos stress application, Bouguennec et al. suggest the normal side-to-side differences in uninjured knees is 1.7 ± 0.33 using 9-kg or (88.2 N). They recommend >2.5 mm as the cut off for pathologic ACL laxity [14]. Thus, proposed ranges from 2 to 6 mm as the threshold for pathologic laxity [8]. However, these numbers are highly dependent on the magnitude of the force applied.

Absolute Values: This is highly dependent upon adhering to a strict protocol to avoid measurement error or operator-depending variation. Measurements of varus/valgus laxity have been described by LaPrade et al. [5, 7]. A cadaveric sectioning study assessing medial collateral ligament (MCL) competency with applied 10-Nm valgus force via an S-type load cell found that medial gapping of 3.2 mm or greater at 20° of knee flexion signified a grade 3 medial injury, with involvement of both the superficial and deep MCL [5]. Similarly, a 10-Nm varus force with the same protocol suggested that an isolated lateral collateral ligament (LCL) is associated with 2.7 mm of lateral compartment gapping, and a grade 3 combined posterolateral corner (PLC) injury reflects 4.0 mm of lateral compartment gapping.

Ratios: Ratios of side-to-side differences have been suggested as a means of developing a threshold for pathologic laxity. The argument for ratios is that this takes variable magnification on XR out of the equation and does not simply rely on absolute value comparisons. Sawant et al. developed a protocol consisting of simultaneous bilateral manual valgus stress application until the valgus endpoint was reached. They found that an SSD ratio of >2 was synonymous with a combined MCL and PCL or ACL injury [6].

6.2.5 Stress Magnetic Imaging

In addition to stress radiographs with manual or device applied pressure, recent reports have suggested stress application during an MRI exam utilizing the Porto Knee Testing Device (PKTD). The theory of this device is to be able to evaluate both anatomy and function of the knee. Under this scheme, a footplate fixes the ankle distally and allows for control tibial rotation and knee flexion. A cuff resting at the level of the posterior calf can then be inflated or deflated to impart an anteriorly directed force on the tibia (Fig. 6.5). An MRI sequence is then performed both with the exerted force and without stress, and quantifiable translational differences can then be measured based on reformatted imaging [15].

The study by Espregueira-Mendes et al. demonstrates similar reliability as the KT-1000 in assessing anteroposterior translation [15]. As for rotational instability, measurements of lateral and medial tibia translation were measured and compared. When referencing the rotational instability to a clinical pivot-shift, the authors found that a 3.5 mm difference between medial and lateral tibial translation correlated with a “2+/3+” pivot-shift, suggesting that this is a valid quantifiable measurement of rotational laxity.

While there are few studies evaluating the utility of this emerging technology, stress MRI exams may be a viable adjunct in guiding clinical management. However, this may be offset by the cost- and resource-intensive nature of this evaluation, so further research is warranted prior to wider-scale implementation.

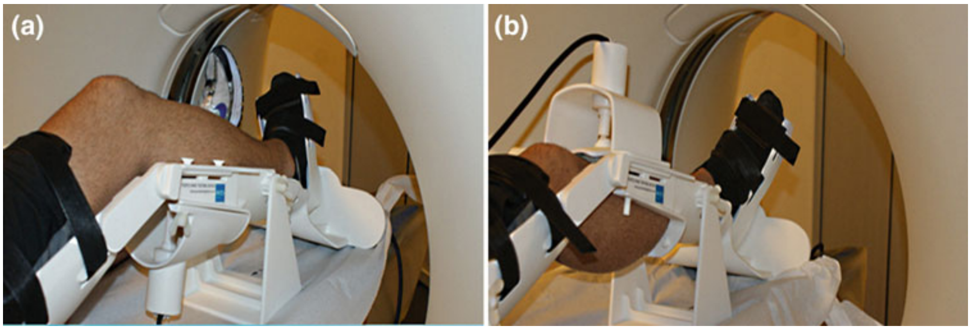

Fig. 6.5 Clinical photograph of the MRI-compatible Porto Knee Testing Device—PKTD®. **a** Patient positioning within the device. **b** The PKTD actively exerting force upon the tibia using the inflatable cuff. Images courtesy of Rogério Pereira, PKTD®

6.3 Arthrometry

Arthrometers are similar to stress radiographs in that they measure a quantitative degree of laxity within a joint in response to an applied force. However, arthrometry standardizes both applied force and offers objective measures the resultant laxity. Measured laxity is typically obtained by recording translation of surface structures in contact with the arthrometry device. There are numerous commercially available arthrometers in use, including the KT1000/2000 (MEDmetric Corp, San Diego, CA), GNRB (Genourob, Laval, France), Rolimeter (Aircast, Neubeuern, Germany), Acufex Knee Signature System (Acufex Microsurgical, Norwood, MA), Vermont Knee Laxity Device (University of Vermont, Burlington, VT), and LARS Laxiometer (Lars Inc, Dijon, France). Historically, the KT series has often been considered the gold standard of arthrometers, although recent literature suggests other arthrometers offer comparable diagnostic value or marginally superiority [10].

6.3.1 KT 1000/2000

Introduced in 1982, the KT arthrometer series (KT-1000, KT-2000) measures laxity by quantifying the anterior–posterior displacement between the femur and tibia via sensor pads on the patella and the tibial tubercle. The patient's knee is positioned in the desired degree of flexion, force is then generated by manually pushing or pulling the attached force sensing handle, imparting a progressive degree of anterior–posterior translation of the tibia (Fig. 6.6). Translation measurements are automatically recorded as increasing thresholds of applied forces are met. The standard thresholds are 15 lbs. (67 N), 20 lbs. (89 N), and 30 lbs. (133 N). The KT-2000 series differs from the KT-1000 in that as opposed to recording three finite measurements, it records continuous data and displays a force–displacement curve on an X-Y plotter [10].

Examination is historically performed on both the injured and uninjured knees. A side-to-side difference is then utilized to assess for pathologic laxity. Reported cutoffs have ranged from 2 to 6 mm; however, 2 or 3 mm is most commonly used. In a study by Bach et al. utilizing the KT-1000 at 30-lbs of force for both acute and chronic ACL tears, respectively, their group assessed how SSD cutoff values impacted sensitivity and specificity.

- 2 mm SSD cutoff: sensitivities 0.77 and 0.72; specificities 0.90 and 0.90.
- 3 mm SSD cutoff: sensitivities 0.90 and 0.77; specificities 0.64 and 0.64.

As expected, these studies demonstrate a higher cutoff value may be used to rule out ACL injury, or a lower value to rule in injury.

In general, the literature supports the use of the KT arthrometer as both a reliable and reproducible device in the diagnosis of ACL injuries [16–21] and PCL injuries [22]. A 2013 meta-analysis comparing the KT-1000, to seven other arthrometers found the KT-1000 to be the most sensitive and specific device for diagnosing complete ACL tears when applied at maximum manual force [23]. In contrast, however, there are published studies that demonstrate the significant inter- and intra-rater variability, raising concern for the utility of this device [24, 25].

Overall, the KT arthrometer is generally accepted as a validated device to quantitatively measure knee laxity. Testing protocols should be carefully documented and executed to obtain the most accurate measures. These protocols can help eliminate sources of error that include improper placement of the arthrometer and sensors, examiner hand dominance, inadequate patient relaxation of hamstrings and quadriceps, incorrect vector and rate of force application, and variations in tibial rotation [26, 27].

6.3.2 GNRB

The (Genourob) GNRB was introduced in 2005 in an attempt to address sources of error attributed to KT inconsistencies in some literature. The GNRB is similar to the KT series in that it measures anterior–posterior translation of the tibia in reference to the patella. However, this apparatus is robotic with an electric actuator that applies a slowly increasing translational force to the tibia and measures motion based on surface landmarks. Additionally, surface electrodes are placed on the posterior thigh to measure hamstring activity, which commonly is a confounding variable in ACL measurements due to patient guarding. When these electrodes capture muscle activity, the device provides a cue to the patient and examiner to relax the thigh musculature or to restart the examination (Fig. 6.7) [28].

Similar to the KT-1000, there are a wide range of applied forces quoted in the literature, with several suggesting 89, 134, and 250 N. Robert et al. suggests the use of 134 N will allow for a diagnosis of a partial thickness ACL tear at 1.5 mm of laxity with a sensitivity of 80% and specificity of 87%. In another analysis, Lefevre et al. suggested a sensitivity of 84% and specificity of 81% at 2.5 mm of laxity with the use of 250 N of force for diagnosing a full tear.

Recent studies have demonstrated a superior accuracy, and intra- and inter-rater reproducibility as compared to the KT arthrometers [14, 28, 29]. Also, current studies suggest less

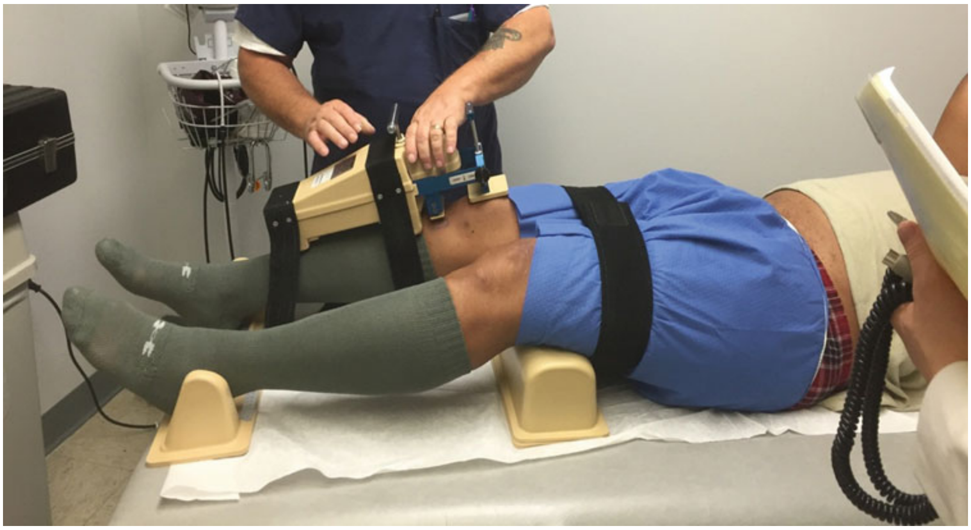

Fig. 6.6 A clinical photo of the KT-1000 device. The image demonstrates the appropriate positioning of the device prior to manually exerting a force on the tibia via the attached T-handle

examiner-dependent variability due to automation. However, contradicting findings by Vauhnik et al. have tempered some initial enthusiasm, in part due to findings of poor intra- and inter-rater reproducibility. They have suggested this variation may be related to patient positioning relative to the device and tibial rotation during the testing [30, 31].

6.3.3 Rolimeter

The Rolimeter is a simple device constructed with the express purpose of quantifying either the posterior drawer or Lachman exam. It consists of a longitudinal steel frame with a padded anchor which rests on the patella and a padded anchor that is strapped to the distal tibia. The actual measuring device is a probe that rests on the tibial tuberosity and has the ability to be translated anteriorly or posteriorly (Fig. 6.8). Upon application of the anterior or posterior force upon the tibia, a plastic stopper attached to the probe will move from a “zeroed” position and measure the amount of maximal anterior or posterior tibial translation with respect to the patella [32].

Fig. 6.7 The GNRB device positioned on the lower extremity of a patient with a representative image of the data readout as seen on the laptop computer screen. Image courtesy of Stéphane Nouveau, Genourob®

This device has not been as widely studied as the GNRB and KT-1000, but is still a prominent arthrometer. When compared to other arthrometers/examinations, it has been demonstrated to be more exact than the Lachman test and shows similar reliability to the KT-1000 in diagnosing ACL tears [32, 33]. However, Panisset et al. showed the Telos with stress radiographs to be more sensitive and equally as specific as the Rolimeter in diagnosing an ACL tear [20, 34]. The Rolimeter has also been used in the evaluation of posterior tibial translation. Hoher et al. compared the Rolimeter to stress radiography and found comparable results in diagnosis of PCL tears [35].

The benefit of the Rolimeter lies in its simplistic design. It provides a method to assign a more specific, quantifiable measurement of laxity to the posterior drawer or Lachman exam in less experienced hands. Additionally, it is able to be sterilized and is an option to have available on the surgical field intraoperatively. However, this device is highly examiner-dependent and still relies on patient relaxation for accuracy [10].

6.3.4 Laxity in Multiple Dimensions

There are other described arthrometers that attempt to quantify a combination of classic AP, varus/valgus, rotational laxity. The Vermont Knee Laxity Device (VKLD), Acufex Knee Signature System, Genucom Knee Analysis System, and other versatile systems are among available

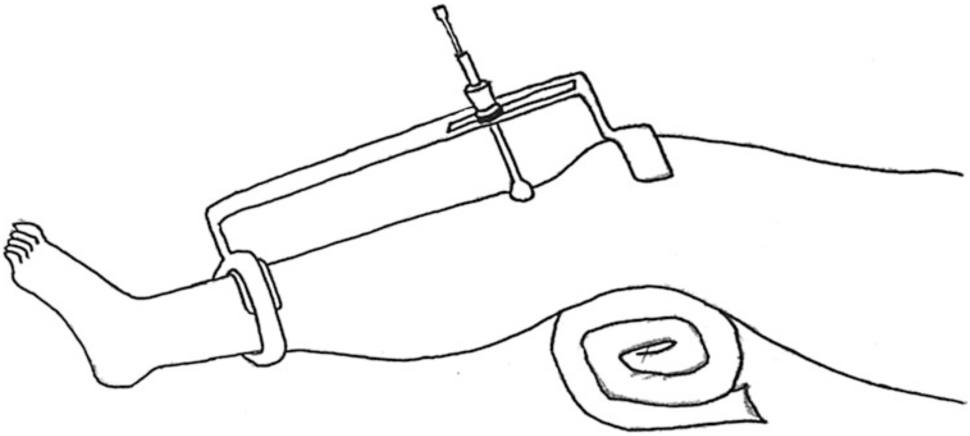

Fig. 6.8 Illustration of the Rolimeter device. A manually directed anterior or posterior force is applied to the tibia, and the resultant tibial translation is captured by the stopper and probe, which can be seen in the middle of the device

options. However, the literature on these devices is relatively scant.

The Vermont Knee Laxity Device anchors to the thigh, just proximal to the knee while positioned in 20° of flexion. A tightly fitting boot is then fixed to the subject's ankle and then fixed to a foot cradle in which rotational forces can be applied. Laxity is measured with electromagnetic position sensors fixed to the skin overlying both the tibia and the femur. To measure varus and valgus laxity, the boot is unlocked and allowed to move in a coronal plane only. With 10 Nm of force then applied with a force transducer to the distal tibia, resultant varus/valgus laxity is then recorded. As for rotational deformity, the foot cradle is unlocked in a fashion to only allow rotation in an axial plane. Again using the force transducer, 0–5 Nm of force is applied via T-handle and the resultant rotational degree of displacement is measured and recorded. The entire cradle apparatus is attached to rails in which the cradle can be fixed or freely sliding, allowing the simulation of non-weight-bearing and weight-bearing measurements by applying or removing an axially based force [36].

The only published study in the literature offered encouraging results with reliable measurements of varus–valgus and internal–external rotation laxity relative to clinical side-to-side differences [37]. However, there have been no further studies available to examine the reproducibility, accuracy, and further reliability.

The LARS rotational laxiometer is another device that is strictly used to measure rotational laxity of the knee. The apparatus is a small instrument which is fixed to the lower leg with the ipsilateral hip flexed to 90°. The femoral condyles of the knee being examined are manually held in position while slow external rotation of the tibia is exerted by a second examiner (Fig. 6.9). Once an endpoint is reached, a

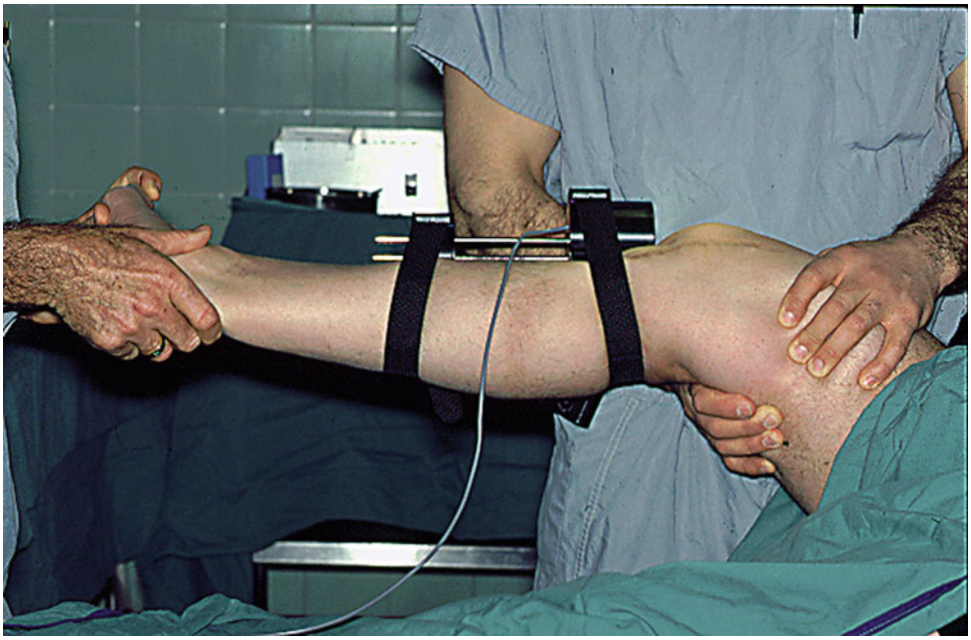

Fig. 6.9 A clinical photo of the LARS Laxiometer, measuring a manually applied rotatory force to the lower leg

quantitative degree of external rotation is captured by the electronic goniometer attached to the device. The exam is then repeated to quantify side-to-side differences [38].

Bleday et al. [38] found that normal external rotation consisted of a side-to-side difference of 4.4° or less at 90° of knee flexion, and 5.5° or less at 30° of knee flexion. Thus, this instrument is most useful in assessing the posterolateral corner in a noninvasive manner. Unfortunately, the degree of applied rotational force and femoral condyle stabilization is subjective and operator dependent as to when an “endpoint” is reached.

6.4 Computer-Based Kinematics

Computer-based navigation has been used in ACL reconstruction since as early as 1995. Its use has been documented to assist in tunnel placement as well as kinematic evaluation of the knee [39]. The concept of computer-assisted surgery (CAS) of the ACL is to map out extra-articular and intra-articular landmarks of the knee with registration devices that are relayed to the computer. The computer overlays this information with preoperative imaging (XR, CT, MRI depending on the system) and tracks the anatomy and kinematics of the knee three-dimensionally [40].

Currently, the primary exam for evaluation of dynamic laxity in the ACL injured knee is the pivot-shift. Particularly, CAS has been used to evaluate the translation, rotation, and acceleration of the lateral tibial plateau during the pivot-shift maneuver [39]. The sensors have a reported accuracy of recognizing a registered point in space to within 1 mm. These values are accurate and can be effectively used intraoperatively. However, this system cannot be used pre- and postoperatively due to the invasive nature of the registration process, making the kinematic data limited.

In response to the invasive nature of CAS, there have been a number of programs developed in an attempt to use surface monitoring to evaluate lateral tibial plateau motion. One example in the literature is the Kinematic Rapid Assessment (KiRA) device (OrthoKey, Lewes, DE). This device utilizes triaxial accelerometers attached to the skin and relays quantifiable data to a tablet or computer regarding acceleration of the lateral tibial plateau in relation to the femur during the pivot-shift exam [41].

Another noninvasive measurement of knee instability utilizing visual recognition was introduced by Hoshino et al. This method involved utilizing visual analysis of laterally based skin markers on the knee to quantify the degree of lateral tibial translation during the pivot-shift examination. It works by utilizing a tablet to record the motion of the knee, and then an algorithm is employed to determine the amount of laxity present in the lateral compartment of the knee during the exam [42].

In a validity study, Musahl et al. compared the KiRA device and visual tablet testing to the pivot-shift. They noted an association of increased tibial acceleration with high-grade pivot-shift testing. They also noticed a similar association of lateral compartment translation with a high-grade pivot-shift utilizing the iPad visualization app [43]. Further investigation is warranted to extrapolate on the available data, but both of these devices show promise in quantifying rotatory instability in the pivot-shift exam.

6.5 Individual Ligament Exam Conclusions

6.5.1 ACL

The literature would suggest stress radiography or arthrometry to be equally effective in diagnosing ACL pathology. Stress radiography should be performed at 20°–30° of knee flexion with 250 N of anteriorly directed force via the Telos apparatus to the posterior tibia. Recommendations would be to use the Blumensaat’s anterior tibia (BAT) lines to quantify the amount of laxity imparted by stress radiography. Cutoff values of >3 mm of SSD should be used for the diagnosis of ACL injury. As for arthrometry, both the KT-1000/2000 and the GNRB in experienced hands will provide accurate, reliable, and quantitative data regarding the anterior tibial laxity. The PKTD during MRI may also be an effective tool in assessing both anatomy and laxity in a single exam.

The gold standard for rotational instability remains the pivot-shift examination. There are a number of options to quantify the degree of laxity during a pivot-shift exam, including CAS, KiRA, and visual monitoring. CAS does have inherent drawbacks due to the invasive nature by which data is extracted, requiring implantation of bicortical screws. Both KiRA and visual monitoring are both emerging technologies that need to be further evaluated prior to widespread implementation.

6.5.2 PCL

The exam of choice for the PCL continues to be stress radiography. The literature suggests performing a stress radiograph at 90° of knee flexion with 150–180 N of posteriorly directed force exerted upon the anterior tibia utilizing the Telos apparatus. Either the Blumensaat’s anterior tibia (BAT) landmarks or the central–peripheral method should be used for measuring the degree of posterior laxity. Thresholds to determine clinical significance suggesting injury to the PCL vary from 3 to 12 mm. 6 mm of SSD seems to provide the best balance of sensitivity and specificity for PCL pathology.

6.5.3 MCL/LCL

Based on available cadaveric research, varus and valgus stress radiographs are the most practical and reliable evaluations of MCL/LCL laxity, particularly when performed in conjunction with an experienced radiology technician. The patient should be placed with knees in 20° of flexion and application of 10 Nm of varus or valgus directed force with an S-type load cell. Medial compartment opening of 3.2 mm suggests a Grade 3, complete MCL complex injury, while lateral compartment opening of 2.7 mm suggests an isolated complete, LCL injury.

6.5.4 PLC

The posterolateral corner may be evaluated by stress radiograph, VKLD, or LARS examination. For stress radiograph, current best practice data is largely based on cadaveric studies. The patient should be placed in 20° of knee flexion with 10 Nm of applied varus force via S-type load cell. Lateral compartment opening of >4.0 mm suggests a complete posterolateral corner injury, with involvement of the LCL and popliteus. If available, promising instrumented alternatives such as the VKLD or the LARS may be considered for measurement of rotational laxity. The LARS should be performed with the patient at 30° of knee flexion with external rotation SSD of 5.5° is consistent with a posterolateral corner injury.

6.6 Conclusion

In summary, there are a wide variety of methods that may be employed to objectively evaluate ligamentous laxity in the knee. These include stress radiography, arthrometry, computer-assisted surgical devices, and newer technologies such as surface-based accelerometers and computerized visual recognition may further delineate more nuanced rotational and combined laxity in the future. However, it is important to reiterate that these are adjunctive tools that should not complement, rather than replace, a thorough history and physical examination.

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7

MRI Imaging in the Multiple-Ligament-Injured Knee

W. James Malone and Sean C. Hostmeyer

7.1 Introduction

Clinical assessment for ligamentous injury can be imprecise, particularly in certain subsets of patients. More difficult clinical exams include obese patients, patients with pain and guarding, and those with complex injuries (e.g., multiligament injuries). The consequences of an inaccurate evaluation and misdiagnosis may be severe as missed ligamentous injuries have been implicated in accelerated secondary osteoarthritis [1–3] and may contribute to cruciate graft failure [4–6]. MRI is not without its own limitations, which include artifacts and interobserver variation. MRI is most accurate when performed in the acute to subacute time period (days after the injury). MRI is less accurate and should be used cautiously in cases of chronic injuries as a previously torn ligament with interval scarring may at times appear morphologically intact although physiologically incompetent. The combination of accurate clinical exam with high-quality imaging and interpretation provides the best opportunity for successful treatment outcome. With this in mind, the following chapter will highlight pearls and pitfalls of knee MRI focusing on the normal appearance and injuries to the central, medial, lateral, posteromedial corner, and posterolateral corner (PLC) stabilizers.

7.1.1 Image Quality

The intent of this article is not to review MRI imaging protocols and equipment, but it is imperative to briefly touch on the subject of image quality. Image quality is dependent upon a number of factors, including imaging equipment and how well the imaging equipment is utilized. The primary factor leading to the varying quality from one MRI to the next is based on the "magnetic field strength" or the strength of the magnet in the MRI. Low field strength MRI ranges from 0.3 to 1.0 T and high field strength MRI ranges between 1.5 and 3.0 T. Higher magnetic field strength results in higher image quality. "Open MRI" usually operates with low field strength and hence results in lower quality images. Thus, it is imperative that both the clinician and patient are aware of the large discrepancy in image quality between low field imaging systems versus those obtained with high field imaging. Without high-quality imaging and appropriate imaging protocols, subtle and sometimes glaring pathology may be missed by even the most imaging astute interpreting physician. Thus, clinicians should be knowledgeable of the equipment and protocols employed by surrounding imaging centers so that they may make educated recommendations to their patients.

7.1.2 Plain Radiographs

Although plain radiographs cannot directly evaluate ligament injury, they are commonly performed in the setting of traumatic injury and there are several signs or fractures that are known to be associated with ligament injuries. Examples include the "arcuate sign" and Segond fracture, which are discussed later in greater detail. As such, having the plain radiographs available when interpreting MRI is useful and can help direct attention to potential sites of injury.

7.2 Central Stabilizers: Normal Anatomy and Injury

To determine the integrity of the ACL, both its signal and morphology must be closely scrutinized. The sagittal plane of imaging is often utilized as the sequence, which lays out

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the ligament from its femoral to its tibial attachment. The axial plane should be used together with the sagittal plane, as it best shows the femoral attachment (Fig. 7.1). In the sagittal plane, the normal morphology of the ACL is appreciated as it parallels the roof of the intercondylar notch, following Blumensaat's line [7]. The normal ACL signal intensity is predominantly hypointense on both T1 and T2 sequences, but the ligament almost always demonstrates internal striations that should not be confused with the injury. There are two functional bundles of the ACL named based on their relative attachments to the tibia: the anteromedial bundle (AMB) and the posterolateral bundle (PLB) [8, 9]. The anteromedial and PLBs of the ACL are not always separated as distinct structures on every MRI. However, they may be seen in the axial and coronal planes.

ACL tears most commonly take place in the midsubstance, but can occur anywhere throughout the course of the ligament [7]. Findings suggesting ACL tear include nonvisualization, discontinuity, or abnormal slope or tilt of the ligament [10]. Figure 7.2 demonstrates classic ACL tears. While classic ACL tears are readily apparent on MRI, a tear at the femoral attachment can be subtle and thus overlooked (Fig. 7.3). This femoral avulsion type of tear may not be well depicted in the sagittal plane and is exceedingly difficult to see on open or low field MRI scanners. Therefore, the axial and coronal imaging planes should be employed in one's search pattern [11]. Despite the lack of clinical instability and characteristic MR appearance, ACL ganglions and mucoid degeneration may at times be confused with an ACL tear on MRI [12] (Fig. 7.4). Finally, MRI should be used with caution in diagnosing chronic ligament tears of any type. A scarred but incompetent ACL may appear intact on MRI and may even scar down to the PCL rather than the femur after an injury (Fig. 7.5).

Classic bone contusion patterns seen on MRI should raise suspicion of, but are not diagnostic of, ACL tear. When present, the ACL must be scrutinized for injury. The most common pattern is the "kissing contusion" pattern seen with pivot shift injury, which shows contusions in the posterior lateral tibial plateau and lateral femoral condyle [7, 13]. The pivot shift pattern is often accompanied by contrecoup contusion in the posteromedial tibial plateau [14] (Fig. 7.6). Less common bruising patterns with ACL tears include hyperextension (Fig. 7.7) and dashboard (i.e., pretibial impaction in flexion) contusion patterns, the latter almost always seen with multiligamentous injuries [7].

The normal appearance of the PCL is quite different than that of the ACL. The PCL is homogeneously low in signal on all MRI sequences and is not taut but is normally curved from its femoral to its tibial attachment (Fig. 7.8). Unlike the ACL, the classic PCL tear may be more subtle since it rarely demonstrates complete discontinuity. Both the completely torn and the more common partially torn PCL are both well seen in the sagittal plane. The latter is denoted by thickening and intrasubstance fluid bright signal with areas of partial discontinuity [10] (Fig. 7.9). Of note, isolated ACL and PCL injuries are the exception, and when present the posteromedial corner, PLC, and menisci should be double checked for injury [10, 15].

7.3 Cruciate Grafts: Normal Appearance and Injury

MRI evaluation of cruciate grafts can be challenging for a variety of reasons. In addition to the standard limitations of MRI (i.e., motion), the postoperative images are often hindered by susceptibility artifact and poor fat suppression. The normal MRI appearance of mature ACL and PCL grafts is uniformly low signal on all MRI sequences (Fig. 7.10). This allows one to utilize the same signal, morphology, and orientation changes seen with native cruciate to diagnose ACL

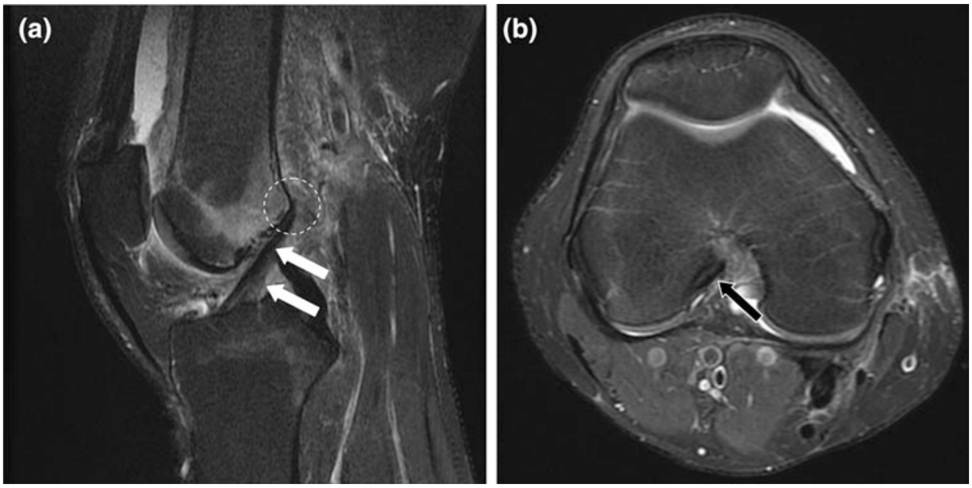

Fig. 7.1 Demonstrates the normal ACL on sagittal and axial T2 images, respectively. **a** Shows the taut, predominantly hypointense ACL (white arrows). Also in **a** note the normal appearance of the tibial attachment (circle). **b** Shows the normal appearance of the femoral attachment in the axial plane (black arrow)

Fig. 7.2 Demonstrates ACL tears in two different patients. **a** Demonstrates a wavy ligament with midsubstance discontinuity (circle). In **b** only the remnant tibial stump of the ACL is visualized (circle). Note the normal PCL (white arrows)

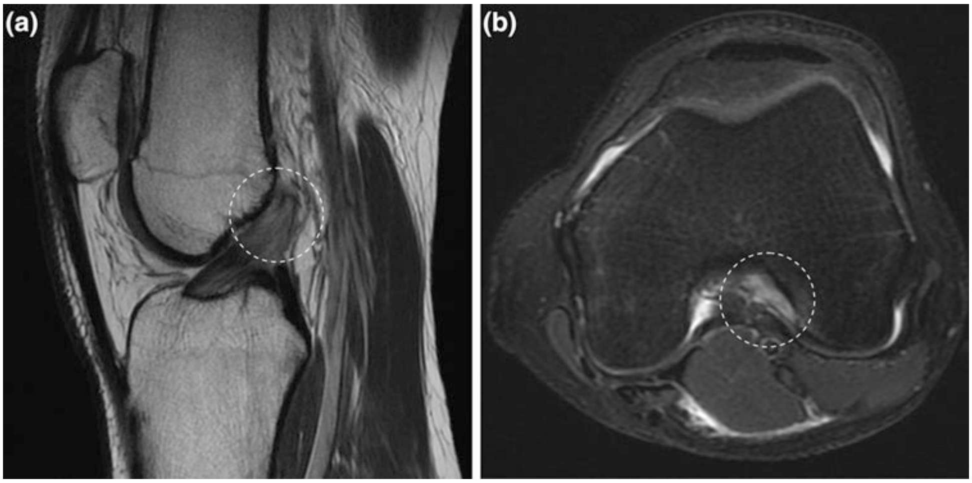

Fig. 7.3 Coronal PD and axial T2 images in a patient with arthroscopically proven femoral avulsion of the ACL. In **a** there is increased signal at the femoral attachment of the ACL and the attachment itself is nonvisualized (circle). In **b** the femoral attachment of the ACL is absent (circle). Compare Fig. 7.3b with Fig. 7.1b, which shows the normal femoral attachment

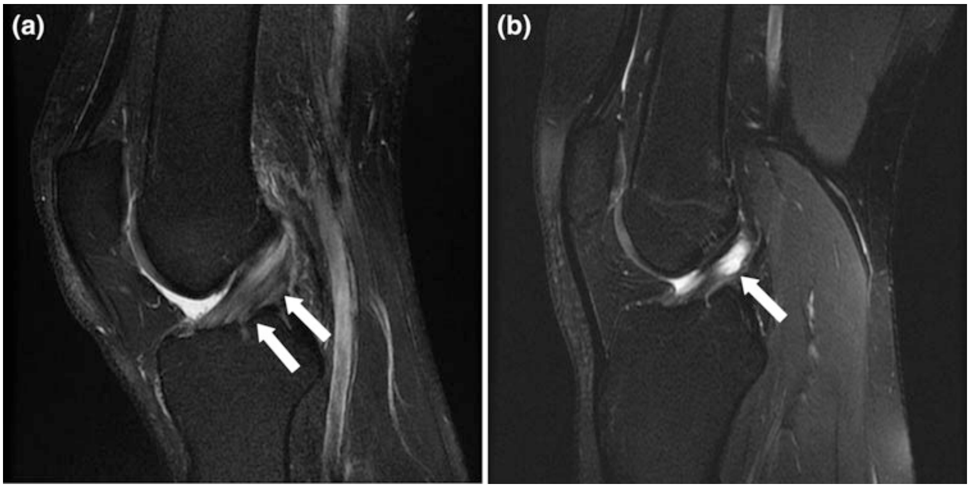

Fig. 7.4 Demonstrates ACL tear mimics. **a** Demonstrates an intact ACL with mild diffuse mucoid degeneration (arrows). In **a** ACL is thickened with T2 bright striations, but the slope is normal, there is no focal discontinuity, and the femoral attachment is intact. **b** Demonstrates an intact ACL with ACL ganglion (arrow)

and PCL graft tears (Figs. 7.11, 7.12, and 7.13). However, the MRI appearance of an uninjured ACL or PCL graft can be variable depending on the age and type of graft. For example, there can be nonpathologic signal changes in a maturing patellar tendon ACL graft for up to 4 years [16]. Focal or segmental increased signal within the graft on

Fig. 7.5 Demonstrates a previously torn ACL, which has subsequently scarred down to the PCL (circle). Findings were confirmed arthroscopically

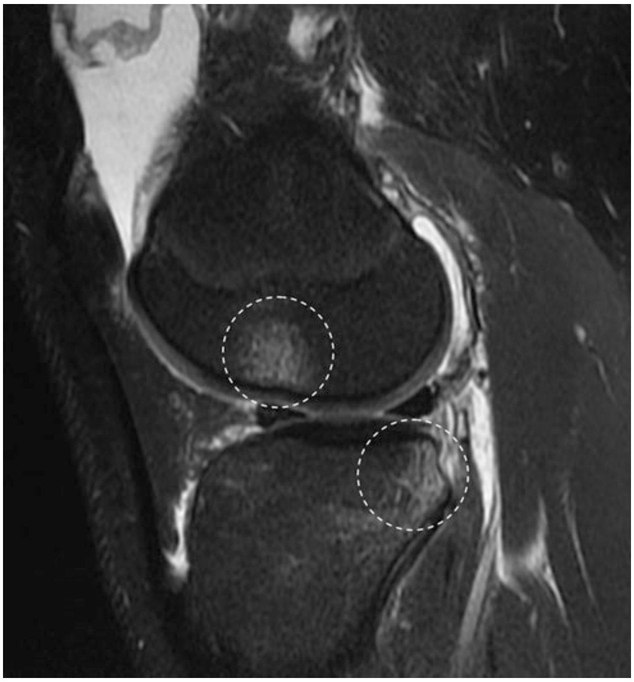

Fig. 7.6 Demonstrates the classic pivot shift bone contusion pattern, which often accompanies acute ACL tears. Note contusions at sulcus terminalis of lateral femoral condyle (circle) and posterolateral tibial plateau (circle)

fluid-sensitive sequences can be seen with partial or single-bundle graft tear, fluid between the two bundles, or signal changes from normal graft maturation [17, 18]. The brightness of the signal and the orientation of the signal can be helpful in distinguishing tear from a normal maturing graft. Intermediate intensity (rather than fluid bright) signal alteration that decreases on follow-up exams is typical of graft maturation [16]. Fluid bright signal changes are more concerning for partial thickness graft tear [2]. Secondary findings supporting graft tear include pivot shift bone contusions or signs of graft impingement, the latter which is often due to poor tunnel placement [18–20]. Graft impingement manifests on MRI as focal anterior signal changes in the graft and/or bowing of the graft as it contacts the intercondylar roof [18, 20, 21].

Fig. 7.7 Demonstrates a hyperextension contusion pattern with edema in the anterior femoral condyle and anterior tibial plateau (circles)

7.4 Medial and Lateral Stabilizers

Numerous interdigitating structural layers stabilize both the medial and lateral knee, including both the posteromedial and PLCs. The terminology for these structures is inconsistent in the literature, with numerous names given to the same structures. Because of this, it is important to make sure there is a clear understanding of the terminology utilized in the radiologic report between the musculoskeletal radiologist and orthopedist. In daily practice as well as in the surgical and radiologic literature, these structures are often collectively called the medial collateral ligament (MCL) and lateral collateral ligament (LCL). However, this antiquated terminology undermines the complexity and importance of the individual structures. More recent improved understanding of the intricate anatomy and function of these

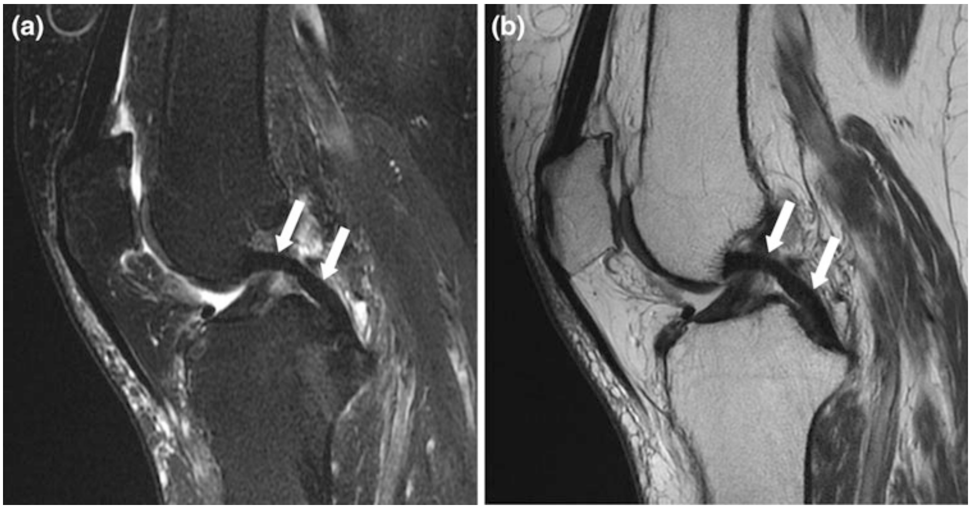

Fig. 7.8 **a** and **b** Demonstrate the normal appearance of the PCL (arrows) on T2 and PD images, respectively. Note the normal curved appearance and the homogeneously low signal on both sequences

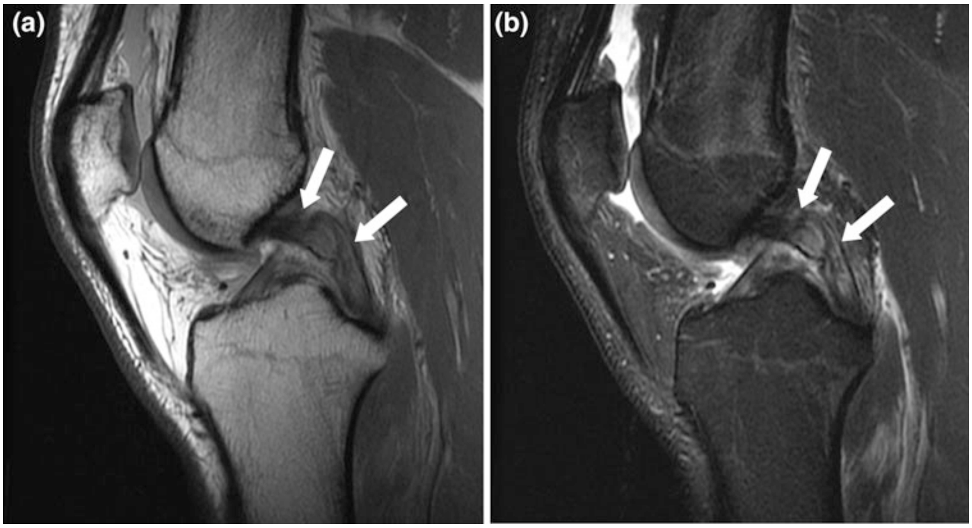

Fig. 7.9 **a** and **b** are sagittal PD and T2 images demonstrating a torn PCL (arrows). The PCL is thickened and edematous but is not completely disrupted

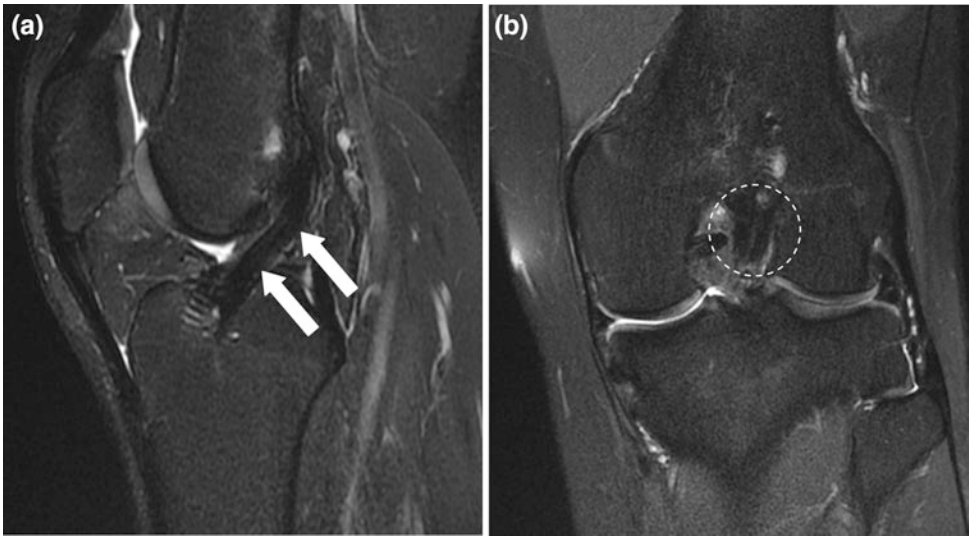

Fig. 7.10 Sagittal and coronal images showing an intact ACL graft. **a** Shows the normal low intensity graft (arrows) with slope following Blumensaat’s line. **b** Demonstrates the two distinct bundles of the double-bundle graft (circle)

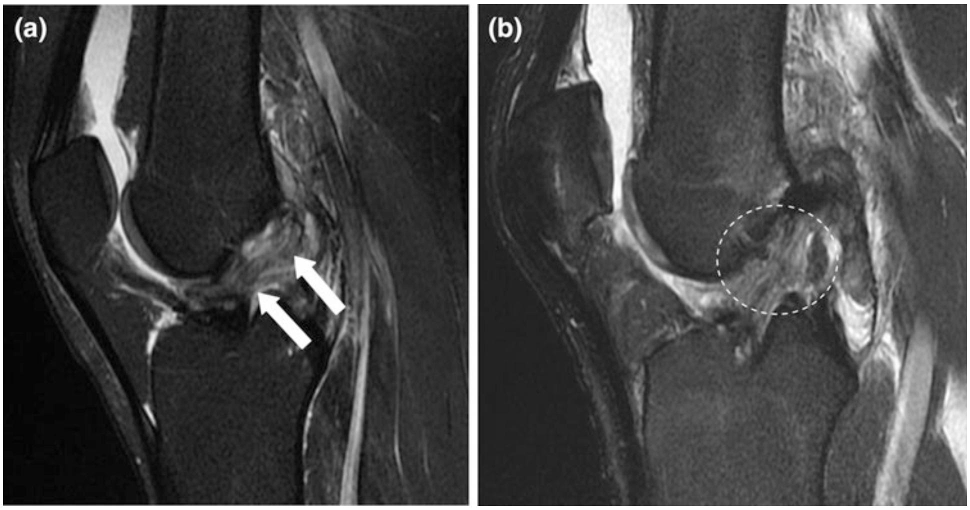

Fig. 7.11 **a** and **b** Demonstrate two different patients with midsubstance ACL graft tears, as denoted by arrows and circle, respectively. Compare to normal graft in Fig. 7.10a

Fig. 7.12 An arthroscopically proven proximal ACL graft tear. Note the thin fluid bright signal gap at the femoral attachment (circle)

Fig. 7.13 A double-bundle PCL graft with single-bundle tear. The tear involves the more anterior bundle near the femoral attachment with an intact posterior bundle (circle). Compare the attenuated PCL graft proximally at site of tear (circle) to the normal graft thickness distally where both bundles are intact (arrow)

stabilizers suggests that injuries to these structures should be distinguished rather than lumped together.

7.5 Medial Stabilizers: Normal Anatomy

Warren initially introduced the layered approach in describing the anatomy stabilizing the middle third of the knee before these structures blend with others as they extend into the anterior and posterior thirds of the knee [22]. These layers, from superficial to deep, are as follows: layer I [crural or sartorius fascia], layer II [tibial collateral ligament (TCL) or superficial MCL (sMCL)], and layer III [deep MCL or middle third capsular ligament]. All three layers are consistently demonstrated on MRI (Fig. 7.14). The deep MCL is a thick condensation of the joint capsule that underlies the TCL and can be broken down into a long thin meniscofemoral ligament and a short thick meniscotibial (coronary) ligament [22, 23]. Of the three layers, this innermost layer may sometimes be challenging to image, and often its components cannot be followed on a single image as they extend from their meniscal to their respective bony attachments. The soft tissue edema that accompanies

Fig. 7.14 The normal medial stabilizer anatomy in the middle third of the knee. Note the thick low signal superficial MCL (thick white arrows). The underlying deep MCL ligament has meniscofemoral (thin black arrow) and meniscotibial components (thin white arrow), which tether the meniscus in place. Also note bucket handle tear (circle)

injury to the deep layer helps to separate these thin structures from the overlying TCL.

7.6 Posteromedial Corner: Normal Anatomy

Further posterior, the deep MCL blends with and reinforces one of the components of the posteromedial corner, the posterior oblique ligament (POL) [22–24]. The POL itself is actually three blending ligaments, but on MRI, it can be conceptualized as a single ligament that contributes in forming the posteromedial capsule (Fig. 7.15). The POL, like the deep MCL, has meniscofemoral (MF) and meniscotibial (MT) components. Also like the deep MCL, they attach to the posterior horn of the medial meniscus helping to tether the medial meniscus in place. On MRI, the POL and TCL can be differentiated from one another based on relative location (posterior vs. anterior) and respective tibial attachments (proximal vs. distal) [11].

The second component of the posteromedial corner, the semimembranosus tendon, fans out and attaches to the tibia posteromedially. The two major arms of the semimembranosus, the anterior and direct arms, are well seen on MRI and rarely appear injured. The anterior arm inserts to the medial aspect of the tibia at the level of the joint line, and the direct arm inserts to the posteromedial tibia just below the joint line. Fascial extensions from both arms of this tendon also help to form and reinforce the joint capsule [22–24].

Fig. 7.15 The normal posterior oblique ligament (POL) in the posterior third of the knee. The normal low signal POL ligament also has meniscofemoral (thin black arrow) and meniscotibial (thin white arrow) components, which are thicker than the deep MCL in the middle third of the knee

7.7 Medial and Posteromedial Structures: Injury and Pitfalls

Clinical grading of injury to the medial stabilizers is similar to that of most other ligaments [25, 26]. Correlating the clinical MCL injury grade with imaging grade has proven difficult, particularly in the setting of multiple injuries, because of the tendency of overlap and interobserver variation on both the radiologic and surgical sides [27]. Generally speaking, the same imaging criteria utilized for all other ligamentous injuries are also used for the medial stabilizers [28, 29]. Grade 1 injuries demonstrate periligamentous signal changes (edema and/or hemorrhage) on MRI without internal signal changes or areas of discontinuity. Grade 2 injuries demonstrate intrasubstance signal changes in addition to periligamentous signal changes, sometimes with areas of partial discontinuity. Grade 3 tears demonstrate complete discontinuity, often exemplified by wavy ligament. Figures 7.16, 7.17, 7.18, 7.19, 7.20 and 7.21 show varying degrees of injuries to the medial and posteromedial corner stabilizers.

Fig. 7.16 A grade 1 injury to the medial stabilizers. There is edema surrounding the taut superficial MCL (white arrows) and the deep MCL. However, there is no discontinuity or intrasubstance edema in either structure

Fig. 7.17 A grade 2 injury to the medial stabilizers. The superficial MCL (white arrows) is mildly wavy and demonstrates signal within and surrounding the superficial and deep components. No focal disruption is seen

Fig. 7.18 A grade 3 injury to the medial stabilizers. There is diffuse edema surrounding the superficial MCL (white arrows) with focal disruption at the femoral attachment (black circle)

It is important to be aware of imaging pitfalls in diagnosing injuries to the medial stabilizers. First, periligamentous edema is not diagnostic of “MCL sprain” because it also may accompany meniscal tears, osteoarthritis [30, 31], or edema tracking from ruptured Baker’s cyst. Another common pitfall is misdiagnosing MCL sprain in the setting of patella dislocation [11]. In this instance, edema often tracks superficial to the MCL from the adjacent injury. The classic bone contusions present on MRI with patella dislocation in the medial patellar facet and anterolateral femoral condyle can readily distinguish the two entities in those instances when the clinical picture is confusing.

7.8 Posterolateral Corner

The large lateral and posterolateral stabilizers including the iliotibial band (ITB), biceps femoris tendon, and fibular collateral ligament (FCL) are well assessed on MRI. However, the evaluation of the smaller ligaments is more challenging because they vary in their configuration anatomically, are inconsistently present, and are obliquely oriented [11]. Despite the above difficulties, evaluation of the PLC can be accomplished with a thorough understanding of the anatomy while correlating all three imaging planes to avoid confusion.

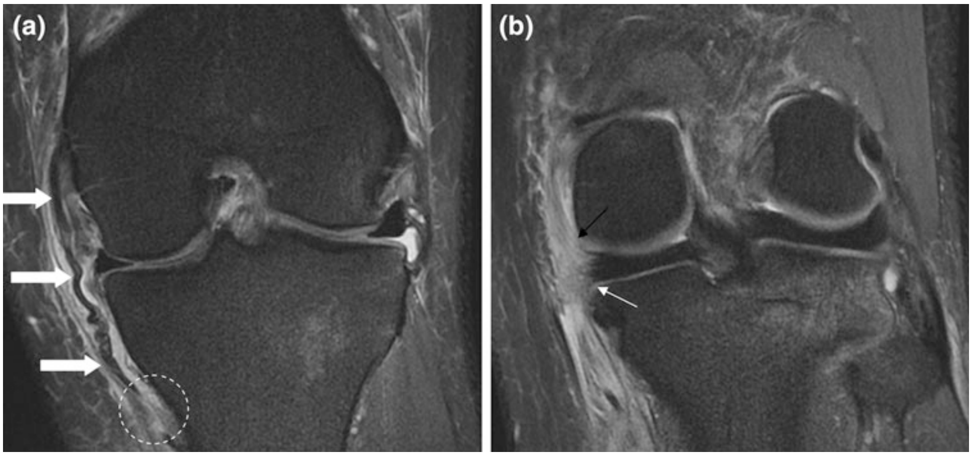

Fig. 7.19 A grade 3 injury to the medial stabilizers and posteromedial stabilizers (POL). **a** Shows a wavy proximal superficial MCL (large white arrows) with focal discontinuity at the tibial attachment (white circle). The deep MCL is nonvisualized and was torn as well. **b** Demonstrates nonvisualization of the meniscofemoral (thin black arrow) and meniscotibial (thin white arrow) components of the POL

Fig. 7.20 A grade 3 injury to the superficial MCL. The femoral attachments of the superficial MCL (large white arrows) and meniscofemoral ligament (small white arrow) are thickened but intact. The tibial attachments of both are torn and retracted proximally (white circle)

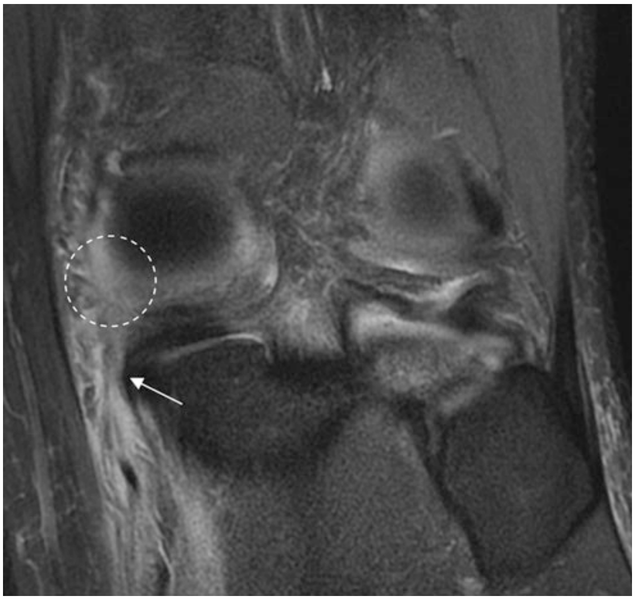

Fig. 7.21 A high-grade injury to the meniscofemoral portion of the POL (circle). The meniscotibial portion of the POL is intact (white arrow)

Prior to discussing MRI findings, two important X-ray signs of PLC injury should be noted. A classic X-ray sign of PLC injury is a bony avulsion fracture from the fibular head termed the “arcuate sign” [32] (Fig. 7.22). This type of fracture may indicate injury to any combination of the posterolateral stabilizers including the “arcuate complex” (popliteofibular, arcuate, and fabellofibular ligaments) and/or the conjoined tendon insertion [33, 34]. Unlike the arcuate sign, the Segond fracture is not a direct sign of PLC injury but is highly associated with cruciate tears and PLC injuries [33, 34]. This thin cortical avulsion fracture typically occurs where the anterior aponeurotic extension of the FCL (termed the anterior oblique band) blends with the thin posterior fibers of the ITB to form and reinforce the capsule as it attaches to the lateral tibial rim [35]. The Segond fracture is subtle on X-rays, but the low signal intensity sliver of the avulsed cortex is even more inconspicuous on MRI (Fig. 7.23).

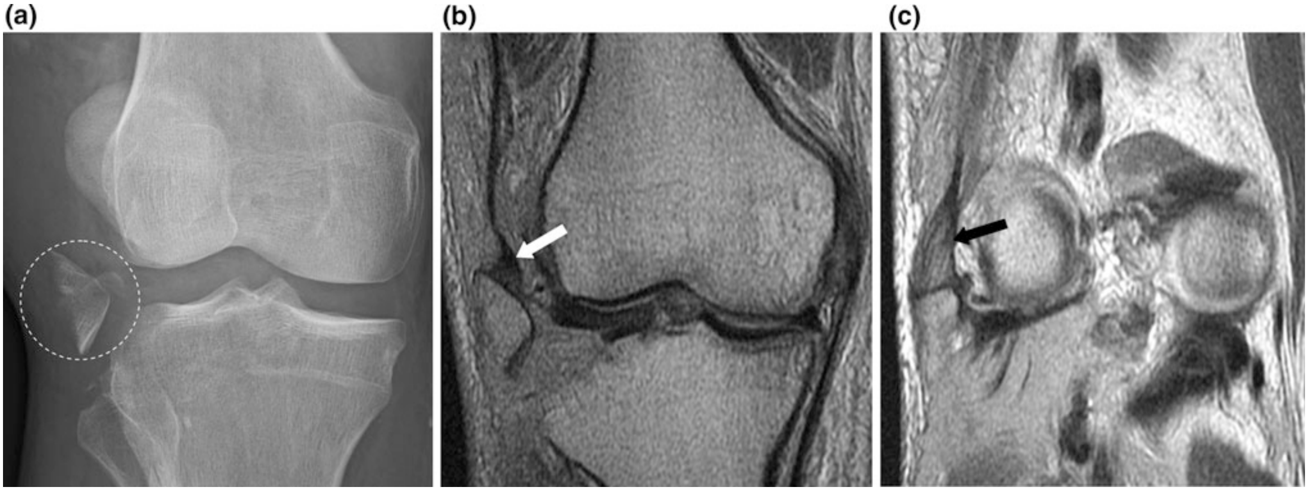

Fig. 7.22 An X-ray with MRI correlation demonstrating a lateral/posterolateral corner injury. **a** Is an AP radiograph, which shows two superimposed avulsed bone fragments from the fibular head (circle). The smaller and more posterior and medial of the two fragments are the fibular head. This bony avulsion has been termed the "arcuate sign." The larger and more lateral fragment is Gerdy's tubercle. **b** Shows bony avulsion of the iliotibial band insertion onto Gerdy's tubercle (white arrow). **c** Shows osseous avulsion of the fibular head, which includes the conjoined tendon (black arrow)

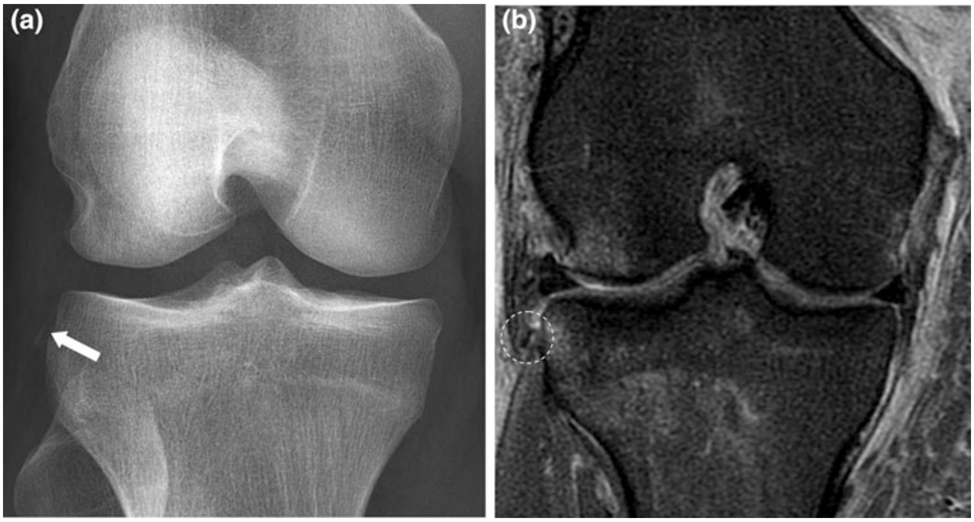

Fig. 7.23 X-ray with corresponding MRI demonstrating the Segond fracture. **a** Demonstrates the lateral capsular avulsion fracture (white arrow). **b** Demonstrates how easily one could miss this small linear low signal sliver of cortical bone on MRI (white circle)

7.8.1 Lateral and PLC: Anatomy and Injury

The ITB is the terminal extension of the tensor fascia latae, which has five blending layers that insert onto Gerdy's tubercle [36]. The distinct layers of the ITB are not consistently separated on MRI with standard imaging [11]. The ITB is uncommonly injured, and both the normal and injured ITB are best visualized in the coronal plane.

The large but obliquely oriented FCL and biceps femoris are both well evaluated on sequential coronal MR images (Fig. 7.24). The femoral attachment of the FCL is approximately 2 cm above the joint line, which abuts and is just anterior to the lateral gastrocnemius origin on the lateral femoral epicondyle. The "conjoined insertion" of the FCL is with the biceps femoris tendon onto the head of the fibula far laterally [37, 38].

The popliteus complex is made up of a number of structures including the popliteus tendon, popliteofibular ligament, and the popliteal meniscal fascicles. The origin of the popliteus tendon is intra-articular from a sulcus on the lateral femoral condyle, inferior, and anterior to the proximal attachment of the FCL [37, 38] (Fig. 7.25). As the intra-articular portion of the popliteus wraps posteromedially, it gives off a thin anteroinferior fascicle and a thicker posterosuperior popliteomeniscal fascicle, both which help tether the lateral meniscus in place [39]. Tear of these fascicles has been correlated with lateral meniscus tear [40]. The popliteomeniscal fascicles are best seen in the sagittal

Fig. 7.24 A coronal MRI demonstrating normal posterolateral corner anatomy. The white arrow demonstrates the normal appearance of the fibular collateral ligament (FCL) (white arrows) from its femoral attachment to its fibular attachment. The conjoined attachment (circle) with the partially imaged biceps femoris (black arrow) can be appreciated. It is abnormal to see the entire FCL on one slice because it is normally obliquely oriented. If seen, as on this image, this is either due to an anteriorly translated tibia from ACL tear or due to technologist error (incorrect obliquely oriented coronal images)

Fig. 7.25 The normal popliteus tendon origin (small white arrow) originating from a notch just below the femoral attachment of the FCL (large white arrow)

Fig. 7.26 The normal appearance of the superior (thin white arrow) and inferior (thin black arrow) popliteomeniscal struts at their attachment to the posterior horn of the lateral meniscus. Note adjacent popliteus tendon (large white arrow)

plane and commonly in the coronal plane (Fig. 7.26). These two fascicles envelope the popliteus tendon as it wraps posteromedially, forming the floor and roof of the popliteus hiatus, respectively [38, 39, 41, 42]. The popliteal hiatus is boundary between the intra- and extra-articular components of the popliteus tendon [43] (Fig. 7.27).

As the popliteus tendon exits the hiatus, it becomes extra-articular, and shortly afterward it gives off its fibular attachment, known as the popliteofibular ligament (Fig. 7.28), which arises laterally from the popliteus at its myotendinous junction. It inserts medial to the attachments of the fabellofibular ligament and arcuate ligament far posterior on the fibular styloid [37, 38, 44]. The thick but short and obliquely oriented popliteofibular ligament is notoriously difficult to image [37, 45] despite being nearly always present on anatomic dissection [46]. The popliteofibular ligament is most commonly a single band, but extensive anatomic variation including multiple bands that differ in their obliquity has been described [37, 38, 41, 47].

The fabellofibular and arcuate ligaments help to form and stabilize the posterolateral knee joint capsule. They are not consistently present in dissection, vary in size and thickness, and can be present alone or in combination [38, 46, 48–50]. When present, the fabellofibular ligament arises from the fabella and inserts distally into the lateral base of the fibular head just anterolateral to the popliteofibular ligament [37] (Fig. 7.29). The arcuate ligament has medial and lateral limbs, which ascend as a single ligament from the fibular

Fig. 7.27 A moderate strain of the popliteus at the proximal myotendinous *junction* (black arrows). The soft tissue edema nicely delineates the posterior capsule/medial limb of the arcuate ligament (white arrows) as the popliteus exits the joint at the popliteal hiatus. A small portion of the intact biceps femoris tendon can be seen (thin white arrows)

Fig. 7.28 The normal extra-articular portion of the popliteus tendon (black arrows) and the intact and nearly horizontally oriented popliteofibular ligament (white arrows)

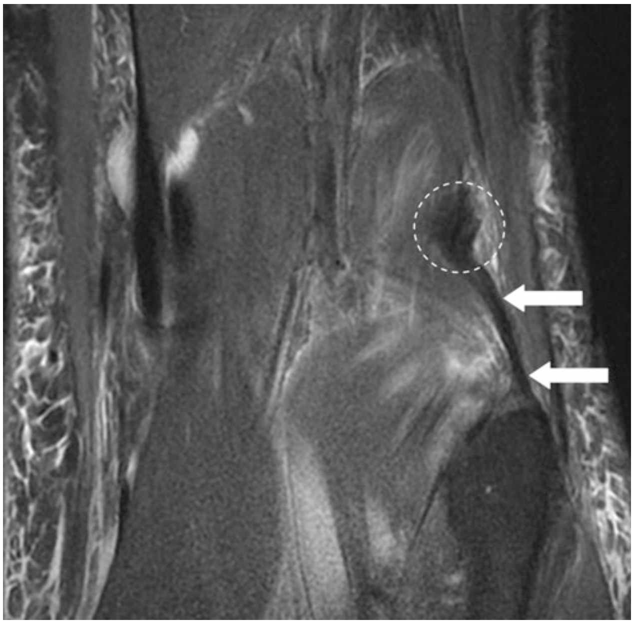

Fig. 7.29 The normal fabellofibular ligament (white arrows) and nonossified fabella (circle)

head just anterior to the fabellofibular ligament (when present together) [37, 38]. The medial and lateral limbs then separate in the form of a Y, with the thicker lateral limb coursing straight proximally and attaching to the lateral femoral condyle in reinforcing the lateral joint capsule [38]. The medial limb courses medial and superficial to the popliteal tendon and then blends with fibers of the popliteal oblique ligament in helping to reinforce the posterior joint capsule [38]. The arcuate ligament, most commonly the medial limb, is usually only seen when thickened or when it is highlighted by edema (see Figs. 7.27, 7.31 and 7.32).

Injuries to the ITB, FCL, biceps femoris, popliteus complex, and capsular structures are rarely in isolation and may occur in various combinations. Attempts should be made to identify injuries to each specific structure, although missed injury to the smallest capsular structures is less consequential than the larger stabilizers like the FCL, conjoined tendon, and popliteofibular ligament. On MRI, the coronal plane best depicts the variety of injuries occurring to the PLC stabilizers (Figs. 7.30, 7.31, 7.32, 7.33 and 7.34). Like the pivot shift contusion pattern with ACL tear, fibular head edema is highly suggestive of PLC injury, and when present, the PLC structures should be closely scrutinized for injury (Fig. 7.35). Knowledge of the PLC insertional relationship to one another on the fibular head (attachments from medial to lateral) may help one to determine which specific structure is injured [43]. For example, edema medially is suggestive of an arcuate complex or popliteofibular ligament

Fig. 7.30 An intact proximal FCL (black arrows). The distal FCL attachment is completely torn and retracted proximally (black circle). Note adjacent popliteus tendon (white arrow), which was intact on the study

Fig. 7.31 A high-grade injury to the conjoined tendon insertion (circle). Note the prominent and intact arcuate ligament (white arrows). The black arrows shows the expected location of the torn popliteofibular ligament, if it were present, which should be located medial to the arcuate ligament

Fig. 7.32 A moderate strain to the popliteus (black arrows), a grade 1–2 sprain of the popliteofibular ligament at its fibular attachment (large white arrow). Minimal linear signal at conjoined tendon insertion is within normal limits (thin white arrows). Note how edema highlights a portion of the intact arcuate ligament (small black arrow), which is situated between the popliteofibular ligament and conjoined tendon

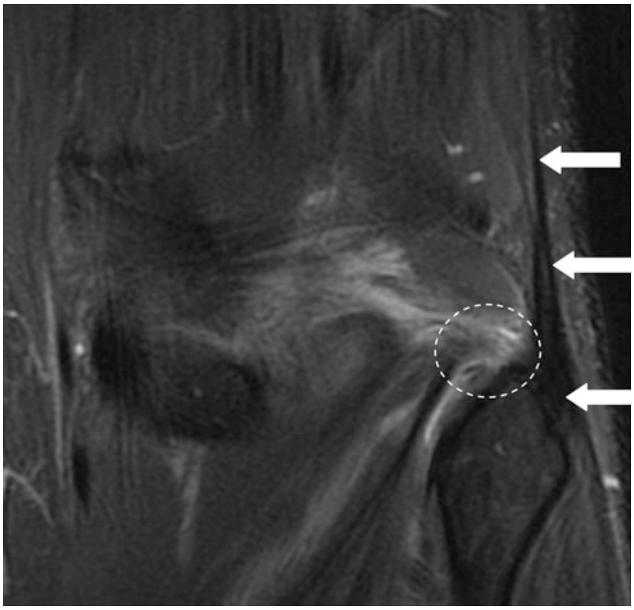

Fig. 7.33 A grade 2–3 injury to the popliteofibular ligament (circled). The conjoined tendon insertion is intact (white arrows)

injury rather than injury to the more laterally inserting conjoined tendon. For the best chance at accurate diagnosis and as not to confuse these structures with one another, correlation with all three imaging planes is suggested. Despite this, even in the best of circumstances, it may at times be difficult to distinguish specific injuries and also between nonvisualization from injury versus absence due to

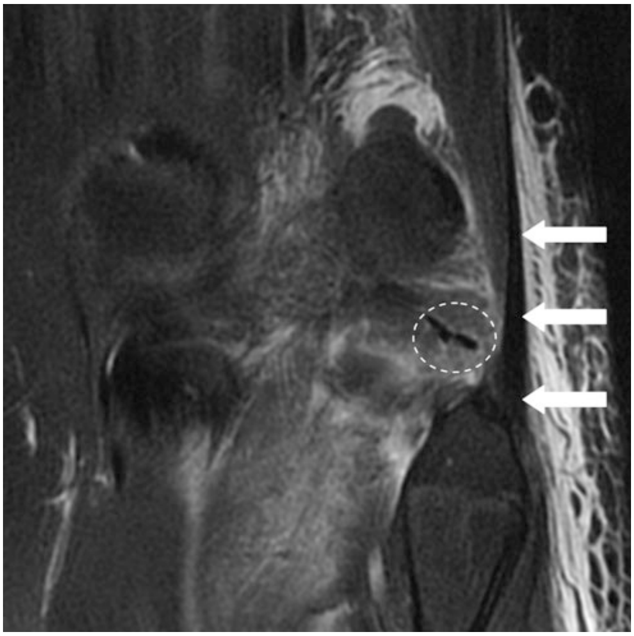

Fig. 7.34 A torn and proximally retracted popliteofibular ligament (circle) and intact conjoined tendon insertion (white arrows)

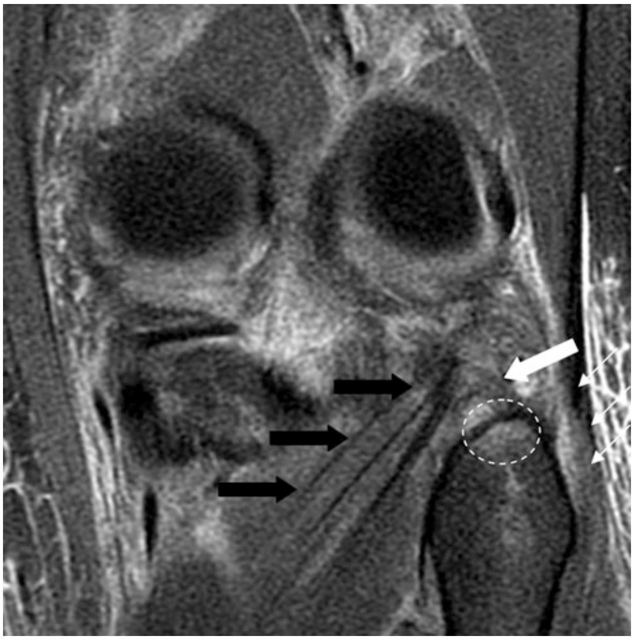

Fig. 7.35 Fibular head edema at the popliteofibular ligament attachment (circle). There is a grade 2 injury to the popliteofibular ligament (white arrow) and a grade 3 injury to the conjoined tendon insertion (thin white arrows). The extra-articular popliteus at the myotendinous junction was intact (black arrows)

anatomic variability [11]. In such instances, the radiologic report may convey the high suspicion for a PLC injury. Although the specific ligamentous injury is not specified, the purpose is to alert the surgeon that the PLC needs to be closely evaluated clinically, perhaps under anesthesia at time of surgery.

7.9 Conclusion

When interpreting complex knee injuries on MRI, it should now be apparent that a thorough understanding of the complex anatomy of the knee, high-quality imaging, and a meticulous search pattern are vital to accurate diagnosis. In the acute setting, knee MRI is extremely valuable for presurgical planning, given its high accuracy in diagnosing the structure injured, the degree of the injury, and the specific location of tear within the involved ligament or tendon.

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Part IV

Non-surgical Treatment

Selective Surgical Treatment of Knee Dislocations

8

Marc S. Haro and K. Donald Shelbourne

8.1 Introduction

Knee dislocations are rare injuries representing only 0.01% of all orthopedic injuries [1]. While uncommon, they can have potentially devastating consequences. A knee dislocation is typically defined as a grossly unstable knee with disruption to at least two of the four major knee ligaments [2, 3]. More commonly, however, knee dislocations involve both cruciate ligaments in addition to either the medial- or lateral-side structures. Given the rarity of these injuries, there is limited prospective data to help guide treatment, and unfortunately, outcomes continue to be mixed. Historically knee dislocations were treated conservatively with prolonged immobilization [4–6]. While some patients had satisfactory results, not all patients did well [7, 8]. Individuals with knee dislocations involving the lateral side of the knee often continued to have persistent instability. Subsequent studies found surgical treatment of knee dislocations may yield better outcomes compared to conservative treatment [9], and many authors began to recommend the repair or reconstruction to all injured structures [5, 10, 11]. Unfortunately, these patients did not all do uniformly well either. While patients often ended up with stable knees, they often continued to high levels of persistent knee stiffness and were not able to return to previous levels of work or sporting activities [5, 11]. As we have seen in isolated ligament reconstructions, stiffness is a major factor for poor outcomes and future levels of knee osteoarthritis [12, 13]. We believe that preventing knee stiffness is paramount in the treatment of any knee injury.

The senior author (KDS) started to collect data on knee ligament injuries in 1982, and as we have studied and cared for patients with knee dislocations, our treatment approach has evolved. Like many other surgeons, we initially recommended the repair and reconstruction of the injured structures [14]. However, as we examined the data, we have become more selective in what we repair or reconstruct, and we base our treatment upon what we know about the healing potential of each structure to maximize outcomes. We will describe our philosophy regarding the selective surgical treatment of knee dislocations.

8.2 Healing Potential

8.2.1 Anterior Cruciate Ligament

Although there has been a renewed interest in the healing potential of the anterior cruciate ligament (ACL) [15, 16], few studies have shown the potential for ACLs to reliably heal without surgical intervention. Lyon et al. [17] found histologically that the cellular composition of the ACL is largely that of fibrocartilage and has limited ability to heal. Also limiting the ability of the ACL to heal is the typical mechanism of injury. When an ACL injury occurs with a pivot-shift type mechanism, the ACL typically pulls completely apart as opposed to interstitially tearing as can be seen with posterior cruciate ligament (PCL) or medial collateral ligament (MCL) injuries. Typically, no or few remaining fibers remain in continuity when the ACL tears.

8.2.2 Posterior Cruciate Ligament

The PCL has shown the capacity to heal into place in continuity. Unlike an ACL tear, the fibers typically do not pull apart completely and are able to heal in a functional position. In an MRI study by Shelbourne et al. [18], 37 out of 40 PCL

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injuries, regardless of degree or location of injury, or if they were associated with other ligamentous injuries, healed in continuity. They often demonstrated an abnormal morphology, such as being buckled or elongated, but intact. In another study by Tewes et al. [19] that evaluated 13 patients with PCL injuries, 10/13 PCL tears regained continuity at 20 months post injury. Clinically, PCL injuries treated well conservatively have similar outcomes to those treated surgically.

8.2.3 Medial Collateral Ligament

The MCL has both superficial and deep components, with the most important medial stabilizer of the knee being the superficial MCL. Histologically, the MCL demonstrates more of a fibroblast appearance compared to the fibrocartilage appearance of the ACL [17]. As a result, the MCL has an increased intrinsic ability to heal. The resultant scar tissue in animal studies has shown similar stiffness and strength to that of the native MCL [20, 21]. Also contributing to the ability of the MCL to heal, is the mechanism of injury. In contrast to the ACL where the ligament sustains a catastrophic failure, the MCL typically is injured from a hypervalgus force that causes it to tear interstitially. Unless the ligament tear retracts above or below the joint, there are some fibers in continuity that can heal with knee stability. In addition, the medial side of the knee also sits on the compression side and as a result, the medial structures are typically not under tension with weight-bearing activity and does not usually retract across the joint line. This allows the ligament to heal in place, though there may be some residual laxity. The one caveat being a situation where the MCL tears and retracts or flips over upon itself or into the knee joint preventing in situ healing from occurring across the joint [13, 22].

The location of injury also appears to play a role in the healing potential. Proximal tears of the medial femoral epicondyle often demonstrate a robust healing response secondary to its considerable blood supply. Frequently, these tears heal quickly and can lead to significant knee stiffness. Distal tears, on the other hand, tend to heal much more slowly and may demonstrate lower rates of stiffness, but increased incidence of residual laxity [23, 24]. It is believed that the extravasation of synovial fluid from the joint with the disruption of the tibial attachment of the MCL may contribute to the slower healing of distal MCL injuries.

8.2.4 Lateral-Side Structures

While the lateral side of the knee is often described as the posterolateral corner, we believe more structures contribute to lateral-side stability than just those on the posterolateral aspect of the knee. From anterior to posterior, these structures include the iliotibial band (ITB), the lateral capsule (more recently described as the anterolateral ligament ALL), the popliteus tendon and its associated popliteofibular ligament, the lateral collateral ligament (LCL), the biceps femoris tendon, and the lateral head of the gastrocnemius. When these structures are injured, being on the tension side of the knee, they typically tear of distally and retract proximally above the joint and start to heal "en masse," unlike the medial side [25]. This retraction prevents these structures from healing in continuity with their native attachment sites. When this occurs, the knee will not heal with functional lateral-side stability and this is the only structure of the knee dislocation injury that needs acute surgery to allow for proper healing. In some rare situations, when the mass does not retract proximally, these injuries can also heal in situ with satisfactory lateral-side stability. In a study by Shelbourne et al., lateral-side injuries that were repaired less than 4 weeks from injury did significantly better than those repaired after 4 weeks [25]. Over time, if these structures are not addressed acutely, the tissue becomes more friable making repair less effective. We now recommend repairing these structures even sooner, typically within the first 3 weeks after injury, but even sooner if possible.

8.3 Clinical Examination

To accurately diagnose a knee dislocation, a careful history and physical examination must be performed. A high index of suspicion must be had with any significant knee injury, as these injuries after occur in the setting of trauma, and due to the variety of potential structures injured, can have varying presentations. Over half of knee dislocations will present spontaneously reduced [3, 4, 26, 27]. A thorough and accurate physical examination is important but may be difficult due to pain, swelling, muscle spasms, and stiffness. On inspection, the knee may appear similar to that of an isolated knee ligament injury with a knee effusion, pain, and stiffness; however, in the setting of a capsular disruption, the hemarthrosis may extravasate into the surrounding soft tissue and they knee may not appear overly swollen. Unfortunately, as a result, these injuries are often overlooked, especially in the setting of a significant trauma. A careful physical examination with a comparison to the contralateral side should be able to reveal the diagnosis.

A tear of the ACL is best diagnosed in the setting of an ACL tear with the Lachman test (Lachman). The Lachman test, when done correctly, has a very high sensitivity and specificity for an ACL tear [28, 29]. Other tests of an ACL, such as the pivot-shift or anterior drawer tests, are typically less useful in the setting of a knee dislocation. The pivot-shift test requires both intact medial structures as well as an intact ITB, both of which can be disrupted in a knee dislocation. Often, the knee is too swollen or stiff to perform an anterior drawer and spasm of the hamstring muscles decrease the reliability of this test.

A PCL injury is best diagnosed with the posterior drawer test at 90° [30] (Fig. 8.1). Unfortunately, as is also the case with the anterior drawer test, frequently, it is difficult to flex the knee to 90° and the test becomes less reliable. The relationship of the tibial plateau to the femoral condyles can also be used to detect a PCL injury in a "sag" test. The tibial plateau commonly sits 1 cm anterior to the femoral condyle. When the tibia sags posterior, especially when compared to the contralateral side, this indicates a disruption to the PCL. The combination of the posterior drawer test and assessment of the anterior tibial step off is 96% accurate in diagnosing a PCL tear [30].

The MCL is best assessed with a valgus stress test in both 0° and 30° (Fig. 8.2). As the knee is often unstable and the patient is swollen, stiff and painful, we recommend dropping the lower leg off the edge of an examination table while palpating the medial joint line. While the valgus stress test in 30° isolates the MCL, when the knee opens in full extension, this is more indicative of a combined medial-side injury with likely disruption to the cruciate ligaments and posteromedial capsular structures such as the posterior oblique ligament. A grade I injury will be painful, but a firm endpoint minimal with no opening of the medial joint space on examination when compared to the contralateral side. Grade II injuries are present when there is increased medial laxity, but an endpoint is present. Grade III injuries have no endpoint with valgus stress testing and indicate a complete disruption of the MCL and likely has other associated cruciate or capsular injuries.

The lateral-side structures are best evaluated with a varus stress test in both 0° (Fig. 8.3) and 30° of knee flexion. Like with the medial side, when there is opening in full extension, there tends to be more extensive disruption, including the ITB and cruciate ligaments. Other tests, such as the dial test, are frequently used to evaluate the lateral side and for posterolateral rotatory instability. In our experience, posterolateral rotatory instability is usually a combination of posterior laxity and lateral laxity. The combination of these two leads to posterolateral laxity. If the lateral laxity is corrected surgically by repairing the lateral capsule back to the tibia and the PCL is allowed to heal in situ, posterolateral laxity does not develop. As a result, the dial test and the external rotation recurvatum tests are less clinically useful.

8.4 Imaging

As these injuries have a high association with fracture, and are often seen in trauma settings, initial anteroposterior (AP), lateral, and oblique radiographs may be done in the emergency room to evaluate for an overt dislocation, subluxation, or fractures. Once feasible, we recommend obtaining weight bearing AP, lateral, Merchant and standing 45° flexed posteroanterior (PA) radiographs to accurately assess the tibiofemoral joint space.

Magnetic resonance imaging (MRI) is helpful in evaluating knee dislocations to show the structure involved by the

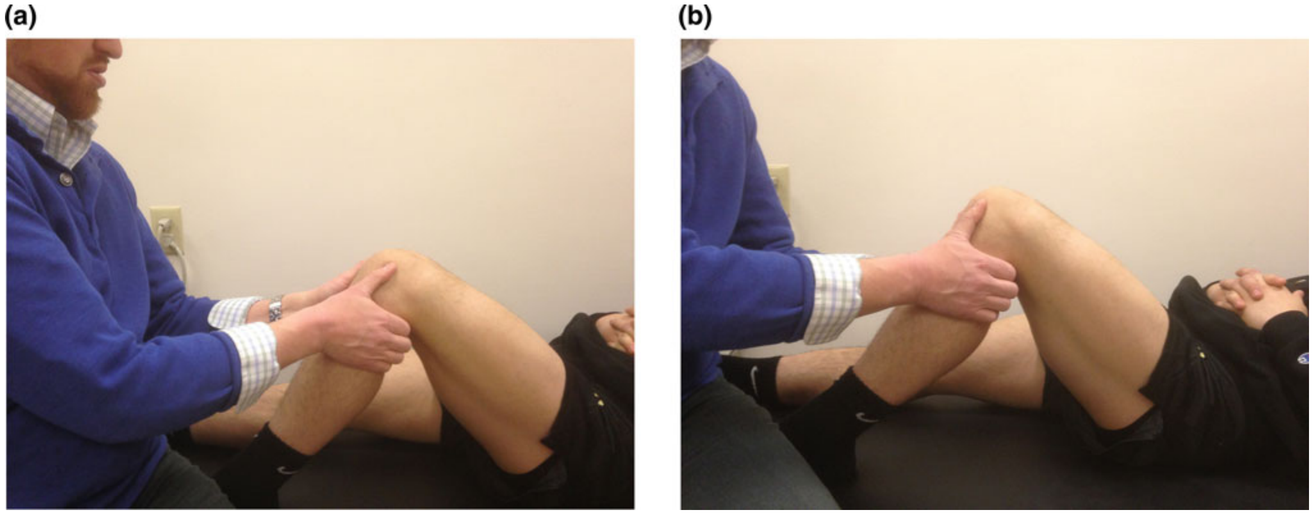

Fig. 8.1 Posterior drawer test: The patient is supine and has the hip and knee flexed to about 90º. The examiner sits at the edge of the patient's foot so the foot cannot slide on the exam table. This allows the patient to relax his/her leg completely. The examiner places his/her hands so that the thumbs can feel for the normal prominence of the tibia in relation to the femoral condyles (**a**). The index fingers can be used to feel for relaxation of the hamstring muscles. The examiner pushes directly posterior on the tibia and feels for translation of the tibia and the loss of normal prominence of the tibia. When the tibia is completely flush with the femoral condyles upon posterior force, the patient has 2 + posterior laxity (**b**)

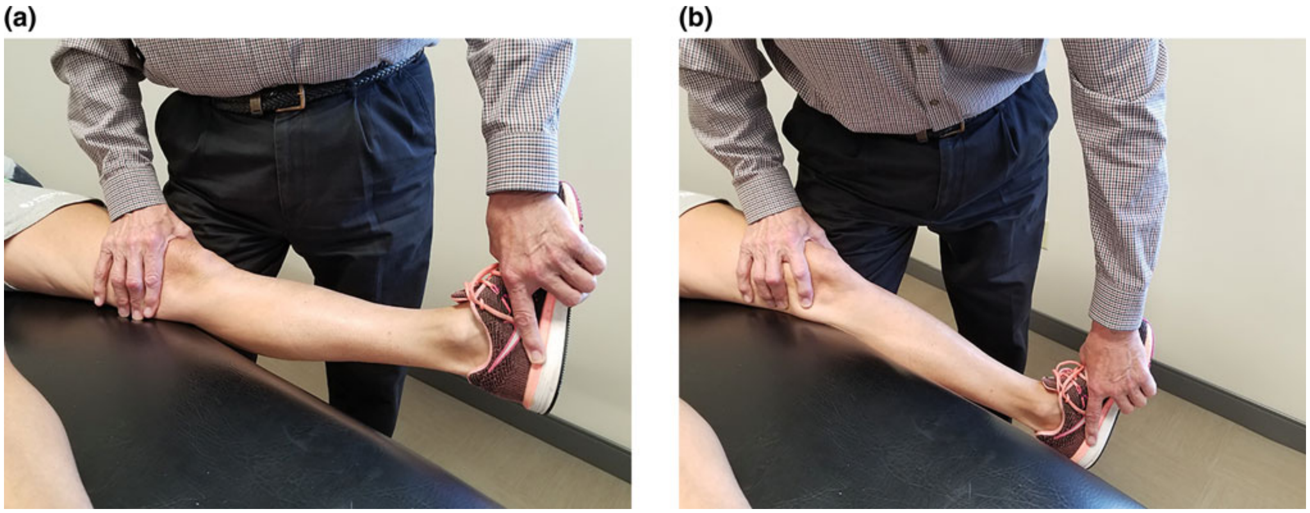

Fig. 8.2 Test for medial collateral ligament laxity. For a patient's left knee, the examiner's right hand is placed above the knee and the left hand is placed around the ball of the patient's foot. The examiner brings the lower leg off the side of the examination table and applies varus stress to the knee at 0° of extension (**a**) and at 30° of flexion (**b**)

Fig. 8.3 Test for lateral-side laxity. For a patient's left knee, the examiner's left hand is placed on the medial side of the knee at the level of the joint line. The right hand is placed on the lateral side of the ankle. The examiner applies valgus stress to the knee joint at 0° of knee extension to test laxity. Lateral knee laxity should also be evaluated at 30° of flexion

clinical evaluation is a key to determining proper treatment. Some of the key features we look for with MRI are the location and nature of the tears to the medial and lateral-side structures. If the structures have retracted or flipped over across the joint line, whether medial or lateral-side structures, they are less likely to heal in situ with conservative treatment and operative treatment may be warranted. We have found these situations to be common with lateral-side injuries but uncommon, however, with medial-side injuries. This is why is it so important to recognize lateral-side knee injuries because acute surgery to repair the lateral capsule to the tibia gives the best chance for healing and providing stability.

With regards to the PCL, MRI is 99–100% sensitive and specific in diagnosing acute ACL tears [31, 32]. However, we do not think the MRI adds to the examination of the PCL. The severity of damage to the PCL on MRI does not correlate with the function or laxity of the ligament; it does,

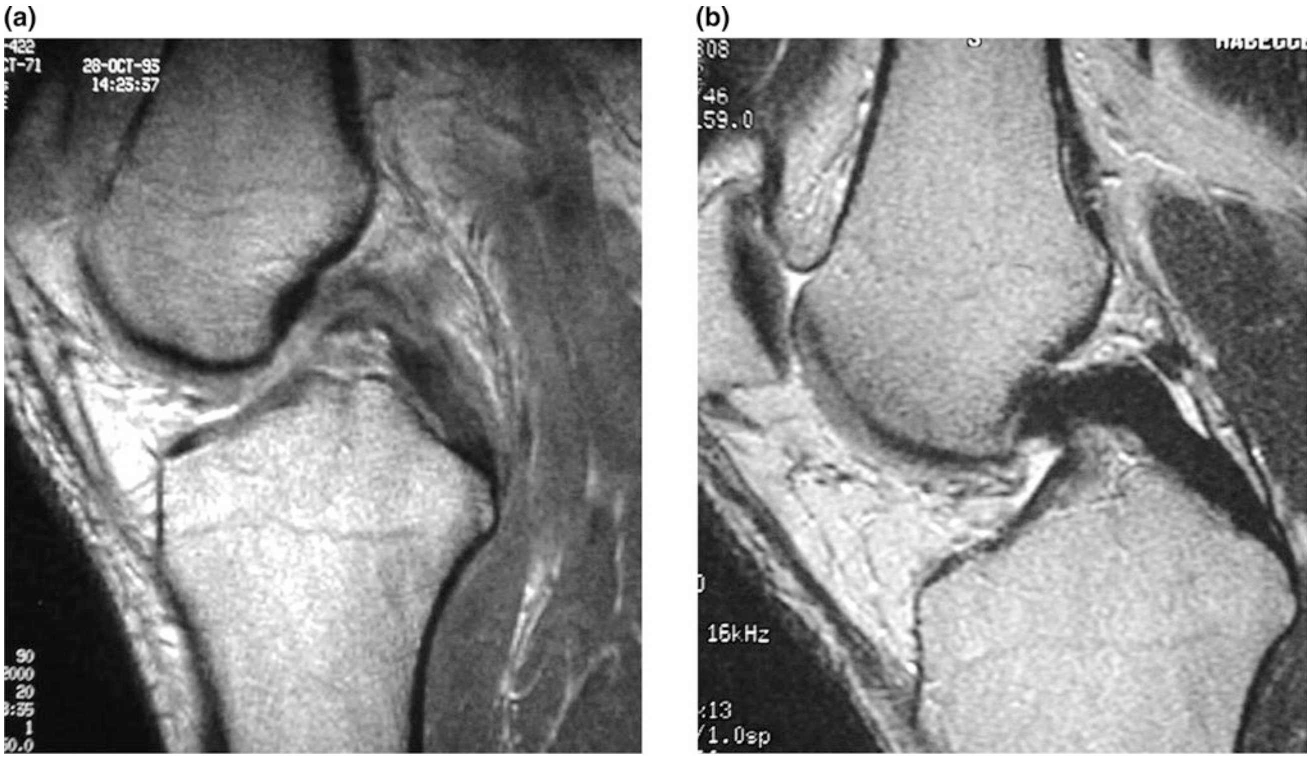

Fig. 8.4 The MRI scan (**a**) of an acute PCL injury determined to be a complete PCL tear. A follow-up scan (**b**) at 8 months after injury shows the PCL to be in continuity. Reprinted with permission from [52]

however, tend to lead to the overtreatment of PCL injuries, especially given that the PCL has shown the capacity to heal in continuity regardless of its original degree of injury [18, 19]. In situations that are more chronic MRIs may show a "normal" PCL, despite patients' feelings of chronic instability (Fig. 8.4). Therefore, we believe treatment decisions for the PCL should not be based upon MRI scans, but on the clinical examination. With PCL laxity, the MRI scan may also show the posteromedial meniscus to be behind the femur and out of contact with the femoral condyle (Fig. 8.5). If this is seen on a scan with a PCL in continuity, it may serve as an adjunctive sign of a previous PCL tear that has healed the chronic laxity.

8.5 Treatment Philosophy

As previously mentioned, we treat all multiple ligamentous knee injuries based upon the structures injured and each of their own healing potentials. We do not reconstruct or repair all ligaments just because they are injured on MRI or because they are associated with another ligament injury. We will go through our treatment protocols the commonly seen patterns of injury, but once you understand the healing potential of each structure, it is easy to develop a logical treatment strategy for each structure, regardless of what is injured or how many structures are injured (Table 8.1).

8.5.1 PCL Injuries with Multiple Knee Ligament Injuries

Regardless of the other associated injuries, we treat all PCL injuries same. While surgical reconstruction techniques have improved, unfortunately, they have not yet demonstrated the ability to reliably restore normal posterior stability [33–42]. Most commonly, PCL reconstruction improves posterior stability by 1 grade [39] and less than 50% demonstrated success in restoring normal stability. There are also only a few studies with long-term follow-up of PCL reconstructions more than 10 years out that include radiographic evaluation for osteoarthritis. Those studies demonstrate an incidence of knee osteoarthritis of 36–69% [34, 35] compared to 17–53% in natural history studies of PCL tears treated nonoperatively [43–46]. Until surgical techniques are able to reliably restore normal posterior stability and provide better short- and long-term results than conservative treatment, we do not recommend the surgical reconstruction of PCL tears when the posterior instability is 2+ or less. Most published studies of PCL injuries treated nonoperatively were conducted

Fig. 8.5 MRI scanning in PCL lax knees often shows the posterior medial meniscus *(white arrow)* to be behind the femur and out of contact with the femoral condyle. Reprinted with permission from [52]

Table 8.1 Treatment Algorithm Based on Healing Potential

Ligaments Injured	Treatment
ACL, MCL	Cast immobilization and delayed ACL reconstruction
ACL, MCL, PCL <2+	Cast immobilization and delayed ACL reconstruction
ACL, MCL, PCL >2+	Attempt at cast immobilization, if PCL laxity does not improve to 2+ or less, PCL reconstruction with conservative treatment of MCL, staged ACL
ACL, lateral side	Semi-acute lateral side repair and if motion satisfactory, ACL reconstruction. If knee too stiff, staged ACL reconstruction
ACL, PCL <2+, lateral side	Semi-acute lateral side repair and if motion satisfactory, ACL reconstruction, conservative treatment of PCL. If knee too stiff, staged ACL reconstruction
ACL, PCL >2+, lateral side	Semi acute lateral side repair and PCL reconstruction if PCL does not improve to <2+ with conservative treatment; staged ACL

retrospectively typically included patients who sought treatment for chronic PCL laxity and painful symptoms, or those with multiple knee ligament injuries. Unfortunately, this does not provide a true natural history of PCL injuries treated without surgery. There are few long-term prospective studies that truly describe the natural history of PCL tears. Patel et al. [45] evaluated 57 patients (58 knees) who were seen acutely for isolated PCL injuries, were treated without surgery and started on a program to restore knee ROM and strength. At a mean of 6.9 years after the injury, no correlation was seen between the subjective scores and the degree of initial laxity. Shelbourne et al. [46] reported the subjective results of 215 isolated PCL tears treated without surgery at a mean of 7.8 post injury and found no correlation between subjective scores and grade of PCL laxity. In a prospective natural history study of 133 patients after an acute isolated PCL injury, 68 returned for follow-up at a mean of 5.4 years and the other 65 returned subjective surveys [47]. No change in laxity was found from the initial exam to the follow-up exam, and patients with great laxity did not have worse subjective or objection scores. There was no correlation found between the grade of laxity and radiographic joint space narrowing. Ten out of 67 patients were found to have knee osteoarthritis in the injured knee alone, while 15 had osteoarthritis in both knees. There was no statistically significant difference in subjective scores between patients who returned for examination, and those who only returned questionnaires in the outcomes of PCL tears that heal with 1 + versus 2+ laxity with regards to future disability or degenerative changes [47]. That is not to say all patients do uniformly well after a PCL injury, it just does not appear to be dependent on the degree of laxity. Surgery that takes a 2+ PCL to a 1+ PCL is unwarranted and will not improve the long-term subjective or objective outcome, and will not lower their risk for developing osteoarthritis. It only adds to the complexity of the case for the surgeon and the risk of complications for the patient.

When in the rare situation, a patient does have 3+ or greater posterior instability (the tibia sits behind the femoral condyles), a semi-acute PCL reconstruction may be warranted. A period of conservative treatment is recommended because the degree of posterior instability may decrease and an endpoint may emerge over the first few weeks after injury. The decision to reconstruct a PCL tear should not be made based upon the degree of tearing on MRI, it should be done clinically. As previously noted, MRI studies have shown that regardless of the degree of initial injury, the PCL can heal in continuity with conservative care. Knowing that the long-term outcome of PCL laxity does not differ based on laxity, as long as medial and lateral stability has been established, allows for an initial conservative approach to PCL reconstruction.

With 3+ PCL laxity in the setting of an MCL injury, we recommend cast immobilization and reassessment of the posterior laxity. We do not ever recommend an ACL and/or PCL reconstruction be performed acutely due to the increased risk of arthrofibrosis [48, 49].

8.5.2 ACL, PCL and MCL Injuries

Given that most MCL injuries will heal with conservative treatment, we, typically, initially treat these injuries with immobilization. Prior to 1990, we used knee immobilizers or braces to limit valgus stress upon the knee and to allow the MCL to heal. Unfortunately, this led to situations where patients would remove the device while showering or sleeping and some patients had unacceptable levels of valgus laxity. Currently, our preferred technique is to immobilize the knee with a cylinder cast with the knee in 20°–30° of knee flexion and a varus mold. This has demonstrated an excellent ability to limit varus stress and leads to satisfactory results of MCL healing. The cast is changed weekly, until a firm endpoint is felt with gentle valgus stress testing. Once an endpoint is felt, physical therapy is imitated to restore normal ration of motion. For proximal MCL disruptions, this typically takes 1–2 weeks, while for distal MCL sprains, it can take 3–4 weeks. We have also found that patients are much more comfortable in a cast compared to a brace, and the added stability allows for immediate weight bearing. During this period of immobilization, the PCL will also typically heal with 2+ laxity or less as earlier described. There may be mild residual medial and posterior laxity, but this is usually asymptomatic and with firm endpoints. Once symmetric motion has been achieved, and they have good control of their leg, an elective ACL reconstruction can be performed along with a standard ACL rehabilitation protocol. Infrequently, patients may continue to have symptoms of medial instability despite appropriate conservative treatment. In these situations, an MCL reconstruction, advancement, reefing or stimulating a healing response with multiple longitudinal incisions within the MCL can be performed. We, however, have found these situations to be extremely uncommon.

8.5.3 ACL, PCL and Lateral-Side Injuries

Unlike the medial side of the knee, lateral-side injuries do not predictably do well with conservative treatment and will typically benefit from an acute or semi-acute (less than 3 weeks from injury) surgical repair. Some surgeons have advocated a repair that involves the dissection and repair of all anatomic structures others have recommended repair and reconstruction [5, 11, 50]. Since 1988, our repair technique has evolved to one that balances the need to decrease swelling and normalizing motion with the body's healing response by reattaching all injured structure back to the tibia "en masse" [25]. If the patient has regained sufficient range of motion preoperatively so that an ACL reconstruction can be performed at the same setting, this is done before the lateral-side repair to prevent overstressing the repair. Once the ACL reconstruction is complete, a longitudinal incision is made midway between the fibular head and Gerdy's tubercle. If there is an associated peroneal nerve injury, we do not typically explore it as the lateral-side repair is typically much more anterior than the fibular head. The injury typically starts immediately posterior to the ITB and a pseudomembrane starts to form over the disrupted lateral-side structures. Once the pseudomembrane is incised and entered, the lateral structures are usually easily seen. Typically, there will be a bare area of bone on the lateral tibia where the lateral capsule has become detached and the retracted healing tissue mass can be found proximal. Instead of dissecting these structures out individually, they are reattached to the proximal tibia "en masse". Two nonabsorbable braided sutures are placed in the mass in a modified Kessler fashion, one anterior and one posterior (Fig. 8.6).

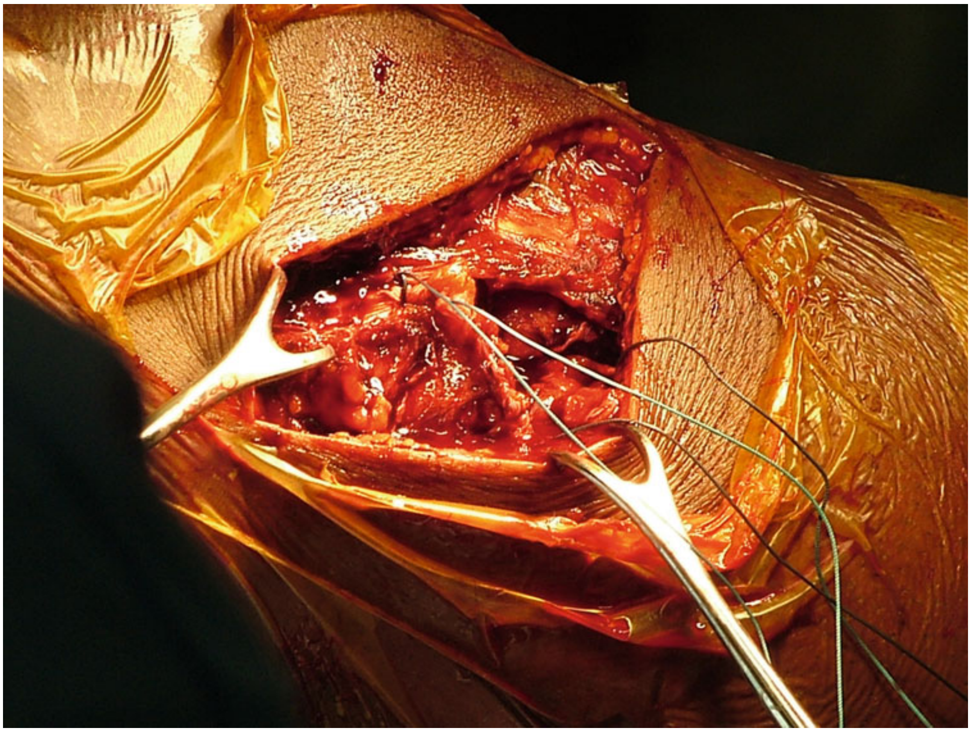

Fig. 8.6 Torn lateral structures retract proximally above the joint and heal "en masse". Sutures are used to pull the "en masse" structure distally

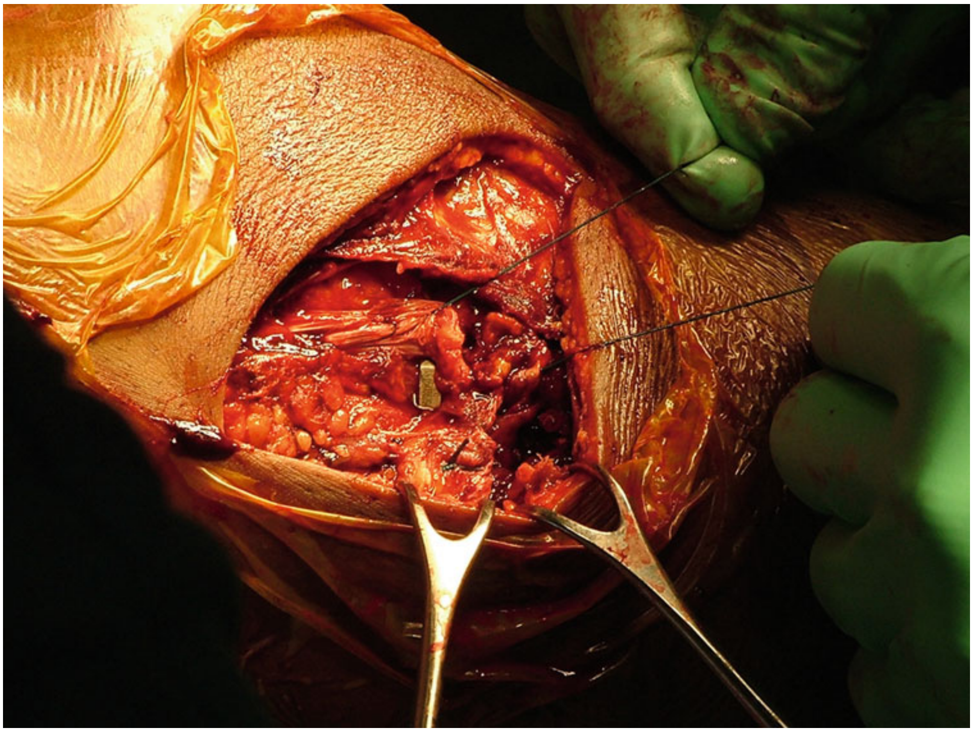

Fig. 8.7 The "en masse" lateral structure is stapled to tibia

The bony recipient site is freshened with a curette. If the biceps femoris or LCL are detached from the fibular head and separate from the healing tissue masse, a suture anchor is placed into the fibular head for reattachment of these structures. The masse is then advanced to the lateral tibia and a valgus stress is applied to the knee in neutral rotation and the soft tissue mass is fixed with a spiked ligament staple (Fig. 8.7). If needed, the sutures from the anchor in fibular head are then placed into the LCL/biceps femoris in a Krakow fashion and secured. This is reinforced with nonabsorbable sutures from the biceps tendon to the remaining cuff of tissue on the fibular head.

If the injury is greater than 3 weeks old, and the tissue is soft and friable, a spiked ligament staple and screw may be necessary. In some situations, especially when there has been a tibial plateau fracture that extends into the lateral plateau, the staple may not achieve satisfactory fixation into the lateral tibial plateau. In these cases, we use suture anchors to repair the lateral capsule; however, this is not our preferred technique. We believe that a ligament staple typically provides stronger fixation and allows for more immediate postoperative range of motion without compromising the repair.

If the knee is too stiff to perform an acute ACL reconstruction or the patient's condition does not allow them to participate in an ACL reconstruction rehab in the first 1–2 weeks after the injury, we will typically stage the ACL reconstruction, only performing the lateral-side repair acutely. Our philosophy regarding the PCL in these situations is similar to that as with ACL, MCL, and PCL, injuries. Given the ability of the PCL to heal with stability with conservative treatment, we typically do not perform a PCL reconstruction. If they continue to have 3+ posterior instability following an ACL reconstruction and lateral-side repair, the PCL can be reconstructed in a staged manner.

8.6 Postoperative Rehabilitation

The rehabilitation is specific to the procedure performed. In the setting of an ACL/PCL/MCL injury, once the MCL and PCL have healed, the only procedure done is the ACL reconstruction. Therefore, our standard ACL reconstruction rehabilitation program is utilized [51]. With regards to an ACL, PCL, and lateral-side injury, we alter the program slightly. For the first week after surgery, the immediate emphasis is on controlling swelling and restoring range of motion. Patients are placed on relative bed rest with the operative leg elevated in a continuous passive motion machine (CPM). Three to five times a day, the patient will also perform a specific range of motion protocol with the emphasis on restoring normal range of motion. However, if the lateral gastrocnemius muscle was injured, we do not emphasize restoring knee hyperextension, until after the third or fourth week after surgery to allow this structure to heal. Patients may be weight bearing as tolerated, but they wear an immobilizer when up for the first 1–2 weeks. They may discontinue the use of the immobilizer once they are able to demonstrate good quadriceps control. After this period, the remaining rehabilitation is similar to our normal ACL protocol. We initially emphasize restoring symmetric knee range of motion, including full hyperextension compared to the contralateral side. We do not begin the aggressive strengthening phase of the protocol until the patient has demonstrated symmetric motion and good quadriceps control. The timing of return to normal activities is individualized based upon what their goals are, with most individuals returning to all activities without limitations by 5–7 months after surgery.

8.7 Summary

The current trend with multiple ligament knee injuries is to repair or reconstruct all injured structures. Unfortunately, this leads to high levels of complications, specifically with regards to postoperative stiffness and the ability to return to their prior level of function. We recommend treating each knee based upon the healing potential of each involved structure. Our top priority is to obtain functional stability of the knee without the loss of motion that can lead to long-term pain, weakness, loss of function and the subsequent development of osteoarthritis. To do this, you need to see all knee dislocations acutely. We have demonstrated that the PCL and MCL can do well in the majority of cases with conservative treatment. Unfortunately, ACL and lateral-side injuries do not do well without surgical treatment. The only structure that needs acute or semi-acute surgery is the lateral side and the ACL can be done in a staged manner if needed. Regardless of what structures are injured, the PCL will typically heal with nonoperative treatment and it does not need to be reconstructed. This treatment approach will lead to stable functional knees and prevent the high levels of postoperative stiffness seen with other reconstruction techniques.

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Part V

Surgical Treatment of the Multiple Ligament Injured Knee

Graft Selection in Multiple Ligament Injured Knee Surgery

Natalie L. Leong, Thomas J. Kremen, and David R. McAllister

9.1 Introduction

There are many factors to take into account when assessing patients with multiple ligament injured knees. We present here a brief overview of some of the issues influencing management of ligamentous knee injuries. Knee injuries involving multiple ligament disruptions can be associated with other significant bodily traumas, and thus the hallmarks of managing any trauma patient and all associated injuries take precedent to the ultimate management of their ligamentous knee injuries.

Knee dislocations and multiple ligament injured knees are complex injuries and oftentimes present challenging clinical problems. The type of ligament graft selected by a surgeon can have a significant impact on the clinical management and outcome of these patients. Thus, it is necessary for surgeons to have a broad understanding of the variety of graft options available. Unfortunately, for multiple reasons, many surgeons do not have much specific knowledge surrounding the tissue grafts that are commercially available to them at individual hospitals and surgery centers [1]. There is wide variation among allograft distributors with regard to the donor pool from which the grafts are obtained, the screening process of donors, and sterilization processes (if any). In addition, there are multiple different allograft tissue types that can be selected for knee ligament reconstruction. In this chapter, we will present the medically relevant differences among the many graft options currently utilized in knee ligament reconstruction including a discussion of their biomechanical properties and biological differences.

9.2 Patient Factors

The age of the patient is an important factor to consider when developing an appropriate treatment plan specific to a given patient. In young patients, an open physis with significant growth remaining can mandate an alternative surgical reconstructive technique or an alternative graft that does not include a bony component in order to minimize the risk of physeal arrest and resultant angular deformity. Allografts might be particularly beneficial in middle-aged and older patients who are hoping to avoid donor site morbidity associated with the use of autografts, to minimize postoperative pain, and to reduce their time away from work. In addition, a patient's desired activity level, the types of activities in which they participate, and their profession can also influence medical management and graft selection.

The acuity of knee ligament injuries also influences the reconstructive approach. Compromise of vascular structures, compartment syndrome, or the presence of an open or irreducible joint can necessitate an urgent surgical intervention consisting of revascularization, surgical reduction, or compartment release [2]. Additionally, earlier intervention may allow easier visualization of anatomy and surgical planes and increase the likelihood of primary repair. However, most authors prefer to delay ligament reconstruction for a few days to weeks in an attempt to decrease swelling of the soft tissue envelope, provide time for healing of the capsule to reduce fluid extravasation during arthroscopy, and possibly allow collateral ligament healing [3]. In general, definitive ligament repairs and/or reconstructions performed within 2–3 weeks from the time of injury have been associated with better outcomes in several reports [4–7]. Others have advocated different timing of surgical intervention based on which constellation of ligamentous injuries exist with

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concomitantly anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), and posterolateral corner (PLC) injured patients being treated surgically within 2–3 weeks, and ACL, PCL, and medial collateral ligament (MCL) injured patients being delayed for 6 weeks [8, 9]. Chronic injuries may necessitate ligament reconstructions be performed in conjunction with osteotomies either concurrently or in a staged fashion, and this subset of patients may require additional imaging as well as more extensive gait analysis [10, 11].

Prior surgical procedures can present challenges as a result of retained hardware, prior autograft tissue harvest, prior tunnel placement, tunnel osteolysis, and geography of prior skin incisions. Additionally, medical comorbidities, psychological impairment, and concomitant CNS injury all can influence surgical recommendations.

9.3 Graft Factors

The goal of surgical intervention is to obtain an anatomic repair, when possible, or reconstruction of all associated ligamentous and capsular injuries. Several options exist regarding the material used to perform ligament reconstruction with the mainstays of treatment consisting of either allograft or autograft. Each option has a multitude of advantages and disadvantages, which will be discussed in this chapter. It is essential that treating surgeons have an understanding of the particular grafts that are available for implantation in their individual surgical practice because, as mentioned previously, the recruitment of donors, harvesting, screening, and possible sterilization procedures of grafts can vary between graft distributors. The use of allograft versus autograft tissue for ligamentous reconstruction is still debated in the literature with some authors advocating autograft as the gold standard and yet others demonstrating decreased pain and stiffness with equivalent objective and subjective outcomes with allograft compared to autograft [12–14]. Despite the controversy, the efficacy of both graft options has been demonstrated, and thus, both appear to be good options [8, 15–23].

9.4 Availability of Graft

There is a limited supply of both autograft and allograft tendons available for clinical use. Autograft tendon choices include ipsilateral and contralateral bone-patellar tendon bone grafts (BPTB), hamstring grafts, and quadriceps tendon grafts. They are limited not only by what is anatomically available in the injured knee but also by the inherent limitations on rehabilitation that contralateral harvesting incurs upon the uninjured extremity. In addition, there can be damage to and contamination of ipsilateral soft tissue structures, which can greatly limit autograft availability. Furthermore, some surgeons are concerned about the donor site morbidity which occurs with harvest of two or more autograft tendons from the same knee. For these reasons, many authors have advocated the use of allograft tissues, especially in the setting of the multiple ligament injured knee. However allograft tendon also has limited availability and this availability can vary greatly by geographic region. Allograft distributors acquire specimens from a limited donor pool as the preferred grafts arise from uninjured, young, appropriately screened donors who have themselves or by virtue of their family members voluntarily agreed to donate their tissues [1]. Although the grafts are screened for infectious diseases including hepatitis B virus (HBV), hepatitis C virus (HCV), and human immunodeficiency virus (HIV), it is still possible that these illnesses or others could be transmitted.

Although not available in the United States (US), an alternative to autograft and allograft ligaments in some other countries is synthetic grafts. Synthetic grafts theoretically would have the advantages of being readily available, would have highly resistant mechanical properties, and would eliminate autograft morbidity as well as the risk of disease transmission associated with allograft. Carbon fiber, Dacron, bundled polytetrafluoroethylene (GORE-TEX™), ABC carbon, polyester, and ligament augmentation devices have all been investigated in either animal models or even implanted clinically to ACL-deficient knees in the past. Some of these implants exhibited promising initial results; however, longer term follow-up demonstrated recurrent instability and chronic effusions as a result of catastrophic failures, chronic inflammatory reactions, particulate debris, or poor biologic scaffolding properties [23–33]. As a result, the use of synthetic ligaments is not currently recommended, and none of these are unconditionally approved by the US Food and Drug Administration (FDA) for use in the US.

Bioengineered ligament grafts are also not currently approved for implantation in the US. However, clinical applications of this technology are actively being pursued and have demonstrated considerable promise. Hopefully, bioengineered ligaments will be available in the future as their use could potentially eliminate the risks currently associated with the use of both autografts and allografts [34–45].

9.5 Autograft

Several autograft tissue options are available for harvest either in the ipsilateral or contralateral extremity among patients with a multiple ligament injured knee including BPTB, hamstrings (semitendinosus and/or gracilis), and quadriceps or quadriceps tendon–patellar bone (QTB). With regard to ACL reconstructions specifically, BPTB autograft has historically been one of the most commonly utilized grafts and is the gold standard to which all other grafts are compared [16, 46]. Despite this there is certainly an abundance of literature to support the use of hamstring autograft, either for the treatment of an isolated knee ligament injury or in conjunction with an allograft reconstruction for the multiple ligament injured knee [47, 48]. Furthermore, Ohkoshi et al. have demonstrated excellent range of motion and stability in their series of nine acute knee dislocations with multiple ligament injuries, which were reconstructed in a staged fashion using contralateral hamstring autograft followed by ipsilateral hamstring and BPTB autografts 3 months after the index surgery [49]. For a variety of reasons, quadriceps or QTB grafts are less popular than other graft options and is thus utilized much less frequently [50, 51]. However, good short- and long-term results have been reported for primary ACL reconstruction with QTB [52, 53]. Two independent series of QTB autograft ACL reconstructions demonstrated no significant difference in functional outcomes when retrospectively compared to autograft BPTB reconstructed patients including one series that utilized quadriceps tendon grafts both with and without bone plugs. Both studies showed a statistically significant decrease in the incidence of anterior knee pain lending support in the literature to the use of quadriceps tendon as an excellent graft alternative for autologous knee ligament reconstruction [53–55]. More recently, both a randomized controlled trial and a systematic review of quadriceps tendon autografts in isolated ACL reconstruction demonstrated equivalent results and lower complication rates as compared to BPTB autografts [56, 57]. In light of these varied options, there is no uniformly ideal autograft choice, especially in the setting of the multiple ligament injured knee where multiple grafts are usually needed. Each graft has its own strengths and weaknesses with regard to biomechanical properties, ease of harvest, morbidity, biology of healing as well as fixation strength and this will be discussed in greater detail later in this chapter.

Autograft does enjoy several advantages over the use of allograft for ligamentous reconstructions. Autograft tissues are associated with virtually no risk of transmission of an infectious disease; they exhibit faster incorporation with adjacent tissues and essentially have no risk of immune-mediated tissue rejection. Additionally, autograft tissues are not exposed to sterilization modalities, which, as discussed later in this chapter, can have a negative impact on the biomechanical and/or biological properties of the graft.

However, donor site morbidity is associated with autograft tissue harvest and this can be a significant disadvantage. Autograft hamstring use has been associated with symptomatic neuroma, numbness, arthrosis, symptomatic hardware requiring removal, posterior knee pain, tunnel osteolysis, terminal flexion deformity, and hamstring weakness [58–63]. Autograft BPTB harvest is associated with patella fracture, patellar tendon rupture, infrapatellar contracture, loss of range of motion, arthrosis, patellar tendonitis and calcification, quadriceps weakness, and, most significantly, an increased incidence of anterior knee pain [23, 51, 59, 64–72]. QTP has a similar constellation of associated complications to BPTB, albeit to a lesser degree, consisting of a low incidence of decreased range of motion, anterior knee numbness, anterior knee pain, and residual laxity [54, 55]. Moreover, the multiple or larger skin and soft tissue incisions as well as bony cuts that are associated with autograft harvest expose an already injured body region to even more trauma. Although some authors propose that hamstring tendons can regenerate after harvesting and that anterior knee pain is not exclusively observed in autograft BPTB-grafted patients, there is no doubt that the risk of morbidity associated with autograft tissue harvest is significant and necessitates appropriate surgeon consideration and preoperative patient counseling [73–75]. For these reasons, as well as the difficult balance between the limited number of available autografts in the setting of a multiple ligament injured knee, many surgeons prefer allograft, when available, for most of the ligament reconstructions performed in these patients.

9.6 Allograft

For knee ligament reconstruction several allograft options exist including Achilles tendon–bone (Figs. 9.1, 9.2 and 9.3), tibialis anterior or posterior (Figs. 9.4 and 9.5), B–PT–B (Figs. 9.6, 9.7 and 9.8), hamstrings (Fig. 9.9 and 9.10), and QTB (Fig. 9.11) Surgeons are attracted to allograft ligament reconstructions because they eliminate donor site morbidity as well as the additional risks associated with autograft tissue harvest. Furthermore, allografts provide multiple graft size options, shorter operative and tourniquet times, and fewer incisions as a result of not needing to harvest autograft tissue [17, 21, 76, 77]. Unfortunately, the use of allograft tissues is also associated with its own set of complications such as small risk of infectious disease transmission, slower incorporation of graft tissue, and the potential for immunologic rejection [1, 16, 28, 42, 78–80].

9.7 Risk of Infectious Disease Transmission

Infectious disease transmission, albeit exceedingly rare, is a distinct possibility when implanting allograft musculoskeletal tissues, and there have been multiple documented cases of disease transmission in this manner, some of which have resulted in death of the patient [1]. It is possible to

Fig. 9.1 Achilles allograft in tissue bank packaging. Image kindly provided by Musculoskeletal Transplant Foundation [MTF]

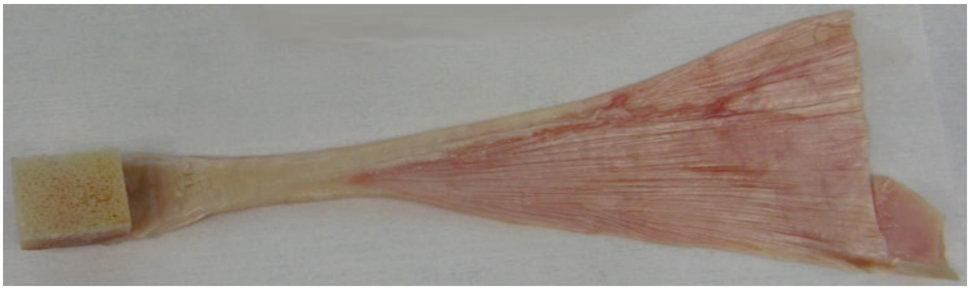

Fig. 9.2 Achilles tendon–bone allograft removed from package. Image kindly provided by Musculoskeletal Transplant Foundation [MTF]

transmit HIV virus type 1 and type 2, HBV, HCV, bacteria such as clostridia or *Treponema pallidum* (syphilis), fungi, parasites, West Nile virus (WNV), and human transmissible spongiform encephalopathies (prions).

The risk of HIV transmission in a properly screened donor ranges between 1 in 173,000 and 1 in 1 million, and the corresponding risk of HCV is 1 in 421,000 for unprocessed tissue [1]. The most concerning incident regarding HIV transmission in the setting of allograft ligament implantation was in 1986 when a fresh-frozen BPTB allograft, which was not secondarily sterilized and was derived from a young male donor with no known risk factors for HIV and who tested negative for HIV-1 antibodies, was implanted into a patient [78]. Three weeks following surgery the recipient was treated with supportive therapy for flu-like illness and lymphopenia was noted. The patient was not

Fig. 9.3 Achilles tendon–bone allograft being prepared for implantation. Image kindly provided by Musculoskeletal Transplant Foundation [MTF]

Fig. 9.4 Tibialis anterior allograft. Image kindly provided by Musculoskeletal Transplant Foundation [MTF]

Fig. 9.5 Tibialis anterior allograft ready for implantation. Image kindly provided by Musculoskeletal Transplant Foundation [MTF]

diagnosed with HIV until several years later after an investigation was carried out to identify the cause of seroconversion in a woman whose only risk factor for HIV was the receipt of bone allograft from the same donor. Other non-musculoskeletal allografts from the same donor also resulted in disease transmission. At the time of this incident, HIV testing of donors was performed via detecting the presence of anti-HIV antibodies, which may take several months to become detectable in the peripheral blood of recently infected individuals [78]. Currently, nucleic acid testing (NAT) is now required by the American Association of Tissue Banks (AATB). HIV, although it is a retrovirus, synthesizes DNA that is detectable within the leukocytes it infects, and NAT can be carried out effectively within 48 h of a donor's death. In addition to this case of HIV transmission, there have been at least two separate documented reports of hepatitis C transmission as a result of receiving patellar ligament allografts from infected donors [81, 82]. Again, these incidents occurred as a result of harvesting tissue from an anti-HCV antibody-negative donor where NAT was not performed. Although the pool of allograft donors who fall into the category of anti-HCV antibody-negative yet HCV-RNA positive is unknown, in 2003 this serology pattern was present in approximately four out of every one million blood transfusion donors [81]. Although sterilization of allografts will be discussed later, it should be noted that studies have demonstrated that although freeze-drying and radiation may decrease the already low risk of HIV transmission, these processes may not eliminate this risk completely [83–85].

In addition to viral transmissions several bacterial infections have resulted from musculoskeletal allograft implantation [1, 85]. Allograft tissues distributed by vendors operating with questionable standards that occurred between 2001 and 2005 prompted the FDA to require more stringent surveillance of organizations procuring allograft tissue. As a

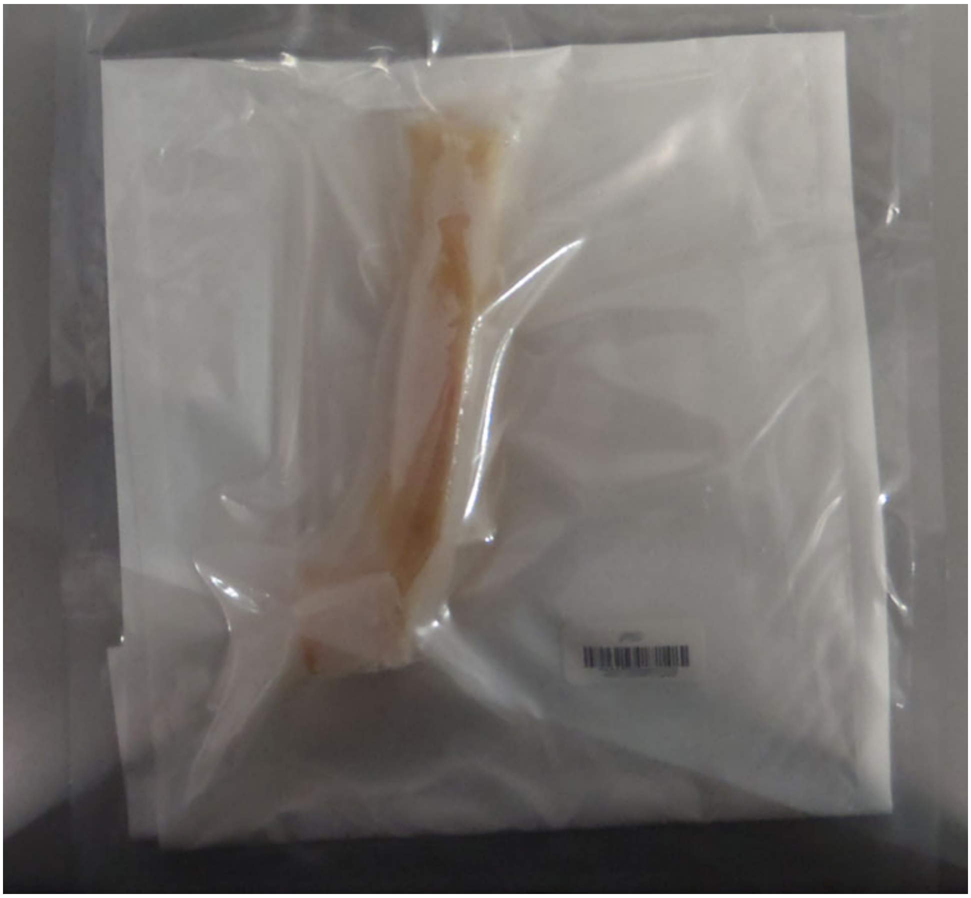

Fig. 9.6 B–PT–B allograft in tissue bank packaging. Image kindly provided by Musculoskeletal Transplant Foundation [MTF]

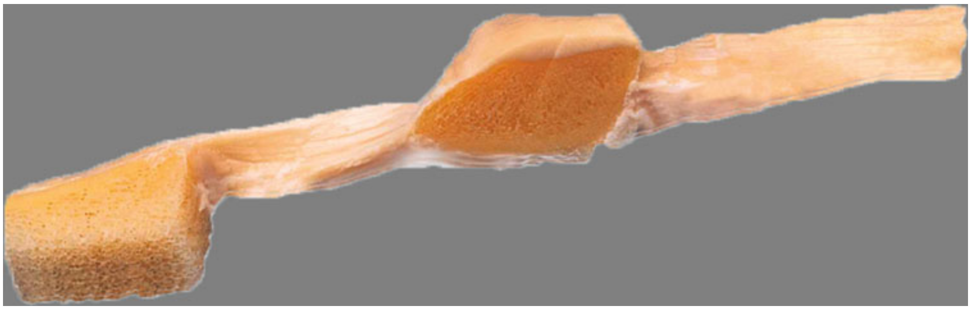

Fig. 9.7 Quadriceps tendon-patellar bone-patellar tendon-tibial bone allograft after removal of packaging.

Fig. 9.8 B–PT–B allograft ready for implantation. Image kindly provided by Musculoskeletal Transplant Foundation [MTF]

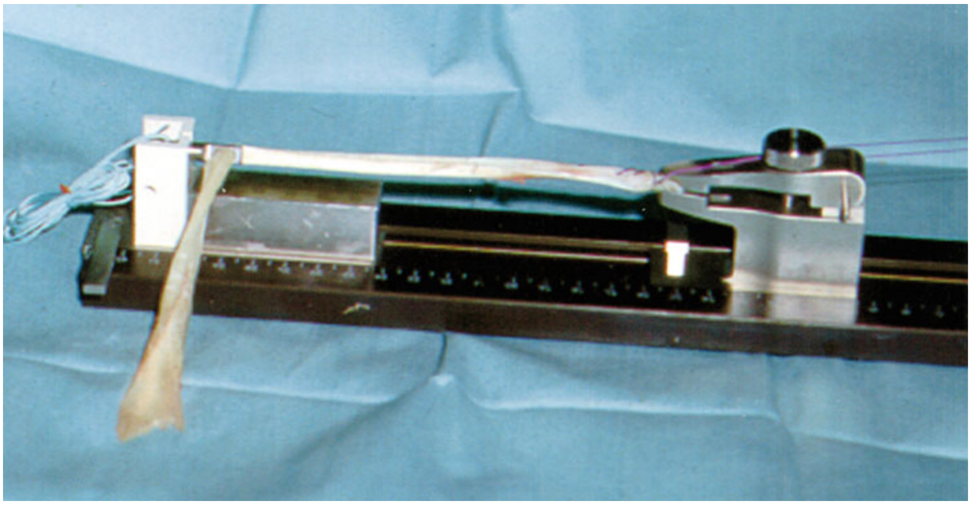

Fig. 9.9 The hamstring tendons were directly looped through the eyelet of the anchor. From [112]. Fig. 9.1. Reprinted with permission from Springer

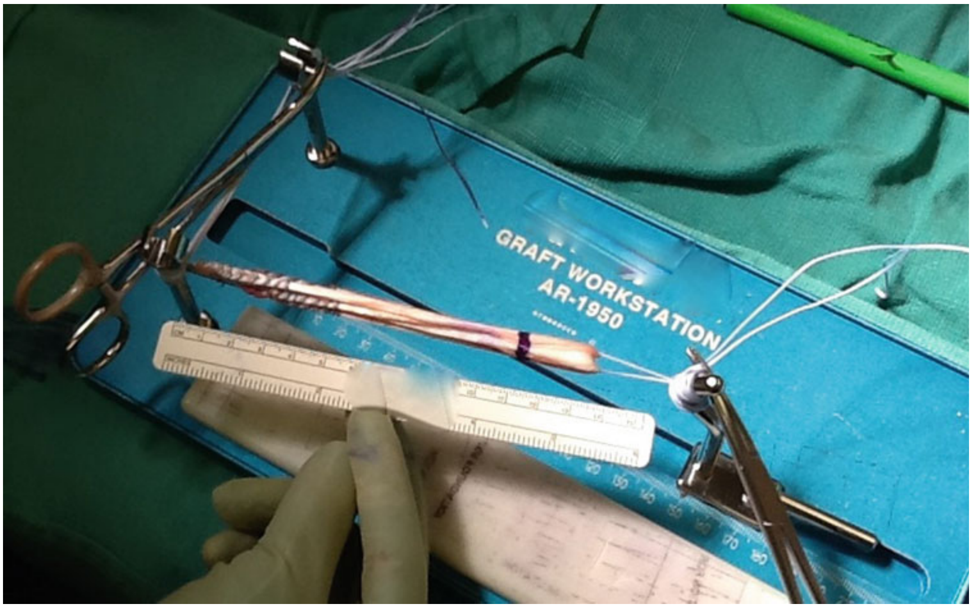

Fig. 9.10 Hamstrings allograft tensioned on graft station

result, all tissue banks in the USA are now required to register with the FDA and follow Current Good Tissue Practice requirements designed to minimize risk to allograft recipients [1, 85]. These examples bring three points to light: (1) There is a definite time lag between a donor contracting of a virus and our current ability to detect its presence (approximately 7–10 days with NAT testing), (2) secondary sterilization processes have the potential to effectively decrease the risk of viral disease transmission, yet (3) there will always be a finite risk to patients when implanting musculoskeletal allografts [1, 86].

As mentioned previously the risk of HIV and HCV is exceedingly low, and the authors are unaware of any documented transmissions in the setting of appropriately screened donors and modern NAT. Additionally, an investigation by Greenberg et al. in a large series of patients failed to demonstrate an increased risk of bacterial disease transmission associated with implantation of allograft tissues [87]. Again this underscores the importance of becoming knowledgeable about the procurement practices of individual allograft providers so that surgeons can help their patients make informed decisions about their care.

9.8 Delayed Incorporation of Allograft

Healing of a ligament graft occurs in three phases: inflammatory, proliferative, and remodeling. Within the inflammatory phase, neutrophils and other inflammatory cells arise, and the water content of the graft increases, ultimately leading to decreased biomechanical properties of the tendon itself. Graft necrosis then occurs, which is believed to be the

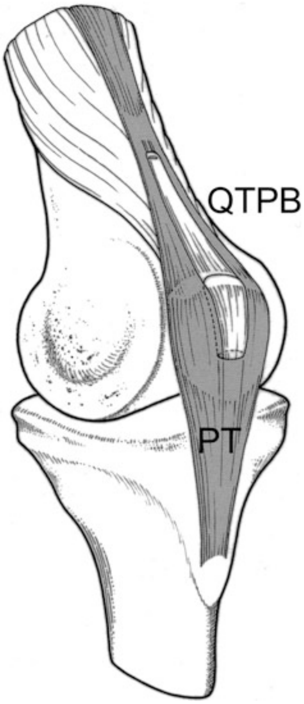

Fig. 9.11 Diagram of QTB harvesting. From [113]. Reprinted with permission from Springer

cause of the permanent strength loss observed in reconstructed ligaments, when compared to their biomechanical strength at the time of implantation [79]. Next is the proliferative phase in which fibroblasts and synovial cells infiltrate the graft from the bone tunnels and vascular granulation tissue engrafts into the ligament matrix. Finally the disorganized fibroblast and extracellular matrix mass is reorganized into a more highly cellular tissue with tensile strength properties. This process is termed “ligamentization.” Although a similar pattern of revascularization and incorporation of the graft with host tissue occurs among both autograft and allograft tissues, it has been well documented that autograft tissues incorporate faster than allograft tissues [79, 80, 88, 89]. It may take up to one and a half times longer for allograft to completely remodel and gain comparable strength to autograft [90]. ACL retrieval studies at autopsy suggest that allograft incorporation continues for more than 2 years [89]. Despite the slower rate of incorporation, the eventual healing is almost identical to the healing of autograft [91, 92]. Inherent to this delayed incorporation is the potential for graft rejection. Although this has been reported with the use of musculoskeletal allografts, it rarely impacts the clinical course of the patient [92, 93].

9.9 Procurement of Allograft Donor Tissue

The screening of acceptable donors is quite rigorous as this is the first barrier to preventing disease transmission. Prospective donors or their relevant family begins by filling out a questionnaire detailing their medical, social, and sexual history. An inquiry is made regarding drug use, neurologic diseases, autoimmune diseases such as rheumatoid arthritis, metabolic diseases, collagen disorders, sick contacts, and unprotected or anal sex. Any positive field disqualifies them as a donor. Next a thorough physical exam is performed, evaluating signs of infectious diseases such as sexually transmitted diseases, hepatosplenomegaly, lymphadenopathy, thrush, and skin lesions. Again, any positive findings disqualify the donor. Next a blood culture is taken. The FDA requires that recovered tissue must be negative for HIV-1 NAT, HCV NAT, and hepatitis B core antibody. AATB-accredited banks require testing for HIV type 1 and type 2 antibodies, hepatitis B surface antigen, total antibody to hepatitis B core antigen (IgG and IgM), HTLV-I/HTLV-II antibody, HCV antibody, a syphilis assay, as well as NAT for HCV and HIV-1. Tissues are then harvested using sterile technique within 15 h of asystole for an unrefrigerated donor or within 24 h of asystole for refrigerated donors, and specimens are contained in wet ice for transport with a maximum of 72 h on wet ice before transfer to colder environment is required [1, 86, 87].

9.10 Sterilization of Allografts

A vast majority of surgeons believe that the sterilization process had deleterious effects on the biomechanical strength of allograft tissues [1]. Gamma irradiation to 1.5 mrad combined with antibiotic soaks is a common method of sterilization. Yet, gamma irradiation to a level of greater than 3.5 mrad is estimated to be required to eliminate HIV [84]. Furthermore, gamma irradiation above 3 mrad has been shown to decrease allograft maximum failure force by up to 27% and strain energy to maximum force by up to 40%, and as a result, doses below 2.5 mrad are currently recommended to prevent damage to graft biomechanical properties [86, 94]. In response to this, research involving free radical scavengers in conjunction with radiation is currently underway in order to balance adequate infectious disease transmission prevention with the preservation of biomechanical properties [95].

Ethylene oxide was formerly a commonly implemented sterilization technique; however, after demonstrating an association of a resultant chronic inflammatory reactions and increased graft failures with its use, it has now been eliminated from AATB-approved tissue banks [96, 97].

There are many other proprietary sterilization techniques involving serial soaks alternating tissue culture grade water with denatured 70% ethanol, biologic detergents, dimethyl sulfoxide, antibiotics, or hydrogen peroxide. Additional treatments may consist of ultrasound, centrifugation, and repeated irradiation cycles [85]. Some tissue banks with proprietary sterilization techniques claim that tissue integrity is not damaged by the sterilization process [98]. However, sterilized grafts have been associated with poor clinical outcomes in several investigations [99–101].

9.11 Storage of Allograft

Cryopreservation is a process of slowly cooling a graft while extracting the intracellular water using various chemical soaks such as dimethyl sulfoxide or glycerol. Next, a controlled rate of progressive freezing down to −135 °C is carried out with the graft, ultimately being stored at −196 °C for up to 10 years. This controlled freezing in cryoprotectant solution inhibits the formation of ice crystals and thus preserves collagen integrity. It was theorized that this would also preserve cellular integrity and thus be associated with an increased risk of graft rejection; however, Jackson et al. demonstrated minimal histological inflammatory response at the allograft ligament as well as normal, rather than accelerated, rejection of corresponding allograft full-thickness skin graft. This as well as a complete absence of donor DNA by 4 weeks post-transplantation indicates that there was minimal cell survival among these cryopreserved allografts [101].

Fresh-frozen treatment of allografts is the most commonly utilized storage modality and consists of rapid freezing of the graft to −80 or −100 °C without additional sterilization processing. It has been shown to eliminate cellular components that lead to immunologic rejection of allograft tissue [80]. Freeze-dried samples are created by removing the marrow and blood from the specimen and freezing the tissue for a quarantine period. After quarantine the tissues are unthawed, treated with antibiotic soaks, and exposed to serial alcohol rinses in order to dehydrate the specimens. They are subsequently lyophilized in a vacuum and packaged. The resultant graft can be stored for up to 5 years. There is very little immunogenic response when implanted; however, unlike freeze-dried bone, the biomechanical properties of freeze-dried tendons have been demonstrated to be inferior to fresh-frozen specimens, and the potential for viral disease transmission is not completely eliminated [83, 102, 103].

9.12 Authors' Recommendation

It is clear that allograft tissue plays a substantial role in the reconstruction of a multiple ligament injured knee. Any surgeon utilizing banked tissue should become familiar with the practices, protocols, and results of whichever allograft vendor is to be utilized. Some organizations providing allograft tissues surpass the requirements of the AATB and US FDA. It is our recommendation that surgeons, at the very least, utilize allograft tissues from organizations whose processing and distribution comply with all of the required AATB and US FDA criteria for current good manufacturing practices. Furthermore, surgeons should be familiar with the sterilization processes (if any) used for grafts which will be implanted. Because of the potential deleterious effects of the sterilization processes on both the biomechanical and biological properties of allografts, the authors currently utilize only fresh-frozen nonirradiated allografts from an AATB-member tissue bank. Some surgeons have previously recommended swab culture of allografts prior to implantation. However, this practice is not currently recommended because there is little correlation with swab culture results and future allograft-associated infection [1, 104].

9.13 Biomechanical Strength of Graft

The ultimate loads to failure values for the major knee ligaments are listed in Table 9.1, as well as the corresponding biomechanical data for a variety of grafts available for reconstruction. Although absolute values vary somewhat from one study to another and no single study

Table 9.1 Ultimate load to failure and stiffness of current graft selections

	Tensile load (N)	Stiffness (N, mm)
Native ACL	2160 [114]	242
Bone–patellar tendon–bone	2977 [115]	620
Tibialis anterior (double stranded)	4122 [116]	460
Tibialis posterior (double stranded)	3594 [116]	379
Gracilis 1st strand	837 [117]	160
Gracilis 2nd strand	1550 [117]	336
Semitendinosus 1st strand	1060 [117]	213
Semitendinosus 2nd strand	2330 [117]	469
Quadruple hamstrings	4090 [117]	776
Quadriceps tendon	2352 [118]	463

comprehensively compares each graft's biomechanical properties utilizing the same techniques, the general trend is consistent across multiple studies. The values listed in Table 9.1 are often cited in the literature and are certainly representative. Again, it should also be noted that after implantation, soft tissue autografts are known to undergo necrosis and, as a result, loose a portion of their intrinsic strength [79]. It is this reason that most surgeons choose a graft with biomechanical properties superior to the native ligament that they are reconstructing. Thus, single- and double-strand hamstring grafts do not have adequate mechanical properties for cruciate ligament reconstruction and quadruple hamstrings grafts are utilized instead. Donor age has been proposed as a factor in the biomechanical strength of available allograft tissues; however, Flahiff et al. have demonstrated no statistically significant difference in the biomechanical properties of allograft tissues among donors up to age 55 [105]. Another factor that affects both the biomechanical strength of the fixation construct and the incorporation of graft into a bone tunnel is bone-to-bone healing versus soft-tissue-to-bone healing. The duration required for significant bone-to-bone healing of an autograft ligament reconstruction based on animal data is 6–8 weeks, much like the typical time frame for primary bone healing of a fracture [106], whereas the duration required for significant tendon-to-bone healing of an autograft ligament reconstruction is approximately 8–12 weeks in an animal model [107]. Clinically, Noyes et al. concluded that BPTB allografts more effectively restored anterior–posterior translation in their report comparing allograft BPTB to fascia lata soft tissue allograft ACL reconstructions [108]. More recently, meta-analysis comparing soft tissue hamstring autografts to BPTB autografts has also demonstrated significant benefits with regard to less residual laxity and a lower graft failure among BPTB-grafted patients [59]. In light of these animal and clinical studies, different postoperative rehabilitation restrictions may apply to soft tissue grafts without an osseous component.

9.14 Graft Choice for Specific Ligament Reconstructions

As mentioned previously, graft necrosis occurs with both autograft and allograft, and as a result, many surgeons choose a graft for ligament reconstruction based on its biomechanical properties (see Table 9.1). In light of this, most authors prefer to use a large graft for PCL reconstruction, which usually consists of QTB, double-stranded tibialis, or Achilles tendon–bone. All other ligament reconstructions are performed with a multitude of graft choices, and these options are relatively interchangeable and largely depend on surgeon preference and experience level.

9.15 Surgical Technique

Harvesting of autograft tissue can be performed via multiple approaches with regard to separate skin incision and desired dimensions of the harvested graft; however the basic techniques described are quite similar. A brief surgical description of specific autograft harvesting techniques is discussed below.

9.15.1 Patellar Tendon

An infrapatellar midline incision is performed, slightly medial to the midline. Dissection is carried out down to the subcutaneous tissue and the paratenon is identified. The paratenon is sharply incised and reflected, thus exposing the patellar tendon. A central section of the tendon is excised measuring 9–11 mm wide throughout its length. Bone plugs of 20–30 mm in length on both the tibia and the patella are created with an oscillating saw and osteotomes [109].

9.15.2 Hamstrings

The hamstring tendons insert 2 cm distal and 2 cm medial to the tibial tubercle. An anteromedial incision is made, and the subcutaneous tissue is dissected away to reveal the sartorius fascia. The semitendinosus and gracilis tendons are located directly beneath the sartorius fascia with the interval between them being more easily distinguishable proximally. The sartorius fascia is incised and the tendons are identified. Careful blunt and sharp dissection can be used to further isolate the tendons and to free them from the surrounding tissues. A tendon stripper is passed up the tendons proximally to release them from the muscle [110].

9.15.3 Quadriceps Tendon Harvest

Quadriceps tendon autograft is harvested through a longitudinal midline incision extending from the superior pole of the patella. After dissecting through subcutaneous tissues, the prepatellar retinaculum is isolated and preserved. The quadriceps tendon and its junction with the vastus medialis obliquus and vastus lateralis obliquus are identified proximally (see Fig. 9.11). The desired tendon graft width and length are measured. An incision is carried out through some or all layers of the quadriceps tendon. It is important to remain cognizant of the articular surface and adherent synovium as well as the relatively sclerotic bone of the superior pole of the patella. The graft may be harvested with or without a bone plug from the superior patella [53, 111].

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Part VI

Surgical Treatment of the ACL Based Multiple Ligament Injured Knee

10

Surgical Treatment of Combined ACL and Medial-Sided Knee Injuries: Acute and Chronic

Erin M. Cravez, Izuchukwu Ibe, and Michael J. Medvecky

10.1 Introduction

The following chapter will review the evaluation and treatment of combined anterior cruciate ligament (ACL) and medial collateral ligament (MCL) injuries. Although medial collateral ligament injuries are one of the most frequently seen knee injuries and the typical ACL injury occurs by noncontact mechanism, the less frequently seen combined ACL–MCL injury pattern more commonly occurs via a contact or collision mechanism, causing valgus stress with combined tibial external rotation. The treatment algorithm is usually dictated based upon the severity of the medial-sided knee injury as well as injuries to associated structures such as the posterior oblique ligament (POL), medial meniscus, medial retinaculum, or medial patellofemoral ligament (MPFL).

Treatment of this combined injury pattern requires a thorough understanding of the complex anatomy of the medial aspect of the knee as well as key biomechanical principles involved in assessment of isolated and combined knee injury patterns, which will involve the superficial medial collateral ligament (sMCL), the posterior oblique ligament, semimembranosus tendon (SM), and the cruciate ligaments (ACL and/or PCL).

10.2 Anatomy of the Medial Aspect of the Knee

A recent quantitative evaluation of the anatomic attachment sites of the primary medial knee structures as well as a qualitative anatomical review of these structures has helped provide clarity and uniformity to our understanding of the osseous landmarks as well as ligamentous attachment sites (Fig. 10.1) [1].

The sMCL is the primary stabilizer to valgus stress and the largest structure on the medial aspect of the knee [1, 2]. The attachment site on the femur is located in a depression that is slightly proximal (3.2 mm) and posterior (4.8 mm) to the medial epicondyle. The femoral attachment is a direct insertion, where the fibers insert directly into the cortical bone. On the tibia, there are two attachment sites. The distal tibial attachment site is broad and located on the anteromedial aspect of the tibia, 61 mm from the joint line, and parallels the posteromedial crest of the tibia. The proximal tibial attachment site is primarily a soft tissue attachment to the anterior arm of the semimembranosus tendon, which courses from posterior to anterior. The tibial attachment is an indirect insertion with a broad attachment site, superficial fibers that insert obliquely into the periosteum and deeper fibers that attach via Sharpey's fibers. Deep to the sMCL lies the inferior medial geniculate artery and vein [1].

10.3 Deep Medial Collateral Ligament (Mid-third Capsular Ligament)

The deep medial collateral ligament (dMCL) consists primarily of the thickening of the medial joint capsule and is most distinct along its anterior border where its fibers parallel the sMCL. The dMCL contains two distinct components (meniscofemoral and meniscotibial ligament) [1, 3].

10.4 Posterior Oblique Ligament

The posterior oblique ligament (POL) has been described in the past by Hughston consisting of three distinct components (superficial, central, and capsular arms) (Fig. 10.2) [4]. The attachment site on the femur is located 1.4 mm anterior and 2.9 mm distal to the newly described osseous prominence on the medial femoral condyle, the gastrocnemius tubercle [1]. The largest portion of the POL is the central arm. Anteriorly,

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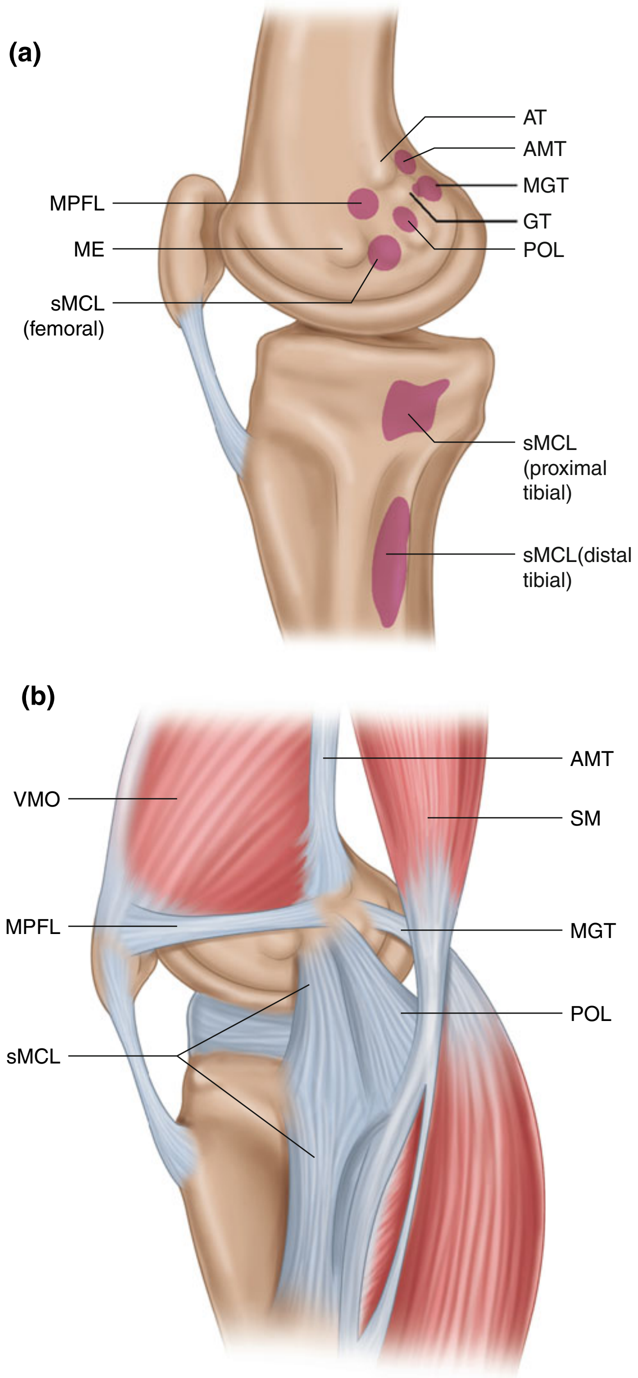

Fig. 10.1 Anatomy of the medial aspect of the knee. **a** Ligamentous attachment sites. **b** Medial ligament anatomy

it merges with the posterior fibers of the sMCL, and distally, it attaches to the posteromedial aspect of the medial meniscus, the meniscotibial portion of the posteromedial capsule, and the posteromedial tibia. The capsular arm consists of a thin fascial expansion from the SM tendon that blends with the posteromedial joint capsule and the oblique popliteal ligament (OPL) and has no osseous attachments [1, 4].

10.5 Semimembranosus Tendon Tibial Attachments

The semimembranosus tendon has been recently shown to have eight attachments to the posterior aspect of the knee [5] (see Fig. 10.2). A detailed quantitative and qualitative analysis was performed and demonstrated the inconsistency in prior descriptions of the posterior knee anatomy [6]. Previous descriptions had agreed upon three consistent attachments: a direct arm, an anterior arm, and the oblique popliteal ligament (OPL) [3, 4]. The direct arm attaches to the osseous prominence of the posteromedial tibia, the tuberculum tendinis. The anterior arm arises from the bifurcation of the common tendon just proximal to the direct arm attachment and courses deep to the proximal tibial attachment of the superficial MCL. The OPL was formed by the merger of a branch of the semimembranosus common tendon and the capsular arm of the POL. The OPL had no direct attachment to the lateral femoral condyle but attached to the fabella, the posterolateral joint capsule, the plantaris muscle, and the lateral aspect of the PCL tibial attachment site.

10.6 Medial Patellofemoral Ligament

The medial patellofemoral ligament (MPFL) is located in a distinct extra-articular layer from the medial joint capsule (see Fig. 10.1a). The MPFL attaches to the proximal half of the medial patella. It courses medially to attach to a site on the femur between the medial epicondyle and the adductor tubercle [1, 5, 7].

10.7 Clinical Evaluation

A detailed history is obtained from the patient including mechanism of injury and any subsequent treatment is also delineated. A mechanism of injury or clinical presentation consistent with a multiligamentous knee injury needs expeditious careful assessment of ligamentous stability and neurovascular status and limb-threatening injury ruled out.

The patient typically will present with a knee effusion and/or soft tissue swelling or ecchymosis. The examination is typically somewhat limited by pain, swelling, and muscle guarding. A comprehensive knee examination is performed including soft tissue assessment, neurovascular status, and knee range of motion including assessment of hyperextension, patellofemoral alignment and stability, focal areas of tenderness, standing limb alignment and gait as well as comprehensive assessment of knee motion limits in comparison to the contralateral knee [8].

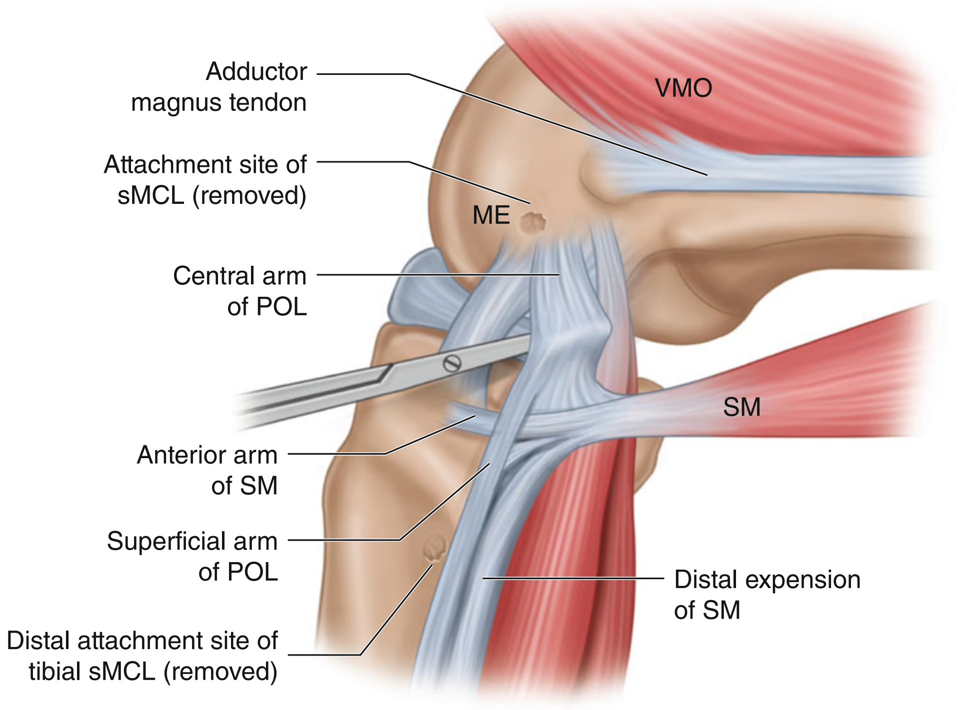

Fig. 10.2 Semimembranosus tendon tibial attachments. Please note this represents an oblique view of the posteromedial aspect of the knee and due to the rotation, the lateral femoral condyle comes into view posteriorly

10.8 Classification of Injury

The scientific literature pertaining to MCL injuries demonstrates wide variability in the classification schemes used to categorize injury patterns, and this leads to considerable difficulty in comparing treatment algorithms or clinical outcome studies [9–11]. Among the earliest classification systems for describing ligament injuries was that proposed by The American Medical Association Standard Nomenclature of Athletic Injuries [12]. Injuries were broken down based upon structural injury and abnormal motion limits resulting from such injury. The first-degree (1°) sprain results in injury to a few ligament fibers without abnormal motion change. Second-degree (2°) injuries result in partial tearing of ligament fibers with increased joint motion but still maintaining structural endpoint. Third-degree (3°) injuries result in complete ligamentous disruption with no functional endpoint achieved.

Modifications of the classification system are seen in various articles pertaining to MCL injury with some classification systems using gradations of absolute joint opening (grade 1+, 2+, and 3+). Other classification systems utilize a grading system (grade 1, 2, and 3) with each grade representing an additional 5-mm increase in abnormal joint space opening (grade 1 = Δ (Delta) 0–5 mm, grade 2 = Δ6–10 mm increase, grade 3 = Δ11–15 mm). The author utilizes the AMA classification system as outlined by Noyes [11] which is based upon the increase in millimeters in joint space opening compared to the contralateral limb, with gradations based upon biomechanical and kinematic in vitro selective ligament cutting studies by Grood et al. [2] (Fig. 10.3).

10.9 Clinical Biomechanics

10.9.1 Valgus Stress and Medial Compartment Motion Limits

The sMCL provides the primary restraint to medial joint space opening [2, 13, 14]. It is responsible for 57% of the total restraining moment at 5° of knee flexion and 78% at 25° of knee flexion. Injury to the sMCL at the three primary attachment points (femur, proximal tibia, and distal tibia) has been shown in vitro testing to result in differences in stability. The proximal (femoral) attachment of the sMCL has been shown by Griffith et al. to be the primary stabilizer to valgus stress [15]. The medial restraint provided by both the ACL and PCL is approximately 14% at both 5° and 25°. Upon isolated sectioning of the MCL, medial joint space opening increases by approximately 1.25 and 4 mm at 5° and 25° of flexion, respectively (Fig. 10.4). This demonstrates only a small amount of increased joint space opening

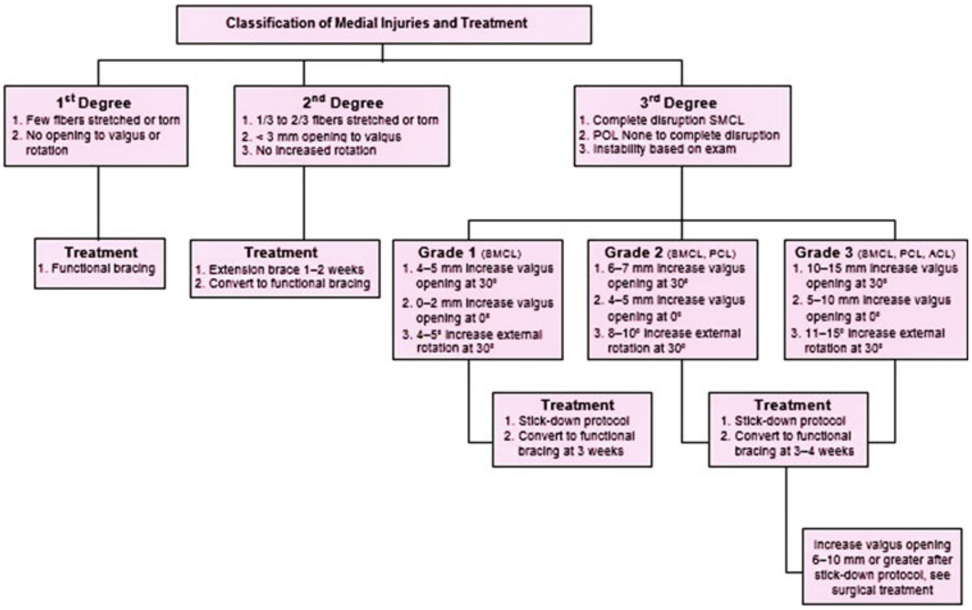

Fig. 10.3 Classification of medial-sided knee injuries. From Noyes and Barber-Westin [10]. Reprinted with kind permission from Elsevier

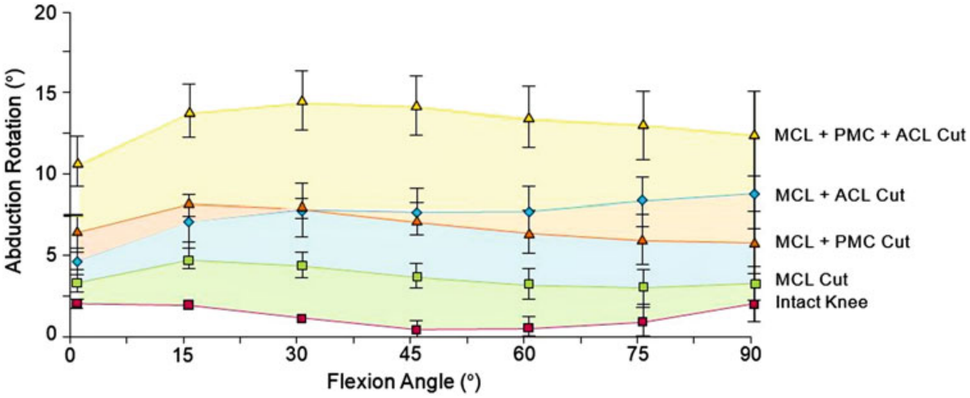

Fig. 10.4 Valgus opening with selective ligament sectioning. From Noyes and Barber-Westin [10]. Reprinted with kind permission from Elsevier

is seen on clinical examination even when the primary medial restraint is completely injured (third-degree sprain).

When all medial structures are sectioned (MCL, POL), there is approximately 7 mm of increased medial compartment joint space opening at 30°. At this point, the cruciate ligaments are acting as the primary restraint to further increased abduction stress. With further ACL sectioning, approximately 14 mm of medial compartment joint space opening will be noted.

The POL acts as an important stabilizer to valgus force with the knee in full extension [2, 13, 14]. With combined injury patterns at the 30° flexion position, there is not much difference in joint space opening of the combined MCL–POL injury versus MCL–ACL injury. The difference noted between these two injuries is the increased joint space opening in full extension in the MCL–POL injury. Addition of an ACL injury to this (ACL–MCL–POL) results in even more significant medial compartment joint space opening in the full-extension position (approximately 9 mm). Recent literature recognizes that combined MCL–POL injury leads to anteromedial rotatory instability, which if left untreated can place undue strain on cruciate ligament reconstructions and contribute to graft failures [16].

10.9.2 Anterior Translation

As demonstrated by cadaveric testing studies, sectioning of the ACL resulted in predominantly increased anterior translation at low flexion angles (30°) versus higher flexion angles (90°) [17]. This demonstrates the utility of the Lachman test versus the anterior drawer test. In the ACL-deficient knee, sectioning of the MCL results in significant increase in anterior translation at 90° without increase at 30°. With sectioning of the MCL and POL, significant anterior translation occurred at both 30° and 90°. In the ACL-intact knee, sectioning of the MCL and POL resulted in no increased anterior translation at any degree of knee flexion [18].

10.9.3 External Rotation Limits

The rationale of performing the dial test in the assessment of ACL–MCL injuries is shown in Fig. 10.5 [18]. Sectioning of the ACL alone produces no increased external rotation. Sectioning of the sMCL produces significant increase in external rotation more in flexion than extension. As demonstrated by Griffith et al., the distal attachment of the sMCL is the primary external rotation stabilizer [15]. Additional sectioning of the POL resulted in additional increase of external rotation at all flexion angles with the increase again greater in flexion than extension. Addition of ACL sectioning produced immediate greater increase in external rotation predominantly at 30° but also at 90°. It is necessary to perform the dial test in the supine position in order to delineate that the increased external rotation is occurring due to the anterior displacement of the medial tibial plateau with the axis of rotation localized to the lateral compartment. This is in distinction to the increased external rotation seen with posterolateral corner injury where there is posterolateral tibial subluxation with the center of rotation shifted to the medial compartment.

10.9.4 Internal Rotation Limits

The posteromedial capsule also carries an important function in resisting internal tibial rotation (Fig. 10.6 [18]). Sectioning of only the superficial MCL produced a small increase in the internal rotation limit. Combined sectioning of the MCL and PMC caused a large increase in the internal rotation limit from 0° to 45°. In particular, the distal attachment of the MCL has been shown to be the relatively more important structural component of the sMCL with regard to internal rotation restraint [15]. Additional sectioning of the ACL did not result in significant increase in internal rotation in the range of either 30° or 90° position.

10.10 Diagnostic Imaging

X-rays are obtained during initial evaluation of the patient. If the patient is able to weight bear or partially weight bear with crutches, we obtain weight-bearing AP in full extension and PA at 45° of flexion, a non-weight-bearing patellofemoral axial view, and a lateral at 30° of knee flexion.

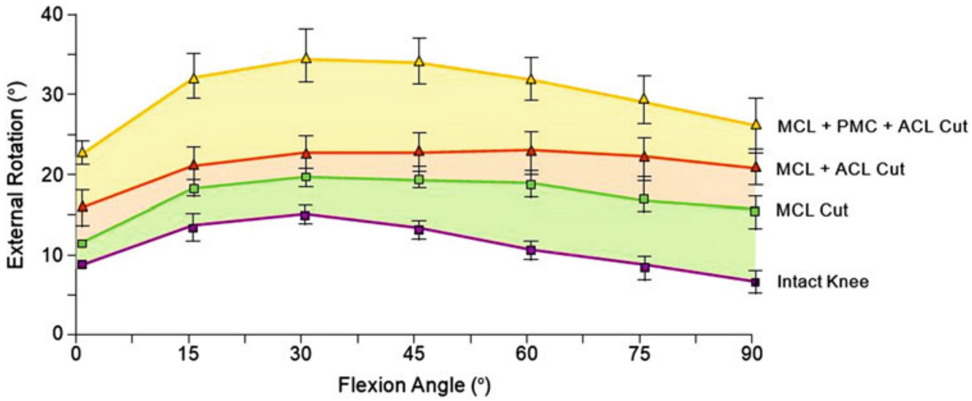

Fig. 10.5 External rotation limits with selective ligament sectioning. From Noyes and Barber-Westin [10]. Reprinted with kind permission from Elsevier

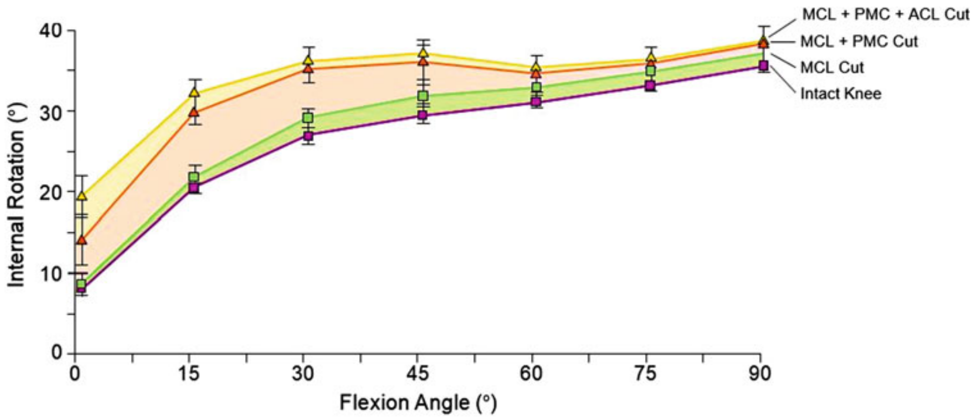

Fig. 10.6 Internal rotation limits with selective ligament sectioning. From Noyes and Barber-Westin [10]. Reprinted with kind permission from Elsevier

Valgus stress radiographs may also be obtained but are typically too painful to obtain during the acute injury and are much more effective for the assessment of chronic injuries. LaPrade et al. [19] demonstrated the reproducibility of clinician-applied valgus stress where isolated 3° sMCL injury resulted in an increase of 3.2 mm medial joint gaping at 20° and the increase of 1.7 mm in full extension. A complete medial knee injury (sMCL, dMCL, and POL) resulted in increased medial joint gapping to 6.5 and 9.8 mm at 0° and 20°, respectively. Combined complete medial knee injury and ACL injury resulted in increased medial joint gapping of 8 and 14 mm at 0° and 20°, respectively (Fig. 10.7).

In the treatment of chronic injuries, particularly where ligamentous reconstructive surgery is being considered, we obtain full-length bilateral standing lower extremity X-rays to assess the mechanical axis and weight-bearing line. This is to exclude a valgus malaligned knee where corrective osteotomy may need to be considered before ligamentous reconstruction.

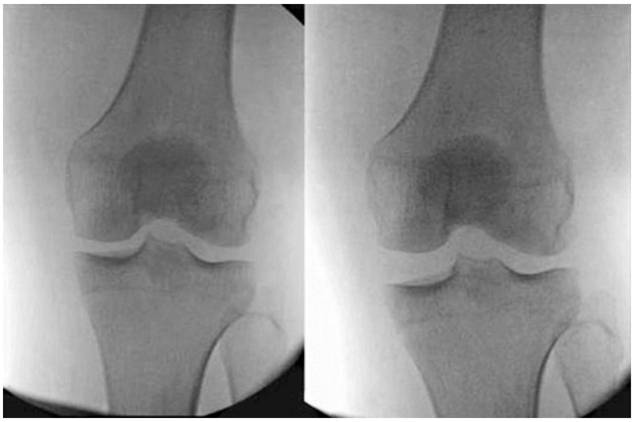

Fig. 10.7 Fluoroscopic images obtained during examination under anesthesia demonstrating excessive medial compartment gaping at 30° of flexion, consistent with 3° injury of sMCL

MRI is considered essential in the workup of these soft tissue injuries, particularly in the 3° injury in the high-demand athlete. For those injuries with clinically apparent involvement of the posteromedial capsule and possibly a cruciate ligament, an MRI is obtained for delineation of the site of ligamentous injury, assessment of the tear pattern and residual tissue configuration as well as associated injuries of the meniscus or articular cartilage (Fig. 10.8) [20–22].

10.11 Treatment Algorithm

There is a fairly uniform consensus in the literature that non-operative management of first- and second-degree MCL injuries is appropriate [23–27]. With regard to acute third-degree medial-sided injuries, some controversy does exist regarding non-operative versus operative intervention [27–29]. However, most studies advocate non-operative treatment of the medial-sided knee injury.

For 1° and 2° injuries, the author utilizes an off-the-shelf neoprene hinged knee brace for compression effects and coronal support during the early healing phase of approximately 6 weeks. For 3° injuries, particularly those that demonstrate involvement of the POL and medial compartment joint space opening in full extension, the author advocates the use of non-operative management but utilizes short-term immobilization in full extension with a cylinder cast as described by Noyes [10]. It is felt that functional bracing is insufficient in controlling medial compartment apposition against valgus and external rotation forces, potentially resulting in healing of the medial-sided structures in a compromised and attenuated alignment. For these 3° injuries, an MRI is also obtained acutely to identify the zone

Fig. 10.8 MRI images demonstrating MCL avulsion seen on coronal MRI image (**a**) as well as ACL disruption on sagittal MRI image (**b**)

of injury, any associated injuries, and to exclude the need for operative repair (see Fig. 10.3) [20, 30, 31].

A long-leg cylinder cast is placed with the knee in full extension, and the patient is instructed on foot-flat touch-down weight bearing, avoidance of walking in an externally rotated position (to minimize valgus-external rotation force), quad isometrics, straight leg raises, and ankle pumps in the cast. In approximately 7–10 days, the cast is bivalved and the patient initiates physical therapy to begin range of motion exercises 3–4 times per day, in an alignment to lessen the stress on the medial ligaments. This involves rolling chair seated flexion with the hip externally rotated and knee aligned in varus as well as figure-of-four position knee flexion in the supine position.

After 3 weeks of cast immobilization, the patient is switched over to a short-hinged neoprene brace or long-leg hinged range of motion brace depending upon the quickness of ligament healing, pain with range of motion and ligament testing, and the degree of quadriceps weakness. Progressive weight bearing continues over the next 3–4 weeks as well as gait retraining, cryotherapy, and electrical muscle stimulation in an effort to control pain, swelling, and improved quadriceps reactivation. Continued emphasis on the range of motion in the figure-of-four position is encouraged to minimize stress to the healing medial-sided ligamentous structures.

10.12 Surgical Indications

The authors feel that acute medial-sided repair has very limited indications, which include a displaced peripheral meniscus tear, severe retraction or displacement of the sMCL likely to result in healing in a nonfunctional position, a newly described Stener-type lesion of the MCL and pes anserinus [30] (Fig. 10.9), associated patella dislocation with concomitant MPFL avulsion, associated bucket-handle meniscus tear, particularly medial meniscal tears that would have insufficient medial capsular tissue to sustain an all-inside or inside-out meniscus repair, or avulsion of the direct attachment of the semimembranosus tendon. Some authors feel the elite athlete is best treated with acute repair of high-grade medial-sided ligament injury [10].

Some authors advocate acute ligamentous reconstruction for medial-sided knee injuries that involve the superficial MCL and POL [27]. At this point, no clinical data supports this versus acute repair of these structures [32]. A recent systematic review of the treatment of complete ACL–MCL injuries showed no consensus on the optimal treatment options for this combined injury pattern, which evaluated five different combinations of surgical and nonsurgical options [33].

In cases of acute sMCL, POL, and ACL injuries, where acute surgical repair is indicated, we will consider doing the ACL reconstruction in a staged fashion. If the soft tissue swelling has sufficiently resolved from the acute injury and if the range of motion to at least 90° is achieved, we can consider doing simultaneous semitendinosus/gracilis (STG) autograft ACL reconstruction due to the decreased graft harvest morbidity versus bone-patellar tendon-bone graft (BTB) in the acutely injured knee.

When operative intervention is performed for acute severe medial-sided knee injury, operative goals are the restoration of normal anatomical continuity of the ligaments as well as repair of the normal attachment sites onto the femur or tibia (Fig. 10.10). Pending the quality of the repaired tissue and the surgical judgement of restored stability, the authors have accepted a low threshold for sMCL augmentation, especially given the support of recent in vitro biomechanical testing [34] (Fig. 10.11). This is achieved through as limited an incision as possible to decrease additional surgical morbidity to the region, and there should be sufficient integrity of the ligament complex to allow immediate range of motion. The MRI provides valuable information to localize the zone of injury and develop a surgical preoperative plan [20].

10.13 Operative Strategy for Acute Medial Ligamentous Repair

Operative strategy and sequence of repair or reconstruction are similar for acute and chronic injuries. Progression of anatomical restoration will proceed from deeper structures to superficial [1, 35]. Deepest layers consist of the meniscofemoral and meniscotibial ligaments and the associated attachment to the medial meniscus, which is repaired if disrupted. The intermediate layer consists of the POL and semimembranosus attachments (direct and anterior arm) followed by the superficial layer, consisting of the sMCL.

We use as limited and focused an incision as possible based upon the MRI findings, but the exposure will need to be sufficient to allow assessment of all injured regions, particularly the sMCL attachment sites, posteromedial capsule, and semimembranosus tendon. Meticulous soft tissue dissection is performed to minimize the risk of injury to the saphenous nerve and sartorial and infrapatellar branches [36, 37]. The sartorial fascia is incised anterior to the medial epicondyle and the underlying gracilis and semitendinosus tendons. The pes tendons are retracted posteriorly to allow visualization of the sMCL on the tibial surface. Identification of all major structures and their attachment sites is performed as there can be both interstitial injury and disruption of the femoral or tibial attachment sites. Repair is performed from

Fig. 10.9 Surgical photos demonstrating **a** sMCL tibial avulsion retracted above the pes anserinus and curled up horizontal to the joint line consistent with MRI images as seen in **b**. Note the infrapatellar branch of the saphenous nerve crossing the operative field a few centimeters distal to the joint line. **c** sMCL shown to be detached from its two native proximal tibial attachment sites but robust tissue remains for repair

deep progressing toward superficial layers. This is performed using both absorbable and nonabsorbable suture materials. Absorbable suture anchors are considered for repair of bony attachments of some of the deeper structures such as the meniscofemoral ligament or anterior arm of the semimembranosus tendon (Figs. 10.12, 10.13, 10.14 and 10.15).

Avulsion of the direct semimembranosus attachment site can be repaired by the placement of locking Krackow sutures through the tendon and placement of intraosseous bone tunnels from anterior to posterior, pulling the sutures out of the anteromedial aspect of the tibia and tying this over the anterior cortex or a small button. Pull-through suture

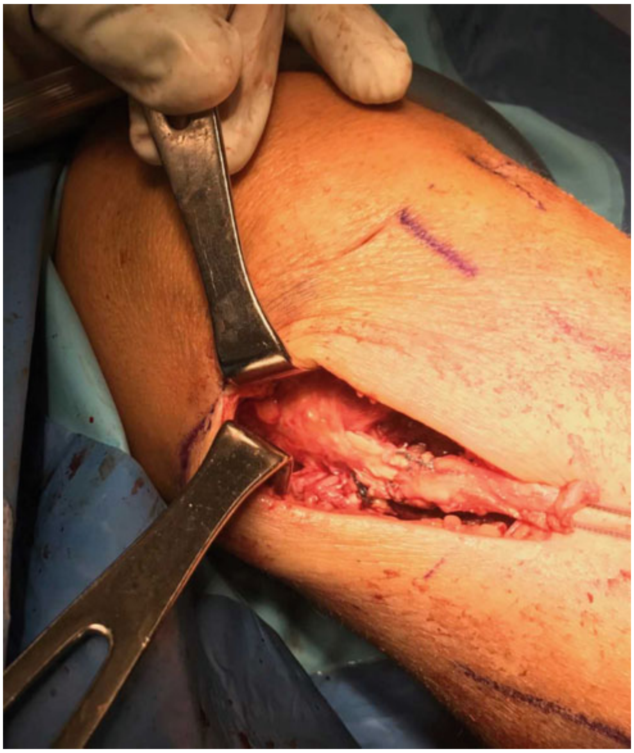

Fig. 10.10 Example of tibial avulsion of sMCL. Note the normal appearing medial epicondyle femoral attachment site between the retractors. Both tibial attachment sites were involved and repaired separately in attempt to restore the normal anatomy and biomechanics of the sMCL

technique (Fig. 10.16) can also be considered for femoral avulsions of the sMCL, POL, or MPFL. Locking sutures may be placed in the structure and a beath pin passed from medial to lateral, tensioning the sutures on the lateral cortex and tying these over the bony cortex or a small button. This technique is preferred over the use of suture anchors, if possible, secondary to the secure hold on the avulsed structure obtained with locking sutures and the ability to more securely tension the structure with this technique. If two or more sutures are to be passed, place all the beath pins in their respective positions in the condyle and then drill them all the way across, as sequentially placing the pins and passing sutures can potentially lacerate previously passed sutures. We typically place sutures into the avulsed structures first followed by progressive repair from deep toward superficial. The sMCL is tensioned at approximately 25° of flexion. The POL is tensioned at approximately 10–20° of knee flexion, to avoid over-constraining the knee and result in loss of terminal extension. Plication of the POL is also typically needed with direct suture repair of the anterior portion of the POL to the posterior aspect of the sMCL. Several sutures may be placed and stability is assessed. Tension is applied to the sutures in approximately 20° of flexion, the knee was then brought into full extension to verify that there is no loss of terminal extension and adjustment of the tension and/or number of sutures is performed [4, 10, 35]. The knee is taken through a full range of

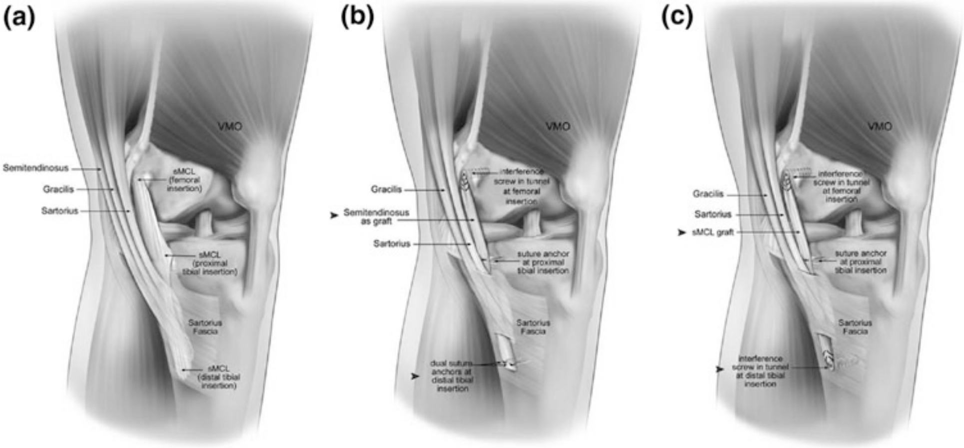

Fig. 10.11 Anteromedial view of the left knee. **a** The superficial medial collateral ligament (sMCL) is shown with the location of the femoral origin and the proximal and distal tibial insertions of the sMCL. Also displayed are the pes anserine tendons (sartorius, gracilis, and semitendinosus) coursing distally to their insertion of the tibia anterior to the distal sMCL insertion. Further note the Sartorius fascia overlying the distal sMCL. **b** Anatomic augmented repair of the sMCL in a left knee. Distal tibial fixation of the semitendinosus was performed with two double-loaded suture anchors by suturing the semitendinosus to the sMCL remnant 6 cm distal to the joint line. The semitendinosus was passed deep to the sartorius fascia. Anatomic fixation of the femoral tunnel 3.2 mm proximal and 4.8 mm posterior to the medial epicondyle was performed with 60 N of traction applied to the graft at 20° of knee flexion and neutral rotation. Proximal tibial fixation was located 12 mm distal to the joint line and directly over the most anterodistal attachment of the anterior arm of the semimembranosus. **c** Anatomic reconstruction of the sMCL. Femoral and distal tibial fixation achieved with an interference screw. Proximal tibial fixation performed with a suture anchor 12 mm distal to the joint line. *Arrowheads* in (**b**) and (**c**) highlight differences between the anatomic augmented repair and anatomic reconstruction techniques. From Wijdicks et al. [34]. Reprinted with permission from SAGE Publications

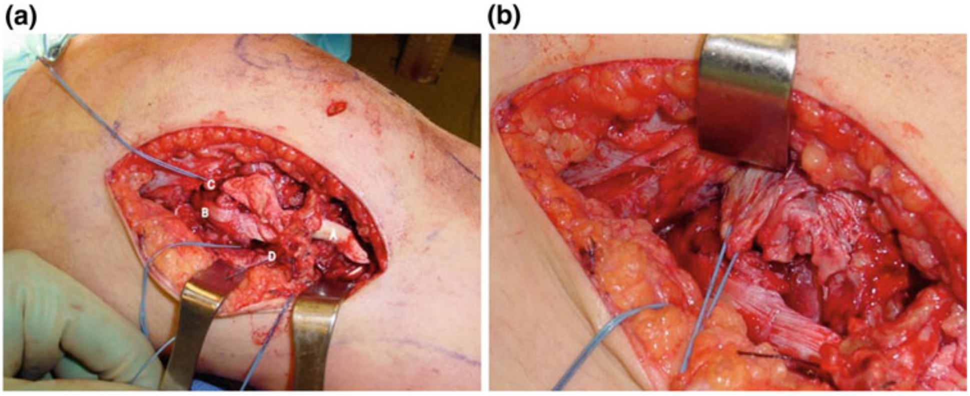

Fig. 10.12 (**A**) sMCL tibial attachment, (**B**) sMCL femoral attachment, (**C**) MPFL, (**D**) infrapatellar branch of saphenous nerve, **a** surgical exploration of medial-sided knee injury. **b** traction suture placed in MPFL in preparation for pull-through repair

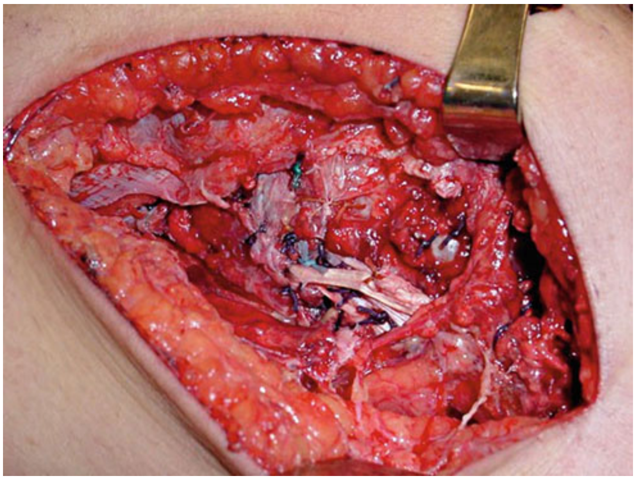

Fig. 10.13 Medial structures after direct repair of sMCL, MPFL, POL, and medial retinaculum

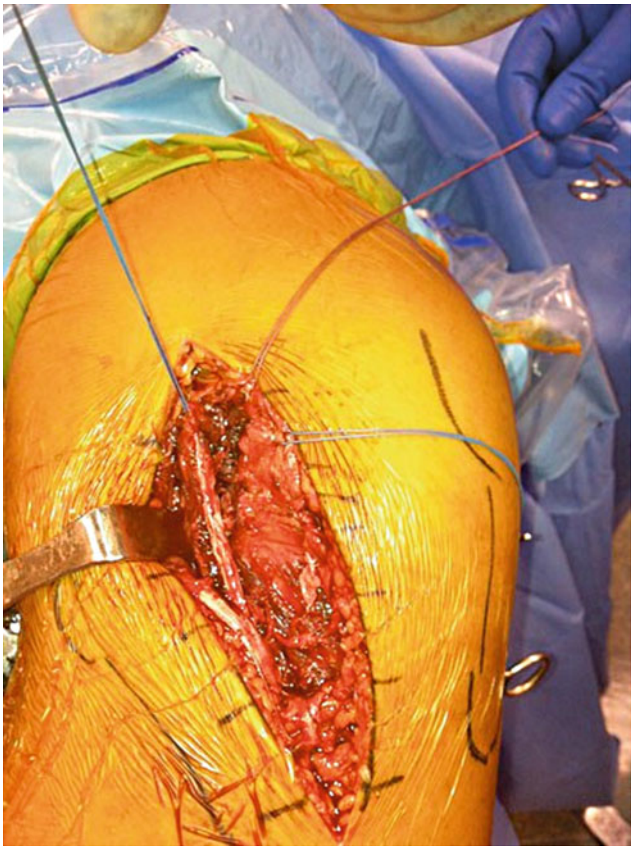

Fig. 10.14 Intraoperative image of left knee demonstrating avulsion of the sMCL off femoral attachment site, medial retinaculum tear, MPFL avulsion, and avulsion of meniscofemoral ligament

motion on the table prior to closure to verify joint motion is not over-constrained. If there is MPFL or medial retinacular disruption, this is repaired at approximately 20° of flexion to also avoid over-constraining of the patellofemoral joint.

The patient is also consented for the potential use of allograft tissue in a rare case that ligamentous disruption is so severe that it precludes adequate direct repair. Limited repair may need to be considered with reconstruction of the sMCL and/or POL as described in the next section. sMCL anatomic augmented repair is supported by an in vitro biomechanical study by Wijdicks et al. [34] which demonstrated improved stability and provided less than 2 mm of medial joint space opening at 0° and 20°. It was also equivalent to sMCL reconstruction compared to a deficient sMCL state [34] (see Fig. 10.11).

The sartorial fascia is loosely repaired. Hemostasis is verified. Subcutaneous closure is performed to minimize dead space and potential subsequent hematoma. The patient is placed into a compression dressing with cotton and Ace wraps followed by a bivalved cylinder cast in full extension. We typically initiate early immediate range of motion under the guidance of the physical therapist. The bivalved cylinder cast is used for the initial 3 weeks with subsequent transition to a hinged range of motion knee brace, as swelling subsides.

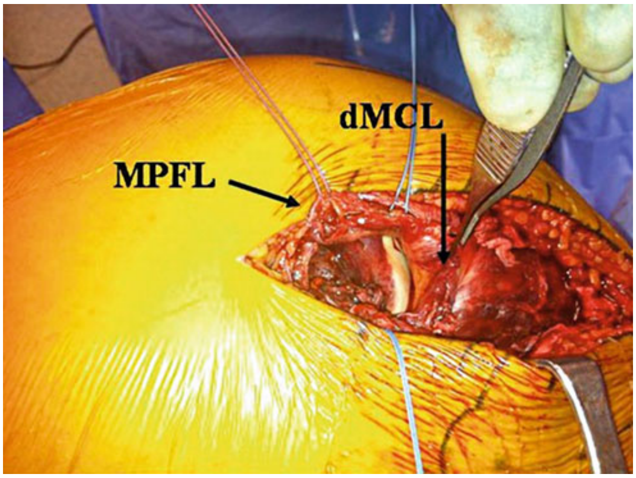

Fig. 10.15 Intraoperative photograph of a left knee demonstrating the disruption of the medial retinaculum including the MPFL and the dMCL

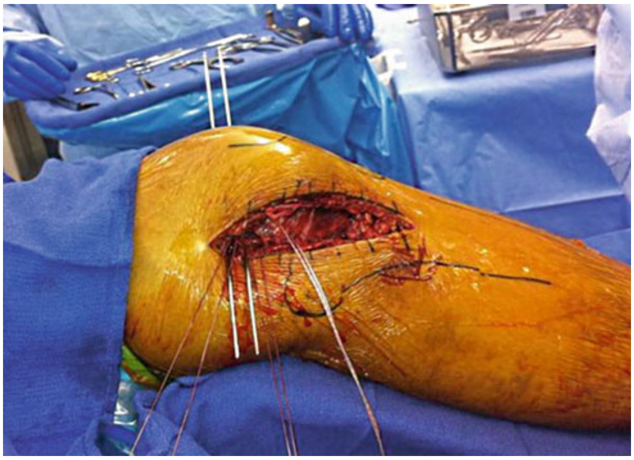

Fig. 10.16 Beath pins placed into MPFL and sMCL femoral attachment sites on femur in preparation for direct repair via pull-through technique, with sutures tied over button on lateral condyle

10.14 Chronic Medial-Sided Ligamentous Deficiency

In patients who present with a history of a distant, severe knee injury or known prior severe medial-sided knee injury, a thorough evaluation is required to assess for many confounding conditions which will affect the treatment algorithm.

Weight-bearing X-rays are obtained to assess the degree of potential arthritic changes. The patient is also questioned about degree of pain and swelling that occurs with certain activity levels. The patient's standing alignment is assessed for skeletal malalignment, and full-length standing hip-to-ankle X-rays are obtained, if indicated. Gait is assessed for a dynamic valgus thrust that can occur in stance phase. Depending upon the time frame from the injury or upon the extent of post-injury rehabilitation, the patient may present with residual muscle atrophy or deconditioning, which will also affect the patient's subjective symptoms or may give an indication of the patient's rehabilitative potential, if surgical intervention is being considered. Patients who are symptomatic enough to present for evaluation for medial-sided knee injuries are also likely to have combined instability patterns to include concomitant ACL and/or PCL injury.

Based upon the physical examination, we classify the degree of residual laxity into one of the three subclassifications of 3° injury (grade 1, grade 2, and grade 3) (see Fig. 10.3).

In patients with combined ACL–MCL deficiency and grade 1 residual medial laxity, which involves primarily the sMCL, we do not feel the additional morbidity of MCL reconstruction with associated ACL reconstruction and the increased risk associated with surgical dissection and postoperative motion complications provides much additional benefit to the patient. Residual sMCL laxity has not yet been shown to be a risk factor for failure of ACL reconstruction. Unless the patient specifically feels activity limitations by the medial compartment coronal laxity, this grade 1 sMCL residual laxity is treated non-operatively, and ACL reconstruction is treated in isolation.

Patients with residual grade 2 and 3 laxity demonstrate much more noticeable medial compartment opening at both 0° and 30° as well as increased external rotation at low flexion angles (see Fig. 10.3).

Previous reports on reconstruction techniques for chronic medial-sided knee injuries are small case series or technique descriptions without biomechanical evaluation [38, 39]. Recent in vitro testing of an anatomical medial knee reconstruction restored knee stability in a simulated sMCL and POL injuries [32]. Feely et al. also demonstrated in vitro ability of two separate double-bundle reconstructions (anatomic double-bundle and modified Bosworth) to restore valgus and external rotation stability to near-normal levels in comparison to two other historical single-bundle techniques [40]. Prior studies have investigated the biomechanical changes that occur with various advancement procedures of either the proximal or distal insertions sites of the sMCL [41, 42]. Distal advancement has been shown to better approximate the natural tension and isometry of the sMCL and is less sensitive to the position of knee position at the time of the advancement, in spite of one small case series (seven patients) showing good results with proximal advancement of the femoral origin of the sMCL [43]. These biomechanical findings are becoming more historical as biomechanical studies demonstrate support for an anatomic sMCL reconstruction.

An initial diagnostic arthroscopy is performed to assess the status of the articular cartilage and menisci. Disruption of the meniscotibial ligament would result in visible elevation of the meniscus from its attachment site on the tibia which will be necessary to repair during the open part of the procedure (Figs. 10.17 and 10.18).

If POL advancement or imbrication is performed, the knee is placed at about 10° of flexion to avoid over-constraining the knee in full extension. This is sutured back to the posterior aspect of the sMCL as illustrated by Hughston [4].

For anatomic sMCL reconstruction, we utilized a technique described by Coobs et al. [44]. A femoral tunnel is placed at the native sMCL attachment site on the femur, just posterior and proximal to the medial epicondyle (see Fig. 10.1). The tibial tunnel is placed 6 cm distal to the joint line and along the posterior edge of the distal sMCL footprint to avoid too anterior positioning and potential flexion loss [32]. If a proximal advancement is performed, the double-bundle graft may be incorporated into the staple fixation of the advancement procedure, with the proximal extent of the doubled graft fixated at the native femoral attachment site of the sMCL [10, 32]. The POL component of the described technique by Coobs et al. is reserved for severe loss of medial-sided tissue where there is insufficient POL tissue to imbricate and restore full-extension stability [10, 34, 44] (Figs. 10.19 and 10.20).

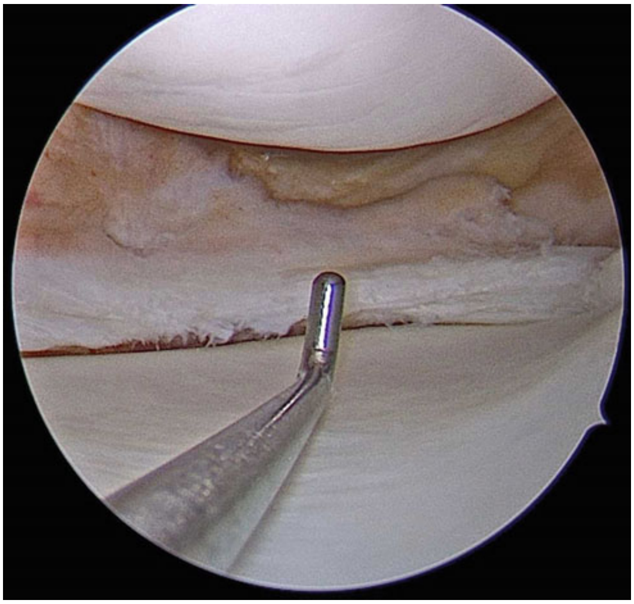

Fig. 10.17 Obvious medial compartment gapping consistent with medial collateral ligament deficiency. Note no lift-off of medial meniscus from tibial plateau and therefore intact meniscotibial ligament, status post resection of complex bucket-handle medial meniscal tear

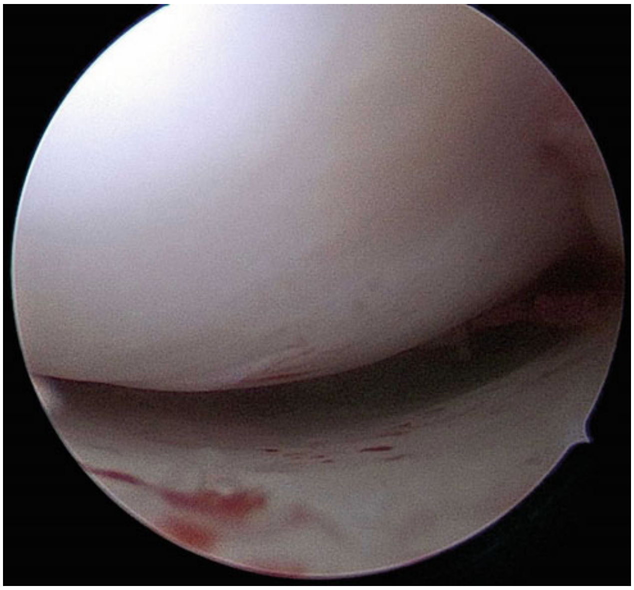

Fig. 10.18 Arthroscopic image demonstrating improved valgus stability immediately after sMCL reconstruction

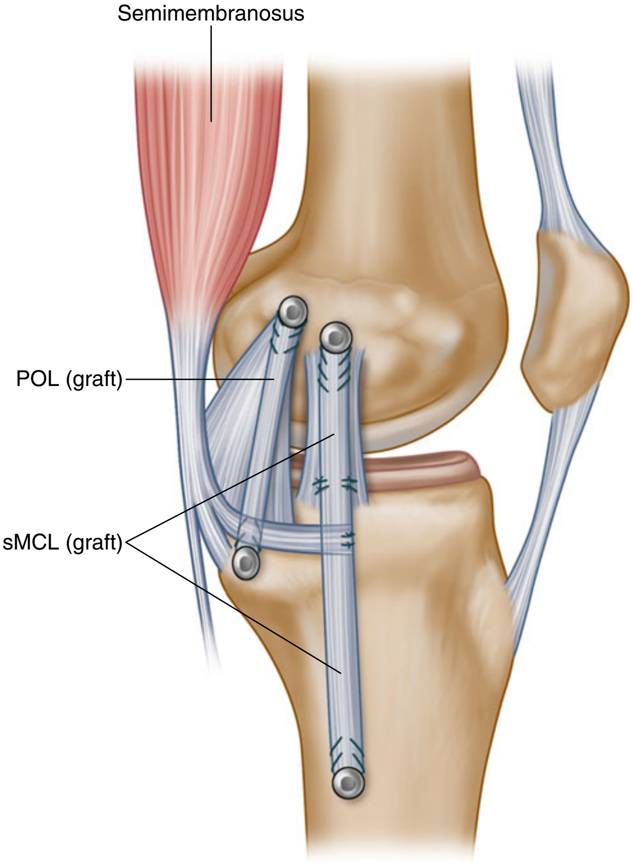

Fig. 10.19 Anatomical medial knee ligament reconstruction

Fig. 10.20 Left knee s/p ACL quadriceps tendon autograft and MCL allograft reconstruction

Graft tissue for this component of the procedure is dependent upon which autogenous tissue is utilized for the ACL graft. Consideration for utilizing contralateral semitendinosus autograft is discussed with the patient, and both limbs may be prepped and draped into the operative field. Otherwise, a doubled semitendinosus allograft is used or consideration to the use of the modified Bosworth reconstruction is given. The proximal end of the semitendinosus is released with the use of a pigtail-ended hamstring stripper. The isometry of the graft is assessed with the graft looped over a K-wire placed at the femoral attachment site, the graft tensioned and positioned at the distal attachment site of the sMCL [40].

10.15 Conclusion

Superficial medial collateral ligament sprains are common knee injuries but less commonly seen in combination with ACL tear. Accurate diagnosis of both sMCL and POL injuries is critical to determine the optimal treatment plan. Typically, this injury is able to be effectively treated with non-operative management of the medial-sided sprain and delayed treatment of ACL disruption, but early evaluation with MRI is important in the assessment of 3° sMCL sprains and associated POL injuries to rule out associated problematic injuries that may lead toward surgical intervention.

Our literature on the diagnosis and management of collateral ligament injuries is still lacking in the accurate communication in the type of ligament injuries that are being assessed (isolated sMCL versus combined sMCL and POL, degree versus grade injury), and this has led to disparity in the classification of types of injuries being evaluated, and therefore, comparative analysis of studies is limited by this discrepancy. However, recent literature has consolidated our knowledge of the anatomy of the medial aspect of the knee, supported the use of stress radiography for objective assessment of medial ligament injury as well as provided biomechanical support for a medial ligamentous reconstructive option. We hope an emphasis on consistency in our communication of the diagnostic classification of knee injury patterns will lead to improved clinical studies on the optimal treatment of the variations on this type of knee ligament injury.

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11 Surgical Treatment of Combined Anterior Cruciate Ligament and Lateral-Side Injures: Acute and Chronic

Laura A. Vogel, Cory M. Edgar, and Robert A. Arciero

11.1 Introduction

Combined injuries to the anterior cruciate ligament (ACL) and lateral knee ligaments are an increasingly well-documented injury pattern. ACL reconstruction is one of the most commonly performed procedures in orthopedic surgery, but is at risk of failure if existing concomitant pathology, such as a lateral ligament injury, is not addressed [1]. Studies have suggested that lateral or posterolateral knee instability occurs concomitantly with ACL injuries in 11–19.7% of patients [2–5]. This combined injury pattern is important for orthopedic surgeons to recognize and treat appropriately in order to optimize patient outcomes.

The purpose of this chapter is to discuss the current state of combined anterior and lateral knee instability. It will begin with a brief overview of the pertinent anatomy, pathophysiology, and biomechanics of the ACL and lateral knee ligaments. Then, a discussion of clinical evaluation including history, physical examination, imaging studies, and diagnostic arthroscopy findings will assist the clinician in the appropriate evaluation of these injuries. Finally, the treatment options for combined ACL and lateral knee injuries in both the acute and chronic setting will be reviewed.

11.2 Pathophysiology

Knee stability is a function of the balanced interactions between the cruciate ligaments and medial and lateral ligament complexes. The ACL is the primary restraint to anterior tibial translation and at 30° of flexion is responsible for 82–89% of the restraint to anterior applied loads [6]. There has also been shown to be a "coupled" increase in the internal tibial rotation in the ACL-deficient knee [7–10]. The "coupled" function of the ACL as a secondary restraint against rotatory loads occurs since the axis of rotation of the tibial plateau is close to the ACL [7, 11]. However, the primary structures responsible for rotational stability are likely the peripheral ligamentous structures, including the lateral knee ligament complex [7]. Cadaveric studies have shown increased internal tibial rotation with combined sectioning of the ACL and posterolateral structures, but no increase with isolated ACL sectioning [12].

Early anatomical descriptions by Seebacher et al. described the posterolateral knee as a three-layer structure [13]. Clinically, the important structures of the lateral knee ligament complex are the lateral (fibular) collateral ligament (LCL), popliteus tendon, popliteofibular ligament, and lateral knee capsule and are often referred to collectively as the posterolateral corner (PLC) [14, 15]. The primary function of the PLC is to resist posterior translation, primary varus and external rotation, and coupled external rotation [16–18].

Isolated PLC injury is uncommon and the majority of PLC injuries occur as part of a multiligament injury, most commonly associated with an ACL tear [4]. The incidence of combined ACL and PLC injuries was likely historically under reported and the injury pattern often missed. Corten and Bellemans [19] reported on a series of 21 patients in which 76% of PLC injuries were missed with a mean time delay of 4.5 years from injury to treatment. Recent estimates on the incidence of PLC injuries suggest they occur in 9.1% of all acute knee injuries with a hemarthrosis and in 16% of all knee ligament injuries [4].

There has been some discrepancy in cadaveric studies looking at the biomechanics of combined ACL and PLC injuries. Veltri et al. showed increased primary varus, primary external rotation, posterior translation, and coupled external rotation with sectioning of the posterolateral structures of the knee, but reported in a subsequent study that

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combined ACL and PLC sectioning did not increase external rotation [17, 20]. In comparison, a similar cadaveric study by Wrobel et al. did report increased external rotation with combined sectioning of the ACL and PLC [21]. When looking at the aggregate available data, a combined ACL and PLC injury likely results in increased primary anterior and posterior translation, primary varus, coupled external rotation, and likely primary internal rotation [12, 14, 16, 20–22]. LaPrade et al. performed a cadaveric study which emphasized the significance of untreated PLC injuries after ACL reconstruction [1]. In this study, they performed bone–patellar tendon–bone autograft ACL reconstructions on fresh-frozen cadaveric knees and then assessed the forces on the ACL graft before and after sequential sectioning of the PLC. They found that graft forces were significantly higher after LCL transection with varus loading at 0° and 30° of knee flexion. These forces were further increased by coupled loading of varus and internal rotation moments. Further sectioning of the popliteofibular ligament and popliteus tendons continued to increase graft forces. Thus, the authors concluded that untreated grade III posterolateral knee injuries may contribute to clinical failure after ACL reconstruction due to increased graft forces. Other studies have similarly shown that isolated ACL reconstruction after combined ACL and PLC injuries does not restore knee stability, particularly at high degrees of knee flexion [23].

11.3 Clinical Evaluation

Successful treatment of patients with ligamentous knee injuries requires the surgeon to establish a proper diagnosis. Thus, the evaluation of patients with ligamentous knee injuries requires a thorough history and physical examination, as well as a careful assessment of appropriate imaging studies. After aggregating all pertinent data, the surgeon should then develop a comprehensive preoperative plan with the patient before the day of surgery so that the patient is prepared for and knows what to expect throughout their perioperative and postoperative experience.

11.3.1 History and Physical Examination

A thorough history and physical examination is crucial during the evaluation of a patient with a multiple ligament knee injury. While ACL injuries may be readily diagnosed, concomitant injury of the lateral and posterolateral knee are too frequently missed and can result in significant delays in diagnosis of up to 30 months [3, 14, 24–27]. Failure to recognize and treat PLC injury can negatively affect the success of ACL reconstructions [2, 3] and missed PLC injury has been suggested to be one of the primary causes of ACL graft failure [1, 3, 20, 24, 28]. Thus, early and accurate diagnosis is critical to optimizing patient outcomes.

Clinical evaluation of patients with a multiple ligament knee injury begins with obtaining a detailed history of the injury. Patients should be queried on their recollection of the mechanism of injury and the position of the limb during the event. Varus force applied to a hyperextended knee has been reported as the most common injury mechanism that affects the PLC [29, 30]. A small cohort of 13 patients with combined ACL and PLC injuries from sports injuries reported that all injuries occurred from a varus hyperextension mechanism [31]. Patients should also be asked if they felt a “pop” at the time of injury, if there was any associated swelling immediately after the injury or after some time passed, whether or not they were able to ambulate after the injury, and whether or not they have had any feelings of instability, mechanical symptoms, or loss of motion since the injury. Furthermore, lateral knee pain, and/or transient paresthesias, numbness in the distal part of the leg and foot may indicate a stretch injury to the peroneal nerve that can suggest a lateral-sided knee injury.

The initial physical examination of a multiple ligament knee injury should focus on neurovascular function. Distal pulses, motor function, and sensation should all be assessed early in the setting of an unstable knee. The incidence of peroneal nerve injury after posterolateral corner injury has been reported to be 12–26.2% [30–32]. Ankle–brachial index (ABI) measurements should be performed to assess for vascular injury. Serial measurements should be performed to ensure a developing occlusion is not missed. Proper ABI measurements are performed with the patient supine and use the ipsilateral upper extremity in the calculation. Peripheral arterial disease or calcifications may affect the reliability of ABI measurements. An ABI less than 0.9 is typically used as the cutoff below which the concern for arterial injury increases [33]. A study by Weinberg et al. reported that an ABI greater than 0.9 in combination with palpable dorsalis pedis and posterior tibial pulses was 100% sensitive for a vascular injury after knee dislocation at 6 months clinical follow-up [34].

After assessing for any neurovascular dysfunction, the physical examination should assess the patient’s standing limb alignment. Varus alignment which cannot be attributed to the existing lateral injury should be identified and 3 joint standing mechanical axis radiographs may aid in this assessment. The surgeon should also observe the patient’s gait pattern, particularly for the presence of a varus thrust. These findings may be indicative of injury to the PLC in what Noyes et al. termed “double varus” (separation of the lateral compartment due to incompetent lateral structures) and “triple varus” (varus recurvatum with a progressive injury to the posterolateral structures) knees [35] (Fig. 11.1). Baseline varus increases graft forces after ligament

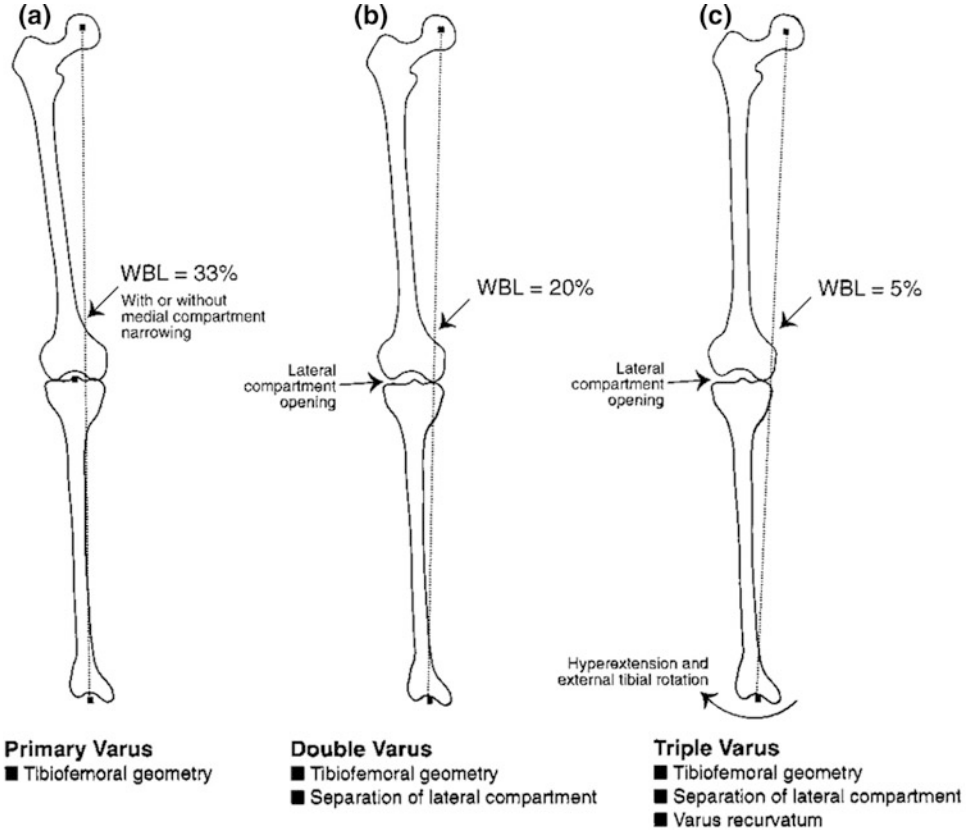


Fig. 11.1 Categories of varus angulation based on clinical findings. **a** Tibiofemoral geometry causes include loss of medial meniscus or articular cartilage. **b** Separation of the lateral compartment is due to lateral soft tissue deficiency. **c** Varus recurvatum includes chronic stretching or traumatic injury to the posterolateral ligament structures. From Noyes FR, et al. [35]. Reprinted with permission from SAGE Publications

reconstruction and some patients may benefit from a high tibial osteotomy prior to ligament reconstruction [1, 28, 35]. Conversely, failure to appreciate varus mechanical malalignment places any soft tissue reconstruction of the ACL and PLC at risk for higher graft loads and early failure.

Examination maneuvers to test the ACL include the Lachman test, anterior drawer, and pivot-shift test. The Lachman test is the most sensitive exam maneuver for ACL integrity and should be performed with the knee in 20°–30° of flexion [36–38]. In this maneuver, the examiner should ensure that their proximal hand simply stabilizes the thigh and does not push posteriorly in order to avoid dampening the perception of anterior tibial translation. The anterior drawer is performed with the knee flexed to 90° and is less sensitive than the Lachman test [38]. The pivot-shift test is performed by applying a valgus and internal rotation force to the tibia while flexing the knee [39]. A palpable clunk can be felt when the subluxated tibia reduces with increasing knee flexion. The iliotibial band plays a role in reducing the tibia as its line of action changes from a knee extensor moment to a knee flexor moment [40]. The pivot-shift test is the most specific test for ACL deficiency, but has poor sensitivity (as low as 32% reported by some authors) due to the discomfort patients experience with the maneuver and subsequent guarding [36, 38].

A thorough examination of the PLC is a critical part in the evaluation of all patients with suspected ACL injuries. The knee should be assessed for varus and valgus stability in full extension and in 20°–30° of flexion. Instability at 20°–30° of flexion indicates injury to the collateral ligaments and continued instability in full extension suggests concomitant injury to a cruciate ligament. Examination maneuvers to specifically test the PLC include the posterolateral drawer test, the external rotation recurvatum test, reverse pivot-shift test, and the posterolateral rotatory drawer maneuver [41, 42]. The posterolateral drawer test is performed with the hip in 45° of flexion, the knee in 80° of flexion, and at 10°–15° of external rotation [9, 43] (Fig. 11.2). If the PLC is deficient, the lateral tibial plateau will rotate around the posterior cruciate ligament (PCL), as well as undergo posterior translation with a posterior-directed force. The external rotation recurvatum test is performed by elevating both legs from the exam table while holding the great toes [9, 43]. A limb with an injury to the PLC will have relative tibia vara and hyperextension of the lateral knee, somewhat analogous to Noyes' triple varus knee previously discussed in this section. The reverse pivot-shift test is performed with the knee in 70° of flexion with the foot externally rotated, which causes posterior subluxation of the lateral compartment in the setting of PLC injury. The knee is then extended to about

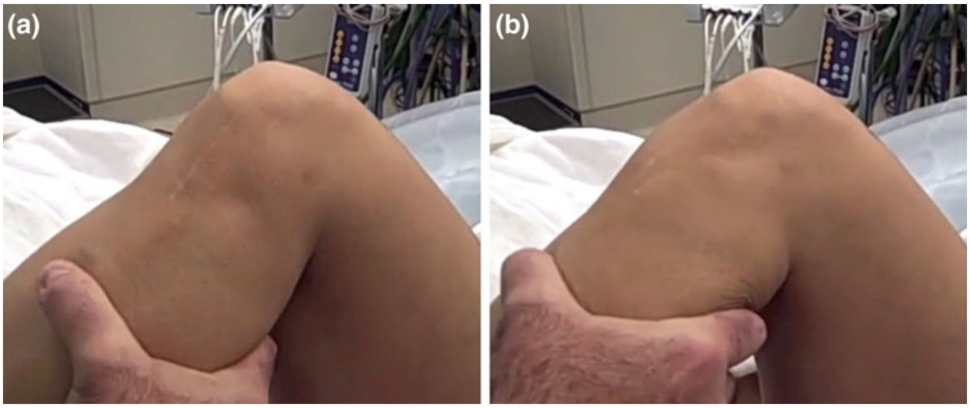


Fig. 11.2 Clinical photographs demonstrating the posterolateral drawer test for the assessment of posterolateral corner insufficiency. **a** Note the relative posterior translation upon application of a posterior force with the knee at 80° and slight external rotation. **b** Reduced knee state

20° of flexion, at which point the iliotibial band force vector changes and the tibia is pulled forward and reduced [44]. The posterolateral rotatory drawer maneuver is performed with the hip flexed to 45° and knee flexed to 90° with the heel resting on the examination table. The examiner places one hand at the injured knee with fingers posterior to the proximal calf and thumb at the joint line to assess the position of the lateral tibial plateau in relation to the femoral condyle and the other at the ankle to externally rotate the leg. In the setting of PLC injury, as the limb is externally rotated there will be external rotation and posterior subluxation of the lateral tibial plateau in relation to the anterior edge of the lateral femoral condyle [42]. Finally, the dial test can assist in differentiating isolated PLC injury from a combined injury to the posterior cruciate ligament (PCL) and PLC [45, 46]. Asymmetric external rotation of the tibia of 10° or more at 30° of knee flexion suggests injury to the PLC. If this asymmetry is also present at 90° of knee flexion, then it is likely that there is a combined injury to the PCL and PLC.

Superficial palpation may also assist in diagnosis. A palpable defect just proximal to the fibular head may correspond to a biceps femoris tear. A large joint effusion can indicate intra-articular injury, but may be absent in the setting of a complete PLC injury with capsular disruption [31].

11.3.2 Imaging

Plain radiographs of the knee allow for evaluation of peri-articular and intra-articular fractures, as well as secondary findings that may be seen in conjunction with a ligamentous knee injury. A Segond fracture, suggestive of an ACL injury [47], is a small avulsion fracture of the lateral tibial plateau that occurs due to pull of the lateral capsule (Fig. 11.3b). The arcuate sign is an avulsion fracture off the fibular head and is suggestive of a PLC injury, often to the LCL or biceps femoris (Fig. 11.3a) [48]. Subtle lateral joint space opening on standing Rosenberg view may suggest a PLC injury. Stress radiographs of the knee with varus and valgus stress compared to the contralateral non-injured knee may also help assess for medial or lateral ligament injury. LaPrade et al. showed that isolated LCL injuries increase varus opening by approximately 2.7 mm, a complete PLC injury increased opening by 4.0 mm, and a combined ACL and PLC injury increased opening by 5.3 mm compared to the intact state [49]. External rotation radiograph techniques have also been described to assess for PLC injuries [50].

Full standing mechanical axis films are indicated if there is any concern for varus malalignment or a varus thrust gait is present. The mechanical axis of the leg is measured as a line drawn from the center of the femoral head to the center of the ankle joint and should fall between the tibial eminences.

MRI of the injured knee allows for evaluation of the extent of injury and may assist the surgeon in preoperative planning. The sensitivity of MRI for evaluating acute complete tears of the ACL has been reported as high as 92.3% [51]. Good sensitivity and specificity for PLC injury with MRI have been reported and it is likely better at assessing the LCL or popliteus than the popliteofibular ligament, but other studies have shown a significant number of missed injuries [52–54] (Fig. 11.4). This may be a result of differences in the MRI protocol technique, image resolution, or radiologist experience. MRI findings should be compared and correlated with the physical examination. It is also important to evaluate the lateral structures distal to the joint line as they are commonly avulsed in this region [31]. Avulsion of the biceps femoris insertion frequently results in anterior displacement of the common peroneal nerve and having this information preoperatively can help the surgeon avoid iatrogenic nerve injury [55].

Bone bruise patterns may also help in the assessment of a patient's injury pattern. The classic pattern of bone bruises

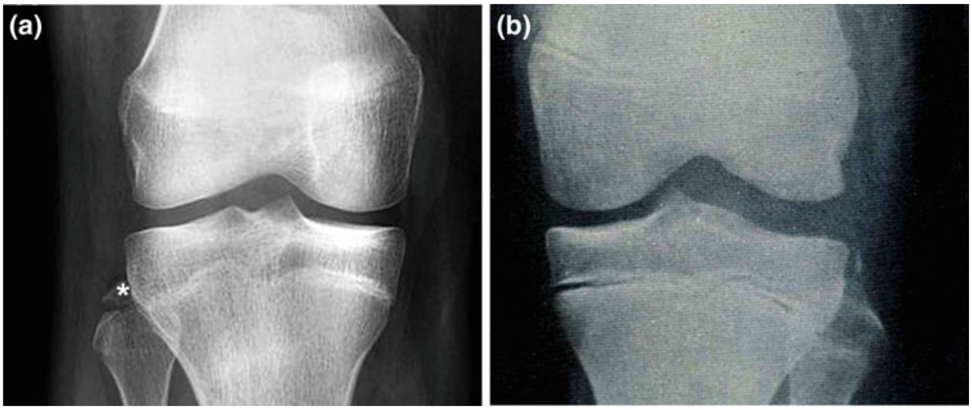
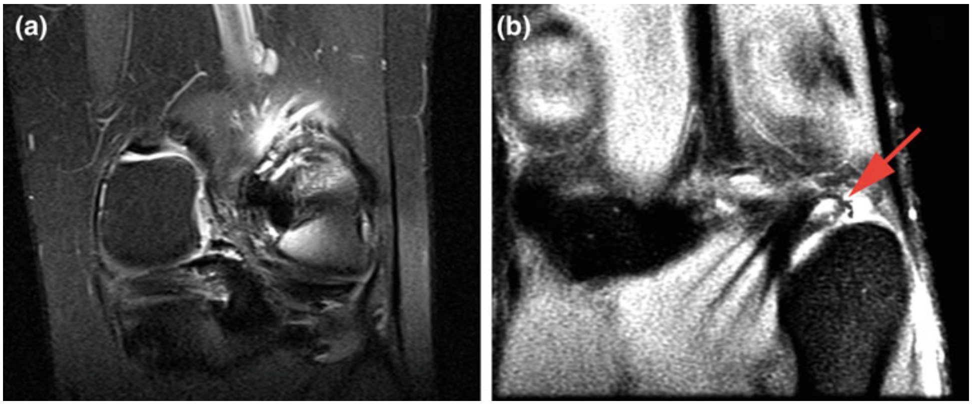


Fig. 11.3 Radiographs portraying secondary signs of knee ligamentous injury. **a** Arcuate sign, suggestive of a posterolateral corner injury (*asterisk*). From Malone WJ, Verde F, Weiss D, Fanelli GC. MR imaging of knee instability. Magn Reson Imaging Clin N Am. © 2009;17:697–724, vi–vii. Reprinted with permission from Elsevier. **b** Segond fracture, suggestive of an anterior cruciate ligament injury

Fig. 11.4 T-2 weighted coronal oblique MR images depicting. **a** Intact popliteofibular ligament. **b** Disrupted ligament (*arrow*)



seen with an ACL injury is in the anterolateral femoral condyle near the sulcus terminalis and the posterolateral tibial plateau [56]. Additional bone contusions can be seen with a combined injury to the cruciate ligaments and PLC. Geeslin et al. published a series of 102 patients with acute PLC injuries in which 38 had a concomitant ACL injury; of those patients, 50% had an anteromedial femoral condyle bone bruise and 29% had a posteromedial tibial plateau bone bruise (Fig. 11.5).

Imaging studies, including MRI, may be particularly helpful when the diagnosis of ligament injury is in question, but it should not serve as a substitute for a thorough physical exam and assessment of symptomatic instability.

11.3.3 Diagnostic Arthroscopy

Diagnostic arthroscopy of the knee at the time of ACL reconstruction can pick up subtle findings of a lateral knee injury that may have been missed on initial physical

Fig. 11.5 T-2 weighted MR image depicting a posteromedial tibial plateau bone bruise that should raise the surgeon's suspicion for the existence of a PLC injury

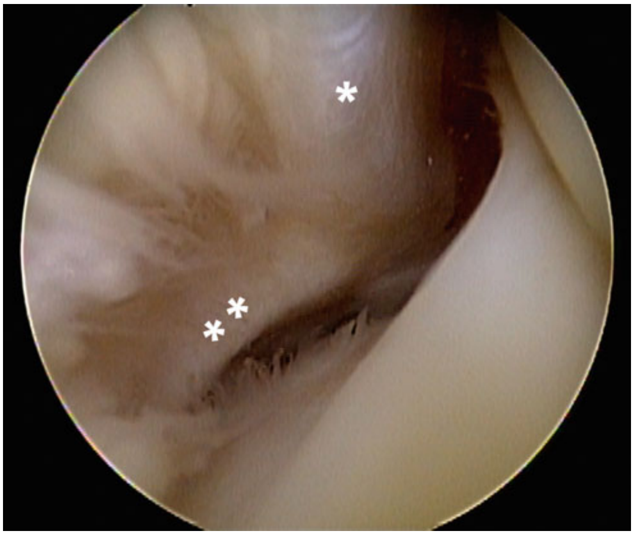


Fig. 11.6 Arthroscopic visualization of the popliteus and popliteofibular ligament from the lateral gutter in a right knee. * popliteus, ** popliteofibular ligament

examination or MRI. The popliteus can routinely be identified from the lateral compartment and the popliteofibular ligament can be assessed in the lateral gutter as the vertical fibers descending from the inferior surface of the popliteus tendon [57] (Fig. 11.6). The arthroscopic "drive-thru" sign occurs when the lateral compartment opens greater than 1 cm with varus stress at 30° of knee flexion and suggests grade III injury to the lateral knee [58]. A "lateral gutter drive-thru" sign similarly indicates lateral-side injury when the arthroscope can be placed deep into the posterolateral compartment from the lateral gutter due to increased space between the lateral femoral condyle and popliteus [59].

11.4 Nonoperative Management

Electing to pursue nonoperative management should be a shared, informed decision between the surgeon and patient based on the patient's activity level, medical comorbidities, and nature of the injury. There is limited information regarding nonoperative treatment of combined ACL and PLC injuries, but studies have shown reasonable success with nonoperative treatment of isolated ACL or isolated low-grade PLC injuries [60–63]. Nonoperative treatment of patients with high-grade PLC injuries is less successful. Kannus et al. found worse outcome scores in patients with grade III lateral injuries and that 75% of those patients had to decrease their activity level due to pain and/or instability, whereas 82% of their patients with grade II instability were able to return to full activities. Thus, they suggested that nonoperative management be limited to patients with grade II or less lateral instability [63].

There is conflicting evidence in the literature regarding the increased risk of osteoarthritis with nonoperative management of ACL injury [64, 65]. A recent study by van Yperen et al. reported no difference in the rate of osteoarthritis between patients with ACL tears treated non-operatively with physical therapy and activity modification and those patients treated with ACL reconstruction at 20-year follow-up [65]. In that series, patients who were treated surgically did have objectively more stable knees on physical examination than those treated without surgery. Of note, patients in the nonoperative arm of this pair-matched study were those who responded well to 3 months of nonoperative treatment and those who underwent surgery were those who had persistent instability after 3 months of nonoperative treatment. Thus, patients who are able to "cope" with physical therapy and bracing may be fundamentally different from those who remain symptomatically unstable after ACL injury and require surgical reconstruction.

If a patient elects surgical reconstruction of an ACL injury in order to participate in high-level sports activities or due to continued symptomatic instability, it is imperative that the surgeon assess and treat injury to the PLC at the same time. As previously discussed, untreated lateral ligament injury increases forces on the ACL graft after reconstruction [1] and should be treated surgically.

11.5 Surgical Indications

Our institution favors surgical intervention in patients, who present with a combined ACL and PLC injury. Isolated injury to either structure can be treated successfully non-operatively, particularly in the less active patient, but the combined injury pattern often produces significant symptomatic instability that patients are less likely to tolerate. Surgical indications and contraindications are listed in Table 11.1. Our surgical indications include active patients involved in cutting, pivoting, or deceleration activities, young patients, concomitant meniscal or cartilage pathology, mechanical symptoms, loss of motion, and failure of nonoperative management with continued pain and instability. Relative contraindications include morbid obesity, advanced age, significant medical comorbidities that preclude surgical treatment, limited pre-injury function or ambulatory status. Patients who are contraindicated for surgery should be treated with initial immobilization, aggressive rehabilitation, and functional bracing.

Table 11.1 Surgical indications and relative contraindications in patients with combined ACL and PLC injury

Indications	Relative contraindications
• Active patients involved in cutting, pivoting, and deceleration activities • Young patients • Concomitant meniscal, cartilage pathology • Mechanical symptoms • Loss of motion • Failed functional trial of nonoperative management with continued pain/instability	• Morbid obesity • Advanced age • Significant medical comorbidities that preclude surgical treatment • Limited pre-injury function or ambulatory status

11.6 Surgical Management

There is no consensus regarding the surgical treatment of combined ACL and PLC injuries. Treatment algorithms are often based on time from injury and classified as acute (less than 3 weeks) or chronic (more than 3 weeks) [66–68]. While the authors may agree on the surgical treatment of the PLC with ACL reconstruction in combined ACL/PLC injuries, the preferred surgical technique is variable and can range from repair to a variety of reconstructions. Several options will be discussed and our preferred surgical technique described.

11.6.1 Acute Combined Injuries to the ACL and Lateral Knee

Initial management of an acute ACL and PLC injury should consist of immobilization, modalities to reduce soft tissue edema and joint effusions, and therapy to restore preoperative range of motion. These efforts are made to decrease the risk of postoperative arthrofibrosis. During the initial evaluation, the preoperative workup described above should be completed. The surgeon should develop an operative plan and ensure that any necessary allografts are available prior to the surgical date. It is important to consider patient expectations, compliance and motivation, and postoperative resources in this pre-op planning time period as well. It is our institution's preference to perform surgical reconstruction within the initial 2 weeks after injury. Previous studies have shown good results with early treatment within 2 weeks of combined surgical treatment of ACL and PLC injuries [31]. In a series of 9 patients by Ross et al., they reported 3 normal and 6 nearly normal knees according to the International Knee Documentation Committee (IKDC) score, 100% patient satisfaction, and 7 patients who were able to return to their pre-injury activity level [31].

There is significant literature that suggests that there is a higher failure rate with PLC repair versus reconstruction [66–68]. Staged repair of PLC injuries with delayed cruciate reconstruction has also shown to have a higher failure rate compared to concurrent treatment of both injuries [69]. A prospective study of 57 patients by Stannard et al. reported a 37% failure rate with primary repair of PLC injuries versus only 9% failure with a PLC reconstruction with a modified two-tailed technique [68]. Similarly, Levy et al. reported a higher failure rate of 40% with PLC repairs versus only 6% with PLC reconstruction with a dual femoral and fibular tunnel technique [66]. A systematic review showed the best outcomes were achieved with combined ACL and PLC reconstruction compared to ACL reconstruction with PLC repair or nonoperative treatment of PLC injuries [70]. Thus, many surgeons now supplement repair of PLC injuries with graft reconstruction in the acute setting within 3 weeks of injury [28, 66–68]. This is our preference as well; even with acute injuries, particularly mid-substance ruptures, the soft tissues may be inadequate to perform a robust repair and reconstruction is more reliable. The exception is the PLC injury that is avulsed from the tibial and fibular as collective injury, where the main portion of the ligament is still robust. Multiple nonanatomic and anatomic PLC reconstruction techniques have been described. Clancy et al. first described the biceps tendon transfer procedure in which the full biceps femoris tendon was transferred onto the lateral epicondyle to re-create the lateral collateral ligament and remove the biceps tendon as a deforming force [71]. However, this technique does not address the posterolateral structures and may further accentuate any injury to the PLC by removing the dynamic effect of the biceps femoris and was later modified by Fanelli et al. into a split biceps tendon transfer technique [72–74]. A series of 41 patients with combined PCL/PLC injuries treated with ligament reconstruction and a split biceps tendon transfer technique with a posterolateral capsular shift showed restoration of posterolateral stability and overtightening of the knee in 71% of patients [73]. Biomechanical cadaveric studies have also shown that biceps tenodesis procedures can overconstrain external rotation and varus angulation of the knee [75]. The long-term effects of overconstraint with nonanatomic biceps tenodesis procedures is unknown; while patients may achieve good functional outcome scores, there may be significant secondary effects to the intra-articular structures and longevity of the joint stability that are unknown at this time.

The popliteofibular ligament has been shown to play a significant role in posterolateral stability of the knee and modern techniques emphasize reconstruction of both the popliteofibular ligament and lateral collateral ligament [17]. Veltri and Warren described a technique in which the popliteus and popliteofibular ligament are reconstructed with a split patellar tendon or Achilles tendon graft with the bone plug fixed in a common femoral tunnel and the graft limbs passed through tunnels in the proximal tibia and fibula [76]. This technique requires the surgeon to address the LCL separately. In comparison, Stannard et al. described a “modified two-tailed” technique which reconstructs the popliteus, popliteofibular ligament, and LCL by drilling the fibular tunnel in an anterolateral to posteromedial direction [77] (Fig. 11.7). In this technique, an allograft tendon is tensioned through transtibial and transfibular tunnels and fixed on a single isometric point on the lateral femoral condyle. The authors reported excellent functional outcomes in a series of 22 patients (7 with combined ACL/PLC reconstructions) with a 9% failure rate at 2-year follow-up [77].

Reconstruction technique that does not require a tibial tunnel and utilizes only a transfibular tunnel has also been described with good results [78]. These techniques are appealing as they are technically easier and reduce the potential for tunnel convergence in the setting of multiple ligament reconstructions. Moatshe et al. reported the average distance between tibial tunnels in combined ACL and PLC reconstructions was 21.9 mm [79]. A biomechanical study by Rauh et al. showed that a transfibular tunnel technique was as effective as dual transtibial and transfibular tunnels at restoring external rotation and varus stability [80]. Reconstruction of the PLC with a single sling through a fibular tunnel compared to a tibial tunnel has been shown to have improved rotational stability and decreased operative time [81]. A retrospective series of 44 patients who underwent combined ACL reconstruction and PLC reconstruction (hamstring autograft in a modified posterolateral corner sling with an oblique fibular tunnel from anteroinferior to posterosuperior and single isometric femoral tunnel) showed 89% normal or near-normal IKDC scores and 91% similar or improved rotational stability compared to the contralateral side at minimum 2-year follow-up [3] (Fig. 11.8). According to an MRI study, the anatomic orientation of a fibular-based tunnel for PLC reconstruction is angled at 50° of external rotation from the tibial tubercle and 60° cranially from the lateral joint line [82].

The authors have also reported excellent results with anatomic PLC reconstruction techniques, which utilize 2 femoral tunnels to replicate the LCL insertion on the lateral epicondyle and the popliteus tendon 18.5 mm anterior and distal to the LCL [83–86]. Biomechanical studies have shown that an anatomic reconstruction better restores joint mechanics than nonanatomic reconstructions [87, 88]. A cadaveric study by Ho et al. showed improved rotational stability and resistance to posterior translation with an anatomic PLC reconstruction with 2 femoral tunnels compared to a nonanatomic technique with single femoral tunnel [89].

Our institution published a series of 24 patients who underwent combined cruciate and PLC reconstruction (7 with combined ACL and PLC reconstruction) with 70% good to excellent outcomes at 39-month follow-up [86]. Our preferred technique, described below, includes an oblique

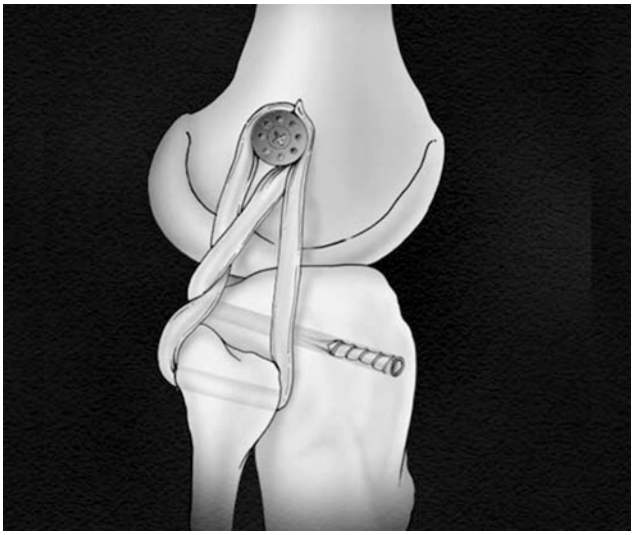


Fig. 11.7 Diagram depicting the modified two-tailed reconstruction of the posterolateral corner, which addresses the popliteus, popliteofibular ligament, and the LCL. From Stannard JP, et al. [68]. Reprinted with permission from SAGE Publications

Fig. 11.8 Modified posterolateral sling technique with oblique fibular tunnel and single isometric femoral tunnel. From Lee SH, et al. [3]. Reprinted with permission from Springer Nature

fibular tunnel and dual femoral attachment sites for the PLC reconstruction. This technique has been shown to better restore varus and external rotation stability near that of the PLC intact state at multiple degrees of flexion compared to other reconstruction techniques [90] and avoids overconstraint that may occur with other technique variations [91].

11.6.1.1 Senior Author's Preferred Technique

In the acute injury, it is preferable to surgically intervene within 2–3 weeks of injury after decreasing edema and optimizing knee range of motion. Reconstruction of both the ACL and posterolateral corner is done to augment any attempted primary repair of the PLC structures. Anatomic principles guide the reconstruction of both the ACL and the posterolateral corner [92, 93]. A careful exam under anesthesia should be performed to confirm physical examination findings and the operative plan. If there is any doubt remaining regarding the need for PLC reconstruction at the time of surgery, stress radiographs may also be performed and compared to the contralateral side. A brief outline of key surgical steps, as well as technical pearls and pitfalls, is detailed in Table 11.2.

The patient is positioned supine with a circumferential leg holder and a well-leg support using a padded boot or stirrup. The leg holder allows for adequate varus or valgus stress if there is concomitant meniscal pathology that must be addressed. Careful attention to placing the leg holder high on the leg and the contralateral leg out of the way with sufficient hip flexion and external rotation is important if there is any concern that a concomitant ramp lesion may be present. If the surgeon prefers, a lateral post may also be used. A non-sterile tourniquet is placed and set at 250 mmHg for use during the case since it has not been shown to affect strength or functional performance at 6 months after knee ligament surgery [94].

In the multiple ligament-injured knee, graft selection becomes very important. Our choice is to reconstruct the ACL in a single-bundle manner with autogenous bone–patellar tendon–bone in our young high-level athletes. This is supported by recent literature that suggests that allograft ACL reconstruction has a higher failure rate in this population than autograft [95]. In older active individuals, we offer the patient all the graft options, but tend to recommend either autologous hamstring or Achilles tendon (or quadriceps tendon) allograft with a segment of bone for femoral fixation. In order to minimize donor site morbidity from the harvesting of multiple grafts, we use a posterior tibialis allograft in all patients for PLC reconstruction since it is easily available and robust.

There are several key points to graft preparation. The bone–patellar tendon–bone autograft is sized to 10–11 mm, with 22–23-mm-long bone plugs, and bone crimpers are

Table 11.2 Key steps, pearls, and pitfalls for anatomic reconstruction of combined ACL and PLC injuries

<table>
<tr><th colspan="2">Recommended order of key steps</th></tr>
<tr><td colspan="2">• Harvest grafts
• Prepare grafts concurrently during diagnostic arthroscopy
• Address meniscal pathology (with repair preferable to resection, if possible)
• Prepare notch for ACL
• Drill ACL femoral tunnel from low anteromedial portal
• Drill ACL tibial tunnel
• Pass ACL graft and fix in femur
• Approach PLC and perform peroneal neurolysis
• Drill fibular head tunnel
• Drill femoral sockets for LCL and popliteus
• Pass PLC graft through fibular head
• Fix PLC graft in popliteus socket
• Fix tibial end of ACL graft in 20° flexion
• Secure PLC graft in LCL socket in 30° flexion, neutral rotation, and slight valgus</td></tr>
<tr><th>Pearls</th><th>Pitfalls</th></tr>
<tr><td>• Leave some native ACL tissue at the footprint to clearly delineate patient anatomy
• Maintain tibial “shelf” of bone on bone–patellar tendon–bone ACL grafts to protect during femoral side interference screw fixation
• Place suture both through bone plug and through the tendon–bone junction of ACL grafts as backup in case of bone plug fracture during graft tensioning
• Hyperflex the knee during ACL femoral tunnel drilling from the low anteromedial tunnel
• PLC fibular tunnel should be oriented from anterolateral to posteromedial</td><td>• Be aware of possible abnormal peroneal nerve position during PLC approach, particularly with biceps femoris injury
• Consider downsizing fibular tunnel from 7 to 6 mm to avoid fibular head fracture in small patients during PLC reconstruction
• Femoral socket for popliteus graft limb should not exceed 30 mm to avoid notch violation
• Avoid PLC and ACL femoral tunnel convergence by limiting PLC femoral socket diameter, utilizing anteromedial portal ACL drilling techniques, and aiming LCL tunnels slightly anteriorly</td></tr>
</table>

Fig. 11.9 Prepared bone–patellar tendon–bone autograft. Note the shelf of bone on the left side of the graft *(darkened with marker)* that has been maintained to protect the graft from injury during screw insertion

used to compress and round the edges (Fig. 11.9). A drill hole is placed into each bone plug and a #2 FiberWire suture (Arthrex, Naples, FL) is passed. A second #2 FiberWire suture is passed into the patellar bone plug, and then a locking stitch is placed through the tendon–bone junction and back through the drill hole. This allows a level of protection in case of the bone plug fractures when tensioning the graft, as this end will be placed into the tibial tunnel. The tibial bone plug has a natural bony shelf, which is maintained and placed anteriorly in the femoral tunnel for interference screw purchase and to protect the collagen that is placed posteriorly in the tunnel. If an allograft Achilles or quadriceps tendon is used, the bony end is prepared the same way as the tibial bone plug for femoral fixation and the soft tissue end is prepared with 2 whipstitch sutures of #2 FiberWire. If autologous hamstrings are used, the senior author will attempt to harvest only the semitendinosus tendon. It is important to start the dissection as laterally toward the tibial tubercle as possible in order to maximize graft length. If the harvested tendon is 26–27 cm in length, it may be adequate to create a quadrupled graft with the semitendinosus only and avoid harvesting the gracilis. We believe this may have a significant effect on postoperative pain and patient rehabilitation. The semitendinosus is harvested with a #2 FiberWire whipstitch on one end and then prepared over a closed-loop ENDOBUTTON or RetroButton on the back table. If both the semitendinosus and gracilis are harvested, they are similarly prepared with a whipstitch of #2 FiberWire in each end and folded over a closed loop ENDOBUTTON or RetroButton for lateral cortical femoral fixation, creating a quadrupled graft. The posterior tibialis allograft for PLC reconstruction should be 24 cm long, and each end is prepared with a whipstitch of #2 FiberWire. All grafts are pre-tensioned on a tensioning board at 10# for 10 min.

Any autograft tissue is harvested initially so that an assistant may prepare the grafts, while the surgeon is continuing with the diagnostic arthroscopy. The torn ACL tissue is debrided so that the over-the-top position can be clearly identified and the anatomic footprints of the native ACL are delineated. It is our preference to leave some of the ACL tissues at both footprints to facilitate this. Any meniscal injury identified on the diagnostic is addressed at this time. If a repair can be attempted, it is, since evidence has shown that a meniscectomy significantly increases the strain on the ACL [96].

The femoral tunnel is drilled with a low-profile reamer from a low anteromedial portal to allow placement into the central aspect of the footprint, and a passing suture is placed (Fig. 11.10). It is essential to hyperflex the knee during this step to ensure the guide pin exits above the equator of the femur and avoid neurovascular injury (Fig. 11.11). If a circumferential leg holder is used, the hyperflexion maneuver can be facilitated by having the circulating nurse remove the top piece of the knee holder. The tibial tunnel is then drilled at the center of its footprint in an anterograde manner, the passing suture is brought down, and the graft is pulled up into the femur and fixed with a metal interference screw (Fig. 11.12).

The posterolateral corner is then approached via a curvilinear incision, and three fascial incisions are made, as described by Terry and LaPrade [97]. The first incision is made over the posterior aspect of the biceps femoris, exposing the peroneal nerve for a neurolysis and protection throughout the remainder of the procedure. After elevating the muscle fibers of the gastrocnemius from the posterior fibular head, a finger can be placed to feel the groove on its posteromedial aspect. A guide pin can then be accurately directed from just distal to the LCL insertion toward this groove to create an obliquely oriented (anterolateral to

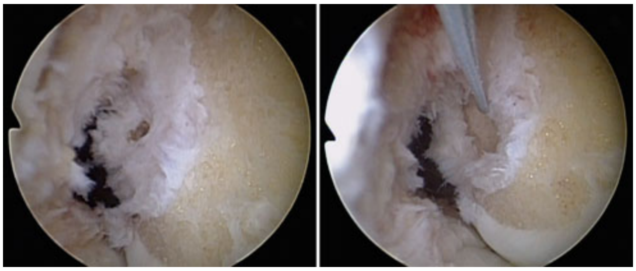


Fig. 11.10 Femoral ACL tunnel. **a** An awl is used to mark the center of the anatomic footprint. This is facilitated by not removing all of the footprint soft tissues. **b** Drilled femoral tunnel with passing suture in place

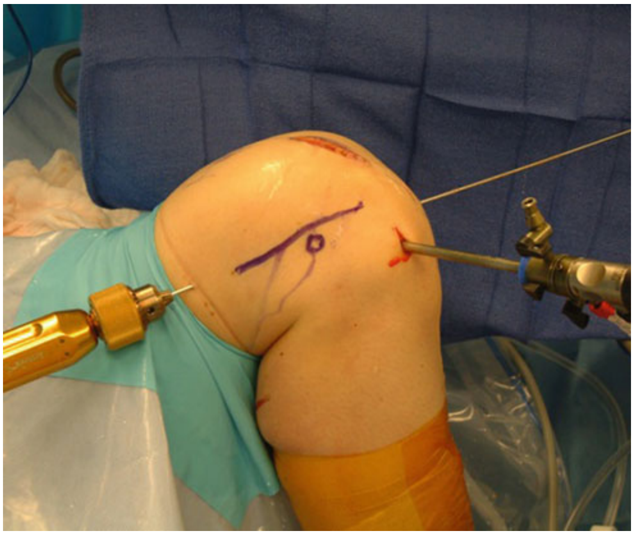


Fig. 11.11 Appropriate trajectory of guide pin during the drilling of the femoral tunnel is achieved by hyper-flexing the knee

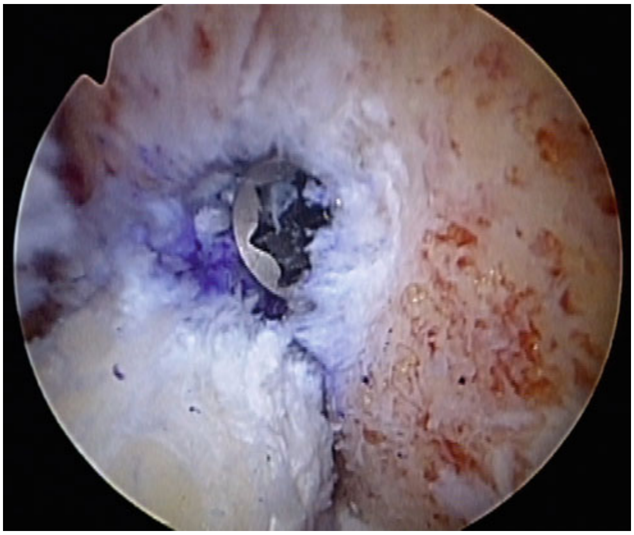


Fig. 11.12 Metal interference screw fixation in femur of bone–patellar tendon–bone ACL graft. Note the shelf of bone is anterior against the screw and the collagen of the tendon is protected posteriorly

posteromedial) fibular tunnel (Fig. 11.13). This is drilled to yield a 6- or 7-mm tunnel, and a looped passing suture is placed. The second fascial incision is between the IT band and the short head of the biceps tendon and exposes the lateral joint capsule for arthrotomy and imbrication. The third fascial incision is through the IT band over the lateral epicondyle and will be used to identify and re-create the femoral attachments for the popliteus and the LCL. A 7- or 8-mm LCL femoral socket is made just anterior to the LCL origin and drilled up to (but not through) the medial cortex and a looped passing suture is placed. A 7- or 8-mm popliteus femoral socket is then drilled just distal and anterior to its insertion, located 18.5 mm distal and anterior to the LCL origin. It is important to only drill this socket 30 mm deep so the notch is not violated (Fig. 11.14).

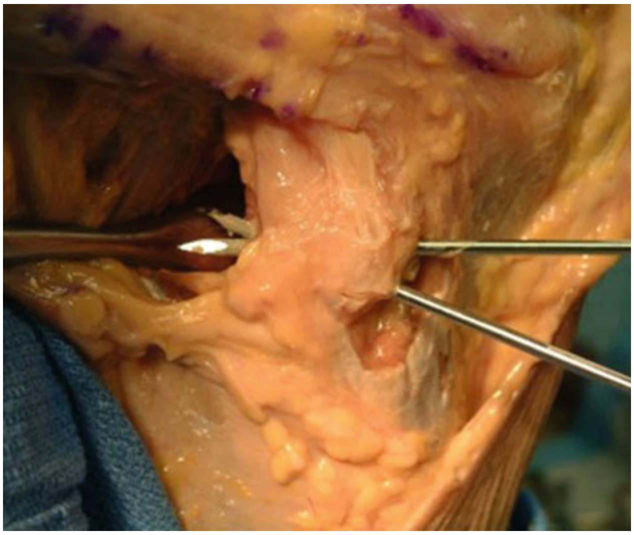


Fig. 11.13 Photograph demonstrating the oblique fibular tunnel. (Note the difference compared with traditional direct anterior–posterior guide-wire placement.)

The prepared tibialis allograft is passed through the fibular tunnel from anterior to posterior and tunneled, with the assistance of a curved clamp, posteriorly through the popliteus hiatus and then pulled up into the popliteus tunnel and secured with a 7 or 8 × 23 mm Bio-Tenodesis Screw. The anterior limb is tunneled deep to the biceps femoris, brought out near the LCL origin, and then pulled into the LCL socket via the passing suture. The knee is then brought into 10°–20° of flexion, and the tibial end of the ACL graft is tensioned and secured with a screw post and washer device (Fig. 11.15). Finally, with the knee in 30° of flexion, neutral rotation, and slight valgus, the medial sutures of the LCL limb are pulled, and a 7 or 8 × 20 mm Bio-Interference Screw is inserted into the LCL socket (Fig. 11.16).

This technique anatomically reconstructs both the ACL and the key structures of the posterolateral corner responsible for stability. In this multiligament reconstruction, concern for tunnel convergence in the lateral femoral condyle has been noted [98–100]. Shuler et al. reported collision frequencies of 29–43% for 25-mm lateral tunnels and 43–86% for 30-mm tunnels, depending on the axial angulation from 0° to 40° [98]. We do not routinely experience this phenomenon, due to certain technical pearls. We drill size 7- or 8-mm PLC tunnels, whereas theirs were 10 mm. We also drill our ACL femoral tunnel from the low anteromedial portal causing it to be more horizontal, whereas in their study the ACL tunnel was steep (30°) and similar to the transtibial technique. We also aim slightly anterior for our LCL femoral tunnel, as they recommended. These technical

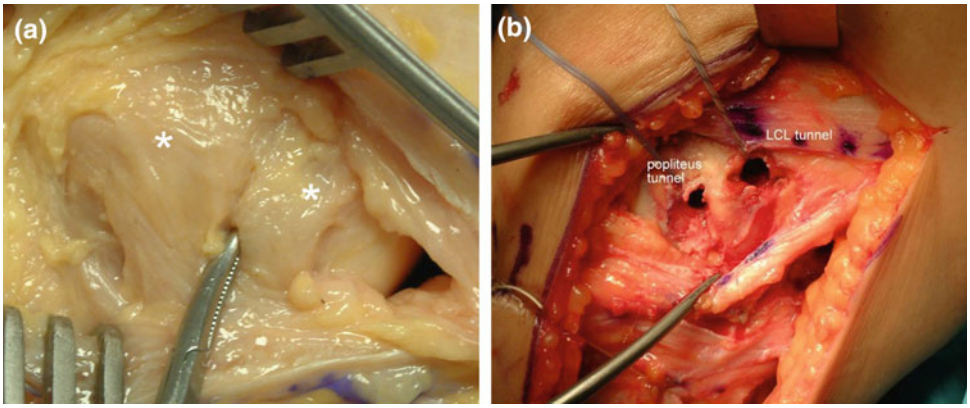


Fig. 11.14 Anatomic posterolateral corner reconstruction. **a** Photograph of the anatomic femoral attachments of LCL and popliteus tendon (*asterisks*). Note the popliteus is 18.5 mm distal and anterior to the LCL origin. **b** Intraoperative photograph showing the dual femoral tunnels. From Arciero RA [28]. Reprinted with permission from Elsevier

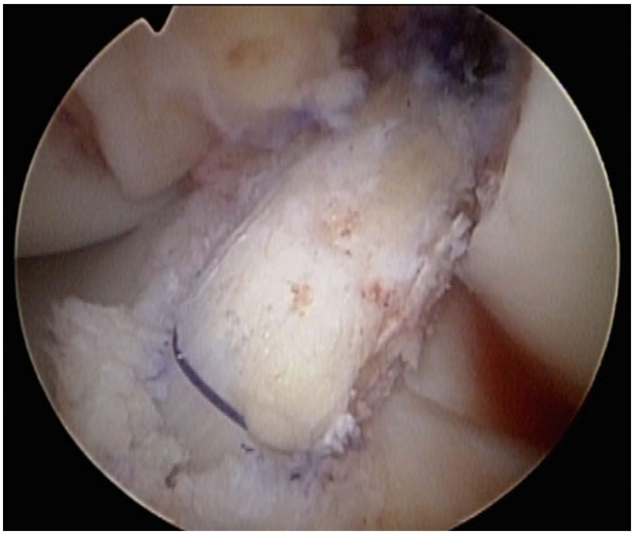


Fig. 11.15 Arthroscopic view of completed ACL reconstruction

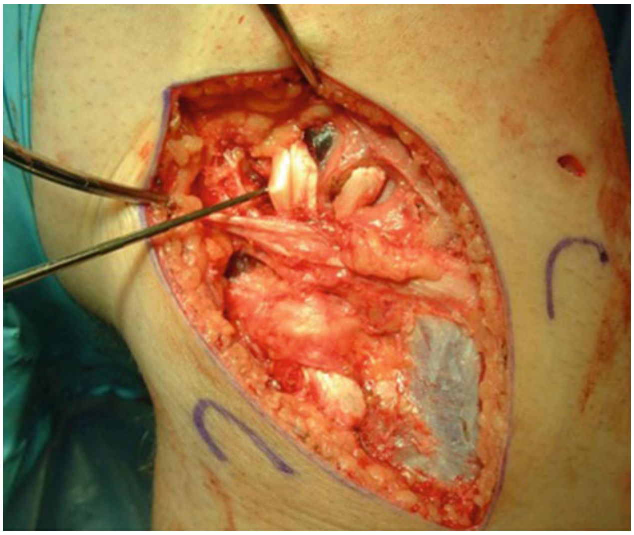


Fig. 11.16 Completed anatomic posterolateral corner reconstruction. From Arciero RA [28]. Reprinted with permission from Elsevier

points allow our trajectories for the PLC tunnels to be distinct from the ACL tunnel.

We have also developed an alternative fixation strategy to further decrease concerns regarding tunnel convergence. The graft is passed from anterior to posterior as described above. One suture tail from the popliteal graft limb can be loaded onto a 4.75 mm knotless suture anchor (i.e., PEEK SwiveLock 4.75 × 19.1 mm suture anchor, Arthrex, Naples, FL) and fixed at the anatomic popliteus origin. This technique requires a smaller tunnel with a 4.5 mm diameter drill to a depth of only 20 mm. For alternative LCL fixation, a RetroButton suspensory fixation device may be used (i.e., ACL TightRope RT, Arthrex, Naples, FL). For this technique, a spade tip guide pin should be placed from medial to lateral at the anatomic site of the LCL origin. Aiming slightly anteriorly as previously discussed will help minimize the risk of tunnel convergence. A 6 mm drill is used to create a 40 mm socket (note, this socket can be shorter if the graft is measured such that it will not create graft/socket mismatch) and a looped passing suture is placed. The LCL graft limb is looped through the RetroButton device and the tensioning/passing sutures on the device are passed with the looped passing suture. The graft limb is pulled partially into the socket and then sewn to itself with 0 VICRYL suture while held on tension; after the graft sewn to itself it is now a closed-loop structure and the RetroButton may be fully tensioned. A small 5 mm interference screw may be used at the LCL socket for backup fixation if desired.

11.6.2 Chronic Combined Injuries to the ACL and Lateral Knee

Patients may present to the office with a combined ACL and PLC injury in a delayed fashion. Chronic injuries may present more than 6 weeks from initial injury due to missed diagnosis or failure of initial nonoperative management. Subacute presentation within 3–6 weeks from initial injury may be due to delays in workup or patient referral. Patients may still present with significant swelling, reduced range of motion, or utilizing crutches for ambulation. Similar to the management of acute injuries, these patients should undergo therapy to regain range of motion if they have loss of extension greater than 5° or loss of flexion beyond 100° and normalize their gait prior to surgical reconstruction. Again, these efforts are made to decrease the risk of arthrofibrosis associated with performing ligament reconstruction on a stiff or swollen knee.

Chronic injuries generally have poor quality tissue and there is no role for primary PLC repair of chronic injuries. In chronic combined ACL and PLC injuries, surgical reconstruction of both structures is indicated. The technical guidelines for treatment are the same as in the acute setting and good outcomes have been reported with surgical reconstruction of chronic injuries [101, 102]. Long-standing instability may result in triple varus knee malalignment that would benefit from opening wedge high tibial osteotomy in addition to surgical reconstruction [35]. Again, at our institution, all chronic cruciate-deficient knee injuries, multiple knee ligament injured knees and patients with failed cruciate ligament surgery undergo standing mechanical axis radiographs. Some surgeons advocate performing the osteotomy as a first stage prior to soft tissue reconstruction or waiting to see if second-stage ligament reconstruction is necessary. Noyes et al. published a study that reported good results in a subset of their cohort with triple varus knees who underwent HTO, ACL reconstruction, and posterolateral stabilization [35].

11.7 Postoperative Rehabilitation

After combined reconstruction of the ACL and PLC, the patient is immobilized in full extension for 3–4 weeks. During this time, they are 20 lb. partial weight bearing on crutches and encouraged to do static quad sets and four-way straight leg raises. At therapy, the brace is opened from 0° to 90°, and they work on a range of motion with the therapist in a controlled environment. After 4 weeks, the patient is allowed to advance to full weight-bearing as tolerated and progress to full range of motion over a period of 2 weeks. They come out of the hinged postoperative knee brace and go into a functional brace at 8 weeks. It is also at this time that they begin closed chain isokinetic strengthening exercises. If desired, they are also permitted to do open chain exercises from 30° to 60° flexion only. Hamstring strengthening is avoided until 6 months. Rehabilitation continues until strength is 80% that of the contralateral leg. The patient is allowed to begin straight line jogging at 4 months, advance to sports-specific drills from 4 to 6 months, and then participate in full unrestricted sports activities at 9 months. We recommend that they wear a brace in their first year back to play.

11.8 Complications

Potential complications from after surgical reconstruction of combined ACL and PLC injuries include wound infection, hematoma, loss of postoperative knee range of motion, overconstraint, failure of the reconstruction with recurrent pain and/or instability, and hardware failure or irritation [14, 103, 104]. The peroneal nerve can also be injured during the operative approach or reconstruction, and the surgeon must be alert and careful with dissection, especially in the setting of a biceps avulsion where the nerve may be anteriorly displaced [55].

Lee et al. reported a complication rate of 11.4% (5/44 patients) in patients undergoing combined ACL and PLC reconstructions at a median of 5 months from injury [3]. Complications in this cohort included arthrofibrosis (n = 2), recurrent injury (n = 1), and septic arthritis (n = 2). A series by Stannard et al. of 15 multiligament knee reconstructions, which included 7 combined ACL/PLC reconstructions, had a wound complication rate of 20% (i.e., hematoma, infection, or fistula) and a 27% incidence of postoperative arthrofibrosis requiring an arthroscopic lysis of adhesions [77].

11.9 Conclusion

There are several key elements when approaching the patient with a ligamentous knee injury. First and foremost, the surgeon's attention to diagnostic accuracy is essential. Suspicion for multiligamentous injuries should dictate a diligent and thorough physical examination and utilization of appropriate imaging studies.

In the setting of an ACL injury, it is crucial to not miss a concomitant PLC injury or varus malalignment as these entities can lead to early graft failure of the reconstructed ACL if left unaddressed. The authors believe that PLC reconstruction should include both a fibular tunnel orientated to re-create the LCL and popliteofibular ligaments and dual femoral tunnels, as both details are important in controlling varus and external rotation.

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Surgical Treatment of Combined ACL Medial- and Lateral-Sided Injuries: Acute and Chronic

12

Eric D. Wicks and Steven B. Cohen

12.1 Introduction

Suspicion of a multiligament knee injury can be gained through a careful history and physical examination. These injuries can occur from high-energy forces experienced during motorcycle or motor vehicle crashes and in pedestrians struck by motorized vehicles. Low-energy events are more commonly associated with falls and sporting activities [1, 2]. Ultralow velocity knee dislocations have been described in obese patients resulting from nominal traumatic events [3]. The initial history from the patient and medical personnel can elicit the presentation of a knee dislocation with spontaneous reduction or visual inspection revealing one requiring relocation of the tibiofemoral joint. Examination of the overt dislocation provides the immediate confirmation of a multiligament knee injury, but more importantly the potential for neurovascular injury. More insidious in nature, spontaneous reduction of the dislocated knee can often be missed without proper history and physical examination. The examining physician must be cognizant of either scenario because vascular and nervous compromises are common with mechanisms producing multiple knee ligament damage. Recognition with proper and timely treatment can be limb sparing. Neurovascular assessment is therefore required prior to and after the reduction of a knee dislocation. After addressing any limb-threatening injuries, further examination is required to fully determine which knee structures are compromised and the severity of the damage [4, 5].

The purpose of this chapter is to describe the management of anterior cruciate ligament (ACL) tears combined with medial- or lateral-sided injuries. The treatment of these injuries starts with proper recognition of all injured structures. Failure to diagnose concomitant injuries is one of the most common reasons for failure of ACL reconstruction and chronic knee instability. When present, injuries to the posterior cruciate ligament (PCL), posteromedial corner (PMC), medial collateral ligament (MCL), anterolateral ligament (ALL), posterolateral corner (PLC), and lateral collateral ligament (LCL) must be considered in the reconstructive process. Timing and potential staging of knee reconstruction is impacted by the extent of injury, condition of the soft tissues, comorbidities, and the acuity of patient presentation.

12.2 Knee Dislocation Classification

Multiligament knee injuries can essentially be thought of as knee dislocations. In order to cause damage to more than one ligament, the knee must sublux or dislocate at least transiently [6, 7]. These injuries can be ordered into a classification system outlined by Robert C. Schenck, Jr., MD. The classification system is based on the specific ligaments and number of ligamentous structures injured. KD I involves a cruciate and a collateral ligament, KD II involves both the ACL and PCL, and KD III is a bicruciate injury and further subclassified by damage to one of the collateral ligaments and the PLC in the case of a lateral-sided injury. KD III-M is an injury to the ACL, PCL, and MCL. KD III-L involves both cruciates of the LCL and PLC. KD IV is a bicruciate and bicollateral ligament injury as well as the PLC. KD V is a knee dislocation with associated fracture [8, 9].

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12.3 Neurovascular Compromise in Combined ACL Medial- and Lateral-Sided Injuries

Neurovascular compromise is a concern with any multiligament knee injury. The rates of nerve injury have been reported to range from 5 to 48% with knee dislocations [1, 6, 10–14]. The most commonly reported range is about 20–30% across all types of multiligament knee injuries [15–18]. Ridley et al. found a 26.2% peroneal nerve injury rate at initial presentation in 61 knees with PLC injuries. Thirteen of these had a complete loss of function while the other three were partial nerve injuries. Three of the 13 complete injuries were caused by a traumatic transection of the nerve. The other 10 were the result of a stretch injury to the nerve. Five out of these 10 and all of the partial injuries had spontaneous recovery at final patient follow-up ranging from 6 to 48 months [19].

Moatshe et al. reported a peroneal nerve injury rate of 19.2 with 10.9% being partial and 8.3% complete. They also reported a vascular injury rate of 5% in their cohort of 303 patients with knee dislocations. KD III-L patients were significantly more likely to have a peroneal nerve injury and popliteal artery injury accompanying the PLC injury than those without. This finding also established a significant association of PLC injury with vascular injury [1]. Becker et al. uncovered a 21% vascular injury rate in 106 patients [15], while Levy et al. stated a 12.8% vascular injury in a study of 125 knee dislocation patients [16]. Sanders et al. found a 6.6% combined peroneal and vascular injury rate across all knee dislocations [18]. The results of these studies show how critical it is to suspect neurovascular injury and conduct a diligent examination.

12.4 Combined ACL/MCL/Posteromedial Corner Injuries

Combined ACL and MCL injuries with or without posteromedial corner injuries have the highest combined frequency estimated at 6.7% of all knee injuries [20]. When the posteromedial corner is involved, injury to the posterior oblique ligament (POL) is seen in conjunction with MCL damage. There can also be injury to the oblique popliteal ligament (OPL), posteromedial joint capsule, and the semimembranosus tendon [21]. Failure to recognize injury to the PMC will result in anteromedial rotatory instability [22, 23].

The ACL provides the primary restraint to anterior tibial translation with respect to the position of the femur. Lachman's, anterior drawer and pivot-shift examination can provide information about the competency of the ACL. Assessment of the ACL performed with the Lachman's test can be graded with an "A", firm endpoint or "B", no endpoint. Further numerical grading is represented by the amount of translation of the tibia. Grade I injury is characterized by 3–5 mm (mm) of translation; Grade II by 5–10 mm; and greater than 10 mm of laxity representing a Grade III injury [24]. The anterior drawer test can also provide information on the status of the ACL and PMC. The test is performed with the knee ideally flexed to 90°, but lesser amounts of flexion to as low as 60° have been described for this test. The patient's foot is stabilized in a neutrally rotated position, and an anterior force is imparted on the tibia by the examiner. The same grading as the Lachman's can be used to classify laxity of the ACL. The examiner must note the starting position of the tibia with respect to the femur because posterior cruciate ligament tears may give a false positive result. In these cases, there is an apparent increase in anterior tibial translation due to sagging of the tibia to a posterior starting position with an incompetent PCL. Modification of the anterior drawer with 15° of external tibial rotation may help to diagnose anteromedial rotatory instability represented by increased tibial excursion in this rotated position [25]. The well leg must be taken into consideration to establish the normal laxity of the knee as there can be a range of normal findings beyond the strict numerical grading described.

The MCL is the primary restraint to valgus force across the knee joint. It is well described to have superficial and deep fibers. The superficial fibers are tested with valgus stress at 30° of knee flexion. The deep fibers resist valgus stress at full knee extension. The amount of gapping of the medial knee defines the grade of injury. Medial joint opening of less than 5 mm at 30° of knee flexion is characteristic of a Grade I superficial MCL injury. Medial joint laxity between 5 and 10 mm would represent a Grade II tear, and opening greater than 10 mm is present in a Grade III MCL rupture [26]. Gapping of 5–10 mm at full extension is consistent with a medial-sided injury combined with an ACL tear. Ten millimeters or greater of medial joint laxity in full extension is suspicious for a combined medial-sided and bicruciate ligament injury [27]. Laxity at full knee extension has also been associated with medial patellofemoral ligament (MPFL) disruption [28], tearing of pes anserinus tendons and vastus medialis obliquus [29].

12.5 Imaging

Plain film radiographs are required to assess for fractures and tibiofemoral alignment. Associated lower extremity fractures in patients with knee dislocations causing multiple-ligament injured knees have been reported to range from 31% to as high as 57% by some authors [1, 30, 31]. They can encompass obvious fractures of the femoral and tibial shafts, articular surfaces and tibial plateau, or present as subtle avulsions. In the acute setting anteroposterior (AP), oblique and lateral projections can evaluate subluxation or dislocation of the tibiofemoral and patellofemoral joints. If patient presentation is delayed and the patient is tolerating weight-bearing, a posteroanterior (PA) 45° flexed knee view can be performed to further assess the medial and lateral tibiofemoral joint spaces [32]. A patellar axial or sunrise view can also be obtained but may be limited by pain and stiffness restricting knee flexion. Stress views, more specifically valgus stress for medial knee injury, may also be taken, but will likely cause significant pain [33]. They may only be warranted in a patient with restrictions precluding magnetic resonance imaging (MRI) of the knee.

Magnetic resonance imaging is the gold standard for assessment of the soft tissue structures of the knee. The examination can provide diagnostic information regarding the cruciate and collateral ligaments, menisci, tendons, posteromedial and posterolateral corner structures as well as osteochondral injuries of the articular surfaces [34, 35]. The information gleaned from MRI and physical examination can be utilized in preoperative planning. Medial collateral ligament injury location is important to determine the necessity of operative treatment and guide surgical technique and exposure when performing a repair or reconstruction.

12.6 Anatomy of the Medial Knee

The anatomy of the medial knee has been well described, and clinical consideration of all injured structures is essential for optimal results. Warren et al. described a three-layered configuration of the medial knee [36]. Layer 1 is comprised of the sartorius and sartorial fascia. The second layer is made up of the parallel fibers of the superficial MCL, POL, and semimembranosus tendon. The gracilis and semitendinosus tendons traverse a path between the first and second layers. Layer 3 is defined by the deep MCL and the posteromedial capsule. The posteromedial corner is further developed by the blending of the posterior portion of layer 2 with layer 3.

LaPrade et al. further defined the medial-sided structures of the knee [37]. The proximal portion of the superficial MCL attachment was shown to be 3.2 mm proximal and 4.8 mm posterior to the medial epicondyle. The MCL has an average length of 10–12 cm and attaches just over 6 cm distal to the medial joint line. The tibial attachment lies within the pes anserinus bursa and extends posterior to merge with fibers from the semimembranosus tendon. The deep MCL expands from the femur and has close connection with the medial meniscus along its course to the tibial attachment. A defined thickening of the posterior capsule represents the POL. Proximally, it attaches 8 mm distal and 6 mm posterior to the adductor tubercle on the femur. The POL tibial attachment is comprised of superior, tibial, and distal arms. The superior arm is continuous with the posterior capsule and oblique popliteal ligament. The tibial arm extends to the tibial articular surface, while the superficial and less defined distal arms extend to the semimembranosus attachment on the tibia.

12.7 Nonoperative Treatment of Combined ACL and Medial-Sided Injuries

There are no specific indications to definitively guide nonoperative management of combined ACL and medial-sided injuries. Relative indications for conservative management may include head trauma, polytrauma, multiple medical comorbidities, compromised knee soft tissue envelope, non-ambulatory patients, and those of advanced age or with the potential for poor compliance. The decision to treat any multiligament knee injury must be tailored to the needs of the patient by also taking into consideration the demands of their life and occupation.

The ACL is an intra-articular structure and does not have the ability to heal. The fibroblast composition, increased ability to synthesize collagen, and increased blood supply of the MCL afforded by extraarticular positioning provide it a greater ability to heal [38, 39]. Zhang et al. also reported that human stem cells in the MCL formed larger colonies and grew at a faster rate in culture compared to ACL stem cells [40]. These findings provide further cellular evidence of the greater healing capacity of the MCL.

Zhu et al. conducted a biomechanical analysis of ACL reconstructions with and without MCL reconstructions in a porcine model [41]. Their results showed that ACL reconstruction alone in the presence of a deficient MCL was unable to restore knee kinematics, consisting of anterior translation, valgus, and external rotation of the tibia, back to normal. Even with the biomechanical results of such studies, many authors have shown that MCL injuries can be successfully treated clinically without surgery even in conjunction with ACL tears [42, 43]. Midsubstance and femoral-sided tears have fared the best when treated nonoperatively (Fig. 12.1). Grade I tears are treated conservatively when in isolation or combined with ACL tears [44]. Considerations of the patient's activity level, vocation, and competitive level of sports activities guide the treatment of Grade II and III tears. Relatively inactive patients are treated without surgery for isolated Grade II tears and potentially Grade III femoral-sided tears showing good opposition of the MCL at the footprint of the femoral attachment. Superficial and deep MCL avulsions from the tibial attachment do not fare as well with nonoperative management and

Fig. 12.1 Coronal MRI of the right knee demonstrating injury of the femoral MCL attachment. This patient was successfully treated with conservative management

Fig. 12.2 Coronal MRI of the left knee showing a tibial-sided avulsion of the MCL causing laxity of the ligament and medial displacement of the medial meniscus. Characteristic bone bruising from the valgus force causing the injury is noted on the lateral femoral

commonly show residual valgus laxity (Fig. 12.2). Collegiate or professional athletes as well as firefighters, military personnel, police officers, and heavy laborers place demands on their knee such that these same injuries may require repair or reconstruction especially in combination with ACL tears. Anterior cruciate ligament reconstruction in any of these patients should be postponed until full range of motion has been recovered. Any further valgus laxity present after the ACL reconstruction can be surgically addressed at that time.

Zaffagnini et al. performed a prospective study on ACL reconstructions with nonoperatively treated Grade II MCL injury in 20 patients against 37 patients without MCL injury [45]. The MCL injury group did exhibit some residual laxity, but they did not show any significant differences in anteroposterior displacement, WOMAC, IKDC, Tegner scores, nor return to work or sports. Halinen et al. conducted a randomized trial of 47 patients with ACL tears and Grade III MCL injuries [46]. All patients had ACL reconstructions within the first 3 weeks after injury. Twenty-three patients had their MCL injury treated surgically with the other 24 treated conservatively. They were unable to report any significant differences between the two groups with regard to knee stability, range of motion, Lysholm score, nor subjective function. Preliminary results from Westermann et al. reported on outcomes of ACL and Grade III MCL injuries treated operatively against those treated without surgery [47]. At 2 years, the nonoperative cohort exhibited higher KOOS Sports Rec (88.2 vs. 74.4), KOOS QOL (81.3 vs. 68.4), and IKDC (87.6 vs 76.0) scores compared to the MCL repair group. There was also a higher reoperation rate for arthrofibrosis in the MCL repair group (19%) compared to the nonoperative group (9%).

Treatment of combined ACL with medial-sided injuries starts with the basic principles of protection, relative rest, cryotherapy, compression, and elevation of the injured extremity. A hinged knee brace locked in extension for ambulation is initiated with crutches for protected weight-bearing. The amount of time to have the brace locked in extension at all times is 1 week unless other comorbid conditions present a contraindication. The brace may be unlocked for therapy at this point, but it is still locked in full extension while ambulating. Continued progression of weight-bearing is advocated, and crutches are discontinued once the patient can bear weight fully. Therapy primarily focuses on regaining full knee extension and flexion. Reactivation of the quadriceps and strengthening of the hamstrings and hip musculature can start as soon as tolerated after the injury. Hip adduction exercises while lying on the injured side or with any resistance placed distal to the knee joint is strictly prohibited.

12.8 Operative Management of Combined ACL and Medial-Sided Knee Injuries

The indications for operative management of combined ACL and medial-sided knee injury are continually evolving. It is generally accepted that low-grade MCL injuries can be treated with initial bracing and delayed ACL reconstruction. Anterior cruciate ligament reconstruction is delayed nearly 6 weeks to allow for healing of the MCL and return of normal range of motion. Examination under anesthesia prior to and after reconstruction of the ACL is performed to guide any further MCL treatment. Operative indications for MCL repair and reconstruction are also guided by increased severity and the location of the MCL injury with respect to patient activity demands. In general, displaced femoral avulsions and many tibial-sided ligament ruptures are repaired or reconstructed (Fig. 12.3). The most severe tibial avulsion, an MCL Stener lesion, with entrapment through or over the pes anserinus tendons, is ideally addressed acutely. Avulsions of the MCL can be treated by restoration of the femoral or tibial anatomic footprint with repair by suture anchors or screw and washer constructs (Fig. 12.4). Anatomic repair of the MCL may need to be modified with advancement of the avulsed attachment creating a more proximal femoral or distal tibial attachment if there is a concomitant midsubstance ligament injury to avoid valgus laxity. Repair augmentation with synthetic suture tape creating an internal brace construct can further reinforce MCL and POL repair [48, 49].

Fig. 12.3 A medial approach of the left knee demonstrating a tibial-sided avulsion of the MCL (Courtesy of Paul A. Marchetto, MD)

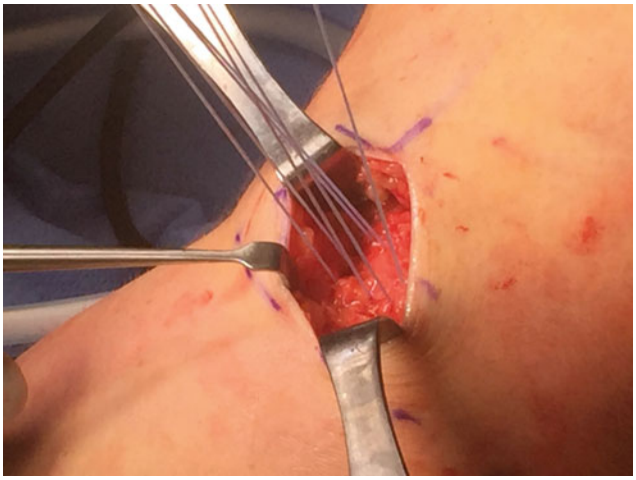

Fig. 12.4 Single incision technique centered over the tibial origin of the MCL. The bony footprint is debrided and anchors placed. The sutures are tied to pull the MCL back to the tibial attachment for isolated repair

It has been shown that patients undergoing repair or reconstruction of acute and chronic Grade III MCL injuries along with cruciate reconstruction has decreased valgus laxity and improved Lysholm scores compared to preoperative scores [50]. These findings seem intuitive, but timing of the repair or reconstruction does appear to have some effect on surgical decision to repair or reconstruct the MCL and the resulting patient-reported outcomes. Hanley et al. presented a retrospective review of 34 multiligament knee injury patients with Grade III MCL injuries undergoing repair or reconstruction [51]. The ligament injuries were all addressed surgically, and the patients had a mean follow-up of 6 years (2–11 years). Lysholm and IKDC scores were predictably lower (≤ 75) in MCL reconstruction patients compared to repaired ligaments in the patients studied. It is important to note that the timing of repair (76.5 days) was much earlier than reconstruction (207.1 days).

Range of motion is a concern no matter how the MCL is treated in a combined ACL and medial-sided knee injury. Robins et al. previously showed differences in the range of motion after combined ACL reconstruction and MCL repair depending upon the location of the MCL tear [52]. They retrospectively reviewed 20 patients. Seven patients had MCL tears distal to the joint line and were able to regain their range of motion at a statistically significant faster rate compared to the 13 patients with tears at the level of or proximal to the knee joint. There was also a statistically significant 8° increase in flexion and a nonsignificant 3° increase in extension of the distal group in comparison to the proximal group. The results of this study may be due to different rehab protocols in the 1990s as more recent results by Halinen et al. found no significant difference in the range of motion in 23 patients treated with early operative ACL reconstruction and MCL repair compared to 24 ACL reconstruction patients with nonoperative MCL treatment [53]. Zhang et al. have also noted return to normal range of motion in 20 out of 21 patients treated with delayed simultaneous ACL and MCL reconstructions [54].

12.8.1 ACL Reconstruction

An anatomic single-bundle ACL reconstruction is our technique of choice. Graft selection is surgeon dependent, and our decision is directed by the patient's age, activities, and concomitant knee pathology. We commonly use bone–patellar–tendon–bone (BPTB) autografts in patients that need to perform hamstring dominant activities or with medial-sided knee ligament injuries to limit any further compromise to valgus stability. Alternatively, when the medial side is uninjured, we utilize a quadrupled combined semitendinosus and gracilis autograft. In older less active patients, we may utilize allograft tissue for the ACL reconstruction.

We routinely use a tourniquet but may defer its use in the case of vascular compromise. The standard anteromedial and anterolateral portals are created. The anterolateral portal serves as the primary viewing portal for the procedure, but may also be utilized to address meniscal tears. The anteromedial portal is primarily a working portal but can provide an unrestricted view of the back wall of the femoral tunnel on the medial aspect of the lateral femoral condyle for the reconstruction. In most cases, an accessory anteromedial portal is needed because a transtibial approach may not allow the creation of an anatomic femoral tunnel. It is important to hyperflex the knee past 90° to be able to fully reach the anatomic footprint on the lateral wall of the femoral notch when creating an anterograde femoral tunnel. In cases not allowing for clear transtibial access to the anatomic femoral ACL footprint, independent anteromedial or an accessory anteromedial approach is utilized. When a BPTB autograft is used, we stabilize the bone plugs with interference screw fixation. We utilize suspensory button fixation on the femoral side with a screw and sheath tibial fixation of hamstring ACL autograft reconstructions.

12.8.2 MCL/PMC Repair

Medial collateral ligament repair is considered during the acute period (within 3–6 weeks) in cases of femoral- or tibial-sided avulsions or significant midsubstance injury with associated cruciate ligament rupture. The surgical approach is dictated by MRI findings illustrating which portion of the MCL is affected. In cases of femoral avulsion, a 3–4-cm longitudinal incision is made over the posterior edge of the medial femoral epicondyle. Soft tissue dissection is carried down to the femoral fascia overlying the MCL. The fascia is incised to access the proximal MCL attachment. In cases of tibial-sided avulsion, a 3–4-cm-long vertical incision is made starting about 4 cm below the medial joint line along the tibial flare, and dissection is continued until the sartorial fascia is reached. The fascia is incised, and the pes anserinus tendons are elevated to expose the tibial MCL footprint. The MCL is mobilized and the footprint debrided to create a bleeding osseous bed. The avulsion often retracts, but in the acute period the dense fibers of the deep MCL are usually able to be reattached with suture anchors or a screw and washer construct. When suture anchors are utilized, we suture the ligament with a locking suture pattern (Fig. 12.5). The suture is then secured in place with the anchor (Fig. 12.6). Alternatively, an anchor loaded with suture may be placed first, and then the ligament may be suture repaired with sliding suture configuration and tied over the MCL to secure it to the attachment. The POL, capsule, and superficial MCL are then advanced and imbricated to take up slack from plastic deformation of the ligament.

A technique for synthetic reinforcement of MCL repair has been outlined in the literature [48]. We do not commonly

Fig. 12.5 Tibial MCL avulsion sutured with two #2 biocomposite sutures in a locking grasping technique. The sutures were then delivered through a suture anchor to secure the repair to debrided tibial footprint (Courtesy of Paul A. Marchetto, MD)

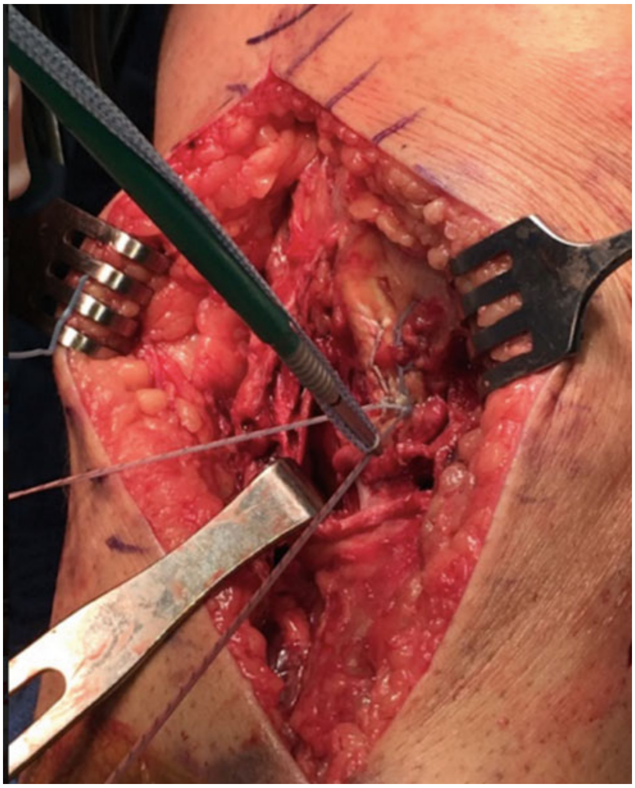

Fig. 12.6 Suture anchor placement just distal to the MCL tibial footprint. The anchor is loaded with a suture tape for further reinforcement via internal bracing (Courtesy of Paul A. Marchetto, MD)

Fig. 12.7 MCL tibial-sided repair with reinforcement by suture tape internal bracing. A hemostat is placed under the suture tape while inserting the final anchor to avoid overconstraining the knee (Courtesy of Paul A. Marchetto, MD)

perform this augmented repair, but it may have the advantage of strengthening the repair. A longitudinal incision is marked from the posterior edge of the medial femoral condyle to about 6 cm distal to the medial joint line with the knee fully extended. This will provide an incision that is in line with the long axis of the limb with the knee extended but will have a curvilinear appearance when the knee is flexed. Alternatively, femoral and tibial incisions can be made as described for each respective repair. The incision is made, and dissection is continued as already described. The saphenous vein and nerve as well as the infrapatellar branch of the saphenous nerve will lie within the surgical field and should be protected. Medial collateral ligament repair is performed as already described. The internal brace augmentation is performed with ultrahigh-molecular-weight polyethylene/polyester (UHMWPE) suture tape. The UHMWPE suture tape is loaded through the 4.75-mm-diameter suture anchor used in the repair of a femoral avulsion when present. The femoral anchor may be placed with fluoroscopic guidance, but knowledge of the MCL proximal attachment located 3.2 mm proximal and 4.8 mm posterior to the medial epicondyle can guide dissection and positioning of the anchor. Another 4.75-mm-diameter suture anchor is placed 6 cm distal to the medial joint line. Initially, guide pins are drilled into these anatomic locations. A suture can be wrapped around the guide pins of the proposed internal brace construct to determine isometry as the knee is taken through a full range of motion. Once isometry is confirmed, the femoral-sided anchor is placed in the location of the guide pin and screwed into the cancellous bone. The tibial side is placed in cortical bone at the guide pin and drilled creating a 4.5-mm-diameter unicortical hole that is then tapped with subsequent delivery of the suture anchor. The biocomposite suture can be used for repair or imbrication of a tibial-sided MCL tissue. The suture tape is passed through the eyelet of the tibial anchor before it is screwed into bone. The sequence of placing the femoral and tibial anchors can be reversed if there is a femoral-sided MCL injury. If a two-incision technique is used, the suture tape is tunneled under the soft tissues to lie on the superficial MCL fibers. A hemostat is placed under the UHMWPE suture tape during final anchor placement to avoid overtensioning of the internal brace construct that could lead to knee stiffness and loss of range of motion (Fig. 12.7). The final fixation of the suture anchors is completed at 30° of knee flexion with a varus force on the knee to maintain neutral alignment. It is important to check range of motion to assure that the knee has not been overconstrained restricting full extension or flexion. The POL is sutured and advanced anterior and superior to imbricate it to the posterior MCL. In larger patients, a second anchor set can be placed at the POL attachments and suture tape can be independently secured. Final tensioning of the POL limb is performed at full knee extension with varus stress.

12.8.3 MCL/PMC Reconstruction

We perform a diagnostic arthroscopy prior to any repair or reconstructive procedures. The medial compartment will gap and exhibit a drive-through sign if there is laxity of the damaged MCL (Fig. 12.8). With combined ACL and MCL injuries, we will first drill the femoral and tibial tunnels and complete the ACL reconstruction. Any other pathology such as meniscal tears will also be addressed at this time. When nonoperative treatment of an MCL injury was undertaken, special attention is paid to avoid significant valgus stress on the knee during the diagnostic arthroscopy and while performing ACL reconstruction and meniscal repair procedures.

Following the ACL reconstruction, we will assess the stability of the knee. The ACL graft is first checked to assure appropriate restoration of stability without increased anterior tibial excursion or pivoting of the knee. The knee is then tested for valgus laxity at 0° and 30° of knee flexion. Significant valgus laxity along with preoperative imaging and planning will indicate the need for MCL reconstruction.

Our preferred technique is similar to the one described by LaPrade and Wijdicks [55]. An anteromedial incision is made along the knee starting about 4 cm proximal to the joint line and medial to the patella. The incision is then carried along the medial knee and joint line ending over the mid-portion of the tibia about 7 cm distal to the medial joint line. The fascia overlying the sartorius is incised to uncover the gracilis and semitendinosus tendons. Deep to the tendons and the pes anserinus bursa is the attachment site of the superficial MCL about 6 cm distal to the medial joint line. We then drill an eyelet pin along the posterior border of the MCL at the tibial footprint. The pin is then over-drilled with a 7-mm reamer to a depth of 25 mm. The posterior oblique ligament (POL) tunnel is then prepared. The posterior edge of the semimembranosus anterior division attachment is incised and cleared to expose the central arm of the POL at its attachment on the posteromedial tibia. Another eyelet pin is aimed toward Gerdy's tubercle and drilled into this site. It is then over-reamed with a 7-mm reamer to a depth of 25 mm.

Attention is then turned to the proximal superficial MCL and POL attachment sites. The medial epicondyle of the femur is identified, and the proximal MCL tunnel is started with an eyelet drill pin placed just anterior and proximal to this landmark. The pin is advanced across the femur transversely exiting the lateral femoral cortex. The POL attachment is identified at a distance of 7.7 mm distal and 2.9 mm anterior to the gastrocnemius tubercle which is found 2.6 mm distal and 3.1 mm anterior to the medial gastrocnemius femoral attachment [55]. An eyelet pin is then drilled across the femur transversely in the same fashion as the proximal MCL pin. Isometry of the future graft positions can be tested by wrapping suture around each of the matched pin sites and taking the knee through a full range of motion. Fluoroscopy can also be used to verify the pin positioning in the proximal and distal anatomic footprints of the MCL and POL. Once these locations have been confirmed, the proximal MCL and POL pins are reamed with a 7-mm reamer to a depth of 25 mm once again.

A semitendinosus or tibialis anterior allograft comprises the preferred graft depending upon availability. The free ends of the graft are whipstitched with #2 biocomposite suture for a length of about 20 mm from the free end of the tendon. Two separate grafts are necessary to reconstruct the MCL and POL. The MCL allograft needs to measure 16 cm, and another allograft 12 cm in length is needed for the POL. We dock the proximal ends of each graft into their respective tunnels and secure them with bioabsorbable screws. The grafts are then passed to their distal attachments. The POL graft can freely be passed within the remaining native POL, but the MCL graft must be passed under the sartorial fascia

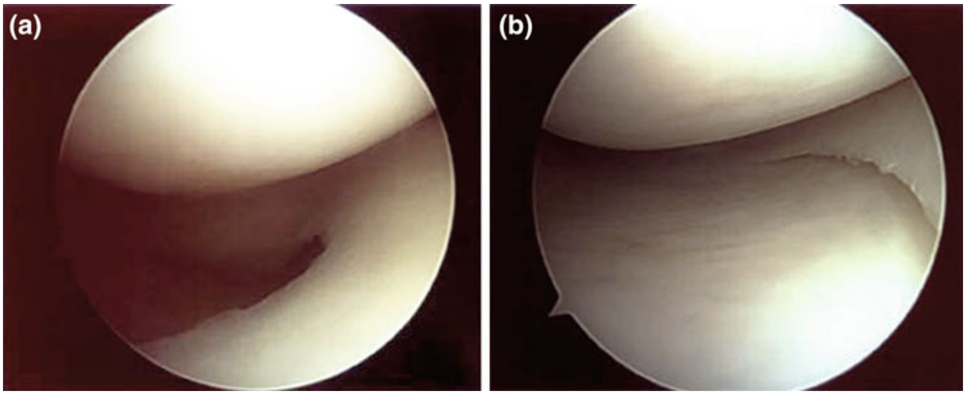

Fig. 12.8 **a** Arthroscopic image demonstrating increased medial joint space and drive-through sign characteristic of medial-sided knee injury. **b** Arthroscopic image showing medial joint space decreased to normal after MCL repair

and pes anserinus tendons to reach its distal attachment. The free ends of the whipstitched graft are drawn through the tunnels once again with the eyelet pin. The POL is tensioned first at full extension, and then the distal MCL graft is docked and tightened at 20° of knee flexion with slight varus to assure the medial joint line is closed. Both grafts are fixed with bioabsorbable screws with the tibia in a neutrally rotated position. We then secure the proximal tibial attachment of the native superficial MCL with a suture from an anchor placed about 1.2 cm distal to the medial joint line along the medial aspect of the most anterior attachment of the semimembranosus tendon. Stability is tested with valgus stress, and the wounds are copiously irrigated and closed in a layered fashion.

12.9 Postoperative Management

The early postoperative period requires strict protection with the patient in a long-leg hinged brace locked in extension at all times for 1 week. The brace is unlocked after this first week only while working on gentle range of motion as tolerated. Zero to 90° of range of motion is desired by 4 weeks. Full range of motion including hyperextension, if normal for the patient, is expected by 3 months. The patient is non-weight-bearing with the brace locked in extension for 2–4 weeks. Progression to partial weight-bearing with the brace locked in extension is started after this time point. The brace is unlocked at all times with protected weight-bearing starting at 6 weeks. Weaning to one crutch is initiated between the sixth and eighth weeks after surgery once the patient exhibits a steady gait with good general control of the lower extremity. The patient should be fully weaned from crutches between 8 and 10 weeks postoperatively. Full knee extension, performance of a straight leg raise without extensor lag and ambulation without a limp fulfills the requirements to discontinue crutches.

Strengthening and reactivation of the quads starts with quad sets and straight leg raises are initiated when regional nerve block anesthesia wears off. They are progressed in the number of sets, repetitions, and sessions in the first 6 weeks. Adduction straight leg raises while lying on the operative side are never performed during this period. Starting at the sixth postoperative week, strengthening is progressed through wall slide mini-squats (0°–45°), unsupported mini-squats, toe (calf) raises, and step-ups starting with a 2-in. step. The step height is progressively increased to a full step as long as neutral knee alignment is maintained during the exercise. Stationary bike pedaling within the flexion range tolerated by the patient can begin at the sixth week.

Progression of closed-chain exercises from 0° to 60° and continued utilization of stationary bike with initiation of elliptical, stair stepper, and walking on flat ground or a treadmill are performed between 3 and 6 months post-op. Proprioception and balance exercises are also started during this period. The emphasis of all exercises is valgus and varus control of the knee. Straightforward running is started at 5–6 months. All closed-chain exercises are advanced and open-chain exercises, including leg extension and curls, can now be performed. Small stationary hops such as jumping rope are also added to the program. At 9 months postoperatively, work hardening or sports functional training is started with progression of all other exercises. Cutting, forward and backward running, crossover, and carioca-type exercises are all added into the program for the first time with the goal of full return to the pre-injury vocation or sport.

12.10 Combined ACL and Lateral-Sided Knee Injury

Combined ACL and lateral-sided injuries make up only 0.4% of all knee ligament injuries [20]. The lateral side of the knee is stabilized by several structures. The most noted is the lateral collateral ligament, but the popliteofibular ligament (PFL) and the posterolateral joint capsule contribute to lateral knee stability. The ALL also contributes to lateral and rotatory knee stability. The biceps femoris, popliteus, iliotibial band (ITB), and the lateral gastrocnemius assist in active lateral knee stability. The muscular activation and pull on their tendons provides dynamic lateral and posterolateral knee stability.

Ligamentous examination of the knee needs to be carefully and completely performed to avoid missing any combined injuries. The ACL can be examined with the Lachman's, anterior drawer, and pivot-shift tests. The Lachman's test can identify an ACL tear as previously described. The anterior drawer test in neutral rotation and with 30° of internal tibial rotation may help to diagnose ACL rupture and anterolateral rotatory instability represented by increased tibial excursion [25]. The pivot-shift test usually cannot be tolerated by the patient in a clinical setting. Complete relaxation is necessary so this test is best performed during the initial exam under anesthesia prior to ACL reconstruction. It can provide further information about the amount of general anterolateral rotatory instability associated with ACL, ALL, and iliotibial band tears. A combined valgus, internal rotation, and axial load is applied to the leg while moving the knee from full extension to flexion. The tibia will reduce at about 30°–40° of knee flexion due to the influence of the ITB and ALL [56, 57].

The LCL is the primary restraint to varus force applied to the knee. Varus stress testing of the knee can allow grading of the LCL injury. The test is initially performed at 30° of knee flexion. Lateral joint gapping of less than 5 mm is characteristic of a Grade I LCL injury. Lateral joint gapping between 5 and 10 mm would represent a Grade II LCL tear and opening greater than 10 mm is indicative of a Grade III LCL rupture. Grade III injury noted at 30° of flexion can indicate associated PLC injury. The test is repeated at full knee extension. Gapping at full extension reveals LCL rupture with likely damage to the PLC structures and cruciate injuries with possible ITB involvement [58]. The external rotation recurvatum test can detect posterolateral rotatory instability due to ACL rupture and PLC injury [59]. The test is performed by stabilizing the thigh and lifting the leg by the Great toe with the knee fully extended. A positive test exhibits increased recurvatum, varus, and possible external rotation of the tibia compared to the contralateral leg. The dial test is performed with the knee in 30° and 90° of knee flexion and is combined with external rotation. Increase of greater than 10° of external rotation at 30° of knee flexion indicates PLC injury. The test is repeated at 90°, and an increase of 10° or more at this amount of knee flexion represents a combined posterior cruciate ligament tear along with PLC injury. Posterior drawer testing can be included as part of the basic knee exam. It can provide information about the integrity of the PCL. Posterior translation in neutral or internal tibial rotation tests the PCL. It can be performed with external rotation of the knee, and laxity in this position raises suspicion for additional popliteus and PLC injuries [60].

Pacheco et al. [61] reported on missed PLC injuries. There were 68 patients (59 men and 9 women), averaging 27 years of age, with PLC injuries in their study. Eight (11.8%) were isolated PLC injuries, 29 (42.6%) were associated with ACL tears, 19 (27.9%) had PCL injuries, 11 (16.2%) accompanied bicruciate ligament tears, and 1 (1.5%) also had ACL, PCL, and medial-sided knee injury. It was found that only the PLC injuries associated with knee dislocation (11 patients) were correctly identified. Seventy-two percent of the PLC injuries were incorrectly diagnosed at the time of initial presentation. Only 50% had been properly diagnosed by the time they were referred to the knee specialty clinic, and the average time delay to PLC injury diagnosis was 30 months.

12.11 ALL Involvement in Lateral-Sided Knee Injuries

There has been quite a bit of attention recently regarding the contribution of the ALL in rotatory stability of the knee. The ALL is not a newly discovered ligament, and its origin can be traced to the work of Paul Segond in 1879. The ligament originates from the lateral femoral epicondyle near the proximal attachment of the LCL. It traverses the knee joint obliquely to insert between Gerdy's tubercle and the fibular head. Some ALL fibers attach to the external surface of the lateral meniscus. The Segond fracture is described as an avulsion of the tibial insertion of the ALL and alerts to the high likelihood of an ACL tear. This is further supported biomechanically by studies showing the ALL to be a secondary stabilizer to anterior translation and internal rotation of the tibia, thus preventing the pivot-shift phenomenon of the knee [62–64].

The ALL has only recently been considered in multiligamentous knee injuries. Marwan et al. studied 48 patients suffering 49 knee dislocations [65]. Forty-five (91.8%) knees were shown to have complete ALL injuries and three others (6.1%) had incomplete injury. Forty (81.6%) of the knees had a complete ALL injury of the proximal fibers, and 23 (46.9%) had complete distal ALL injury. The proximal ALL fibers were damaged in all patients with LCL injury or tibial plateau fracture. The ALL may deserve greater attention when treating combined ACL and lateral-sided knee injuries, but at the current time we do not have a recommendation to surgically address this structure.

12.12 Imaging

Plain film radiography is once again the initial imaging study to assess for fractures and tibiofemoral alignment. Combined ACL and lateral-sided injuries can present with avulsion fractures of the LCL and biceps femoris tendon (Fig. 12.9). Anteroposterior and lateral radiographs are the minimum views to evaluate subluxation or dislocation of the tibiofemoral joint, but the oblique projection completes a standard series of imaging for a joint. If the patient can tolerate weight-bearing, a 45° flexed knee PA view or hip–knee–ankle views can be performed to further assess the medial and lateral tibiofemoral joint spaces and alignment [32]. Weight-bearing long-leg views can show a medial shift in the limb axis through the knee joint due to varus laxity and gapping of the lateral knee compartment. Weight-bearing projections are usually only possible with a delayed presentation. A patellar axial or sunrise view can once again be obtained, but adequate knee flexion may be limited by pain or stiffness in the acute and chronic settings. Stress views can once again be obtained, but are not customary to assess lateral joint laxity. Magnetic resonance imaging is a critical part of diagnosis and preoperative planning to properly address all injured structures [35]. The information gathered from MRI can guide preoperative planning and intraoperative expectation (Fig. 12.10).

Fig. 12.9 AP knee radiograph demonstrating a femoral-sided avulsion fracture and subtle lateral tibiofemoral joint gapping due to LCL and PLC injuries

12.13 Anatomy of the Lateral Knee

The arrangement of the lateral and posterolateral anatomic structures is important to know when evaluating imaging and preparing for surgical intervention. The LCL has an origin on the femur 1.4 mm proximal and 3.1 mm posterior to the lateral epicondyle. The fibular attachment is found an average of 28.4 mm distal to the fibular styloid and 8.2 mm posterior to the anterior edge of the fibular head. The popliteus takes its origin from the posteromedial tibia and passes proximal and lateral. The tendon becomes intra-articular prior to its proximal attachment on the posterolateral femoral condyle.

Fig. 12.10 Coronal MRI demonstrating midsubstance LCL injury (*white arrow*) causing laxity and proximal retraction of the ligament. Associated PLC injury is also noted

The popliteus tendon attaches anterior and distal to the femoral origin of the LCL. The PFL has anterior and posterior divisions that arise from the proximolateral musculotendinous junction of the popliteus. The anterior portion attaches 2.8 mm distal to the anteromedial tip of the fibular styloid, and the posterior division is located 1.6 mm distal to the posteromedial tip of the fibular styloid [63, 66].

12.14 Nonoperative Treatment of Combined ACL and Lateral-Sided Knee Injuries

Indications for nonoperative treatment of combined ACL and lateral-sided injuries are very limited. Non-ambulatory patients or the critically ill may represent the only candidates for conservative treatment with initial immobilization and longer term bracing. Ambulatory patients have historically not fared well with nonoperative management [67]. Kannus provided one of the earliest reports on 2+ and 3+ lateral knee injuries treated nonoperatively. The possibility of successful treatment of 2+ injuries due to higher outcomes scores was claimed, but the study did not consider varus instability as a failure. The author does note the presence of continued varus laxity and progression in 2+ and 3+ lateral knee injuries [68]. Krukhaug et al. reported on a small group of seven patients with isolated 1+ lateral instability. All patients were treated without surgery and allowed early mobilization. Six of the seven were completely stable to varus stress at final follow-up. They did conclude that 2+ or 3+ lateral knee injuries were more often associated with cruciate ligament tears and should be treated operatively [69]. We will initially attempt nonoperative treatment for 1+ isolated varus instability and will provisionally brace and monitor the patient for increasing instability or varus thrust during ambulation. We will surgically reconstruct the lateral and PLC structures with the presence of increasing instability, 2+ or 3+ varus instability at initial presentation or varus thrust.

12.15 Operative Management of Combined ACL and Lateral-Sided Knee Injuries

Operative treatment of combined ACL and lateral-sided injury is a bit more defined due to known worse outcomes associated with nonoperative management. The general operative techniques for the lateral-sided encompass primary repair, augmentation, and reconstruction. In the acute setting, repairs can be performed, but may only do well for fibular styloid and head fractures or avulsions of the LCL and posterolateral corner structures (Fig. 12.11). Shelbourne et al. presented 21 patients treated with lateral-sided repair with ACL reconstruction or nonoperative treatment of PCL tears when present [70]. They performed an en masse repair of all torn structures back to the tibia without a specific report of the injury grade. Better results were reported when the repair was performed within 3 weeks with more unpredictable results after 4-week post-injury.

In cases with significant midsubstance or extensive damage to the LCL, biceps, or popliteus tendons, a reconstructive procedure is required to restore varus and posterolateral knee stability (Fig. 12.12). Stannard et al. evaluated 63 patients with 64 PLC injuries in a prospective study in which 39 underwent primary repair and 25 had primary reconstructions [71]. Fifty-six patients with 57 PLC tears completed follow-up to at least 24 months. Patients had a mean age of 33 years with a higher percentage of males (35 male, 21 female). Out of the 35 patients with repair alone, 13 (37%) had failures. Primary reconstruction was performed on 22 patients with only 2 failures (9%). In another systematic review, Geeslin et al. summarized that Grade III posterolateral corner injury repairs failed 38% of the time and reconstructions failed in only 9% of patients [72]. Levy et al. provided 28 cases of surgically treated LCL and PLC tears in multiligament knee injuries [73]. Ten of the knees underwent lateral-sided repair with staged cruciate reconstruction. The other 18 knees underwent reconstruction of the LCL and PLC along with the cruciate ligament during the same operation. Four out of the 10 repairs failed and only 1 of the 18 reconstructions failed. Failures were deemed to have instability requiring revision. In another study

Fig. 12.11 Coronal MRI showing fibular styloid fracture (*white arrow*) and posterolateral corner injury causing lateral tibiofemoral joint gapping and dissociation of the lateral meniscus from the tibia due to associated capsular injury

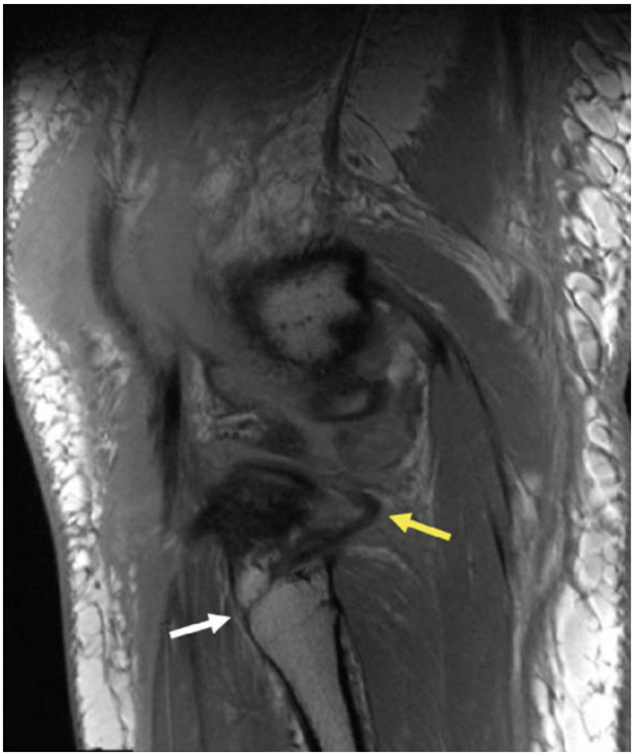

Fig. 12.12 Sagittal MRI in a patient with a fibular styloid avulsion fracture (*white arrow*), LCL and PLC injuries (*yellow arrow*)

evaluating 61 multiligamentous knee injury patients who had a single-graft PLC reconstruction, the most important finding leading to satisfactory functional knee outcomes was a stable knee upon physical examination. All patients had a minimum of 2 years of follow-up with average IKDC scores of 74.1 (±22.3) and Lysholm scores of 80.3 (±21.8). The average range of motion was from full extension to 126° of flexion. Ninety-five percent of patients had no varus laxity at full knee extension and 88.5% had grade 0 laxity at 30°. Female gender was associated with poorer IKDC scores [18].

The outcomes of surgical intervention of lateral-sided injury have also demonstrated inferiority to medial knee injury surgical treatment. Tardy et al. compared medial and lateral reconstructions in multiligament injured knees and found that the entire medial-sided group was operated on in the acute phase [7]. This group consisted of 9 cases in the repair and 10 cases in the reconstruction group. The multiligament knee injury group with lateral-sided injury all had reconstructions performed. Nine of the cases were reconstructed acutely, and 11 were reconstructed in a chronic timeframe. IKDC and Lysholm scores were significantly different between the two groups with higher scores in the medial-sided group. The acute lateral reconstruction group had better subjective outcomes compared to the chronic reconstruction group, and the delayed lateral reconstructions had a greater number of patients with residual varus laxity.

Our preference is to perform LCL and PLC reconstructions with a single cruciate reconstruction in the acute setting of multiligamentous knee injury. A staged procedure reconstructing the LCL and PLC with the PCL and delayed ACL reconstruction is performed in multiligamentous knee injury with bicruciate injuries. The patient is taken back about 6–12 weeks after the first stage for ACL reconstruction after range of motion has been restored and soft tissues have adequately healed. It may also be advisable to get a Doppler ultrasound prior to any delayed procedures to assess for deep vein thrombosis sometimes present due to prolonged decreased activity or hypercoagulable states. This may be the case in the polytrauma patient, or with any other delay in presentation for definitive treatment. This decision can be guided by physician preference and clinical presentation.

12.15.1 Acute LCL/PLC Treatment

Acute treatment of LCL and posterolateral injuries is ideally performed within the first 3 weeks after injury when the patient has regained their range of motion and the soft tissue edema has mostly subsided. When these injuries are seen in combination with ACL rupture, we will perform both procedures during the same operation. If there are injuries to the PCL or medial-sided structures also, then we will stage the reconstructive and repair procedures. In these cases, we will address the PCL, collateral, and corner structures with the first surgery and stage further reconstruction of the ACL after rehabilitation to restore range of motion and increase strength of the limb.

We commonly use tourniquet for these procedures unless there is a preexisting neurovascular contraindication. We also keep pump pressures as low as possible to allow for visualization but minimize extravasation of fluid into the tissues that may lead to compartment syndrome. The procedure starts with a diagnostic arthroscopy to assess all intra-articular knee damages. A drive-through sign will be noted in the lateral compartment with LCL and PLC injuries. The popliteus tendon may be lax upon examination if it has been avulsed from its attachment or otherwise significantly damaged.

We will complete all parts of the anatomic ACL reconstruction other than final tibial fixation. Any other intra-articular knee pathology is addressed before focusing on the lateral-sided injury. Our approach to the lateral structures is similar to the technique by Terry and LaPrade and described in more detail in the next section [74]. The MRI findings can guide the expected structures to repair, but we will be ready to perform a reconstruction depending on the condition of the tissues at the time of surgery. Reconstructive augmentation of the repair is very commonly performed. We start the exposure focused on the preoperative plan to address LCL, popliteus, or biceps femoris injuries or avulsions. The femoral origin of the LCL just posterior to the lateral femoral condyle is identified to treat such an avulsion. The footprint is decorticated, and the proximal LCL is whipstitched with a number two nonabsorbable suture. The same technique is utilized for a femoral popliteal avulsion at its proximal attachment. A Beeth pin is placed at the attachment and driven through the femur from the lateral cortex to the medial femur just proximal to the medial femoral epicondyle and adductor tubercle. This pin placement can be guided by fluoroscopy to avoid the ACL tunnel and assure that the pin is not directed too proximal, anterior, or posterior to the femur. A small incision is made over the medial thigh over the existing pin. Blunt dissection is carried out to the medial femoral cortex. The lateral portion of the pin is over-drilled with a 5-mm reamer to a depth of about 10 mm. The whipstitched ends are placed in the Beeth pin and drawn through the femur. The sutures are then tied over a button making sure the LCL or popliteus tendon recess into the lateral femoral tunnels. An alternative technique is to place a drill pin in the femoral footprint of the LCL or popliteus tendon. This can then be over-drilled with an 8-mm reamer for the LCL or a 5-mm reamer for the popliteus to a depth of 20 mm. These are the same measurements for reconstruction. The whipstitched ends can be placed into a 7-mm (LCL) or 4.75-mm (popliteus) knotless suture anchor and secured to the femoral attachment site.

Fibular avulsions are addressed by dissecting the structures from the fibular head and styloid. Care must be taken to note the position of the common peroneal nerve, and it always needs to be identified and protected during tunnel preparation and repair of the structures back to the fibular head. The LCL or the biceps femoris ends can be whipstitched and then passed through a tunnel created in the fibular head by passing a guide pin from anterolateral to the posteromedial aspect of the fibular head. This guide pin is over-drilled with an 8-mm reamer. The whipstitched ends can be placed through a 7-mm knotless anchor and secured in the tunnel. The tunnel can be modified in its projection to allow for anatomic reattachment of the biceps femoris in an isolated case. An anchor can also be placed in the fibular head, and the suture ends can be used to perform a running locking stitch in the biceps tendon with one free end and a simple pass through the tendon with the other to create a free post. The suture can then be tied to slide the tendon to secure it onto the fibular attachment site. It is not uncommon for the fibular styloid to be fractured off causing disruption of both the LCL and the biceps. In this case, an anchor can be placed in the fibular head with suture fixation of the tissues and fibular styloid drawn to, or through, the anchor for fixation. It is uncommon to find a tibial avulsion of the popliteus tendon without significant LCL and PLC damages necessitating reconstruction, so repair will not be discussed. All LCL repairs are performed 20° of knee flexion with valgus stress placed on the knee. All popliteus repairs are performed at 60° of knee flexion with internal tibial rotation. Tibial fixation of the ACL graft is then performed after the lateral-sided procedures have been completed.

12.15.2 Chronic LCL/PLC Treatment

In the instance of combined ACL and chronic or acute LCL and PLC corner injuries with irreparable tissue, we perform a reconstruction with either a semitendinosus, anterior tibialis, or split Achilles allograft [75] similar to the technique described by LaPrade [76]. We commonly use a tourniquet unless there is vascular compromise or repair not cleared for its use by the vascular surgeon. Pump pressures are kept low to decrease fluid extravasation and decrease the risk of compartment syndrome. The ACL reconstruction tunnels are drilled, and the graft is passed. The femoral portion of the graft is secured, but tibial fixation is held until the PLC reconstruction is complete. We then proceed to address lateral and posterolateral instabilities. A gentle curvilinear incision is made extending from the posterior aspect of the lateral femoral epicondyle toward the anterior fibular head. The incision is continued progressing midway between the fibular shaft and Gerdy's tubercle. It is extended superiorly and inferiorly as needed for tissue and tunnel preparation as well as neurolysis of the common peroneal nerve and its branches. The dissection is initially taken down to the level of the iliotibial band (ITB). An incision through the ITB is made to expose the LCL and popliteus tendon attachment onto the femoral condyle. Another fascial incision is carefully made parallel to the biceps femoris tendon and continued distally to its attachment on the fibular head. Blunt dissection is followed through this plane to identify the common peroneal (fibular) nerve (Fig. 12.13). The common peroneal nerve is usually encased in scar in the chronic setting. Meticulous dissection is performed to identify and free the nerve as it traverses the posterolateral knee on its course to and around the fibular neck. It is easiest to initially find the main branch of the nerve at or superior to the joint line. Once defined, any branches and the main tributary can be neurolysed as needed to increase exposure and free the nerve in cases with noted preoperative clinical deficits. The nerve is protected by a Penrose drain or vascular loop throughout the case with great care taken to avoid significant traction while displacing the nerve from the surgical field. Further dissection is needed to free the lateral gastrocnemius and soleus from the posterior tibia. The fibular head is then fully identified, and another window is created to identify and clear Gerdy's tubercle [74]. A guide pin is placed initially posterior to the lateral femoral epicondyle at the origin of the LCL. The second pin is drilled into the femur 18 mm anterior and inferior to this for the popliteus tunnel. The LCL tunnel is drilled to a depth of 20 mm with an 8-mm reamer. The popliteus tunnel is drilled with a 5-mm reamer also to a 20-mm depth. A fibular tunnel is then drilled with a guide

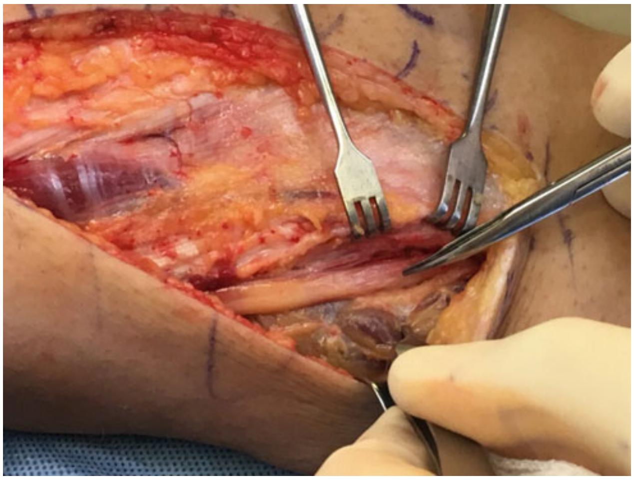

Fig. 12.13 Lateral knee approach with the peroneal nerve (scissor tips) crossing the field posterior to the fibular head and neck (retractors) and anterior to the lateral head of the gastrocnemius (forceps)

pin from anterolateral to the posteromedial aspect of the fibular head. This guide pin is over-drilled with an 8-mm reamer. The final pin is drilled from the anterior tibia starting at Gerdy's tubercle and traversing the tibia to exit the posterior tibia at the popliteal sulcus representing the region of the myotendinous junction of the popliteus. This pin is reamed successively with a 4.5-mm reamer followed by a 9-mm reamer. Great care must be taken to protect the peroneal nerve and posterior neurovascular structures of the knee when preparing the fibular and tibial tunnels. A speculum or curved retractor can be placed posterior to the tibia to protect these structures.

The PLC grafts are then passed prior to fixation of the ACL which is secured in the femoral and tibial tunnels as noted previously. We begin securing the PLC graft by first fixing the LCL limb of the graft to the femoral attachment by an interference screw. The graft is then passed through the fibular tunnel from anterior to posterior and then secured with another interference screw while imparting valgus force across the knee at 20° of flexion. This tunnel can usually accommodate lengths of 23 mm. The remainder of the LCL graft and the popliteal graft are passed through the posterior tibial tunnel and advanced out the anterior opening near Gerdy's tubercle. The grafts are advanced to the popliteus femoral tunnel and fixed in place with a bioabsorbable interference screw with the knee in slight internal rotation at 60° of flexion. The tibial tunnel is then secured with a bioabsorbable interference screw. Stability is tested, and any free graft ends and suture are cut. The biceps is then reapproximated with the fibula if the anterior attachment was taken off or if it was avulsed by the injury. The wounds are copiously irrigated, and the fascia is closed with heavy absorbable suture, noting the position of the peroneal nerve at all times during the closure. The subcutaneous tissues are reapproximated with smaller absorbable suture, and the skin is closed with a running subcuticular monofilament absorbable suture.

12.16 Postoperative Management

The therapy program for combined ACL reconstruction and LCL, PLC repair or reconstruction follows a decelerated pace compared to isolated ACL reconstruction rehabilitation. Progression through the program follows the same criteria as the combined ACL and medial-sided repair or reconstruction. The patient starts in a long-leg hinged brace locked in extension at all times for 1 week. The brace is unlocked after this first week to work on gentle range of motion as tolerated. Ninety degrees of knee range of motion is expected within the first month. Full range of motion should be achieved by 10–12 weeks. Partial weight-bearing is initiated about 4–6 weeks after surgery with the braced locked in extension. The brace can be unlocked at all times with protected weight-bearing as tolerated starting at 6 weeks. Weaning of ambulatory aids begins between 8 and 10 weeks. The degree of protection is dictated by lower extremity and trunk stability during ambulation. Once a steady gait is demonstrated, the patient may discontinue ambulatory aids completely. The brace is generally discontinued by 10–12 weeks after surgery.

Strengthening and reactivation of the quads starts with quad sets and straight leg raises is initiated as soon as basic control is regained from anesthesia. Abduction straight leg raises against gravity are never performed during the early and intermediate rehab periods. About 6–8 weeks after surgery, basic controlled closed-chain exercise may be initiated. Proprioceptive exercises are added about 3 months after surgery. Valgus and more importantly varus control of the knee to protect the PLC must be demonstrated with each exercise before progressing to the next phase of rehab. Straightforward running is started at about 6 months. The addition of open-chain exercises may now be performed. Low-intensity plyometric exercises are implemented between the sixth and ninth month. Once again, lower extremity and trunk control are essential. As the patient nears the ninth month after surgery, work hardening and return to sport is the focus of rehab. Implementation and progression of specific skills and activities guide the patient's return. A focus on core and trunk strength and stability is a prime component of the entire rehabilitative program. Exercises to address the patient's core should be started within the first few days after surgery and continued well past return to full unrestricted activity.

12.17 Conclusion

Comprehensive history and physical examination in conjunction with diagnostic imaging are necessary to uncover all pathology associated with a multiple-ligament knee injury. These injuries can be a result of a knee dislocation and may have limb-threatening neurovascular compromise. Surgical management may be considered once all injured structures have been identified and limb or life-threatening conditions have been resolved. Preoperative planning and timing of surgery are directed not only by the pathology but with regard to the status of the patient's comorbid conditions and the soft tissue envelope of the knee. The repair and reconstructive procedures are influenced by which structures are damaged and the pre-injury demands of the patient. Pre- and postoperative rehabilitation programs are further guided by the surgical techniques and tailored to meet the functional demands of the patient for the best clinical outcomes.

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13 Revision ACL-Based Multiple Ligament Knee Surgery

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Abbreviations

3D-CT	Three-dimensional computed tomography
ACL	Anterior cruciate ligament
ACLR	Anterior cruciate ligament reconstruction
ALL	Anterolateral ligament
ALRI	Anterolateral rotatory instability
AMRI	Anteromedial rotatory instability
BMAC	Bone marrow aspirate concentrate
BPTB	Bone patellar tendon bone
CT	Computed tomography
DB	Double bundle
HTO	High tibial osteotomy
ITB	Iliotibial band
LET	Lateral extra-articular tenodesis
MARS	Multicenter ACL revision study
MCL	Medial collateral ligament
MLK	Multiligament knee
MOON	Multicenter orthopaedic outcomes network
MRI	Magnetic resonance imaging
OTT	Over the top
PCL	Posterior cruciate ligament
PLC	Posterolateral corner
PMC	Posteromedial corner
PRO	Patient reported outcome
PRP	Platelet-rich plasma
PTS	Posterior tibial slope
ROM	Range of motion
SB	Single bundle

13.1 Epidemiology and Rates of Failure

Based on available registry data, the annual incidence of isolated anterior cruciate ligament (ACL) rupture has been estimated to range from 30 to 78 per 100,000 people [1]. Incidence rates vary widely across populations, and are dependent upon factors such as age, sex, sport, and level of competition [2, 3]. In the United States, more than 200,000 ACL injuries occur annually with the majority of those undergoing ACL reconstruction (ACLR) [4, 5]. The utilization of ACLR continues to increase, fueled in particular by rapidly growing rates in the adolescent, female, and aging adult populations [5]. Although a consensus definition of failure has yet to be established, graft re-rupture rates ranging from 2 to 25% have been reported, with unacceptable clinical outcomes reported as high as 40% [6]. While failure rates may be declining due to refinement in surgical indications and techniques as well as technologic advancement, the overall incidence of revision ACLR continues to rise. Based on modern primary ACLR utilization rates exceeding 130,000 per year [4, 5, 7] and reported revision rates ranging from 1 to 13% [8–10], we estimate that at least between 2200 and 14,300 revision ACLR are performed annually in the United States.

ACLR failure is often multifactorial. Unrecognized or unaddressed concomitant ligamentous instability can contribute to persistent or recurrent anterior instability and accounts for approximately 15% of ACL failures [11]. In particular, structures of the posterolateral corner (PLC) and posteromedial aspect of the knee act as secondary stabilizers and provide protective restraint in the ACL reconstructed knee. In a classic study, O'Brien et al. demonstrated that all patients with clinical instability after ACLR had associated ligamentous instability that had not been appreciated or addressed at the time of reconstruction. The authors concluded that major associated instability predisposes to ACLR failure and should be corrected in conjunction with the

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reconstruction [12]. These findings have been echoed by later studies and underscore the importance of addressing multiplanar instability in the setting of revision ACL reconstruction. It is imperative that the clinician maintain a high index of suspicion for concomitant or occult collateral ligamentous instability in the setting of the failed ACLR.

Although ACL injury is often approached as a separate clinical entity, it is becoming increasingly clear that additional structures may be involved and ACL rupture likely falls on a spectrum of multidirectional knee instability. While isolated ACL rupture may lie on one end of this spectrum, multiligament knee (MLK) injuries reside on the other end. Although ACL ruptures have been extensively studied, MLK injuries remain poorly understood and ill-defined. Due to the rarity of these injuries, clinical data is limited to small case series. Recent epidemiologic studies have estimated the incidence of knee dislocation to be 0.072 per 100 patient-years [13]. However, while this figure certainly captures severe MLK instability, it overlooks MLK injuries without frank knee dislocation. Whether due to the paucity or elusive diagnosis of MLK injuries, MLK reconstruction (MLKR) remains relatively rare. MLKR has been estimated to be 60-times less common than ACLR [14]. While failure after MLKR is generally accepted to be more common than ACLR, revision MLKR rates are largely unknown. Available case series report a wide range of failure rates of up to 40% across heterogeneous patient populations with variable follow-up [15–21].

No matter how often they are encountered and where on the spectrum of instability they lay, residual or recurrent ACL and MLK instability after reconstruction should be approached in the same rigorous and comprehensive manner to minimize the rate of repeat failure and optimize outcomes.

13.2 Defining Failure

Reported failure rates after ACLR vary widely. Modern registry studies consistently cite re-rupture rates between 2 and 5% [22–27], but studies focusing on clinical outcomes have reported rates approaching 20% [28]. Although we know that a number of factors may predispose or contribute to failure after ACLR or MLKR, it remains unclear what constitutes "failure". Although many studies have attempted to define this, a consensus definition remains elusive. Nevertheless, it is critical to have clear criteria for failure when considering revision surgery in patients after primary reconstruction.

The concept of failure is inherently broad and nonspecific. In the setting of ACLR or MLKR, it may refer to recurrent patholaxity or instability, postoperative complications, or persistent symptoms resulting in inability to restore preinjury or anticipated post-operative function. In the context of revision reconstruction, we will focus our discussion of failure on recurrent symptomatic patholaxity or instability after primary surgery.

Recurrent instability may be either objective or subjective. Objective anterior laxity may be defined quantitatively by the amount of anterior translation of the tibia relative to the femur with the knee at 30° of flexion and may be measured with a number of commercially available instruments (e.g. KT-1000/2000 arthrometer, MEDmetric, San Diego, CA). Daniel et al. initially demonstrated that a 3 mm side-to-side difference correlated with failure of the native ACL [29, 30]. Many subsequent studies have used this criteria to define failure of the reconstructed ACL [31–34], while others have used less rigid criteria defining graft failure as a greater than 5 mm side-to-side difference [32, 35–38]. Other examination maneuvers, such as the pivot shift, varus- and valgus-stress, external rotation recurvatum, and dial tests may also reveal residual laxity, particularly when performed under anesthesia. While there have been several attempts to quantify the degree of anterolateral rotational instability on the pivot shift test, no single test has been widely adopted [39]. Similarly, quantitative criteria for multidirectional instability remain lacking. Ultimately, our attempts to objectively identify and quantify patholaxity after reconstruction fall short and cannot be relied upon in isolation. Rather, subjective instability (even in the case of an intact graft) must be considered, which can be similarly vague or ill-defined. In general, subjective instability encompasses the sensation of shifting or giving way during movement or activity and is highly patient-dependent. While certain patients may have evidence of objective laxity, subjective symptoms may not be present, and vice versa. In the end, a combination of the two is important for a more strict definition of failure.

Ultimately, the diagnosis of failure after ACLR or MLKR requires a high index of suspicion combined with thorough clinical evaluation. Indications for revision reconstruction depend upon a reliable clinical diagnosis of failure. For the majority of cases, revision ACL-based MLK reconstruction is indicated in the presence of:

1. Objective instability
   a. Defined by greater than 3–5 mm side-to-side difference in anterior laxity or the lack of an endpoint with Lachman examination
   b. Evidence of reproducible instability on provocative testing.
2. Subjective instability
   a. Episodes of "giving way" or unsteadiness
   b. Functional limitation or deficit.

It is imperative to consider these indications in the context of the patient as a whole, including demographic factors, comorbidities, functional demands, and expectations.

Sometimes, fear or hesitancy after a primary knee reconstruction may mimic the feelings of unsteadiness or cause apparent functional limitations. This presents a major challenge for the physician as an improperly indicated revision reconstruction may provide little to no benefit for the patient.

13.3 Etiology

The etiology of ACLR failure is varied; however in the majority of cases the cause of failure is multifactorial. According to the MARS cohort of revision ACL reconstruction, the most common modes of failure are multifactorial (35%), traumatic (32%), technical error (24%), and biologic (7%) [40]. Timing of the failure can provide insight into the etiology. Most authors define early failure as within 3 months of the index procedure. Early failures are typically associated with loss of fixation, sepsis, and aseptic biological reaction. The majority of failures occur within 3–12 months postoperatively, known as midterm failures. Causes include surgical technique errors related to poor tunnel placement, impingement, graft elongation secondary to creep, aggressive physical therapy [41] or patient noncompliance, and unrecognized or unaddressed loss of secondary stabilizing structures around the knee. Late failure, defined as greater than one year postoperatively, usually occurs after graft incorporation and is primarily due to trauma, which can be a cause of failure at any phase of the postoperative recovery. Biologic causes of failure include failed ligamentization, infection, arthrofibrosis, and infrapatellar contracture syndrome (Table 13.1).

13.3.1 Patient-Related Factors

Patient related factors have recently gained more attention and include age, activity level, sex, body mass index (BMI), smoking status, and neuromuscular control. The Multicenter Orthopedic Outcomes Network (MOON) prospective cohort database is a multicenter consortium following clinical outcomes of ACLR. Kaeding et al., using the MOON cohort, demonstrated that patients in their second decade of life had the highest failure rate at 8.2%. For every 10-year decrease in age, the risk of re-tear increased 2.3 times [42]. Other studies have also supported this notion [41, 43], however one major confounder is activity level, and many believe that age is a proxy for activity level. Activity level has also been identified as a risk factor with similar limitations of controlling for age. Borchers et al. compared age- and sex-matched controls with the MOON database and found that patients with re-tears showed a statistically significant greater activity level [44]. This has been validated by previous studies [41, 45].

While women have a higher rate of native ACL injuries than men, there is less data when examining cases of revision surgery. The MOON prospective cohort found a revision rate of 3% ($n = 7$) in a total of 235 subjects at 2-year follow-up. Six out of 7 failures were male [46]. Shelbourne et al. similarly showed no statistical difference between male and female patients, however in patients less than 18 years of age, males had a statistically significant higher graft failure rate [41]. Perhaps intuitively, smoking and a BMI greater than 30 have been shown to correlate with decreased patient reported outcomes after ACLR [47]. However, no studies to date have quantified the effect of smoking or BMI on re-tear rates. Understanding these factors can help better counsel patients on expected outcomes. Additionally, certain factors are modifiable and can be optimized prior to undergoing surgical intervention.

13.3.2 Biomechanical and Technical Factors

Graft failure is typically multifactorial with some combination of technical, biologic, or patient-related factors. As aforementioned, timing can be helpful in terms of understanding mode of failure, and therefore, how to address a failed ACLR. The most common mode of early graft failure is mechanical failure, often attributed to failure of fixation. The goals of graft fixation are broadly defined as

Table 13.1 Cause of failure of ACL reconstruction

Technical	Biologic	Patient factors	Secondary instability	Traumatic
Nonanatomic tunnel placement	Failed ligamentization	Age	Rotatory instability	Early, prior to graft incorporation
Inadequate notchplasty	Infection	Activity level/compliance level	Coronal or sagittal malalignment	Late, after graft incorporation
Improper tensioning	Arthrofibrosis	Sex	Varus/valgus instability	
Graft fixation	Infrapatellar contracture syndrome	BMI/smoking	Meniscus deficiency	
Insufficient graft material	Aseptic biologic failure	Neuromuscular control		

maintaining adequate tension and minimizing motion between the graft and the bone tunnels to afford an optimal environment for biologic incorporation. Modern methods of fixation include aperture (e.g., interference screw), suspensory (e.g., cortical button), or a combination of both (hybrid fixation). Aperture fixation failure is more common in the tibia, as it demonstrates, on average, approximately half the load to failure measurements as those in the femur [48]. Some authors hypothesize that this is also because of the orientation of the tibial tunnel along the force vector of the ACL, with the femoral tunnel being more oblique in its orientation. Graft laceration is also possible with interference screw fixation, more commonly with metal screws than bioabsorbable [49]. Suspensory fixation is more prone to failure secondary to femoral cortical violation or failure to deploy the device properly. Additionally, with longer loop length the tendency for suspensory cortical fixation to plastically deform increases [50]. Sepsis is another early cause of graft failure and occurs in 0.3–1.7% of failures [46]. Clinicians should maintain a high index of suspicion for infection, as prompt treatment can lead to better outcomes.

Graft incorporation and elongation are important contributors to failure. If graft incorporation is the biological indicator of success after ACLR, aseptic biological failure is considered its corresponding failure. Studies show a wide range of aseptic biological failure, from 7 to 27% [46]. It is most commonly related to graft type, graft interface, and patient immune response. Autograft is known to incorporate in less time than allograft due in part to an immunologic response. Additionally, bone-tendon-bone grafts require less time to incorporate. True graft versus host disease or immune system mediated graft rejection is thought to be very rare. Graft elongation occurs when elongation or creep due to a non-recoverable stretch and loss of stiffness leads to gradual failure [51]. An important technique to prevent this is preconditioning grafts with a constant tensile load [52, 53]. Overly aggressive early postoperative physical therapy prior to graft healing or improper tensioning angle may also promote elongation. Soft tissue grafts have been shown to be more susceptible to failure by elongation or creep [54, 55].

The most common recognized technical error leading to failure is tunnel malposition. This can lead to poor graft kinematics or impingement. The femoral tunnel has historically been the overwhelming culprit, with high/anterior tunnel placement in the intercondylar notch leading to an overly vertical graft orientation and subsequently inferior rotational stability (Fig. 13.1). Anterior placement of femoral tunnels leads to excessive strain in both flexion and extension. Anterior placement of the tibial tunnel can similarly lead to impingement of the graft, which may lead to loss of motion or graft erosion. In the setting of ACLR, tunnel placement is a delicate balance between the risk of instability and impingement.

Secondary stabilizers play a pivotal role in ACLR. Unrecognized associated ligamentous injury has been demonstrated to account for up to 15% of failures [11]. In a classic paper, O'Brien et al. reported that all patients in his cohort of 80 primary ACLR's with postoperative clinical instability had evidence of associated ligamentous instability [12]. Further studies have shown the most common unidentified associated injuries leading to unrecognized instability included posterolateral corner injuries, followed by posteromedial injury and medial meniscus deficiency [12, 56–58]. A cadaveric study showed that sectioning the lateral collateral ligament in the setting of an ACL tear increased anterolateral rotation instability, while sectioning the popliteus complex increased anterior tibial translation but not anterolateral rotational instability [49]. Similarly, combined MCL and ACL deficiency has been shown to increase anterior tibial translation at knee flexion greater than 60° [59]. Medial meniscus tears have been shown to increase anterior-posterior tibial translation at all knee flexion angles except 90° [60].

Additionally, coronal malalignment can contribute to ACLR failure [61]. Primary varus knees occur when tibiofemoral geometry and possible medial meniscus damage or cartilage wear results in medialization of the weight-bearing line or mechanical axis. Double varus refers to an additional damage of the lateral ligamentous structures commonly presenting clinically as a varus thrust. Finally, triple varus

Fig. 13.1 Sagittal image displaying placement of an anterior femoral tunnel. The tunnel is clearly seen beginning anterior to Blumensaat's line

includes an added external tibial rotation and hyperextension. Double and triple varus knees benefit from valgus high tibial osteotomy (HTO) concurrently or staged with ACLR and/or PLC reconstruction [57]. However, primary varus knees have not shown a difference in failure rates with simultaneous or staged HTO and ACLR [62]. Finally, increased posterior tibial slope has been correlated with native ACL injuries [63]. Therefore, in patients with combined varus and increased posterior slope, a dual plane osteotomy correction should be considered, especially in the setting of a failed MLKR.

13.4 Workup and Preoperative Planning

Appropriate evaluation of the failed reconstruction is rarely straightforward and requires thorough understanding of the primary and indirect causes of failure. In the setting of recurrent multidirectional instability, the detection of instability and identification of all structures involved is of critical importance.

13.4.1 History

A comprehensive history should gather details of prior surgeries including indications, procedures, hardware, grafts, and complications. Previous operative reports and arthroscopic images are invaluable. Preoperative and postoperative symptoms should be compared in the context of functional level to determine the efficacy of the initial procedure. Return to activity or sport should be assessed. Timing of failure, as previously discussed, may provide insight into the mode of failure. Persistent or recurrent symptoms should be elicited, including pain, instability, stiffness, swelling, and mechanical symptoms. Frequency, severity, and timing of symptoms are of particular importance and may further elucidate structures involved. Attention should be paid to recalcitrant pain, swelling, and superficial changes which may raise suspicion for indolent infection. In the presence of a new, discrete injury, the traumatic event and mechanism should be explored. Demographics, comorbidities, and social history must not be ignored and should be taken into account to identify risk factors. Lastly, particularly in the revision setting, patient expectations must be explored. Patient expectations of primary and revision ACL reconstruction vary widely and unrealistic expectations may negatively impact outcomes [64].

13.4.2 Physical Examination

Physical examination must be systematic and comprehensive and begins with an evaluation of the patient's alignment and gait. One can assess for a subtle limp, lack of terminal extension, or varus or valgus thrust with ambulation. Prior incisions and skin changes should be assessed and taken into consideration when planning a revision approach. This is of particular importance over the tibia as the subcutaneous nature could lead to wound complications if incisions are not placed appropriately. Plastic surgery consultation can be considered if soft tissue issues will be anticipated. Persistent effusion may be a sign of meniscal or chondral injury. Range of motion should be assessed and quantified. Thigh circumference should be measured to assess for atrophy.

Instability should be assessed in all planes and a high index of suspicion for multidirectional instability should be maintained. Lachman and anterior drawer tests assess for anterior laxity and may be quantified with use of an arthrometer. The pivot-shift test may detect anterolateral rotatory instability (ALRI), even in the presence of a negative Lachman, and may be quantified or graded with a variety of methods [39]. The dial test at 30° and 90° and external rotation recurvatum test are mainstays in the evaluation of the PLC. Anteromedial rotatory instability (AMRI) can be assessed by applying valgus and external rotation stress at 30° of flexion and may indicate incompetence of the PMC, MCL, or both [65]. The integrity of the PCL can be evaluated with posterior drawer or quadriceps active tests. Varus- and valgus-stress testing in full extension and 30° of flexion evaluate the medial and lateral collateral complexes.

13.4.3 Imaging

Imaging with multiple modalities is warranted in the revision setting. A complete radiographic series should include bilateral weight-bearing anteroposterior views and posteroanterior views in 45° of flexion (Rosenberg), lateral views at 30° of flexion, and patellofemoral axial views (sunrise or merchant). Standing full-length lower extremity films are particularly useful to assess alignment and deformity. Plain radiographs are fundamental studies in the initial workup of the failed knee ligament reconstruction and provide valuable information on degenerative changes, alignment, tibial slope, tunnel position and widening, fixation method, and hardware position [66–68]. Serial radiographs can reveal subtle or progressive changes and provide insight into the mode of failure. Stress radiographs are a simple, cost-effective, and valuable method to evaluate and quantify the degree of residual laxity. In particular, valgus and varus stress radiographs at 0° and 30° may provide an objective and reproducible measure of lateral compartment gapping in patients with MCL, PLC and combined injuries [69–72].

Although plain radiographs play a critical role in the initial workup and can predict tunnel placement and direction [66], several studies have demonstrated computed tomography (CT) to be a superior modality for the evaluation of tunnel position and orientation [73–75]. CT is considered more accurate and reliable than MRI in the assessment of tunnel morphology and quantification of tunnel widening [67, 68, 73, 74, 76]. CT scans should be carefully reviewed for tunnel malposition, osteolysis, cystic changes, widening, and fixation failure. Three-dimensional CT (3D-CT) has recently emerged as a promising modality for further elucidating tunnel anatomy and also gives the surgeon an estimate in terms of the size of the tunnel compared to the size of the notch.

Magnetic resonance imaging (MRI) is a mainstay in the evaluation of the unstable knee. Although special attention should be paid to evaluating the integrity of ligamentous structures, care should be taken to identify all concomitant pathology. Concomitant intraarticular pathology, including chondral and meniscal damage, is more commonly encountered at the time of revision than primary surgery and should be identified in advance [77–79]. Although the evaluation of tunnel morphology and widening may be limited by artifact, MRI is useful to evaluate ongoing graft healing and incorporation. Moreover, MRI can reliably detect complications such as tunnel malposition, roof impingement, partial and complete graft tears, arthrofibrosis, tunnel cysts, hardware loosening, and infection [80]. However, the sensitivity of MRI to detect graft failure may be lower than expected. In one study of 50 ACL revisions, 24% of cases had an “intact” ACL on MRI, but confirmed rupture on physical and arthroscopic examination [81]. This underscores that importance of interpreting imaging in the context of the history and examination findings.

13.5 Revision ACL Reconstruction

Revision ACLR poses different challenges than primary ACLR. As our experience with revision ACLR grows, the technical considerations and strategies continue to expand. It is important to keep in mind that preparation for revision ACLR starts long before the operation. Thorough preoperative evaluation is vital to identify all factors related to failure. The operative plan should be tailored to the pathology and multiple contingency plans should be devised. The surgeon should remain flexible and must be familiar with a variety of techniques and implants to optimize outcomes. The following section will review several considerations in revision ACLR and strategies to manage them.

13.5.1 Staging and Tunnel Management

One of the first critical decisions that must be made is whether or not to tackle the revision in a single stage. A number of factors should be considered when deciding between one- and two-stage revision ACLRs. Classically, existing tunnel morphology has been considered of paramount importance. However, other factors, such as retained hardware and concomitant pathology, must be taken into account when deciding between a one- or two-stage procedure, especially in the context of the multiple ligament injured knee and the likelihood of the placing additional hardware into compromised bone.

Single-stage revision ACLR can be considered in the majority of cases. Existing tunnel position may vary along a spectrum from completely anatomic to nonanatomic and may be classified according to a criteria adapted from Wagner et al. [82] (Table 13.2).

If the initial tunnels are anatomic, the same tunnels may be utilized as long as substantial widening is not present. In the presence of completely nonanatomic tunnels, single stage revision ACLR can usually be performed using new tunnels in anatomic positions with an adequate bone bridge. New tunnel placement may allow existing hardware to be bypassed thereby precluding removal, as we find that in some cases hardware removal can actually jeopardize future fixation. In semi-anatomic tunnel position, single-stage revision remains viable, but tunnel overlap is anticipated. In the presence of significant tunnel overlap, the divergent tunnel technique can be utilized to recreate an intact osseous tube for graft incorporation [83]. In this technique, the aperture of the new tunnel remains the same, but the angle and direction of the tunnel are changed. Tunnel trajectory can be altered by utilizing different femoral drilling techniques such as outside-in or anteromedial portal drilling. If the posterior femoral wall is absent or deficient, an over-the-top (OTT) reconstruction technique is particularly useful [84].

Tunnel widening and bone loss is frequently encountered, particularly after removal of existing hardware and debridement, and is a key factor in the decision between one-

Table 13.2 Classification of existing tunnel position and implications for revision anterior cruciate ligament reconstruction [82]

Existing tunnel position	Implications
Completely anatomic (*anatomic-correct*)	No tunnel redirection required
Completely nonanatomic (*complete-incorrect*)	Will not overlap with new anatomic tunnels
Semi-anatomic (*incomplete-incorrect*)	High risk for partial overlapping with new anatomic tunnels

and two-stage revisions. Tunnel expansion can lead to issues with graft fixation, stability, and incorporation [85]. An absolute threshold for the amount of acceptable tunnel widening and bone loss has not been established, but most experts agree that tunnel widening of more than 15–16 mm or greater than 100% may require staged reconstruction (Fig. 13.2) [85–93]. In the case of borderline widening, single stage reconstruction may be performed with use of stacked interference screw fixation or matchstick or bullet bone grafting of the defect [83, 94, 95]. Additionally, allograft tissue with large bony attachments such as bone-patellar-tendon bone allografts or Achilles allograft may be utilized. One of the benefits of these techniques is that the bone blocks can be placed in the orientation that most accurately approximates the anatomic position of the soft tissue graft. OTT reconstruction is another option to avoid the widened tunnel but preserve the femoral footprint [84], and can be extremely useful in pediatric cases or cases with massive femoral osteolysis and the goal of a one-stage procedure.

Two-stage revision ACLR is indicated when placement and stable fixation of an isometric, anatomic graft cannot be performed using the aforementioned techniques. Excessive tunnel widening greater than 100% or more than 16 mm in any direction may necessitate primary bone grafting. Prior to bone grafting, the tunnel should be meticulously prepared. All hardware should be removed and the tunnel debrided of sclerotic bone and fibrous tissue with care to preserve as much native bone as possible. Once the tunnels are prepared, they are filled with bone graft which can be obtained from a variety of sources (Table 13.3). Iliac crest or proximal tibial autograft, allograft, or bone substitutes may be used with varying advantages and disadvantages. If a structural graft is chosen, it is fashioned into a bone dowel or plug and impacted into the prepared bone tunnel. After bone grafting, repeat radiographs and CT are obtained approximately 3–6 months later to ensure consolidation prior to proceeding with the second stage [85, 90].

Two-stage revision may also be considered in the presence of residual complications. Infection and arthrofibrosis should be exhaustively addressed first. An aggressive rehabilitation program is initiated and revision ACLR considered once the complication has resolved and full ROM is restored [96].

Concomitant pathology is another relative indication for two-stage revision ACLR. If the status of the meniscus,

Fig. 13.2 CT imaging. **a** sagittal and **b** coronal views demonstrating significant tibial tunnel expansion measuring greater than 15 mm in diameter

Table 13.3 Bone graft options in revision anterior cruciate ligament reconstruction

Location	Advantages	Disadvantages
Iliac crest autograft	Structural graft, volume	Donor-site morbidity
Anterior tibial plateau autograft	Locally available	Technically difficult to obtain, proximity to desired tunnels, limited quantity
Cancellous allograft	No donor-site morbidity, volume	Osteoconductive only, high cost

chondral surfaces, or ligamentous structures is unknown or in question, diagnostic arthroscopy may first be performed, including intraarticular synovectomy, lysis of adhesions, tunnel debridement, removal of hardware, and/or bone grafting, if necessary. Extraarticular pathology, such as malalignment and concomitant ligamentous instability can be addressed with appropriate osteotomy or reconstruction, as indicated. Once ROM is restored and tunnel healing confirmed, a second stage can be performed to address intraarticular pathology including revision ACLR, meniscal allograft transplantation, and/or cartilage restoration procedures. These decisions are often surgeon-specific as many of these procedures can be performed in the same setting, however these cases can be quite lengthy and have increased chances for complications.

To date, follow-up data comparing one- and two-stage revision ACLR is limited. In a recent study of 88 patients undergoing one- or two-stage revision ACLR with BPTB autograft or allograft, there was no difference in outcomes, including patient-reported outcome measures or failure rates, between groups at a minimum follow-up of two years. However, patients with concomitant pathology were excluded [97].

13.5.2 Graft Selection

The ideal graft choice for all revision ACLR procedures has not been established. Rather, graft choice depends on available graft options, concomitant pathology, surgeon preference, and patient-related factors. The Multicenter ACL Revision Study (MARS) group found that of all of these factors, the surgeon has the largest impact on graft choice [98]. Graft options are similar to primary ACLR and vary in donor (autograft versus allograft) and anatomic location (patellar, hamstring, quadriceps, Achilles, anterior or posterior tibialis tendon).

Autograft has been shown to have a lower failure rate than allograft for primary ACLR in the young, highly-active patient population [42]. Similarly, the MARS group demonstrated that at two years, patients undergoing revision ACLR with autograft had superior sports function and patient reported outcome measures relative to those reconstructed with allograft. Furthermore, subsequent graft rupture was 2.78 less likely if an autograft rather than an allograft was utilized. No significance difference in outcomes between soft tissue and BPTB autografts was detected [99]. A recent meta-analysis of revision ACLR comparing different grafts echoed these findings, demonstrating that autografts had better outcomes than allografts. However, when irradiated allografts were excluded, there was no significant difference between autografts and allografts, suggesting that non-irradiated allografts may achieve comparable outcomes to autograft in appropriate patient populations [100].

Specific scenarios may dictate graft choice. Allografts offer the advantage of decreased donor-site morbidity and operative time and are desirable choices for multiple ligament reconstructions or in the multiply revised ACLR. In cases with tunnel widening, an Achilles allograft with bone block may be fashioned to match the bone defect [91]. Quadriceps tendon autograft is also a viable option, and can be harvested with or without a patellar bone block depending on the need to fill any residual bone voids [101–103]. If hamstring autograft is preferred, tripling the semitendinosus graft to make a 5-strand graft is recommended if tendon length allows [93]. Contralateral autograft could also be considered after weighing the potential risks and benefits of involving the unaffected knee and permits goal-specific rehabilitation to be tailored to each side [104]. Prior use of a specific autograft does not necessarily preclude harvesting from the same site for revision surgery. In some cases, tendon regeneration may be sufficient to re-harvest these grafts for revision [105–107]. Preoperative imaging is vital to assess reconstitution and viability of the regenerated graft prior to attempting re-harvest.

13.5.3 Fixation

Numerous graft fixation methods are available for primary ACLR with similar clinical efficacy [108–112]. As with graft choice, a number of factors play a role in dictating the type of fixation in the revision setting. Accordingly, surgeons must be familiar with the various options available.

There is limited data comparing the results of fixation constructs in revision ACLR. The MARS group evaluated various surgical factors at the time of revision ACLR and found that metallic femoral fixation was associated with superior PROM scores. Although the authors conceded that it is challenging to determine the precise pathophysiologic basis for this finding, they speculated that inert metallic fixation may overcome issues with bone loss and quality without the risk of breakdown or reactivity seen with biodegradable implants [113].

If aperture fixation is selected, the surgeon must consider tunnel position and morphology when choosing and placing implants. Interference fit and screw purchase may be compromised by poor bone quality or volume, so larger diameter or stacked screws may be required [87]. If aperture fixation cannot be accomplished, cortical suspensory or transverse fixation are useful options that the surgeon should have in his or her armamentarium. Regardless of which method is selected for primary fixation, the surgeon should maintain a low threshold for augmenting with secondary or supplemental fixation.

13.5.4 Single Versus Double Bundle Reconstruction

The technical aspects of ACLR that contribute to failure are well established. The common theme in many cases is the failure to anatomically recreate the ACL either through tunnel malposition, incorrect graft tensioning, or insufficient graft fixation. Double-bundle (DB) reconstruction is an attractive option to reproduce the functional anatomy of the ACL after a failed primary single bundle (SB) ACLR, particularly if failure was associated with technical error. Not only does DB ACLR adhere to the principles of anatomic reconstruction, but the use of additional graft tissue and material may provide additional restraint in the highly unstable knee [88].

Early biomechanical studies demonstrated superiority of DB over SB ACLR in restoring native knee kinematics and stability [114–117]. However, recent studies comparing anatomic DB to anatomic SB ACLR have questioned these findings [118]. It appears that anatomic graft placement, rather than number of bundles, is of critical importance in restoring native anterior and rotational stability. A clear clinical advantage of DB over SB for primary ACLR has not been borne out in the literature. Although some high-level studies demonstrate a lower rate of failure and revision with DB over SB ACLR [119–123], others dispute these findings [124, 125]. These equivocal results may reflect a trend towards anatomic ACLR leading to more consistent outcomes, regardless of bundle configuration.

When revising SB to a DB ACLR the same anatomic approach is applied, but must take into account the principles of tunnel placement previously discussed. On the femoral side, for non-anatomically located tunnels, there is usually adequate bone stock to accommodate new anatomic tunnels. If tunnel overlap is encountered when placing a new anteromedial tunnel, an over-the-top position may be utilized. On the tibial side, if the existing tunnel is located posterolaterally, a new anatomic anteromedial tunnel can be safely placed. However, if the existing tunnel is anterior and there is insufficient bone stock for two separate tunnels, the original tunnel may be dilated to a diameter of 10–11 mm to contain both the anteromedial and posterolateral grafts. Of course, if significant tunnel widening or overlap is present, staged bone grafting and revision DB ACLR can be performed, but is rarely necessary in the present of existing nonanatomic tunnels [126].

As primary DB ACLR has gained increasing popularity, so to have the number of failed reconstructions requiring revision. The addition of a second pair of tibial and femoral tunnels in DB ACLR can pose technical challenges for the revision procedure and has been referred to pejoratively as “double-bundle – double-trouble” [127]. Again, preoperative confirmation of tunnel position and size using CT or 3D-CT is invaluable and allows for accurate tunnel classification and planning. Hofbauer et al. have proposed a surgical treatment algorithm for management of previous femoral tunnel locations in revision surgery after failed DB ACLR [128]. Ultimately the same principles previously discussed apply, with goal of achieving anatomic, isometric graft placement with adequate fixation. The surgeon must be prepared to apply the various lessons and tools previously reviewed to accomplish this goal [129].

13.5.5 Concomitant Intraarticular Pathology

Concomitant intraarticular pathology is frequently encountered at the time of revision ACLR. Chondral lesions are more common and higher grade during revision than primary ACLR [77, 79, 130]. In particular, patients who underwent prior partial meniscectomy during the primary ACLR are at substantially higher risk of progression of articular cartilage injury [78, 131, 132]. Meniscal injuries are frequently identified, although the rates of concomitant meniscal tear are comparable between primary and revision ACLR, presumably due to treatment at the time of the index procedure [77–79, 130, 131]. And of course, additional ligamentous injury is common and may be found in as many as 40% of cases [79].

In general, concomitant pathology should be addressed prior to or concurrently with revision ACLR. The meniscus is a secondary stabilizer of the knee and should be preserved and repaired whenever possible. Effectiveness of meniscal repair during primary ACLR is encouraging with success rates approaching 90% [133, 134]. Significant meniscal insufficiency (particularly in the medial compartment), such as that seen after subtotal meniscectomy, may require meniscal allograft transplantation to restore the critical secondary stabilization force that the meniscus provides. Finally, associated ligamentous instability must be vigorously sought out and addressed.

13.5.6 Concomitant Osteotomy

Coronal and sagittal plane malalignment is more common in patients undergoing revision than primary ACLR and may contribute to recurrent instability [79, 135, 136]. Varus malalignment has been shown to generate greater in situ graft forces [61, 137]. As a result, proximal tibial osteotomy to correct varus malalignment may protect the ACLR graft during healing and prevent re-rupture. High tibial osteotomy (HTO) to address varus malalignment is a particularly attractive option in the presence of medial compartment pathology. Additionally, a valgus-producing high tibial osteotomy is particularly useful for posterolateral corner insufficiency in the context of a varus-aligned knee as a posterolateral corner reconstruction alone would be under increased forces and potentially lead to failure of the graft. A recent systematic review of available level III and IV studies of concomitant HTO and primary ACLR demonstrated good results and concluded that it is a “salvage procedure for physically active young patients… [with] satisfactory restoration of anterior instability, alleviation of medial compartment osteoarthritis, improvement of subjective evaluations, and a predictable return to recreational sports” [138]. The correction of mechanical alignment with combined HTO and ACLR may also have a sustained impact on gait mechanics to produce a more even force distribution profile across compartments [139].

Increased posterior tibial slope (PTS) has also been implicated as a major risk factor for graft re-rupture and early failure [45, 140, 141]. In a recent case-control study, medial PTS > 5.6° or lateral PTS > 3.8° after ACLR was associated with increased objective anterior laxity at minimum two year follow-up [142]. Proximal tibia anterior closing wedge osteotomy decreases PTS and results in decreased ACL graft forces and reduced anterior tibial translation in vitro [143]. Clinically, proximal tibial anterior closing wedge osteotomy has been shown to increase the durability and longevity of ACLR [144, 145]. This effect may be magnified in the revision setting. Sonnery-Cottet et al. evaluated 5 patients with failed revision ACLR with pathologic PTS $\geq$ 12° who underwent re-revision ACLR with concomitant anterior closing wedge tibial osteotomy at a mean of 31.6 months. PTS was decreased >4° (13.6°–9.2°) with substantial increase in International Knee Documentation Committee (IKDC) score and decrease in objective anterior laxity [144].

13.5.7 Anterolateral Rotatory Instability

The recent “discovery” of the anterolateral ligament (ALL) rekindled interest in anterolateral rotational stabilizers of the knee [146]. While the ALL has been the subject of numerous recent papers describing its anatomy as well as biomechanical and kinematic properties, the concept of anterolateral rotatory instability (ALRI) is far from new [146]. For decades, authors have recognized the importance of anterolateral structures, in particular the iliotibial band (ITB) and its deep capsulo-osseous layer, as secondary restraints to pathological internal tibial rotation. As a result, various lateral extra-articular tenodesis (LET) techniques emerged to address ALRI [147]. Over the years, these techniques have been largely abandoned in favor of intraarticular anatomic ACLR.

Despite refinements in technique and improvements in outcomes, some patients continue to exhibit ALRI after ACLR manifested by a positive pivot shift phenomenon [148]. Recently, attention has shifted to reexamining the discrete role of the anterolateral structures and revisiting the utility of ALL or LET reconstruction to augment ACLR and reduce ALRI. Modern robotic biomechanical ACL sectioning studies have confirmed that the ACL is the primary restraint to ALRI [149, 150]. Sectioning of anterolateral structures in the ACL-deficient knee, including the ALL and anterolateral capsule, results in a modest increase in internal tibial rotation at high degrees of knee flexion [151–156]. Clinically, this may correspond to the high-grade pivot shift test seen with concomitant ACL and anterolateral insufficiency [149]. Supplementation of ACLR with ALL or LET reconstruction decreases internal tibial rotation, but only marginally, and may do so at the expense of overconstraint [155–158]. As a result, it is unclear if anterolateral reconstruction procedures help mitigate pathologic pivot-shift laxity. In fact, recent biomechanical studies have demonstrated that anatomic ACL reconstruction, even in the presence of ALRI and high-grade pivot shift, restores native kinematics and rotational stability without excessive graft forces or the need for anterolateral reconstruction [156, 159, 160].

Consequently, the role of anterolateral reconstruction remains unknown. Treatment strategies and techniques vary widely and there is no consensus on the indications for combined ACL and anterolateral reconstruction [156, 159, 160]. Many authors recommend augmenting ACLR with ALL or LET reconstruction in cases of ALRI with high-grade pivot shift findings to afford additional rotational stability and protection for the ACL graft. However, it is unclear if the addition of ALL or LET reconstruction definitely reduces the incidence of pivot shift postoperatively, and studies have yet to demonstrate improved objective or subjective outcomes [161, 162].

In the revision setting, recurrent or chronic ALRI is common, and may be related to technical failure of primary ACLR or the chronic stretching of the anterolateral capsule secondary to repetitive anterior translation or rotational forces. While those cases of failed nonanatomic ACLR may be effectively treated with revision anatomic ACLR alone with restoration of both anterior and rotational stability, cases that have failed anatomic ACLR and have significant rotational laxity and evidence of anterolateral injury are potentially the most likely to benefit from adjunctive anterolateral reconstruction. In addition, cases in which anatomic revision ACLR is impossible due to anatomic or technical constraints may benefit from concomitant anterolateral reconstruction. In a retrospective review of 163 revision ACLR with a minimum follow-up of two years, the addition of LET reconstruction was associated with lower rates of positive pivot shift postoperatively [163]. A recent computer navigation study echoed these findings, demonstrating that the addition of ITB tenodesis for persistent pivot shift after revision ACLR improved anterior and rotational laxity [164]. While anterolateral reconstruction will likely play a future role in revision ACLR, further research is required to refine the techniques and indications for this adjunctive procedure.

13.5.8 Outcomes of Revision ACL Reconstruction

Outcome data on revision ACLR can be challenging to interpret due to heterogenous patient populations, pathology, surgical technique, and follow-up. Overall, functional outcomes are inferior, rates of return to play are lower, and failure rates are higher than primary ACLR. Meta-analyses of predominantly case series demonstrate objective failure rates ranging from 6 to 14% at a minimum follow-up of two years [165, 166]. Return to sport outcomes are particularly troubling. Although between 75 and 83% return to sport in general, only 43–52% return to the same pre-injury level [167–169]. In addition, many patients will go on to have subsequent operations. In the MARS group, 11% of patients underwent subsequent procedures, of which 19% were revision ACLR. Patients under the age of 20 year had twice the odds ratio of undergoing reoperation [170]. In a community registry study of 2019 patients who underwent revision ACLR, at a median follow-up of 2.2 years, 212 (10.5%) required a subsequent operative procedure, and 86 (4.3%) were revised a second time [170]. Although these rates are based on pooled data and may vary depending on individual patient characteristics, patients should be appropriately counseled prior to surgery. In general, 1 in 10 patients will have objective failure, 1 in 10 patients will need another surgery, and 1 in 2 will return to the preinjury level of sport.

13.5.9 Re-revision

As the number of revised ACLR continues to grow, the number of failed revision ACLR is expected to correspondingly increase. Although repeat revision ACLR can restore stability and improve function, outcomes, particularly return to play, are significantly inferior to primary ACLR and failure rates are higher [171–173]. Progression of degenerative changes is expected and meniscal and chondral injuries are more common at the time of re-revision [172–174]. The same principles of revision reconstruction should be applied in these cases to optimize outcomes. Extensive preoperative evaluation to identify factors related to failure, careful planning and execution of tunnel placement and graft tensioning and fixation, and correction of concomitant pathology is of critical importance. Nevertheless, patients should be appropriately counseled that repeat revision ACLR represents a salvage option and expectations should be tailored accordingly.

13.6 Revision Concomitant Ligament Reconstruction: PLC, LCL, PMC, MCL

13.6.1 Concomitant Posterolateral Corner and Lateral Collateral Ligament Injuries

The posterolateral corner plays a vital role in varus and external rotation stability of the knee. The anatomically important structures include the lateral collateral ligament (LCL), popliteofibular ligament (PFL), popliteus tendon, popliteofemoral ligament, and posterolateral capsule. Important static stabilizers include the LCL, arcuate ligament complex, fabellofibular ligament, and posterolateral capsule. The popliteus complex, biceps femoris, and iliotibial band provide dynamic stability. While the LCL provides a static restraint against varus forces on the knee, the popliteus complex consisting of the popliteus tendon and PFL functions as a dynamic stabilizer on external rotation while the knee is hyperflexed. Special physical exam tests to identify PLC injuries include the dial test, external rotation-recurvatum, posterolateral drawer, posterolateral external rotation, reverse pivot shift, and varus stress tests at 20°–30° of knee flexion. Plain radiographs may show lateral joint space widening or avulsion fractures and advanced imaging should scrutinize the posterolateral corner, especially in the setting of a torn ACL.

The incidence of posterolateral corner (PLC) injuries in ACL-deficient knees ranges from 7.4 to 13.9% and is likely underreported [175]. Failure to recognize concomitant PLC injuries places the ACLR under higher varus, anterior translational, and anterolateral rotational stresses. There is a paucity of literature on combined ACL and PLC injuries partly due to the lower incidence of combined injuries, and partly owing to the likely under-diagnosis of these injuries. When appropriately identified, surgical management of chronic PLC injuries has a 90% success rate and a 10% failure rate [176]. Historically considered the "dark side of the knee," it is imperative to maintain a high index of suspicion for combined PLC/ACL injuries to address them appropriately. In our practice, we routinely get full leg-length alignment films on all ACL revisions, and in any patient with suspected lateral instability, stress radiography is performed to help confirm the diagnosis. Intra-operative stress testing under fluoroscopy will eliminate patient guarding and lateral sided instability can be arthroscopically confirmed with a posterolateral drive-through or significant gapping in the lateral compartment with varus stress (Fig. 13.3).

The largest systematic review by Bonanzinga et al. included 6 studies and 95 patients with combined ACL/PLC injuries. The majority underwent surgical management of the PLC injury ($n = 72$) with a variety of techniques [177]. However, the best results were those patients who underwent simultaneous ACL and PLC reconstruction. On objective postoperative assessment, there was a mean side-to-side anteroposterior laxity difference of 1.5 ± 1.1 mm, comparable with what is reported in the literature for isolated ACLR [178, 179]. Additionally, 59 (88%) patients undergoing simultaneous ACL and PLC reconstruction were graded as good/excellent on IKDC objective evaluation. Those combined injuries in which the PLC was treated nonoperatively did not perform as well. Kim et al. also demonstrated a comparable result with combined ACL and PLC reconstruction [178]. While there is a paucity of literature on the management of combined ACL and PLC tears, the available data favors simultaneous reconstruction.

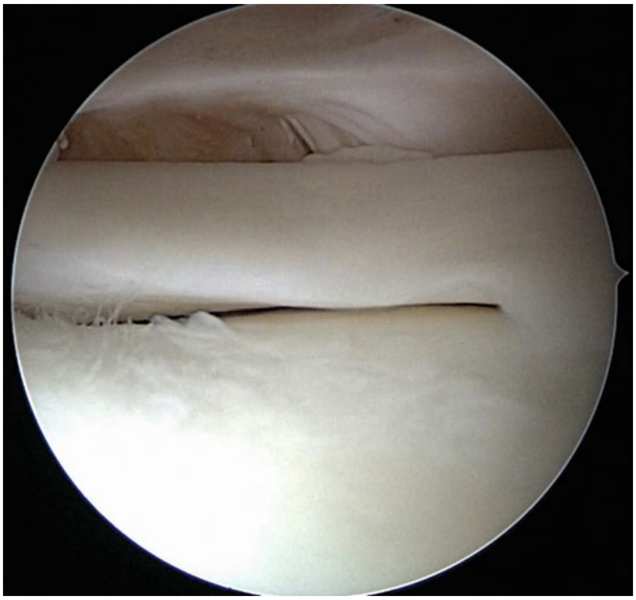

Fig. 13.3 Increased arthroscopic lateral joint line gapping with varus stress in a patient with failed ACL reconstruction and recurrent posterolateral corner insufficiency. This patient went on to receive revision ACL reconstruction with reconstruction of the posterolateral corner

There are numerous techniques described to reconstruct the PLC. They can be broadly classified as anatomic or non-anatomic. In the setting of a MLK injury or revision ligamentous reconstruction, we recommend reconstructing all three clinically significant structures of the PLC, including the lateral collateral ligament (LCL), popliteal tendon (PT), and the popliteofibular ligament (PFL). The largest series of anatomic PLC reconstructions addressing all three structures was published by LaPrade et al. [175] Although technically demanding, biomechanical studies have shown that they restore stability better than non-anatomic techniques or reconstructing two out of three PLC structures [180, 181]. Studies have shown the superiority of reconstruction over repair of the PLC [182, 183]. In the setting of revision concomitant PLC injury associated with ACL tears, we recommend a more robust anatomic reconstruction of the PLC for those patients with significant rotational laxity or those that fall into varus and recurvatum (Fig. 13.4) on EUA. For cases of subtle posterolateral laxity, we typically perform a figure of eight trans-fibular reconstruction with tunnels reapproximating the LCL and popliteal insertions of the femur. For cases of more pronounced rotational laxity, varus thrust, or varus and recurvatum on examination, we perform the split-Achilles method described by LaPrade et al. [175]. In both cases, the posterolateral capsule can be incised longitudinally and imbricated which further enhances post-operative stability.

Regardless of the choice of construct, it is critical in these procedures to recognize the limited amount of bone in the lateral femoral condyle. In the context of ACL fixation, it is important to err the PLC femoral tunnels anterior and proximal in order to avoid converging with ACL hardware or tunnels. Additionally, larger bone defects in the setting of revision ACL reconstruction may have a higher percentage chance of convergence with PLC tunnels. If real estate is limited laterally, one could consider the use of a single fixation device such as a femoral screw and washer in a figure of eight pattern or revising the ACL using an over-the-top type fashion. If a screw and washer is chosen and bone quality is suboptimal, bicortical femoral purchase of the screw is recommended. Outside-in drilling of the ACL may also pose a particular challenge with posterolateral corner reconstructions, as this adds yet another aperture on the lateral side of the femur and the angle of approach of the tunnel is significantly different from the angles subtended by transtibial or anteromedial portal drilling techniques. Surgeons must take caution in these cases as tunnel convergence may subsequently lead to loss of fixation and early failure.

Fig. 13.4 Examination under anesthesia demonstrating varus and recurvatum of the knee. This patient went on to undergo PLC reconstruction using split Achilles allograft

13.6.2 Concomitant Posteromedial Corner and Medial Collateral Ligament Injuries

While the posterolateral corner was long considered the "dark side of the knee," extensive research has focused on evaluation and management of PLC injuries. Considerably less literature exists on the posteromedial corner (PMC), with some authors referring to it as "the neglected corner" [65]. Initially the structures of the medial side of the knee were typically divided into three layers, superficial to deep. Layer I consists of the deep fascia. Layer II consists of the superficial MCL, and layer III includes the joint capsule and the deep MCL. A more recent description by Robison et al. divides the medial side of the knee into thirds from anterior to posterior [184]. The anterior third extends from the medial border of the patellar tendon to the anterior border of the longitudinal fibers of the superficial MCL. The middle third is composed of the width of the longitudinal fibers of the superficial and deep MCL. The posterior third is regarded as the PMC and extends from the posterior border of the longitudinal fibers of the MCL to the medial edge of the medial head of the gastrocnemius muscle. The posteromedial corner includes the posterior oblique ligament, semimembranosus tendon, oblique popliteal ligament, posteromedial joint capsule, and the posterior horn of the medial meniscus. In patients with evidence of posteromedial corner injury, the POL is the most commonly injured structure [185]. Combined ACL/PMC injuries occurred in 78% of patients. Injury to the PMC may result in what is termed anteromedial rotatory instability (AMRI) and can be identified by applying a valgus stress at 30° of knee flexion while the foot is simultaneously externally rotated. Additional testing includes valgus stress at 0° and 30° knee flexion, as a significant PMC injury can cause valgus opening in both 0° and 30° of flexion. Additionally, internally rotating the knee with application of a posterior drawer results in tightening of the posteromedial structures, and laxity in this regard could signify injury to these structures.

Unlike the posterolateral corner, repair of the posteromedial corner and MCL has been shown to effective in restoring knee stability and improving functional outcomes. The failure rate for primary PMC repair ranges from 6.1 to 20% [183, 186]. On the other hand, Stannard et al. showed that for knee dislocations with combined injuries including the PMC, reconstruction was superior with an overall 96% success rate for achieving postoperative valgus stability [183]. In cases of revision concomitant injuries, multiple procedures can restore posteromedial stability, if needed, ranging from anatomic to non-anatomic. We prefer the technique described by LaPrade and Wijdicks [187] for significant anteromedial rotatory instability, whereby the proximal and distal divisions of the superficial MCL and the POL are anatomically reconstructed using two separate grafts. In their series of 28 patients who underwent this technique, they noted a mean improvement of 33 points in IKDC scores, elimination of side-to-side instability in all patients, and a mean of 1.3 mm of increased medial compartment gapping postoperatively (vs. 6.2 mm preoperatively) on stress radiographs side-to-side comparison. Two alternative techniques exist that use the native semitendinosus tendon and keep the distal insertion of the tendon intact have been described with promising early results [188, 189].

Isolated MCL injuries are the most common ligamentous injury to the knee, with the majority lower grade sprains.

Grade 3 MCL injuries have a nearly 78% rate of associated injury, with over 95% of these involving concomitant injuries to the ACL [190]. While isolated MCL injuries can be successfully treated nonoperatively with bracing, there is significant controversy when it comes to multiligamentous knee injuries. Nonoperative treatment of grade I and II MCL injuries is widely accepted. However, as long as ACLR is performed, MCL repair, reconstruction, and nonoperative treatment all have shown good results. Halinen et al. performed a RCT that showed equal results with both surgical repair and nonsurgical management of MCL tears, with the only caveat that the MCL repair group took longer to regain motion and strength [191]. MCL injury morphology may be more important. Nakamura et al. showed that the majority of femoral-sided injuries can heal with nonsurgical management, whereas tears through the mid portion may not regain valgus stability with nonoperative treatment [192]. Robins et al. found that distal MCL injuries allowed a much faster return of knee motion relative to femoral-sided tears [193]. In general, most authors agree that subacute ACLR should be performed once full motion has returned. Valgus instability should be assessed at that time and MCL repair or reconstruction performed in those patients with persistent valgus instability.

In cases of revision ACLR with medial instability, we prefer to first reconstruct the ACL and then re-evaluate medial opening. Often, reconstruction of the cruciate will reduce medial laxity. However, we tend to be more aggressive in the cases of revision reconstruction as coronal instability patterns can lead to ACL failure. Typically, we will completely fix the ACL and then proceed with MCL reconstruction with Achilles allograft with a bone plug contoured to a diameter of 9 mm. We prefer the subcutaneous method of graft passage. A small incision is made directly over the medial epicondyle and dissection is taken to the bone. A guide pin is placed just proximal and posterior to the medial epicondyle and can be checked with fluoroscopy, if needed, for confirmation. We then place another guide pin approximately 6–7 cm distal to the joint line about half-way between the posteromedial flare of the tibia and the tibial tubercle. We then place a suture around the pins and range the knee to assess for isometry. Subtle adjustments can be made with the pins to ensure isometry. The femoral tunnel is reamed in a blind-ending fashion and the bone block placed and affixed proximal to the bone block with a metal interference screw. The graft is then tested to ensure there is no pull-out of the bone block. If the fixation is tenuous, one can upsize the interference screw or back up the fixation with a button which is passed to the lateral side of the knee (Fig. 13.5). The graft is then shuttled distally and affixed with a spiked washer and screw with the knee in 30° of flexion, varus, and neutral rotation. Additionally, suture anchors can be placed more proximal to augment the reconstruction at the proximal insertion site of the superficial MCL. In cases of significant rotatory instability combined with valgus laxity, we will perform the anatomic reconstruction described by LaPrade with the addition of a posteromedial capsular imbrication.

Fig. 13.5 Image depicting an MCL reconstruction using two modes of fixation in the femur; aperture fixation with a metal interference screw and cortical fixation using a cortical button

13.7 Authors' Preferred Technique

Revision ACLR, particularly with concomitant pathology, is complex and every case unique. As a result, it is challenging to recommend a standardized technique that will encompass all cases. While algorithms have been proposed, these are often exceedingly convoluted or oversimplified. Instead, we have tried to present our general strategy and specific techniques to employ when approaching these challenging cases.

As we have previously emphasized, preoperative planning begins long before the operating room. The workup should focus on identifying the etiology or factors contributing to failure. Special attention should be paid to identifying and classifying any concomitant pathology. Imaging should be liberally obtained, and usually includes radiographs, alignment films, MRI, and CT with 3D reformatting if there is a question of tunnel malposition or widening.

Once the diagnosis is confirmed, an in-depth conversation is had with the patient. Goals and expectations should be realistic. The patient should understand that the surgery may be more technically demanding, the recovery more challenging, and the outcomes ultimately inferior to primary reconstruction. Many patients may not wish to undergo the extensive recovery and rehabilitation process required. Proceeding with surgery is a commitment on the part of the patient as much as the surgeon—it is a substantial investment that not every patient will choose to make.

Once we agree to proceed with operative management, we start by assessing the existing bone tunnels. Well-positioned tunnels may simply be reused. If the tunnels are completely malpositioned, new anatomic tunnels can be created. If there is significant tunnel overlap, we generally find that new tunnels may be created, but we will supplement with bone graft or larger interference screws to fill any voids. In cases of significant tunnel widening (considered greater than 14 mm in diameter) we usually elect to perform the procedure in two stages. The first stage consists of hardware and graft removal followed by bone grafting. It is vital to debride the existing tunnels of residual graft, fibrous tissue, and sclerotic bone. Sclerotic borders can be removed with use of curettes or reamers. Revision hip arthroplasty reamers are particularly helpful to over-ream large, capacious defects. We prefer to fill cylindrical defects with press-fit allograft plugs (Fig. 13.6) soaked either in platelet-rich plasma (PRP) or bone marrow aspirate concentrate (BMAC). Large, non-cylindrical defects are filled with a mixture of demineralized bone matrix and corticocancellous chips again soaked in PRP or BMAC (Fig. 13.7). Repeat CT imaging is obtained in 3–4 months and a second stage ACLR is usually performed within 4–6 months once bone graft incorporation has matured.

Graft choice depends on available options, but we generally prefer to use ipsilateral BPTB or quadriceps tendon autograft in revision ACLR as these provide robust autograft material with bone. If autograft is not available or declined, we prefer BPTB or Achilles tendon allograft, as again, the bone block from these grafts is reliable to fill pre-existing defects and the graft can be strategically placed to mimic the

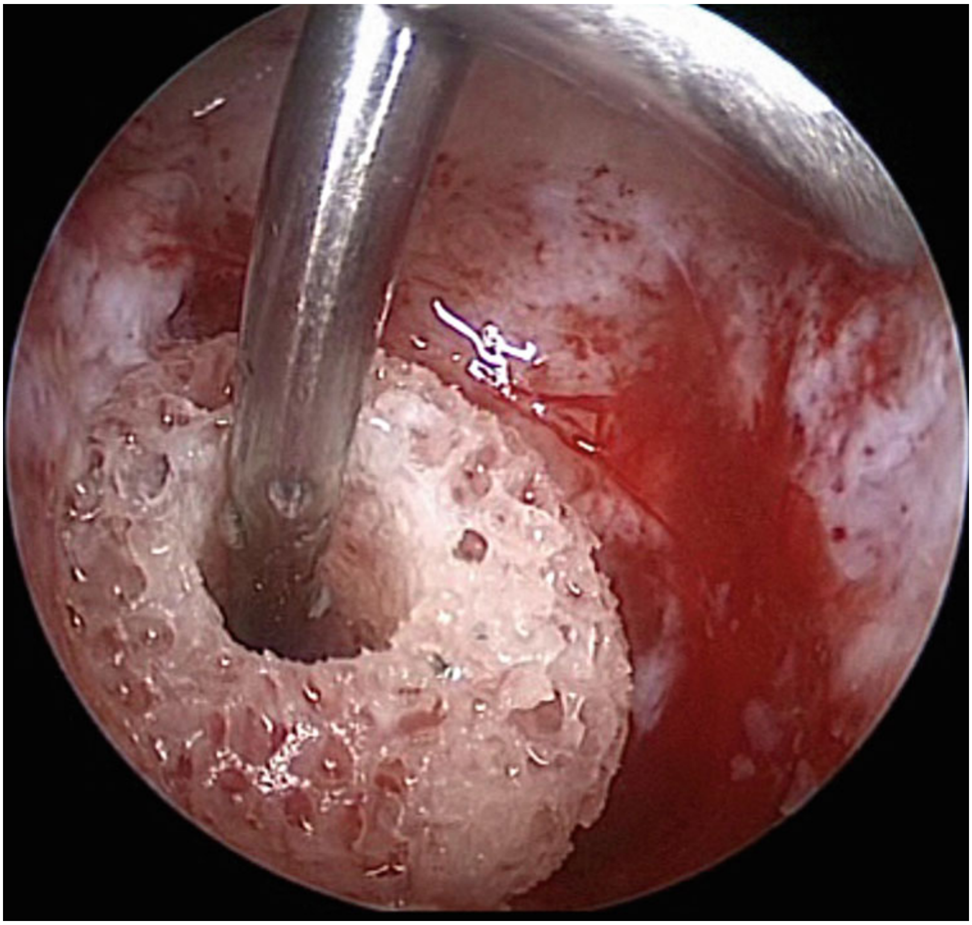

Fig. 13.6 Placement of a pre-fabricated bone dowel into a cylindrical tibial tunnel

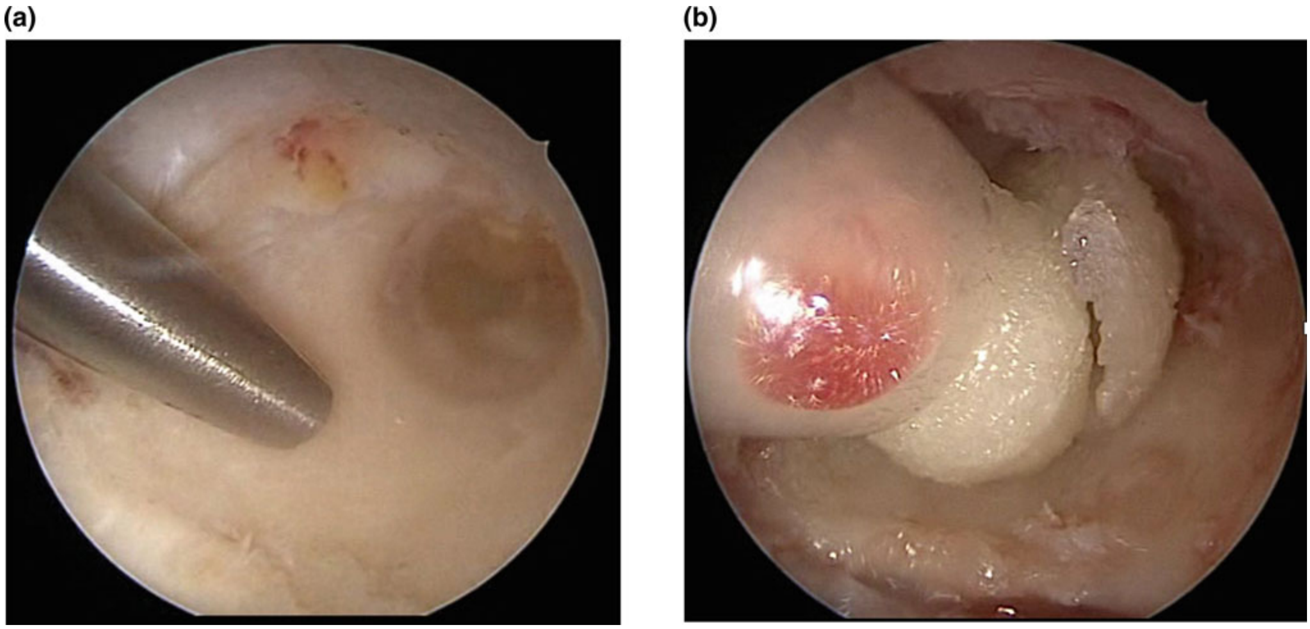

Fig. 13.7 Bone grafting using corticocancellous chips mixed with demineralized bone matrix. This can be delivered into a non-cylindrical tunnel (**a**) using flexible delivery devices (**b**)

natural trajectory of the ACL. We prefer to avoid hamstring autograft as we feel the graft size is unpredictable and healing within a potentially compromised bone tunnel is more efficient and reliable with a bony substitute. Bone blocks can be contoured to match the existing defect and often mitigate the need for a two-staged revision.

Varus malalignment should be addressed with a concomitant opening wedge HTO. Although the hardware construct will depend upon surgeon preference, we prefer systems that permit us to drill the tibial tunnel independently of the osteotomy. Biplanar HTO may be considered for patients with combined varus malalignment and increased posterior tibial slope.

Concomitant intraarticular pathology can be addressed during revision ACLR. Medial or lateral meniscal deficiency may necessitate meniscal transplant. For medial meniscal allograft transplantation we use a bone plug technique to avoid the ACL graft. Cartilage restoration procedures may also be considered, particularly in the revision setting where they are more commonly encountered. We usually reserve cartilage restoration procedures for the final step or second stage of the revision once malalignment is corrected and ligamentous stability is restored.

Concomitant ligamentous pathology is preferably addressed at the time of the revision procedure. If a single stage reconstruction is chosen, we usually reconstruct intraarticular followed by extraarticular ligamentous structures as we prefer the arthroscopic portion to be done under tourniquet, and, if needed, the tourniquet can be easily released for the open portion of the procedure. If a two-stage approach is selected, extraarticular procedures may be performed during the first stage while waiting for consolidation of bone tunnels. When performing revision MLK reconstruction procedures it is important to consider the limited bone stock of the distal femur to avoid tunnel convergence. In particular, when performing concomitant PLC reconstruction, the femoral tunnels are placed anatomically and angled anterior and proximal to avoid convergence with the new ACL tunnel. Fluoroscopy is a valuable tool to predict and confirm accurate tunnel placement. Adjunctive ALL or LET reconstruction is considered in patients with residual rotational instability or evidence of anterolateral injury after revision ACLR. Cases in which anatomic revision ACLR is impossible due to anatomic or technical constraints often fall into this category. In the case of the multiple ligament injured knee, we will tension and completely affix the PCL first to get the tibia anatomically reduced under the femur, followed by the extra-articular structures, then the ACL last.

Although these cases are often complex, outcomes can be optimized with careful planning and systematic execution. On the day of surgery, it is helpful to have an experienced operative team that has been thoroughly briefed. There should be a clear plan with contingencies for different scenarios. Equipment should include instruments for hardware removal, various drilling sets (transtibial, anteromedial, retrograde, etc.), different fixation systems (staples, screw-and-washers, interference screws, suture anchors, etc.), bone graft material or substitute, and fluoroscopic imaging. A well-prepared operative team and surgeon will greatly improve the chances of a successful outcome.

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Part VII

Surgical Treatment of the PCL Based Multiple Ligament Injured Knee

14

Arthroscopic Primary Repair in the Multiple-Ligament Injured Knee

Anne Jonkergouw, Jelle P. Van der List, and Gregory S. DiFelice

14.1 Introduction

Injury of the multiple-ligament injured knee (MLIK) involves injury of at least two of the four major knee ligaments, consisting of the anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), medial collateral ligament (MCL), and the lateral collateral ligament (LCL) or the posterolateral corner (PLC) [1–3]. Multiligamentous injury often results from traumatic knee dislocation or high-energy trauma and is strongly associated with periarticular fractures and neurovascular damage [1–9]. The presence of both ligamentous and associated injuries is commonly described according to the Schenck classification [10, 11].

Initial evaluation of the MLIK should consist of thorough physical and radiologic examinations to recognize all injured structures in a timely fashion. Assessment of popliteal artery injury should include measurements of the ankle–brachial index (ABI), and selective vascular imaging if the ABI is <0.9 [7, 8, 12, 13]. In addition, both sensory and motor functions of the common peroneal and tibial nerve should be tested, and standard radiographs and magnetic resonance imaging (MRI) should be performed to assess the extent of injury [1, 2, 5, 14]. In the non-acute setting, bilateral stress radiographs can further help to identify ligamentous injuries [15, 16].

Treatment of knee ligaments generally consists of an “all or nothing approach” with either conservative management or reconstruction for each individual ligament. In patients with an MLIK, collateral and cruciate ligaments are treated in either combined or staged fashion. Anatomical reconstruction of all injured ligaments concurrently is most advocated, using both autografts and allografts [17–19]. Although good functional outcomes can be achieved, the most common complications are pain, recurrent instability, and knee stiffness, commonly requiring secondary operations [20–25]. There is controversy regarding the timing of surgery and graft choice to reduce such complications; however, the procedure itself remains technically challenging and is surgically invasive. Autografts need to be harvested, while allografts have higher risk of complications and failure, and multiple tunnels need to be drilled, which causes loss of bone stock and risk of tunnel convergence [14, 18, 26]. Subsequently, a rigorous and lengthy rehabilitation program needs to be followed to regain muscle strength, range of motion, and avoid arthrofibrosis [18, 27–29].

Although reconstruction has become the standard of treatment, primary repair of knee ligaments has recently regained interest, due to good clinical outcomes of modern primary repair of both isolated and multiligamentous injuries [30–32]. Differently from historical primary repairs, the significance of careful patient selection is recognized and surgical techniques have advanced, including arthroscopy and use of nonabsorbable sutures [33, 34]. In addition, internal suture augmentation has become available, which provides support and is thought to prevent excessive stretch of the healing ligament. Several authors have advocated adding internal suture augmentation consisting of FiberTape (Arthrex, Naples, FL) to primary ligament repair, which is often described as internal bracing [35–38].

A main advantage of primary repair is the preservation of native tissues, which preserves proprioceptive function and prevents the need for graft harvesting and tunnel drilling, which expectedly minimizes recovery time and makes revision surgery less complicated, if needed in the future (Table 14.1) [39–42]. Furthermore, several experimental studies and long-term historical studies have suggested that the incidence of osteoarthritis is reduced with primary repair when compared to ACL reconstruction [43, 44].

Following encouraging results of primary repair of isolated ligamentous injuries, primary repair has been increasingly advocated for the MLIK. In this chapter, we discuss

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Table 14.1 Advantages and disadvantages of arthroscopic primary repair

Advantages	Disadvantages
Minimally invasive alternative to arthrotomy	Not all patients are eligible
Possibility to repair all injured knee ligaments at once	No consensus in literature on patient selection
Allows early rehabilitation by the use of suture augmentation	Feasibility of the technique is time-dependent
Preservation of native tissues	Reported outcomes are sparse
• Native ligaments	
• Graft harvesting sites	
• Bone stock	
No use of allografts	
No risk of tunnel convergence	
Less complicated revision surgery if needed, comparing with primary reconstruction	

the (I) indications for primary repair in the MLIK, (II) surgical technique of primary repair of all knee ligaments, (III) postoperative management, (IV) historic and recent results of primary repair in the MLIK, and (V) two case examples.

14.2 Indications for Primary Repair

14.2.1 Patient Selection

Patient selection, based on tear type, is considered critical for the success of primary repair. Historically, ACL repairs were performed with an open approach regardless of tear type, which led to disappointing results and ultimately to abandonment of this method in the early 1990s. Reviewing these results and performing subgroup analyses, it was noted that outcomes of primary repair were better in patients with proximal tears when compared to midsubstance tears [33, 34, 39, 45]. Subsequent studies in which patients were selected accordingly have achieved good outcomes [31, 35, 40, 46–50]. Thus, we believe primary repair is well indicated in patients with a proximal or distal avulsion tear with sufficient tissue length to be reapproximated to its footprint and with sufficient tissue quality for good purchase of repair sutures.

14.2.2 Incidence of Repairable Tears

Recent studies have assessed the incidences of tear types for each individual knee ligament. Regarding isolated ACL injuries, Van der List et al. [51] found that 43% of all tears were located within the proximal quarter, which included 16% proximal avulsion tears, and Halinen et al. [52] found 91% were proximal ACL tears. Subsequently, Van der List et al. [53] showed that 90% of proximal ACL avulsion tears were repairable and 46% of the other proximal tears. Goiney et al. [54] reported that 44% of their cohort of 50 PCL tears were repairable, which all had a distal fragment length of ≥ 41 mm. Furthermore, Twaddle et al. [4] assessed eligibility of repair for each ligament in the MLIK and noted that 51% of PCL, 68% of MCL, and 84% of LCL injuries were either repairable proximal or distal avulsion tears, and noted that 19% of ACL tears were distal avulsion tears (unfortunately they did not asses proximal ACL tears as it was believed at that time that these could not be repaired).

These studies indicate that a significant share of ligaments is repairable in the MLIK. Preoperative MRI can initially predict the eligibility for primary repair of each individual ligament, based on tear location (Figs. 14.1 and 14.2) [4, 53, 54]. It should be emphasized that the final assessment for repair will always be made intraoperatively.

14.2.3 Timing

In addition to tear location, tissue quality is important for successful primary repair. Several studies have shown that tissue quality decreases over time, leading to the general principle that primary repair should be performed in the acute or subacute phase [39–41, 55]. Although the demarcation between acute and chronic is arbitrary and used variably in the literature [17, 56], it is generally recommended to perform MLIK surgery between 1 and 3 weeks after injury [2, 17]. Therefore, the senior author generally repairs all repairable ligaments in this time frame, whereas midsubstance tears, or tears with insufficient tissue quality, are reconstructed either concomitantly or in a staged fashion. Although collateral ligaments are known to have

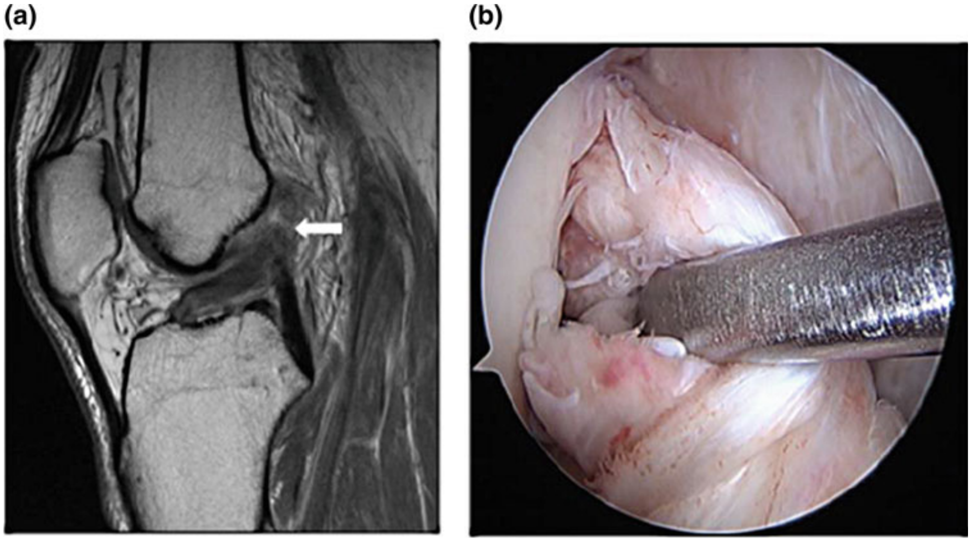

Fig. 14.1 **a** Sagittal fast-spin echo MRI demonstrates a full-thickness tear of the ACL (*arrow*), within the proximal quarter of the ligament. Based on the proximal location of this tear, eligibility for primary repair is likely. **b** Arthroscopic assessment of the ACL tear (in the right knee) of the same patient. The ligament has sufficient length and excellent tissue quality to perform primary repair

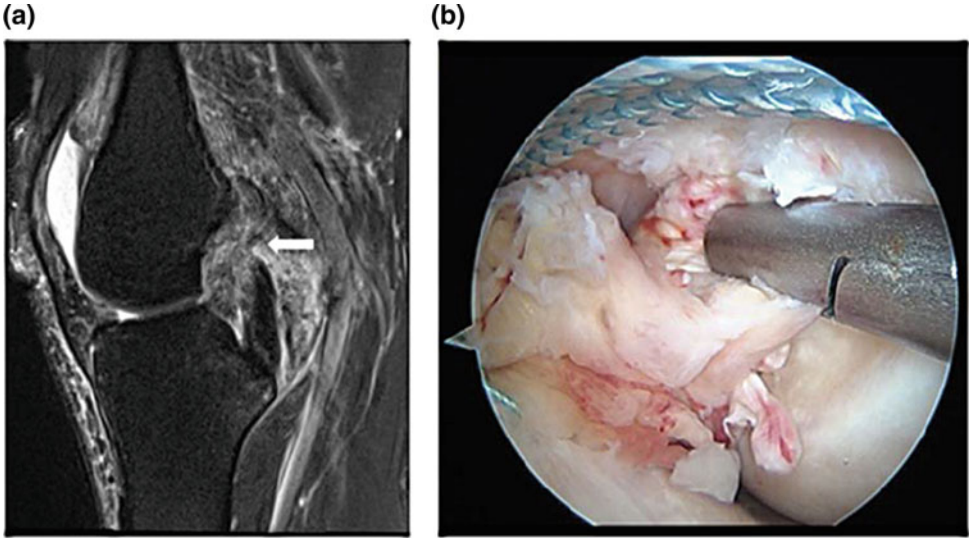

Fig. 14.2 **a** Sagittal T2-weighted fat-suppressed MRI demonstrates a full-thickness tear of the PCL (*arrow*). Based on the proximal location of this tear, eligibility for primary repair is deemed likely. **b** Arthroscopic assessment of the PCL tear (in the right knee) of the same patient. The ligament has adequate length and tissue quality to perform primary repair

spontaneous healing capacity, surgery is performed to prevent residual laxity and allow to start rehabilitation quickly, rather than waiting for the collateral ligaments to heal [52, 57, 58].

It should be mentioned that a proximally avulsed ACL can heal nonanatomically to the femoral notch or PCL, and may therefore be repairable in the chronic setting [59]. Crain et al. [55] reported that 38% of the ACL tears had healed to the PCL, 8% to the intercondylar notch, and 12% to the lateral wall of lateral femoral condyle. Only 42% of all knees had the ACL resorbed after injury. These nonanatomically healed ligaments can, even in the chronic setting, be dissected from the PCL or intercondylar notch, and repaired to the anatomical footprint if sufficient length and quality are present [55, 59, 60].

14.3 Surgical Technique (Table 14.2)

14.3.1 Surgical Preparation

Patients receive general or regional anesthesia and a peripheral nerve block, after which they are placed in supine position on a standard operating table with a tourniquet placed high on the thigh. Intravenous antibiotics are administered prior to tourniquet inflation and skin incision. Then, the affected knee is examined and compared with the contralateral side. Laxity is graded as 1+ (if 0–5 mm), 2+ (if 6–10 mm), or 3+ (if >10 mm). In addition, if desired, medial-, and lateral-sided injuries can be identified using varus and valgus stress radiographs [15, 16]. The operative

Table 14.2 Technique of arthroscopic primary repair

Surgical step	Details
Preparation	Patient in supine position
	Tourniquet high on thigh
	Arthroscopy, ligament reconstruction, and rotator cuff repair instruments
Approach	Standard anterolateral and anteromedial portal for routine arthroscopy
	Accessory inferomedial portal to keep away repair sutures
	Posteromedial portal to visualize the tibial PCL insertion
Ligament suturing	Individual bundles are sutured separately
	Interlocking Bunnell-type suture patterns, using the Scorpion suture passer
	Approximately 3–4 passes from intact substance to torn end
	The final suture passes should exit toward the femur
Anchor fixation	Using 4.75-mm Biocomposite SwiveLock suture anchors
	Anchor deployment in bone sockets at anatomical origin
	One preloaded anchor per ligament, using FiberTape/TigerTape (typically the anteromedial ACL bundle and anterolateral PCL bundle)
Suture augmentation fixation	The FiberTape/TigerTape ends are guided through drill holes through the tibia
	The ACL augmenting internal brace is usually tensioned first, with the knee near full extension
	Both internal braces are fixated at the anteromedial tibial cortex

leg is prepped and draped in the normal sterile fashion. The standard knee arthroscopy and knee ligament reconstruction sets are supplemented with shoulder arthroscopy equipment, including a Scorpion Suture Passer (Arthrex) and various instruments that are used for rotator cuff and labral repair surgery.

14.3.2 Sequence of Repairs

Preferably, all injured ligaments are treated during one surgery, although occasionally non-repairable tears are reconstructed in a staged fashion [17]. Generally, medial- and lateral-sided injuries are treated first in order to achieve fluid control during subsequent arthroscopy. Then, standard knee arthroscopy is performed, followed by assessment of cruciate ligaments for tear type and tissue quality, which define eligibility of primary repair. If both cruciate ligaments are deemed repairable, the ACL is usually treated first to allow control of the ligament substance and better visualization of the PCL.

Recently, addition of suture augmentation, consisting of a braided tape, has become the standard of treatment for the senior author. Due to multidirectional instability in the MLIK, augmentation of ligaments is needed to protect the integrity of the repaired ligaments and to enable early range of motion without endangering ligament healing. The technique of addition of suture augmentation is discussed with each surgical technique per ligament.

14.3.3 Surgical Technique of MCL Repair

For MCL and possible posteromedial corner (PMC) repair, a medial approach is used with the knee in 90° of flexion and the hip in external rotation and abduction. A small incision is made from proximal to the medial femoral epicondyle to distally, approximately extending over 4–5 cm. Superficial dissection is carried out to expose the deep fascia, while the infrapatellar branch of the saphenous nerve is identified and protected if possible, and layer 1 is opened to identify the superficial MCL and posterior oblique ligament (POL). Most commonly, the superficial MCL is proximally (or distally) avulsed, which requires careful exposure and identification of the femoral (or tibial) origin. Both the injured MCL and POL are generally repaired with one proximal suture anchor, as described by Lubowitz et al. [35] and Van der List et al. [38], and additional deep MCL injury can be simply repaired using SutureTak suture anchors (Arthrex). These medial injuries can be variable. At times, simple interrupted repair stitches in the torn capsule can facilitate anatomic reduction of the tissues, especially if there was a large rotational component to the injury mechanism.

After repair of deep layers, a no. 2 FiberWire (Arthrex) suture is placed into the superficial MCL in an interlocking Bunnell-type pattern. Subsequently, a bone socket is punched and tapped in the proximal and slightly posterior aspect of the medial femoral epicondyle. A 4.75-mm SwiveLock (Arthrex) suture anchor (preference of senior author is Biocomposite), which has been loaded with the repair suture and one FiberTape, is used to fixate the superficial MCL at the femur. The remaining suture limbs and core sutures of the anchor are then used to advance the POL proximally and further oppose the torn tissues.

Next, a second small incision is made over the tibial insertion of the superficial MCL, approximately 6 cm distal to the joint line, where layer 1 is opened to expose the distal fibers. Using a clamp, the MCL is followed proximally toward the proximal incision, where the FiberTape is retrieved and shuttled distally. Finally, the FiberTape is tensioned with the knee in 30° of flexion and a varus force applied, after which it is fixated at the tibia with a second suture anchor to complete the suture augmentation. Prior to removing the handle of the SwiveLock, the knee is taken through its full range of motion to ensure that the knee has not been captured and that appropriate tension has been restored. It should be noted that we are describing a two-incision technique that is generally applicable for proximal or distal tears. With more complex medial-sided injuries, a full incisional approach is generally used.

14.3.4 Surgical Technique of LCL and/or PLC Repair

A standard approach to the PLC is performed, using a curved incision over the lateral aspect of the knee, arcing down between Gerdy's tubercle and the fibular head. Sharp dissection is carried out to the level of the iliotibial band (ITB), and the anterior and posterior skin flaps are mobilized. The extent of injury can now be assessed. If the ITB is intact, the fascia between the ITB and biceps femoris is incised, while the peroneal nerve is identified on the posterior border and protected. A windowed approach can be helpful to access the LCL in this situation. One window can be made at the epicondyle to visualize the proximal aspect of the LCL, whereas middle and distal windows (made at the fibular head) are helpful for visualizing the mid- and insertional aspects of the LCL. Further posterolateral dissection is used to expose the structures of the posterolateral corner toward the lateral joint capsule as necessary.

For a proximal LCL avulsion, the fibular head is exposed via a distal window, and an oblique drill hole is placed into the fibular head from anterolateral to posteromedial. A FiberTape is passed through the fibular head using a Micro SutureLasso (Arthrex). Using a clamp to tunnel under the ITB, the ends of the FiberTape are retrieved proximally at the lateral femoral epicondyle, where they are left for later use. A whipstitch of no. 2 FiberWire is placed into the proximal aspect of the LCL. Then, a SwiveLock suture anchor (Biocomposite) is placed into the lateral epicondyle, together with the ends of the FiberWire and FiberTape.

If the LCL is avulsed distally, a 4.75-mm SwiveLock (Arthrex) suture anchor (Biocomposite) is placed into the lateral epicondyle at the origin of the LCL. This is preloaded with FiberTape, which is then passed underneath the ITB with a clamp along the substance of the LCL. Again, a small drill hole is made from anterolateral to posteromedial on the fibular head. The two limbs of the FiberTape are retrieved from opposite directions through this tunnel. A locking repair stitch of No. 2 FiberWire is then placed into the distal aspect of the LCL. The repair stitches and the FiberTapes can then be anchored to the anterolateral aspect of the fibular head by placing a 4.75-mm SwiveLock (Biocomposite) along the course of the drill hole. The anchor will act as an anchor for the FiberWire, and as an interference screw in the tunnel for the FiberTape. The tensioning and fixation step is made with the knee 30°–45° of flexion with a slight valgus force applied in neutral rotation.

In both cases, repair sutures are used to reapproximate the LCL to its anatomical origin or insertion site and the FiberTape acts as internal brace augmentation. There are many ways to anchor repair stitches and tapes, and some authors prefer a drill hole with or without suspensory fixation. These choices will be made by individual surgeon preference. As with the medial-sided injuries, there are often capsular tears and/or avulsions with these injuries depending on the exact mechanism of injury. Commonly noted with distal LCL avulsions are anterolateral capsular avulsions. These structures can be easily reapproximated anatomically using labral anchors such as the SutureTak (Arthrex).

14.3.5 Surgical Technique of Arthroscopic ACL Repair

First, an anterolateral scoping portal and an anteromedial working portal are created and routine knee joint inspection is performed. Any necessary meniscal or chondral work is performed first. The ligamentum mucosum and part of the infrapatellar fat pad can be excised to improve joint visualization. A small opening notchplasty is often performed to improve visualization and encourage some bleeding to enhance ligament healing. Then, the cruciate ligaments are assessed for tear type (length of the distal remnant) and tissue quality (degree of fraying of the fibers and ability to withhold sutures). The ligaments are probed and assessed with a grasper. Attempts are made to reapproximate the ligaments to their anatomical origins (Figs. 14.3 and 14.4) to assess their length and potential for repair. It should be noted that the PCL can falsely appear too short due to posterior tibial sagging, which can be corrected by an anterior drawer force. When primary repair is deemed feasible for either of the cruciate ligaments, a malleable Passport Button Cannula

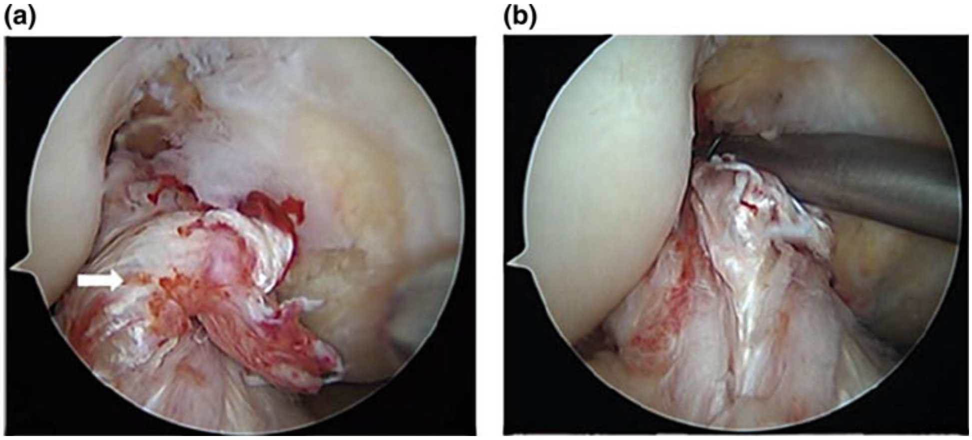

Fig. 14.3 Arthroscopic view of a right knee, viewed from the anterolateral portal with the patient supine and the knee in 90° of flexion. **a** There is a proximal avulsion tear of the ACL. The posterolateral bundle is flipped forward (*arrow*). **b** The bundles are grasped and put back in their anatomical position to assess length and tissue quality of the remnant, which appear sufficient for primary repair

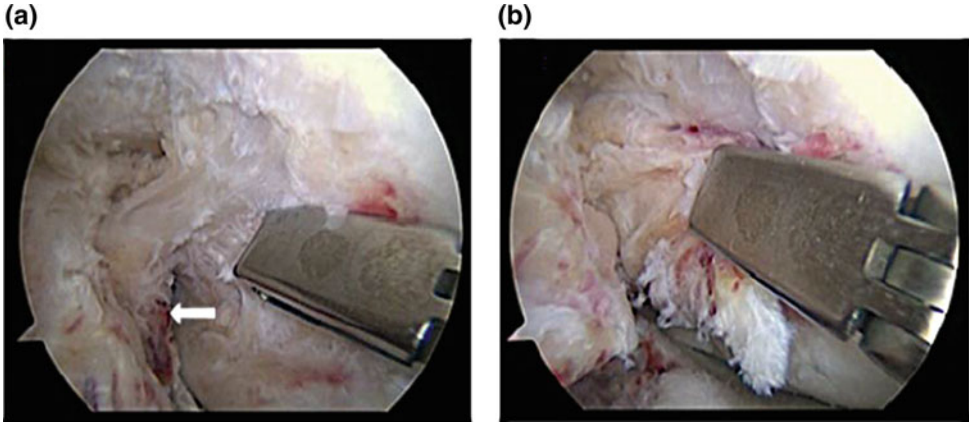

Fig. 14.4 Arthroscopic view of a right knee, viewed from the anterolateral portal with the patient supine and the knee in 90° of flexion. An anterior drawer force is applied. **a** There is a proximal avulsion tear of the PCL and the remnant has been retracted distally (*arrow*). **b** The PCL is grasped and pulled toward its femoral footprint (behind the grasper) to assess length and tissue quality of the remnant, which appear sufficient for primary repair

(Arthrex) is inserted into the anteromedial portal to facilitate suture management and prevent soft-tissue bridges from forming.

The surgical techniques of arthroscopic primary ACL repair with [37] and without [61] suture augmentation have been extensively described previously and will be described here briefly. First, the anteromedial (AM) bundle is sutured (Fig. 14.5a) with nonabsorbable No. 2 FiberWire (Arthrex) using a reloadable Scorpion Suture Passer (Arthrex) in order to create a Bunnell-type suture pattern from the intact substance (distally) toward the avulsed end of the bundles (proximally). Transection of previous suture passes should be avoided. Approximately, three to four passes are made until the final pass exits the end of the remnant toward the femur. At this point, an accessory inferomedial portal is made with the knee at 90° of flexion. Care is taken to position it so as to enable access, with an awl, to the femoral origin of the ACL. Then, the posterolateral (PL) bundle is sutured in similar fashion using a No. 2 TigerWire suture (Arthrex). The sutures ends are then parked away through the accessory inferomedial portal for protection.

A bone socket of 4.5 × 20 mm is drilled, punched, or tapped (depending on bone density) into the origin of the PL bundle with the knee at 115° of flexion in order to prevent posterior blowout. The repair sutures from the PL bundle are delivered out of the accessory inferomedial portal, and fed through the eyelet of the 4.75 SwiveLock (Arthrex) suture anchor (Biocomposite preferred by the senior author). The anchor is then deployed, retensioning the PL bundle back up to its origin. The core stitches are removed and the repair

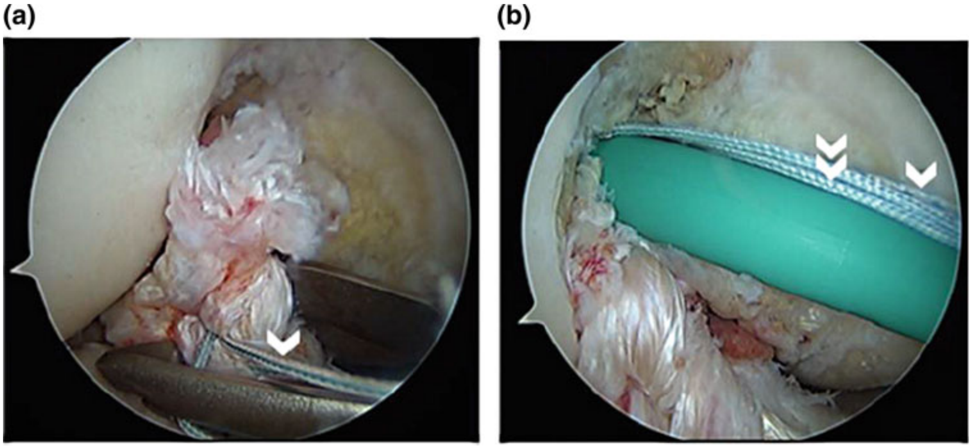

Fig. 14.5 Arthroscopic view of a right knee, viewed from the anterolateral portal with the patient supine and the knee in 90° of flexion. **a** A No. 2 FiberWire suture (*arrowhead*) is passed through the anteromedial bundle of the ACL in a Bunnell-type suture pattern, using a Scorpion Suture Passer (*star*). **b** A SwiveLock suture anchor that is preloaded with FiberTape (*arrowhead*) is used to reattach the anteromedial bundle of the ACL back to its femoral origin. The core sutures (*arrowheads*) of the suture anchor are visible in front of the FiberTape

stitches are cut short. This same procedure is then repeated for the repair stitches of the AM bundle with the knee at 90° of flexion. The suture limbs are retrieved and passed through the eyelet of a 4.75-mm BioComposite SwiveLock anchor that has preloaded with FiberTape. The AM bundle is tensioned and the suture anchor is deployed in the socket of the AM footprint (Fig. 14.5b). The FiberTape is then parked away through the accessory portal which will act as augmentation of the ACL once it is fixated distally. This is generally done after the PCL repair is performed.

The ACL repair is now complete. The ligament is evaluated using a probe, after which all free suture ends, except the FiberTapes, are cut with an open-ended suture cutter (Arthrex). Finally, the ACL is visualized during ROM to check for impingement in the intercondylar notch, which would require additional notchplasty.

14.3.6 Surgical Technique of Arthroscopic PCL Repair

The surgical techniques of arthroscopic primary PCL repair with [62] and without [63] suture augmentation for proximal tears have been extensively described previously and will be described here briefly. In order to obtain good access to the PCL for suturing, a single stitch is often used to draw the ligament anteriorly and superiorly. In similar fashion to the ACL, the anterolateral (AL) and posteromedial (PM) bundles are sutured separately from distal to proximal with No. 2 FiberWire and No 2. TigerWire sutures, respectively (Fig. 14.6a). Subsequently, the suture limbs are parked away and the arthroscope is moved to the anteromedial portal to access the PCL footprint from the anterolateral portal. With the knee at 90° of flexion, the footprint is debrided and bleeding is induced.

With the knee at 90° of flexion, an anterior drawer force is applied to the tibia to reduce posterior sagging. First, the AL bundle is fixated at its origin, using a 4.75-mm SwiveLock anchor (Biocomposite), which has been preloaded with TigerTape (Arthrex). Subsequently, the TigerTape is parked away. Next, the PM bundle is fixated using an unloaded 4.75-mm SwiveLock anchor (Biocomposite) (Fig. 14.6b). After the repair is completed, all suture ends are cut short and intercondylar notch impingement during ROM is checked.

14.3.7 Suture Augmentation Tensioning and Fixation

Following repair of both cruciate ligaments, the inserted FiberTape and TigerTape need to be guided through the tibia, tensioned, and distally fixated. The ACL internal brace is usually tensioned first. It is technically the easier of the two, and as ACL tensioning is performed with the knee near full extension, this provides a neutral anterior–posterior position and prevents extension loss [64]. Overcorrecting anterior or posterior laxity in flexion can lead to permanent posterior or anterior tibial subluxation, respectively, and should be avoided.

To retrieve the ACL augmenting FiberTape, an ACL drill guide is used to drill a 2.4-mm guide pin from the anteromedial cortex of the tibia toward the anterior third of the

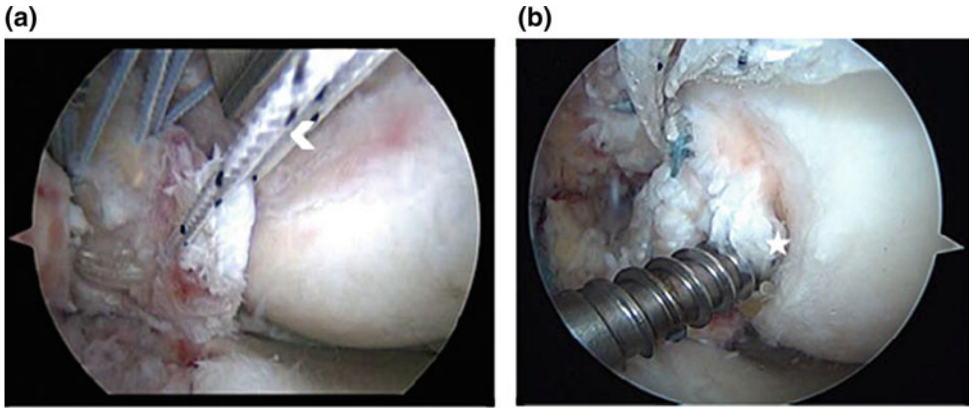

Fig. 14.6 Arthroscopic view of a right knee, with the patient supine and the knee in 90° of flexion. **a** View from the anterolateral portal. The PCL remnant is pulled at with a single stitch (*arrowhead*) in order to reach the distal part for ligament suturing. **b** One suture anchor has been deployed and now a bone socket for the second suture anchor is created at the origin of the posteromedial bundle (*star*)

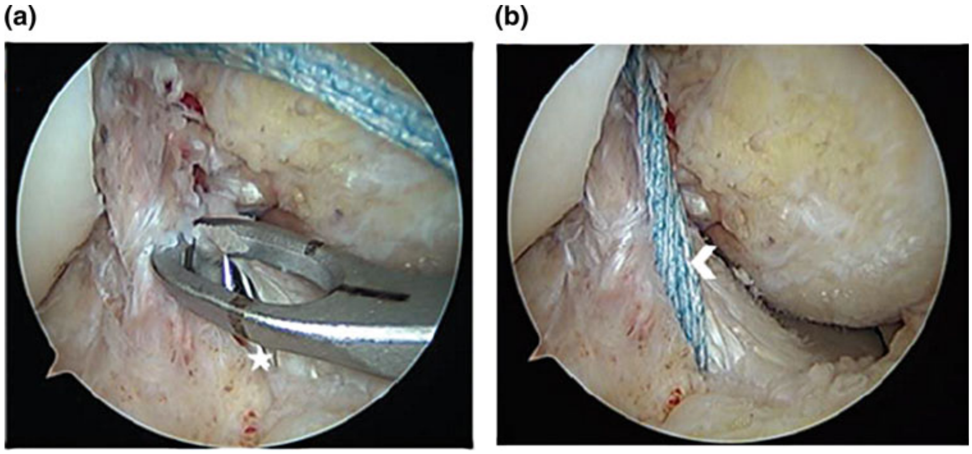

Fig. 14.7 Arthroscopic view of a right knee, viewed from the anterolateral portal with the patient supine and the knee in 90° of flexion. **a** An ACL drill guide is used to drill a guide pin from the anteromedial cortex of the tibia into the anteromedial part of the tibial ACL footprint (*star*). **b** The FiberTape (*arrowhead*) has been shuttled through the tibia and now runs along the ACL. Distally, it will be attached later at the anteromedial tibial cortex with a suture anchor

ACL insertion, very similar to how the guide pin for a tibial tunnel would be drilled (Fig. 14.7a). However, instead of reaming over this pin, here the pin is changed for a straight Micro SutureLasso (Arthrex), which is used to retrieve the FiberTape distally through the tibia (Fig. 14.7b). For the PCL augmenting TigerTape, a posteromedial portal is created to visualize the PCL insertion, using a spinal needle under direct visualization. A curved PCL drill guide is positioned in the PCL fossa (Fig. 14.8a) through the anteromedial portal to drill a 2.4-mm guide pin from the anteromedial cortex, distal to the ACL pin site, into the PCL insertion. The pin is then switched for a straight Micro SutureLasso, which is used to retrieve the TigerTape through the tibia (Fig. 14.8b). Alternatively, for both the ACL and the PCL, a cannulated drill with a nitinol wire or a FiberStick (Arthrex) can be used to accomplish these steps. Both the FiberTape (ACL) and TigerTape (PCL) are now exiting the anteromedial tibial cortex.

The knee is first gently cycled through its range of motion. Then, the ACL augmenting FiberTape is tensioned with the knee near full extension in order to avoid loss of knee extension. The FiberTape is fixated at the anteromedial tibial cortex using a 4.75-mm SwiveLock anchor (Biocomposite) (Fig. 14.9a), which is deployed in a standard bone socket that has been punched and tapped. Finally, the PCL augmenting TigerTape is tensioned with the knee at 90° of flexion, while applying an anterior drawer force to restore the normal tibial step-off and prevent PCL laxity. The TigerTape is fixated using another 4.75-mm SwiveLock anchor (Biocomposite). The ends of both internal braces are then cut short with an open-ended suture cutter. ACL and PCL tension are now arthroscopically evaluated and finally knee stability is checked (Fig. 14.9b).

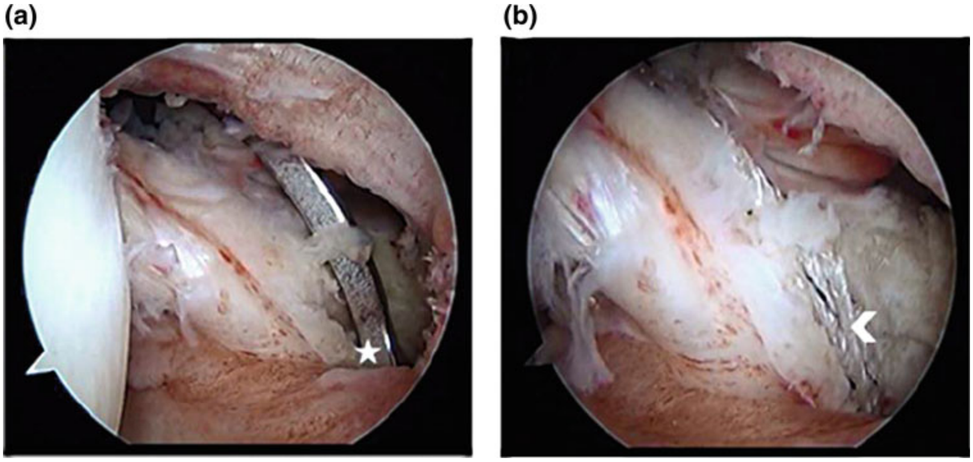

Fig. 14.8 Arthroscopic view of a right knee, viewed from the posteromedial portal with the patient supine and the knee in 90° flexion. **a** A curved PCL guide has been placed from the anteromedial portal down to the tibial PCL footprint (*star*) and will be used to drill a guide pin into the tibial PCL footprint. **b** The TigerTape (*arrowhead*) has been retrieved distally through the knee joint to the anteromedial tibial cortex

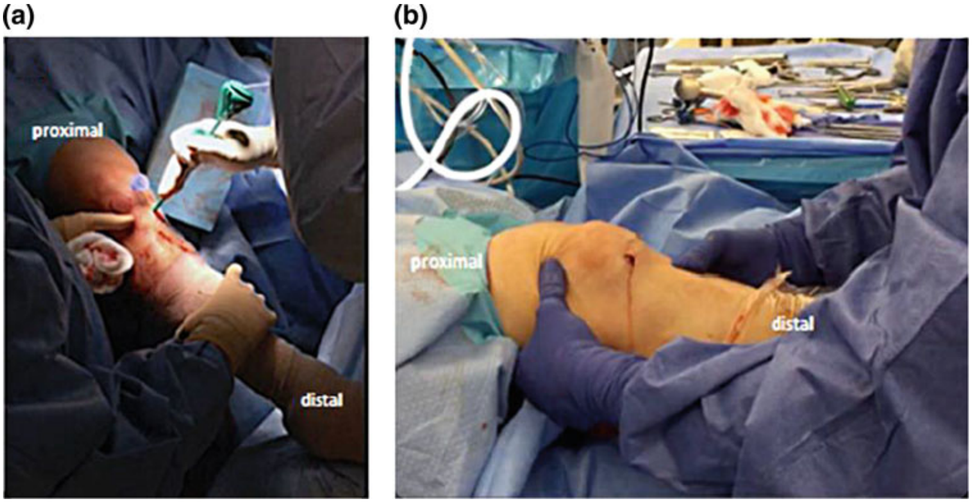

Fig. 14.9 **a** View on a right knee in full extension. The FiberTape has been tensioned and is being attached at the anteromedial tibial cortex with a suture anchor. The TigerTape will be attached at the tibia in the same way, but with the knee in 90° of flexion and while an anterior drawer force is performed. **b** View on a right knee. Range of motion and knee stability are tested before closing the surgical wounds

14.4 Postoperative Management

One of the paramount advantages of multiligament repair, rather than reconstruction, is the minimally invasive nature of the procedure. That, combined with the internal bracing approach that adds a strong suture augmentation along the repaired ligament as a checkrein, allows early motion with less concern over recurrent laxity. In the practice of the senior author, the majority of patients treated with this approach visits the office 4–5 days postoperatively and can often bend to 90° without significant pain. In addition, the majority has at least sufficient quadriceps control to perform an active straight leg raise without significant lag. Approximately, half of the patients discontinued narcotic pain medication at this time. This is a vast improvement over those patients who undergo multiligament reconstruction.

Although one protocol rarely covers the majority of patients after multiligament surgery, in general, early postoperative mobilization and range of motion are recommended to reduce arthrofibrosis and quadriceps muscle atrophy. First, all patients leave the operating room with a hinged brace, which is locked in extension. The brace is worn at all times during ambulation, until sufficient quadriceps strength to control the knee during weight-bearing has returned, typically after 4 to 6 weeks. Immediately, the patient is encouraged to unlock the brace for range of motion exercises, and they usually progress much faster than patients who have undergone reconstructions. Open-chain hamstrings exercises are avoided for at least 3 months.

After 6 weeks, the patient is progressed with gentle strengthening and the rehabilitation schedule is generally advanced on a milestone basis. Intuitively, the worse the injuries and the bigger the surgery, the slower the steps. The goal of the rehabilitation program is to return patients to work and sports activities, ideally at their pre-injury level.

14.5 Results of Primary Repair of the MLIK

14.5.1 Historical Results

While current treatment protocols for MLIK usually recommend multiligament reconstruction, primary repair of all ligaments was the standard treatment historically, until superior results were achieved with reconstruction [1, 17, 26, 33, 65]. Early primary repairs were performed via an open approach and without selection of tear types. Recently, we have learned from the ACL literature that arthroscopic primary repair can lead to good outcomes in a selected subset of patients, and conversely it is known that intra-articular repair of midsubstance tears often leads to failure [33, 45, 66]. Different from the early primary repairs, modern suture techniques and implementation of suture augmentation are used and can be followed by early rehabilitation [33, 39, 45]. The lack of patient selection and modern arthroscopic techniques likely contributed to disappointing historical results of primary repair [17, 27].

14.5.2 Modern Results

Three recent studies have reported on the outcomes of primary repair of all ligaments in the MLIK [30, 67, 68]. Interestingly, these studies present an open approach and repair of all ACL and PCL tear types. Nonetheless, Owens et al. [30] and Hua et al. [67] reported high rates of knee stability at 4- and 5-year follow-up, respectively. Heitmann et al. reported outcomes of multiligament repair with the technique of additional suture augmentation [68]. They reported that six of eight examined knees had a stable ACL, and all patients had a stable PCL and stable collateral ligaments at 12-month follow-up.

DiFelice et al. [31, 40] reported excellent short-term and mid-term outcomes of arthroscopic primary repair of proximal ACL tears, using nonabsorbable sutures, followed by other studies with excellent short-term outcomes [36, 46, 69]. We believe that primary repair of cruciate ligaments should be performed arthroscopically in carefully selected patients with proximal or distal tears and sufficient tissue quality.

The most common problem with MLIK treatments is postoperative stiffness. The studies of Owens et al. [30] and Hua et al. [67] reported an incidence of arthrofibrosis between 16 and 19%. Similar to primary repair, studies on outcomes of arthroscopic reconstruction also report very high rates of arthrofibrosis (up to 29%) [1, 22]. Despite the fact that these studies use arthroscopic surgery, several grafts are harvested and tunnels drilled which may contribute to the high rate of arthrofibrosis.

In the clinic of the senior author, four out of 60 patients (6.7%) had arthrofibrosis after surgical MLIK treatment. One patient underwent bicruciate reconstruction surgery, two patients underwent distal PCL repair (one with concomitant ACL and MCL reconstruction and one with concomitant MCL repair), and one patient underwent distal ACL repair (with concomitant PCL, LCL, and popliteus repair). It has been previously reported that distal cruciate tears have a higher incidence of postoperative stiffness or arthrofibrosis [70]. Interestingly, none of the 23 proximal ACL repair and none of the 19 proximal PCL repair patients had postoperative stiffness or arthrofibrosis.

To our knowledge, no studies have reported on the outcomes of arthroscopic primary repair of avulsed ligaments in the setting of MLIK. In the case series of the senior author, 2 out of 60 patients had a failed distal ACL repair and one patient a failed cruciate ligament reconstruction. Furthermore, two patients had 2+ posterior drawer after PCL repair without suture augmentation. Although no conclusions can be drawn from these results (also because not all patients have reached 2-year follow-up), it can be noted that no large failures are observed in this cohort. The recommendation of the senior author is to use suture augmentation for ligament repair in order to protect the ligament during the healing phase and in light of the multidirectional instability of the MLIK.

14.6 Case Examples

14.6.1 Case 1: Primary Repair with Suture Augmentation of KDIII-M Injury

A 49-year-old male was struck by a motor vehicle, and sustained a right knee dislocation, in addition to several other traumatic injuries. MRI of the right knee demonstrated proximal avulsion tears of the ACL, PCL, and MCL (Fig. 14.10a). Risks and benefits of conservative versus surgical treatments were discussed and the patient opted for surgical management.

Knee surgery was performed 19 days after the initial trauma. Physical examination under anesthesia revealed 20

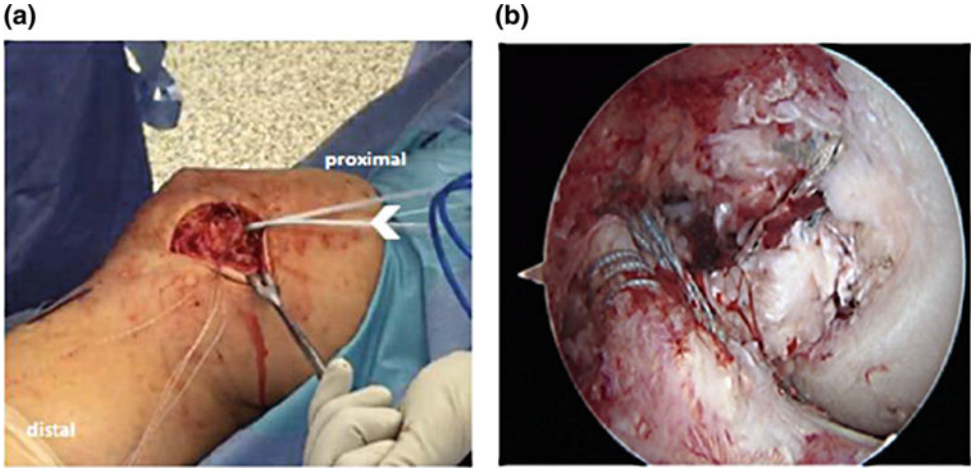

Fig. 14.10 **a** View on the medial side of a right knee. Primary repair of the superficial medial collateral ligament has been performed, using a single preloaded SwiveLock suture anchor at the proximal and slightly posterior aspect of the medial femoral epicondyle. The ends of the FiberTape (*arrowhead*) will be shuttled distally and fixated at the anteromedial tibial cortex. **b** Arthroscopic primary repairs of the ACL and PCL have been performed with additional suture augmentation of both ligaments

degrees of recurvatum, 3+ anterior, 3+ posterior, and 3+ valgus laxity, and a stable knee to varus stress. The medial-sided injuries were addressed first, using a suture anchor to repair the torn posterior oblique ligament, and a primary repair with suture augmentation for the superficial MCL (Fig. 14.10b). A vastus medialis muscle tear was repaired with absorbable sutures, after which arthroscopy was started.

The ACL and PCL were assessed for length and tissue qualities, and both ligaments were deemed repairable. Consequently, ACL and PCL arthroscopic primary repairs with suture augmentation were performed (Fig. 14.10b). Postoperatively, the knee was placed in a brace which was locked in extension and unlocked during non-weight-bearing. The patient was allowed to bear weight immediately.

After 4 days, the patient did not need opioid pain medication and started physical therapy with emphasis on full extension (avoid hyperextension), patella mobilization, and flexion. The following months he progressed appropriately without complaints of the right knee. The patient did suffer from complaints of right hip osteoarthritis, which he had prior to his trauma. At latest follow-up after 4 months, he had 130° range of motion, a negative Lachman and pivot shift, a trace posterior laxity, and 1+ valgus laxity with a good endpoint, with an antalgic gait due to groin pain.

14.6.2 Case 2: Primary PCL and MCL Repair Combined with ACL Reconstruction

A 17-year-old male had collided with another player during football and sustained a right knee dislocation. His knee had been reduced and splinted in an outside hospital, and there was no vascular or nerve injury. MRI showed a midsubstance ACL tear, proximal PCL tear, and a distal MCL avulsion tear.

Knee surgery was performed 12 days following the injury. Physical examination under anesthesia revealed 3+ anterior, 3+ posterior, and 3+ valgus laxity, and a stable knee to varus stress. The medial side of the knee sustained full-thickness ruptures of all posteromedial and anteromedial layers with an avulsion of the MCL from the tibia. The posteromedial capsule was repaired with a suture anchor in the medial femoral condyle. Two suture anchors were placed at the distal insertion of the superficial MCL (sMCL) to tie down the posteromedial capsule and the sMCL. The anteromedial retinaculum and all layers were closed to complete the medial repair. It should be noted that at time of surgery with this patient, internal bracing suture augmentation was not available.

Arthroscopy confirmed a midsubstance tear of the ACL and a femoral avulsion tear of the PCL. The cartilage was unaffected, and both the medial and lateral meniscus appeared intact. First, the ACL was debrided. When posterior tibial sagging was reduced, the PCL was assessed and it was possible to reapproximate the PCL to the femoral footprint. As the tissue quality was good, the PCL was deemed amenable for repair. The AL and PM bundles were sutured separately, and an anterior drawer force was applied to tension and reattach both bundles. At this point, valgus stability and posterior laxity were restored, and only anterior laxity remained. A decision was made to hold off ACL reconstruction for now to prevent postoperative arthrofibrosis. All surgical wounds were closed, and the knee was placed in a brace that was locked in extension.

The patient was allowed to bear weight with crutches within the locked brace and used a continuous passive motion device to increase ROM at home. He started physical therapy after 2 weeks. In 3 months, he had advanced very rapidly and was able to perform shuttle runs and box jumps, without pain. At this moment, the patient had full ROM, slight posterior laxity, 2+ anterior laxity, and no valgus or varus laxity. Physical therapy was continued, and an ACL reconstruction was scheduled. Staged ACL reconstruction was performed 5 months after initial surgery. A standard bone–patellar tendon–bone ACL reconstruction was performed. The repaired PCL was inspected. It had healed slightly inferior to the femoral footprint but had good tension. Postoperatively, a standard rehabilitation protocol was followed which allowed immediate weight-bearing with the knee in a locked brace and gentle build-up of range of motion. At latest follow-up, 5 years after the initial surgery, the patient was playing football two or three hours a week without pain or complaints of instability. Physical examination showed a normal gait, full ROM, a trace posterior laxity, and an otherwise stable knee.

14.7 Conclusions

Treatment of the MLIK currently consists of an “all or nothing approach” in which either ligaments are surgically reconstructed or conservatively managed. Surgical reconstruction has, however, several limitations as this procedure requires (multiple) grafts and tunnel drilling with a risk of tunnel convergence, in addition to high rates of arthrofibrosis.

Recently, there has been a renewed interest in primary repair of knee ligaments. With this technique, proximally or distally avulsed ligaments are repaired to their native footprints and reinforced with suture augmentation in order to protect the repaired ligaments in the early rehabilitation phase. This treatment is less invasive than ligament reconstruction and has a low incidence of arthrofibrosis, resulting in faster recovery and preservation of native tissues. In this chapter, we discussed the patient selection, surgical technique, and outcomes of (arthroscopic) primary repair of knee ligaments in the setting of MLIK. Primary repair with suture augmentation is a reliable treatment option for the MLIK in selected cases.

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Surgical Treatment of Combined PCL/Lateral Side Injuries: Acute and Chronic

15

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Abbreviations

ABI	Ankle–Brachial Index
ACL	Anterior Cruciate Ligament
AP	Anteroposterior
BF	Biceps Femoris
CPN	Common Peroneal Nerve
CT	Computed Tomography Scan
EUA	Examination Under Anesthesia
FCL	Fibular Collateral Ligament
GT	Gerdy's Tubercle
HTO	High Tibial Osteotomy
IT	Iliotibial
LE	Lateral Epicondyle
LFC	Lateral Femoral Condyle
LHG	Lateral Head of Gastrocnemius
LM	Lateral Meniscus
MRI	Magnetic Resonance Imaging
MUA	Manipulation Under Anesthesia
NPV	Negative Predictive Value
PCL	Posterior Cruciate Ligament
PF	Patellofemoral
PFL	Popliteofibular Ligament
PLC	Posterolateral Corner
PLT	Popliteus
PPV	Positive Predictive Value
ROM	Range of Motion

15.1 Introduction

There are few surgical procedures in orthopedics that are as challenging and as gratifying as reconstructing the posterolateral corner of the knee. The anatomy and pathology are complex and variable, making management a thought-provoking and challenging process worthy of collaboration with colleagues. The purpose of this chapter is to stimulate the reader's mind in the management of the acute and chronic posterior cruciate ligament (PCL) and posterolateral corner (PLC) knee injuries. There are many chapters in this book specifically dealing with the PCL, so more depth and focus will be put on the PLC in this chapter.

Historically, the combined PCL/PLC injury was treated nonoperatively, and therefore, limited information on surgical management is available in the literature prior to the 1970s and early 1980s. It is worthwhile considering the contributions of some of the pioneers in the area of PCL and PLC surgery. Dr. Jack Hughston was a true academic in the anatomy, classification, and surgical approach to the PLC. He championed a surgical repair where a bone block—with the insertions of the fibular collateral ligament (FCL) and the popliteus tendon—was advanced proximally on the lateral femoral condyle, thus re-tensioning these two important structures [1–3]. In 1988, Dr. William Clancy described the concept of performing a tenodesis of the biceps femoris to reinforce the FCL and arcuate complex for varus instability of the knee [4]. The advancement of PCL reconstruction cannot be discussed without mentioning the massive body of work by Dr. Robert LaPrade. His contributions include early work from the Hughston clinic, detailed descriptions of anatomy, anatomic reconstructive techniques, and ongoing scientific study of the PLC [5–8]. A number of authors have published reconstruction techniques for the PCL and PLC, including the past author of this chapter, Dr. John Sekiya, who described the use of a bifid Achilles tendon graft to reconstruct the PLC [9]. The editor of this textbook, Dr. Greg Fanelli, has one of the world's largest and most detailed clinical cohorts of multi-ligament knee reconstructions—including combined PCL/PLC injuries—making his published results the gold standard for the reconstructive surgeon to attempt to reproduce [10, 11].

This chapter will present the current understanding of both acute and chronic combined PCL/PLC knee injuries,

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and provide principles for the evaluation and management of this fascinating and complex clinical problem.

15.2 Epidemiology

The true incidence of combined PCL/PLC injuries difficult to ascertain as many of these injuries go undiagnosed [1]. However, with advances in imaging and an improved understanding of multi-ligament knee injuries, the diagnostic accuracy is improving. Laprade et al. [12] analyzed magnetic resonance imaging (MRI) scans performed on 331 consecutive patients presenting with acute hemarthrosis of the knee. Of 187 patients with ligament injuries, 14.4% had PCL injuries and 16.0% had PLC injuries. Fanelli et al. [13] performed an examination under anesthesia along with a diagnostic arthroscopy on 61 trauma patients with knee hemarthrosis and found an incidence of combined PCL/PLC injuries of 41%. Isolated PLC injuries are rare, accounting for <2% of all ligamentous knee injuries [12, 14].

The mechanism of an isolated PLC injury can be either a posterolaterally directed blow to the anteromedial proximal tibia or a noncontact external rotation and hyperextension injury [11, 15, 16]. Combined PCL/PLC injuries are typically due to a varus and posteriorly directed force such as a dashboard injury during a motor vehicle collision [11]. Combined injuries can also occur as part of a knee dislocation from high energy trauma.

Peroneal nerve injury has been reported in up to one-third of PLC injuries [8, 17]. This is likely due to the fact that many PLC injuries present in the setting of knee dislocation following high energy trauma. In a recent study, Ridley et al. [18] demonstrated a 26.2% rate of peroneal nerve palsy in 61 knees with PLC injury with an overall recovery rate of 50%. In another cohort study of patients with knee dislocations, the odds of a peroneal nerve injury was 42 times greater in those with PLC injury [19]. Although a high index of suspicion must be maintained, the incidence of nerve injury in sport-related injuries is much lower.

Despite the diagnostic challenges, it is important to recognize the presence of a PLC injury in the setting of a PCL tear, as failure to do so have been shown to increase the risk of failure of PCL reconstruction [20–22]. Additionally, chronic PLC insufficiency and the subsequent alteration in knee biomechanics increase the risk of early degenerative joint disease [20, 21].

15.3 Anatomy

An understanding of the intricate anatomy of the PCL and PLC is critical in guiding the evaluation and treatment of these complex injuries. Given that the anatomy of the PCL has been described in detail elsewhere in this text, this section will focus primarily on defining the PLC.

The PLC consists of a group of structures defined as either primary or secondary stabilizers. The primary stabilizers of the PLC include the fibular collateral ligament (FCL), popliteus tendon, and popliteofibular ligament (PFL). The FCL originates in a small bony depression slightly proximal and posterior to the lateral epicondyle of the femur, and inserts on the fibular head approximately 28 mm distal to the styloid [23] (Fig. 15.1). The popliteus tendon arises from the lateral aspect of the popliteus muscle, which lies on the posteromedial proximal tibia. The tendon becomes intra-articular as it travels through the popliteal hiatus and inserts on the popliteal sulcus of the femur. Laprade et al. [23] performed thorough dissections of the PLC in 10 non-paired cadavers and determined that the popliteal sulcus is consistently found 18.5 mm anterior to the FCL origin. The PFL originates from the musculotendinous junction of the popliteus and inserts on the posteromedial aspect of the fibular head. It divides into two branches, anterior and posterior, named according to their insertion on the fibular head. The posterior division is more robust and is generally the one targeted during anatomic PLC reconstructions (Fig. 15.2). An “arcuate fracture” of the fibular head is thought to be an avulsion of the posterior division of the PFL [23].

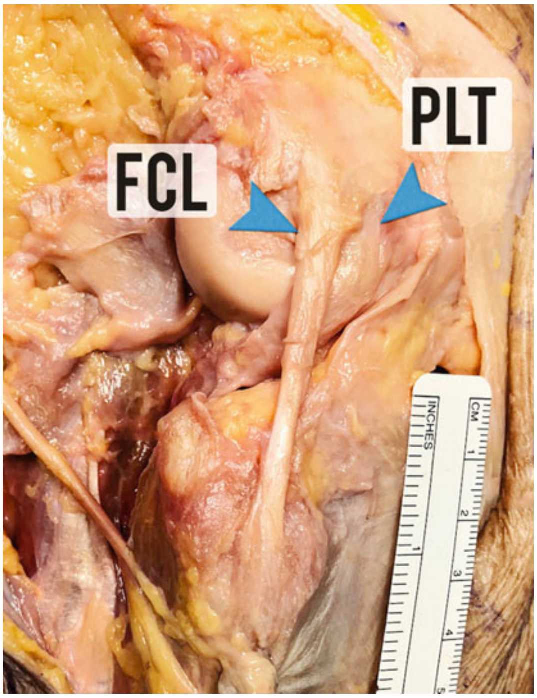

Fig. 15.1 The FCL origin on the femur (slightly proximal to the lateral epicondyle) and insertion on the fibula (approximately 28 mm distal to the styloid). The popliteus origin on the femur lies approximately 18.5 mm anterior to the FCL and directly adjacent to the articular margin

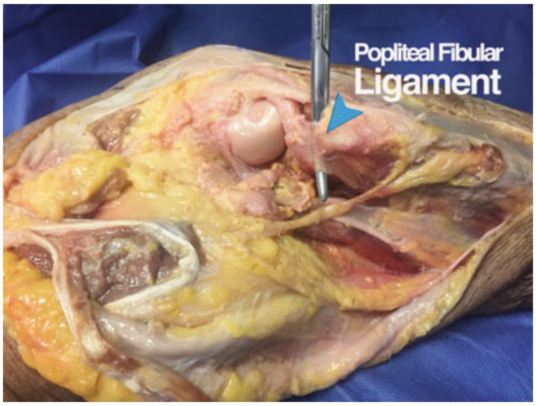

Fig. 15.2 The PFL originates at the musculotendinous junction of the popliteus and has a broad insertion on the posteromedial aspect of the fibular head

In addition to the three primary stabilizers, there are several secondary stabilizers of the PLC. These include the posterolateral capsule, meniscofemoral and meniscotibial ligaments, coronary ligaments, fabellofibular ligament, lateral head of gastrocnemius, long and short head of biceps femoris, iliotibial band, and anterolateral ligament. The long head of biceps femoris serves as a key landmark for identifying the common peroneal nerve, which emerges posterior to this tendon, and approximately 1–2 cm proximal to the fibular head (Fig. 15.3). The lateral head of gastrocnemius is also an important structure in PLC reconstruction, as it defines the interval for both the posterolateral capsular arthrotomy, as well as for the dissection to the popliteal fossa. Its insertion on the lateral aspect of the knee can be quite variable and consists of multiple insertion sites including the fibular head, popliteal fibular ligament, posterolateral capsule, and lateral femoral condyle. Accordingly, the development of these intervals during PLC reconstruction can be challenging.

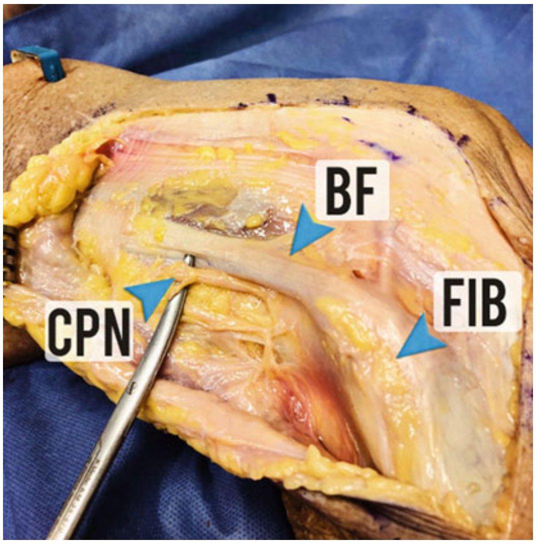

Fig. 15.3 The long head of biceps femoris (BF) serves as a landmark for the common peroneal nerve (CPN) which emerges just posterior to the tendon and approximately 1–2 cm proximal to the fibular head

15.4 Biomechanics

As noted above, the most important stabilizing structures of the PLC are the FCL, popliteus, and PFL [6, 17, 24, 25]. The FCL is the primary restraint to varus stress throughout a 0°–30° arc of motion, and provides resistance to external rotation of the tibia in full extension [26]. The popliteus serves primarily as a dynamic internal rotator of the tibia and as a stabilizer of the lateral meniscus [5, 27, 28]. The PFL acts as a static restraint to varus stress and external tibial rotation [20]. All three structures contribute to resisting posterior tibial translation at low knee flexion angles (0°–30°) [17, 24].

The PLC and PCL act in concert to resist posterior translation, varus, and external rotation of the tibia on the femur. Harner et al. [22] showed that sectioning the PLC in a PCL-reconstructed knee increased posterior tibial translation by 4.6 mm at 90° and by 6.0 mm at 30°. The external tibial rotation was also increased by 14° and varus by 7°. Additionally, the in situ forces on the PCL graft are increased by up to 150%. The PLC has also been shown to provide restraint to anterior tibial translation in the setting of ACL deficiency, highlighting the importance of addressing the PLC in multi-ligament knee injuries [5].

Finally, the PLC is important in maintaining optimal joint mechanics and articular contact pressures. Sectioning the PLC and PCL results in posterior tibial translation, which decreases the moment arm of the patellar tendon, leading to increased force of the quadriceps and increased patellofemoral contact pressures. Furthermore, combined PCL/PLC deficiency results in increased external rotation of the tibia, which leads to abnormal contact pressures in the medial and lateral tibiofemoral compartments. These biomechanical changes have been shown to contribute to early articular degeneration [29].

15.5 Evaluation

The evaluation of both acute and chronic injuries consists of a detailed history and thorough physical examination. The history should include the date of injury, mechanism, treatment to date, any functional limitations, and expected activity level. In the setting of an acute multi-ligament knee injury, the overall medical status of the patient must be evaluated as the associated head, spine, and visceral injuries are not uncommon in high energy trauma. A neurovascular examination must be performed and well documented. A measurement of the ankle–brachial index (ABI) should be undertaken, and if any concerns arise, a computed tomography (CT) angiogram should be completed. The physical examination then progresses to inspection, assessing for any skin and soft tissue compromise, joint effusion, and gross deformity. In chronic cases, an evaluation of gait and alignment is included. Pronounced varus alignment, hyperextension, and/or a varus thrust gait should alert the examiner to a PLC and possible PCL injury. The presence of an effusion, muscle bulk, and asymmetry, as well as posterior sag, is also assessed on inspection. The range of motion and strength should be thoroughly evaluated. Ligamentous examination includes both Lachman and Pivot-shift tests, as well as the assessment of valgus stability and posteromedial drawer. The following examination maneuvers are specific for PCL and PLC injuries and should be carefully assessed in all multi-ligament injury settings:

- **Posterior drawer**—Performed at 90° of flexion. Posterior tibial translation beyond the femoral condyles implies concurrent PCL and PLC injury.
- **Varus stress**—Performed at 0° and 30° of flexion. Instability at 30° suggests PLC injury, while instability at 0° and 30° suggests injury to both the PLC and PCL.
- **Dial test**—Performed at 30° and 90° of flexion. The tibia is rotated externally on the femur. A side-to-side difference of 10° or more of external rotation at 30° implies injury to the PLC. If this difference is greater at 90°, then the injury to the PCL is also suspected [24].
- **Reverse pivot-shift**—Performed by taking the knee from 90° of flexion to full extension while applying a valgus and external rotation force. A positive result constitutes reduction of the tibia (due to tension of the iliotibial band) at 30°–40°. This test has been shown to have a positive predictive value (PPV) of 68% and a negative predictive value (NPV) of 89% [30, 31].
- **Posterolateral drawer test**—Performed in 80° of flexion. Posterior translation of the tibia with applied external rotation is positive for a PLC injury, and posterior translation with external and internal rotation suggests combined PLC and PCL injury [32].
- **External rotation recurvatum**—With the patient lying supine, the examiner elevates the leg by grasping the great toe. In a PLC-deficient knee, the knee will hyperextend with external rotation of the tibia [32, 33].

15.6 Imaging

Imaging of suspected PCL/PLC injuries begins with standard anterior–posterior (AP), lateral, and skyline X-ray views. Although plain X-rays are typically unremarkable, they are useful in ruling out associated injuries such as tibial plateau fractures. Fractures that should alert one to the presence of a PCL or PLC injury include avulsions of the posterior tibial eminence or fibular head (arcuate fracture), respectively. In all chronic cases, full-length standing films should be performed to assess alignment in both the sagittal and coronal planes and determine whether a corrective osteotomy will be necessary. Weight-bearing flexion and skyline views are also helpful to delineate the extent of degenerative changes in the tibiofemoral and patellofemoral compartments. Additional X-ray views to consider include posterior stress and varus stress films. Posterior stress views are performed with the use of a Telos Device (Telos Medical USA, Millersville, MD) or by manually applying a posteriorly directed force to the proximal tibia with the knee flexed to 90°. Posterior tibial translation of >12 mm has been shown to be specific for a combined PCL and PLC injury [34, 35]. Varus stress X-rays are taken in 20° of flexion. A side-to-side difference greater than 4.0 mm suggests a complete grade III PLC injury [36] (Fig. 15.4). Magnetic resonance imaging (MRI) is helpful to assess the grade of ligamentous injury, and to identify concurrent pathology such as meniscal and chondral damage (Fig. 15.5). MRI can also be particularly helpful in settings when clinical examination is compromised. It has been shown to have excellent sensitivity for identifying cruciate ligament injuries; however, MRI is not as effective at characterizing injury to the PLC. A study by Derby et al. [37] assessed 38 patients with traumatic knee dislocation using 1.5T MRI and showed a sensitivity of 97–100% for cruciate ligament injuries, but only 25–38% for PLC injuries. Laprade et al. [38] compared MRI with surgical findings in 20 patients with PLC injuries and reported an accuracy of 95, 90 and 68% for identifying injury to the FCL, popliteus, and popliteofibular ligament, respectively. Other imaging modalities that may be employed in specific scenarios include CT angiograms in the setting of knee dislocation, and plain CT in the setting of a periarticular fracture.

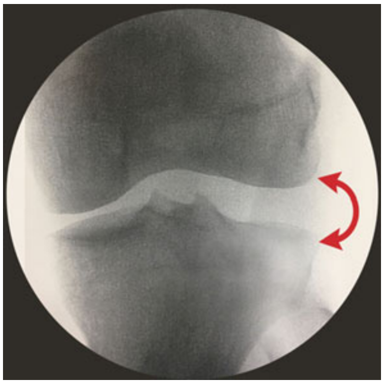

Fig. 15.4 Varus stress X-ray demonstrating a complete lateral sided injury

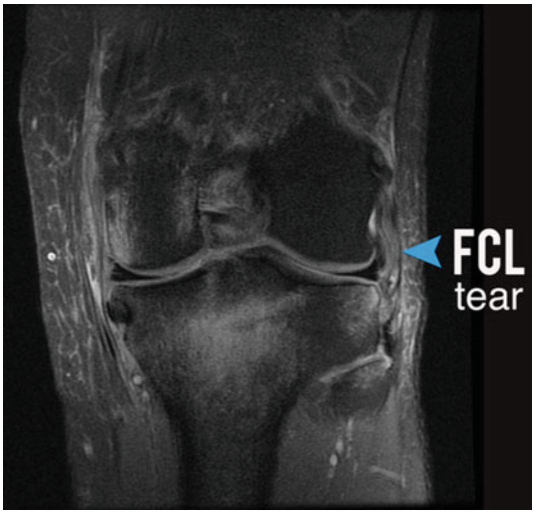

Fig. 15.5 T2-weighted coronal MRI image demonstrating an FCL injury

15.7 Nonoperative Treatment

In general, combined PCL and PLC injuries are treated surgically. However, some small cohort studies have reported positive results with nonoperative treatment of isolated, low-grade (I and II), PLC injuries [39, 40]. In a study of 28 patients with lateral ligament injuries, Krukhaug et al. [40] reported good outcomes with no lateral or sagittal laxity in patients with isolated low-grade injuries treated nonoperatively. Similarly, Kannus et al. [39] followed a cohort of patients with isolated lateral ligament injury for 8 years. These authors demonstrated that patients with low-grade injury had some residual lateral laxity but overall achieved positive results at final follow-up. In contrast, those patients with high-grade injury demonstrated persistent gross laxity, as well as osteoarthritic changes on X-ray. Both studies concluded that nonoperative treatment should only be considered in isolated low-grade lateral ligament injuries. Early mobilization is generally recommended when treating isolated PLC injuries nonoperatively. Crutches and a hinged knee brace may be utilized in the initial 4–6 weeks following injury, followed by progressive motion, strengthening, and return to full activities at 3–4 months post-injury [41]. Further consideration could be given to functional/dynamic bracing. A recent biomechanical study by Welch et al. [42] measured patellofemoral joint pressures in PCL/PLC-deficient knees with and without dynamic bracing, and showed a significant reduction in peak and total pressures at 60°, 90° and 120° of flexion when dynamic braces were used.

15.8 Operative Treatment

When dealing with either the acute or chronic PCL and PLC ligament injuries, the current practice supported by the literature is to reconstruct or augment the injured ligamentous structures and to repair and reinforce the tendinous and capsular structures [43–45]. Published research also supports early intervention of this combined knee ligament injury, optimally within the first 3 weeks [41, 46]. Notably, avulsion fractures of the posterior tibial eminence or the fibular head should be managed by open reduction internal fixation with or without augmentation depending on the status of the corresponding ligamentous structure (Fig. 15.6). Repair of the PCL in a femoral peel off injury with sutures shuttled through drill holes has been described with reasonable results, however, repair of the PLC usually has less than optimal long-term outcomes [47]. Standard et al. [45] assessed a cohort of 57 patients who underwent repair or reconstruction of the PLC, and showed a 37% failure rate in the repair group versus a 9% failure rate in the reconstruction group. Although repair can be considered in select instances, reconstruction has generally shown to result in more favorable outcomes.

Alignment has become a very important consideration for the knee ligament surgeon, particularly in multi-ligament injuries. The tibial slope in the coronal plane, as well as varus and valgus alignment in the sagittal plane, should be assessed in every case. Osteotomy in the setting of chronic PCL and PLC injury is discussed later in this chapter. In acute injuries, the surgical planning and decision-making are much more controversial and thus most surgeons do not address alignment at this stage. However, it may be worthwhile to consider staged or combined osteotomy and ligament reconstruction in the extreme varus or recurvatum knee.

Preoperative planning for reconstructive surgery of the PCL and PLC is almost as important as the procedure itself. It is critical to accurately define the pathology through a thorough physical exam, appropriate imaging, and examination under anesthesia (EUA). A diagnostic arthroscopy is valuable for corroborating the EUA and imaging findings (Fig. 15.7). The most important structures to consider in reconstructing combined PCL/PLC injuries are the PCL, FCL, popliteal fibular ligament, and popliteus. Tailoring the reconstruction to the damaged pathology is the concept that is most important for successful outcomes in multi-ligament knee surgery.

Preoperative graft selection is important as it may be influenced by the availability of allograft tissue in one's center, as well as patient preferences to use autograft tissue.

Fig. 15.6 Postoperative AP **(a)** and lateral **(b)** X-ray views demonstrating open reduction and internal fixation of a PCL avulsion injury

Graft selection and the number of grafts needed are determined by the pathology and the structures that require reconstruction. Modern tissue preparation and storage techniques (i.e., low dose or no irradiation), make allograft use common practice when addressing all four structures. This surgical technique also avoids the resulting secondary deficiencies, as well as surgical trauma from harvesting autogenous tissue. Achilles tendon allograft is attractive for this procedure as it is large and versatile and can be split into numerous grafts. In the previous edition of this chapter, Sekiya and Gomberawalla describe an eloquent use of a bifid Achilles tendon allograft for arthroscopic inlay reconstruction of the PCL and PLC. Other popular allograft options include tibialis anterior for the PCL and semitendinosus for the PLC reconstructions. The availability of autograft varies according to the injury pattern, but may include ipsilateral or contralateral patellar or quadriceps tendons (with or without bone) for the PCL, and semitendinosus and gracilis tendon for the PLC reconstructions.

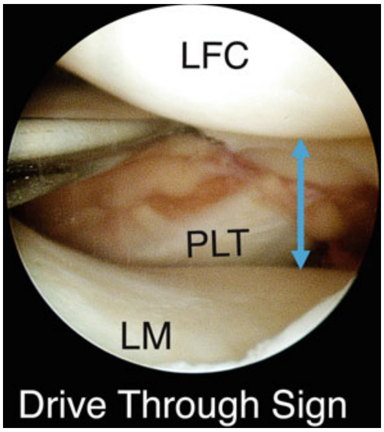

Fig. 15.7 Drive through sign demonstrating excessive gapping in the lateral compartment consistent with a grade III lateral sided injury. (LFC = Lateral Femoral Condyle, PLT = Popliteus, LM = Lateral Meniscus)

The order and method of graft fixation are important variables in a multi-ligament reconstruction. In general, the central pivot (PCL) is reconstructed and secured first in order to reduce the tibia on the femur so that the knee is balanced for the PLC graft positions. In terms of graft fixation, bone tunnels with interference screw have been the mainstay of the knee ligament surgeon. In multi-ligament reconstructions, however, tunnel convergence is a significant concern.

Accordingly, alternate fixation techniques have been proposed, including the use of a screw and washer for the femoral FCL and popliteus insertions of the PLC, as described by Fanelli [46]. Staples and even suture anchors have also been used for femoral fixation in PLC reconstruction. There is a rising popularity of all-inside techniques for PCL reconstruction with suspensory fixation devices that allows the surgeon to tension the graft, then cycle the knee, and re-tension multiple times [48, 49]. This technology advancement allows for multiple adjustments in graft tension in the multi-ligament injured knee. In this chapter, we will introduce a single graft technique for all three lateral structures that utilize a variable loop button in the tibial tunnel which enables graft re-tensioning.

15.8.1 PCL Reconstruction Using an All-Inside Transtibial Technique

15.8.1.1 Set up and Portal Placement

The patient is positioned supine. A lateral and a foot post are used to support the knee in a comfortably flexed position (Fig. 15.8). A tourniquet is applied but not necessarily inflated during the procedure. Appropriate portal placement is critical and enables optimal visualization and working trajectory throughout the procedure. A high and more central anteromedial portal is used to allow visualization over the back of the tibial plateau to facilitate placement of the tibial guide for tunnel drilling. A lower and slightly more lateral anterolateral portal enables easy viewing of the femoral insertion of the PCL and allows for inside out drilling of the femoral tunnel. A third portal placed posteromedially or posterolaterally is necessary to permit distal dissection on the tibia. This is the most critical step in arthroscopic PCL reconstruction. Ensuring that the posterior portal is as proximal as possible enables access to the sulcus between the mammillary bodies on the posterior tibia (Fig. 15.9). The use of both a 30° and 70° arthroscope is also helpful for visualization during tissue dissection. The use of bipolar electrocautery allows the surgeon to stay on bone while dissecting the native PCL footprint off the tibia and femur. A shaver should be used with caution posteriorly due to the proximity of the neurovascular structures and, if used, its aperture should face anteriorly toward the tibia.

15.8.1.2 Tibial Tunnel

The key to a successful PCL reconstruction is drilling the tibial tunnel sufficiently distal along the posterior tibia so that the graft is not too anterior and therefore maintains its mechanical leverage to support the tibia from subluxing posteriorly. Equally important is protecting the neurovascular bundle. This can be achieved by developing the interval between the lateral head of gastrocnemius and the popliteus muscle in the PLC dissection. Alternatively, a secondary safety incision as described by Fanelli [50], a spoon-tipped tibial guide, or another protective instrument can be used. The tibial guide should be placed low on the anterior cortex of the tibia and have as steep an angle as

Fig. 15.8 Operative set up for a PCL reconstruction. The patient is supine with a tourniquet on the proximal thigh. The leg is supported in a flexed position by a lateral post and a foot post

Fig. 15.9 Posterolateral portal (with cannula) placed through the posterolateral corner dissection

possible to dampen the "killer curve". It should also be placed as close to midline as possible—either medial or lateral to the tibial tubercle. Drifting off the midline results in harder cortical bone posteriorly and can cause a stress riser that may lead to a stress fracture. Direct visualization while drilling, through the posterior portal or through the notch with a 70° scope, is helpful to avoid errant pin placement (Fig. 15.10). X-ray or fluoroscopy may be used to confirm tunnel position prior to reaming.

15.8.1.3 Femoral Tunnel

The debate over single-bundle and double-bundle PCL reconstruction continue among knee surgeons, however, no difference in clinical outcomes has been shown in the literature to date [51, 52]. From our experience with double-bundle ACL reconstruction, we have learned that there is a significant learning curve, and this surgical technique can result in a higher failure rate [53]. Given the added complexity of PCL reconstruction, one well-placed large graft is considered more reproducible than a two-tunnel technique. This should, by no means, dissuade surgeons who successfully perform a double-bundle PCL reconstruction from continuing to do so. For the single-bundle technique, reproducing the anterolateral bundle, and if possible preserving the posteromedial fibers in an augmentation, is the optimal strategy. The femoral tunnel can be drilled via a traditional inside out technique, or outside-in using a flip cutter device to create a socket. The tunnel should start high in the notch (in the 11 or 1 o'clock position) with the perimeter within 1–2 mm of the articular cartilage margin, and it should be directed toward the medial epicondyle of the femur (Fig. 15.11). Care should be taken not to drill this tunnel too distal and parallel with the articular cartilage as this can lead to subchondral fracture and collapse.

15.8.1.4 Graft Preparation and Fixation

There are many possible graft and fixation options for reconstructing the PCL. Tibial inlay techniques—both open and arthroscopic—that utilize an Achilles tendon with a bone block have the advantage of a bony union on the tibial side while reducing the chance of graft erosion at the "killer curve" [54]. The transtibial tunnel technique remains

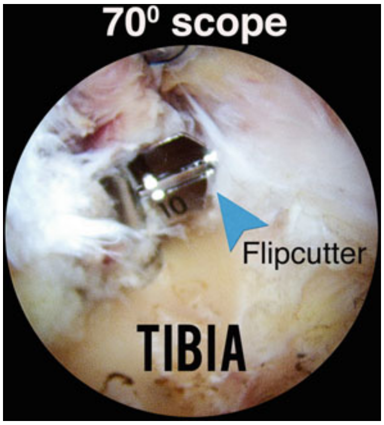

Fig. 15.10 View through the anteromedial portal demonstrating a flip cutter exiting the posterior tibia in the insertion of the PCL between the medial and lateral mamillary bodies

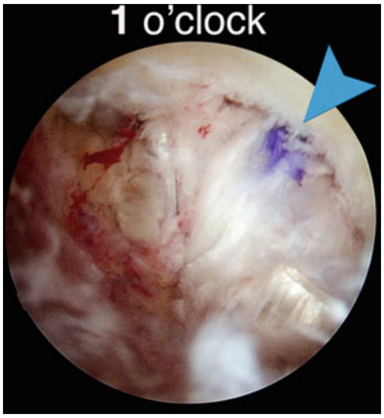

Fig. 15.11 The femoral origin of the PCL is located high on the medial femoral condyle (1 o'clock position) and adjacent to the articular margin

popular, and can be combined with various tensioning and fixation mechanisms such as an interference screw and button as described by Fanelli [46, 55]. Gaining in popularity is the all-inside technique with suspensory fixation as described by Levy et al. [49].

We have modified the dual suspensory fixation quadruple-bundle technique to a triple-bundle technique that allows for a longer (10–12 cm) graft, and ensures more tissue in each socket while still maintaining adequate graft diameter (10–11 mm) (Fig. 15.12). It should be noted that the free ends of the graft are incorporated into the buttons after tensioning to prevent creep. The graft is delivered through the anteromedial portal, and the tibial end is passed first with direct visualization through the posterior portal. Care must be taken not to over deliver the tibial side. As a guide, the femoral end of the graft must still be visible outside the portal. The femoral end is then passed, and tensioning adjustments can be made. Typically, the PCL is tensioned with the knee in 90° of flexion while applying an anterior drawer force to the tibia. The benefit of this technique in PCL reconstruction is that the tibial socket can be drilled long (4 cm) to prevent the graft from bottoming out during tensioning. The ability to tension and re-tension the graft after cycling the knee (and after completing the PLC reconstruction) makes for a robust and very satisfying result at the end of the procedure. A further advantage of this technique is the use of a flip cutter device (Arthrex, Naples, USA) to create the tibial and femoral sockets so that the cortex is only breached by a 4.5 mm drill bit instead of a 10–11 mm reamer when tunnels are used. This is not an essential step, and regular tunnels with suspensory fixation using large (14 mm) buttons can also be used. The main disadvantages of the suspensory fixation technique are that it is limited to single-bundle reconstruction and that it relies only on suspensory fixation on the tibial side. Secondary fixation on the femoral side can be achieved by placing an interference screw from inside out.

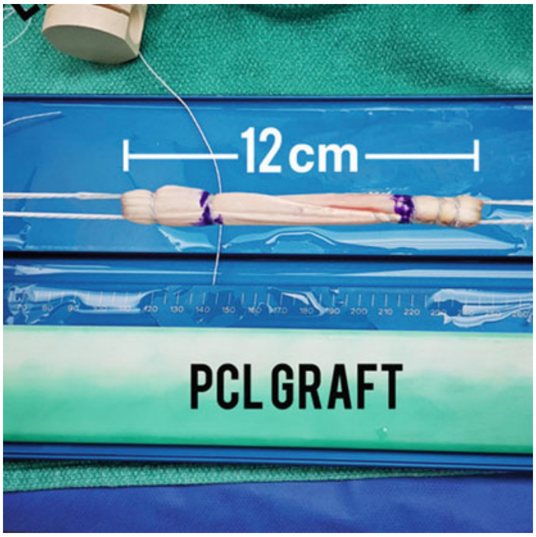

Fig. 15.12 Tripled PCL graft. A tibialis anterior allograft has been used to create a graft that measures 10 cm in length and 10 mm in diameter

15.8.2 Posterolateral Corner Reconstruction Using a Variable Loop Re-tensioning Device

There are numerous techniques described in the literature for reconstructing the PLC of the knee. In this chapter, we will introduce a novel technique that uses a single graft for the reconstruction of all three components of the PLC—the FCL, PFL, and popliteus—and incorporates a variable loop suspensory fixation device that allows for repetitive graft tensioning.

15.8.2.1 Approach

The patient is positioned supine, and a lateral and foot post is used to support the knee in a flexed position. A tourniquet may be used during the procedure. The lateral femoral epicondyle, Gerdy's tubercle, fibular head, and approximate location of the common peroneal nerve (CPN) are marked on the skin with a pen. The skin incision begins proximal to the lateral epicondyle and curves distally between Gerdy's tubercle and the fibular head (Fig. 15.13). Sharp dissection down to fascia maintains the subcutaneous fat and blood supply with the skin flap and reduces the risk of wound breakdown postoperatively. The CPN is exposed and marked with a Penrose drain to avoid damaging this structure throughout the procedure. It is often easiest to identify the nerve as it emerges from under the long head of biceps femoris, approximately 1–2 cm proximal to the fibular head. The nerve is traced distally, until it dives into the fibers of the peroneus longus muscle. Care should be taken to preserve the branches that come off proximally and travel toward the fibular head. The iliotibial (IT) fascia is incised just proximal to the lateral epicondyle. The incision is curved distally toward Gerdy's tubercle, and the fascia is slightly elevated off the tibia to provide adequate exposure. An L-shaped capsulotomy is made, extending distally along the anterior border of the lateral head of gastrocnemius (LHG) from its femoral insertion toward the lateral meniscus, and anteriorly toward the articular surface of the lateral femoral condyle to expose the femoral insertions of the FCL and popliteus (Fig. 15.14). Anatomic studies have shown that these insertions are typically 18.5 mm apart, with the FCL inserting on the bony prominence of the lateral epicondyle and the popliteus inserting in a sulcus next to the articular cartilage distal and slightly anterior to the FCL [5]. Next, the interval between the LHG and the fibular head is developed. This can be done

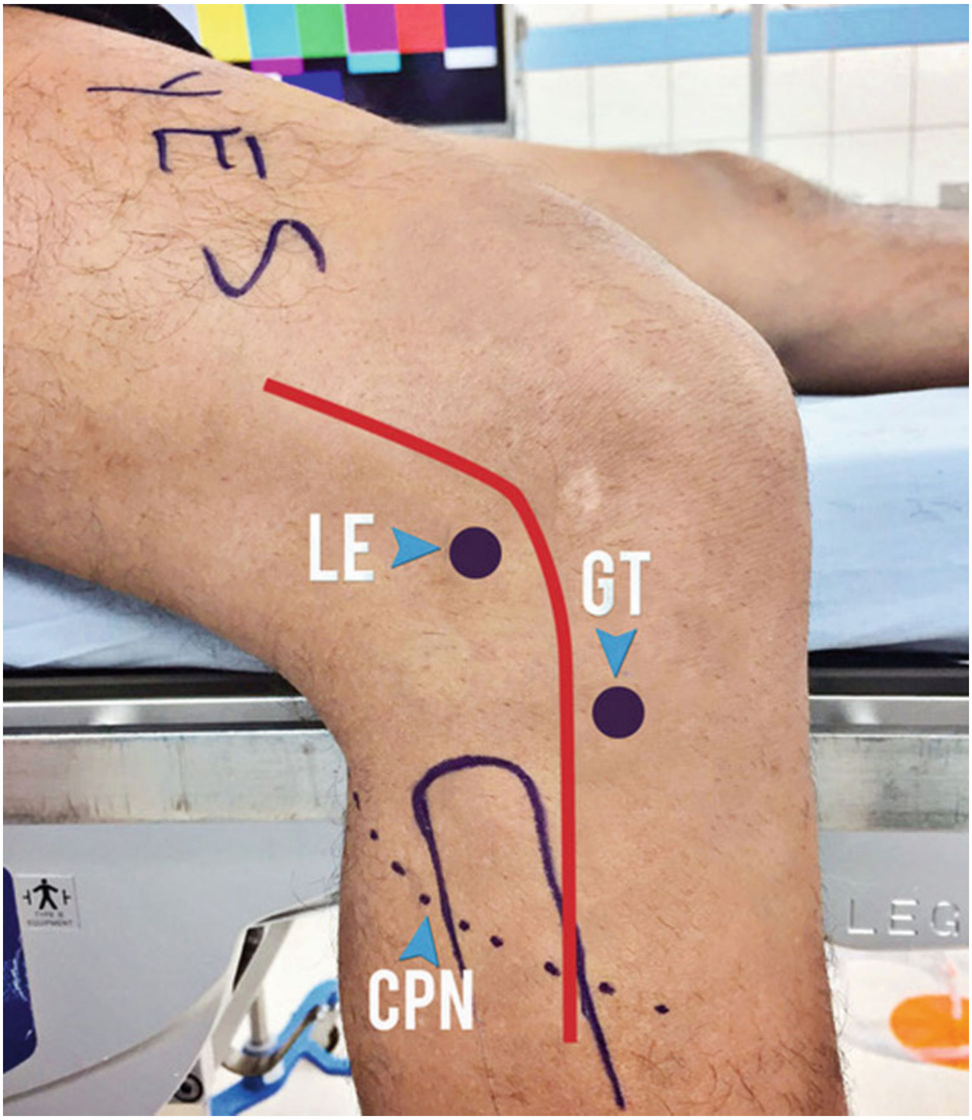

Fig. 15.13 Anatomic landmarks for the approach to the posterolateral corner, including the lateral epicondyle (LE), Gerdy's tubercle (GT), fibular head, and the common peroneal nerve (CPN). The skin incision begins proximal to the lateral epicondyle and curves distally between Gerdy's tubercle and the fibular head

bluntly by palpating the tubercle on which the popliteofibular ligament (PFL) inserts on the fibula, and then developing the plane between it and the posterior tibia.

15.8.2.2 Graft Preparation

This technique employs a single semitendinosus allograft or autograft with a minimum length of 28–30 cm and a diameter of 6–8 mm when doubled in the tibial tunnel. In this technique, the tunnel drilling is described by Laprade [7]; however, we have modified the graft configuration and tibial fixation to allow for the use of one graft and repetitive tensioning. The graft is prepared by whip-stitching each end with a heavy nonabsorbable suture. Passing sutures are incorporated into both ends such that they can be removed after graft fixation, thereby eliminating suture material within the soft tissues.

15.8.2.3 Femoral Tunnel

The FCL femoral tunnel is drilled on the lateral femoral epicondyle just proximal to its insertion site. The popliteus femoral tunnel is drilled slightly superior to its insertion and about 18 mm anterior and distal to the FCL tunnel. Both tunnels are reamed to a diameter of 6–7 mm and a depth of 2.5 cm (Fig. 15.15).

15.8.2.4 Fibular Tunnel

The fibular tunnel is drilled from the insertion of the FCL—beginning 8 mm posterior to the anterior border of the fibula and 28 mm distal to the styloid [5]. This tunnel is aimed toward the insertion of the popliteofibular ligament on the posteromedial border of the fibula. The tunnel is reamed to a diameter of 6–7 mm to allow for smooth graft passage and tensioning (Fig. 15.16).

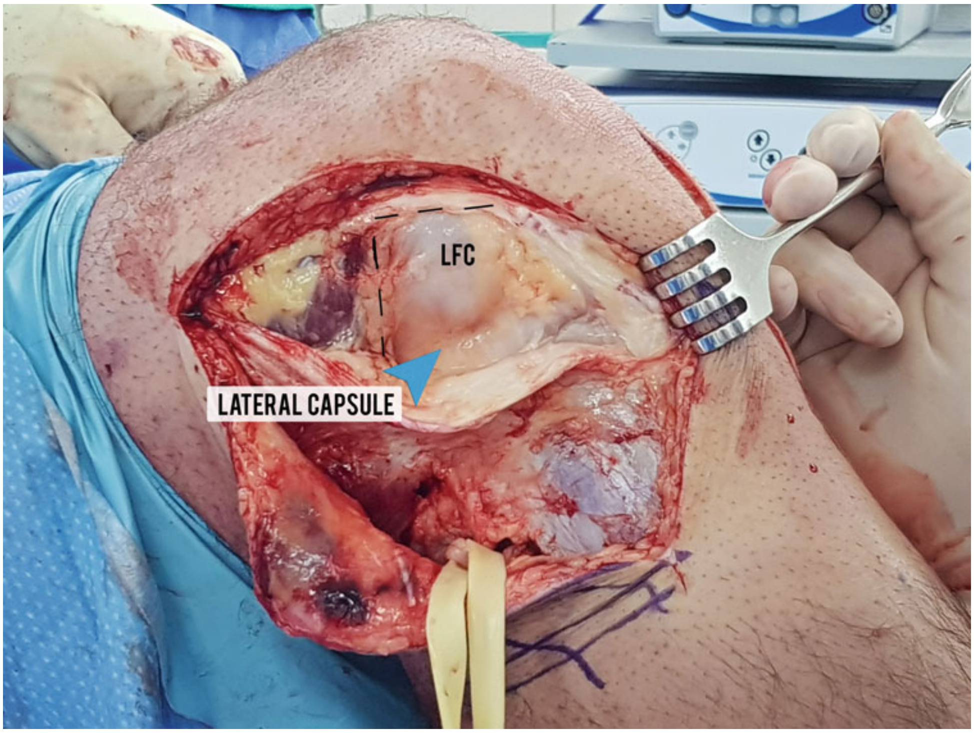

Fig. 15.14 An L-shaped posterolateral capsulotomy, extending posteriorly from the lateral epicondyle and distally along the posterior border of the femoral condyle toward the lateral meniscus

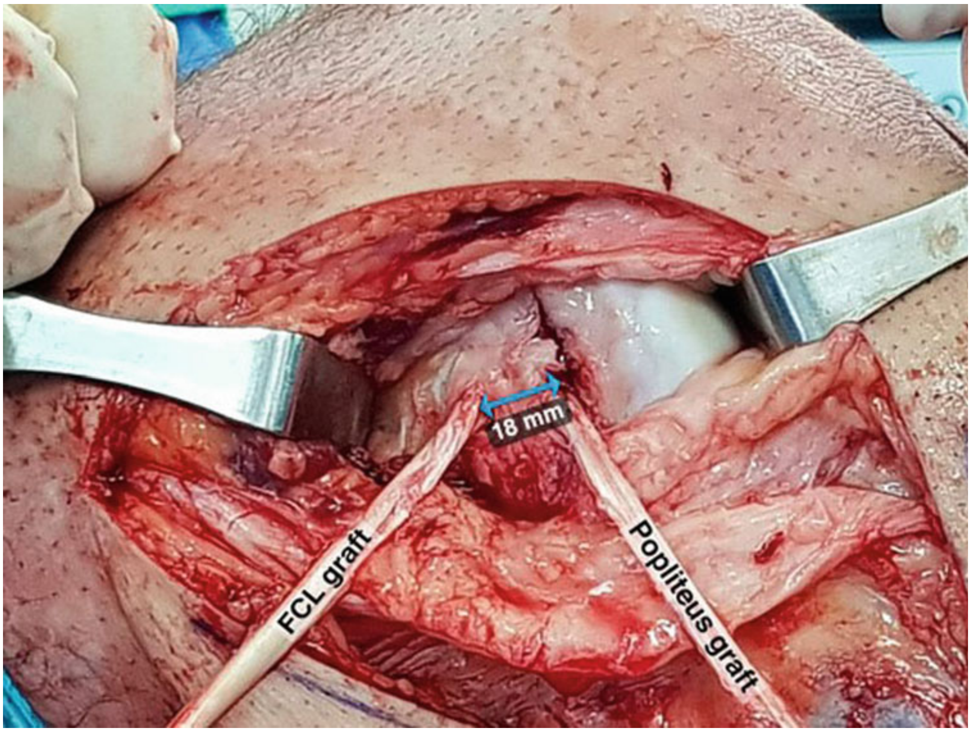

Fig. 15.15 The femoral tunnels for the FCL and popliteus grafts should be approximately 18 mm apart

15.8.2.5 Tibial Tunnel

The tibial tunnel is drilled beginning 1.5–2 cm distal to the joint line and directly below Gerdy's tubercle. This tunnel is directed toward the posterior popliteal tibial sulcus at the level of the popliteal musculotendinous junction and approximately 10–15 mm distal to the articular cartilage [7]. The tunnel should exit just inferior and lateral to the lateral mammillary process, thereby ensuring a safe distance from the PCL tibial tunnel. A tibial guide and a surgical spoon are helpful to ensure appropriate tunnel position, as well as for

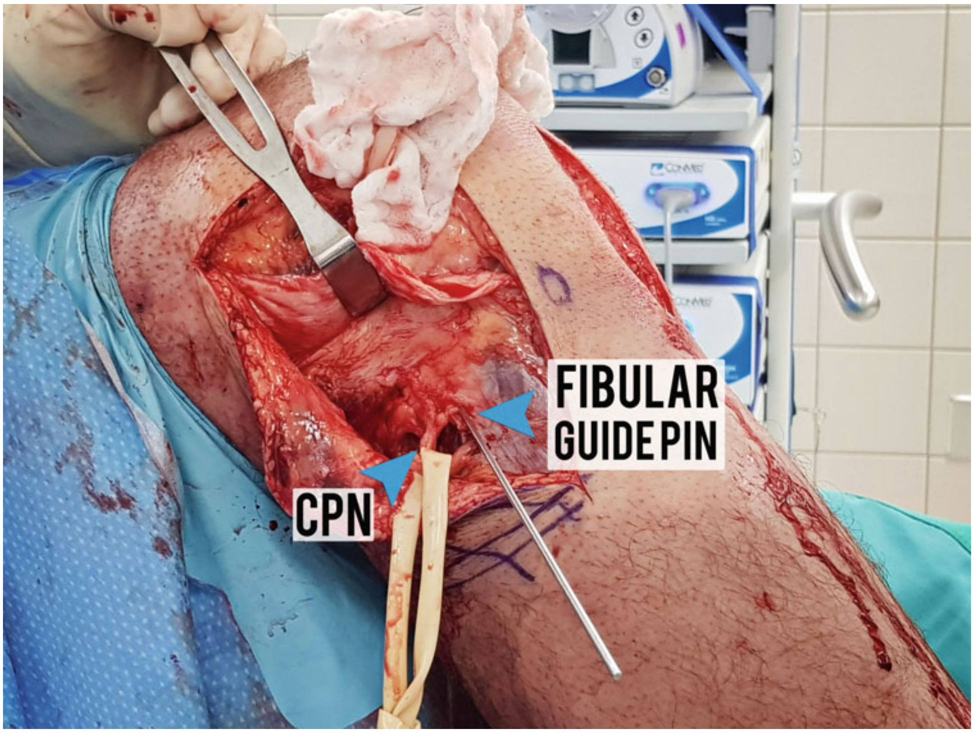

Fig. 15.16 The fibular tunnel begins at the insertion of the FCL approximately 8 mm posterior to the anterior border of the fibula and 28 mm distal to the styloid. It is aimed posteromedially to exit at the insertion of the popliteofibular ligament

retraction of the LHG and the fabellar ligament while protecting the central neurovascular bundle (Fig. 15.17). It is important that this tunnel is wide enough to accommodate the looped graft and fixation device.

15.8.2.6 Graft Passage and Fixation

One end of the graft is inserted and secured in the popliteus femoral tunnel with an interference screw (typically 6 × 25 mm). The graft is then passed intra-articularly,

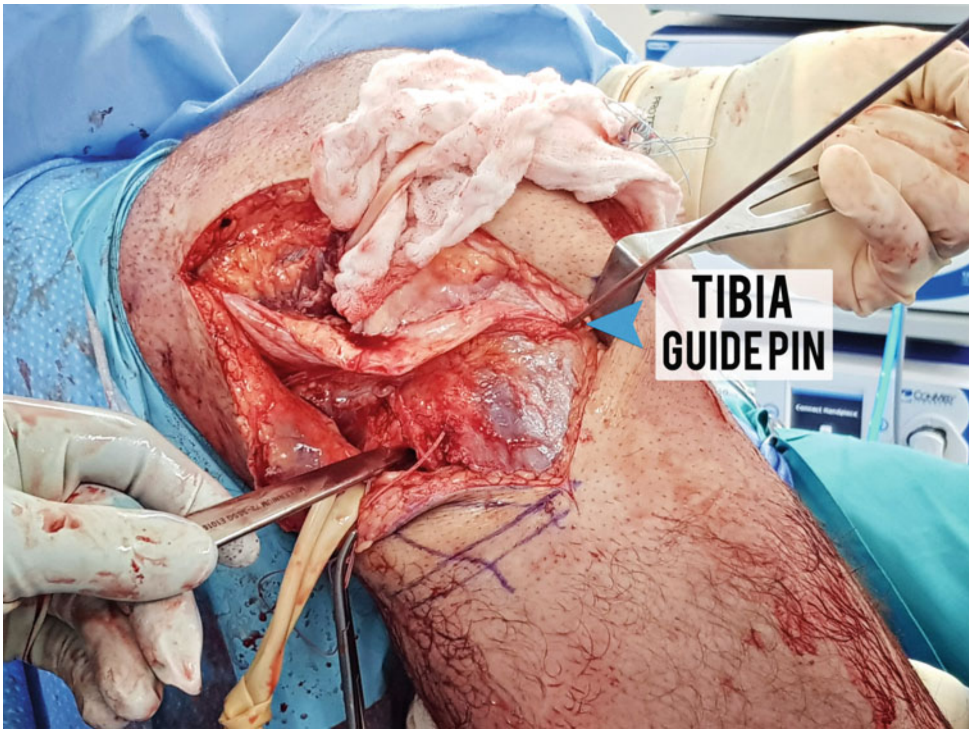

Fig. 15.17 The tibial tunnel begins 1.5–2 cm distal to the joint line (below Gerdy's tubercle) and exits in the popliteal sulcus of the posterior tibia (10–15 mm distal to the articular cartilage). It is located just lateral to the lateral mamillary body to avoid tunnel convergence with the PCL tunnel

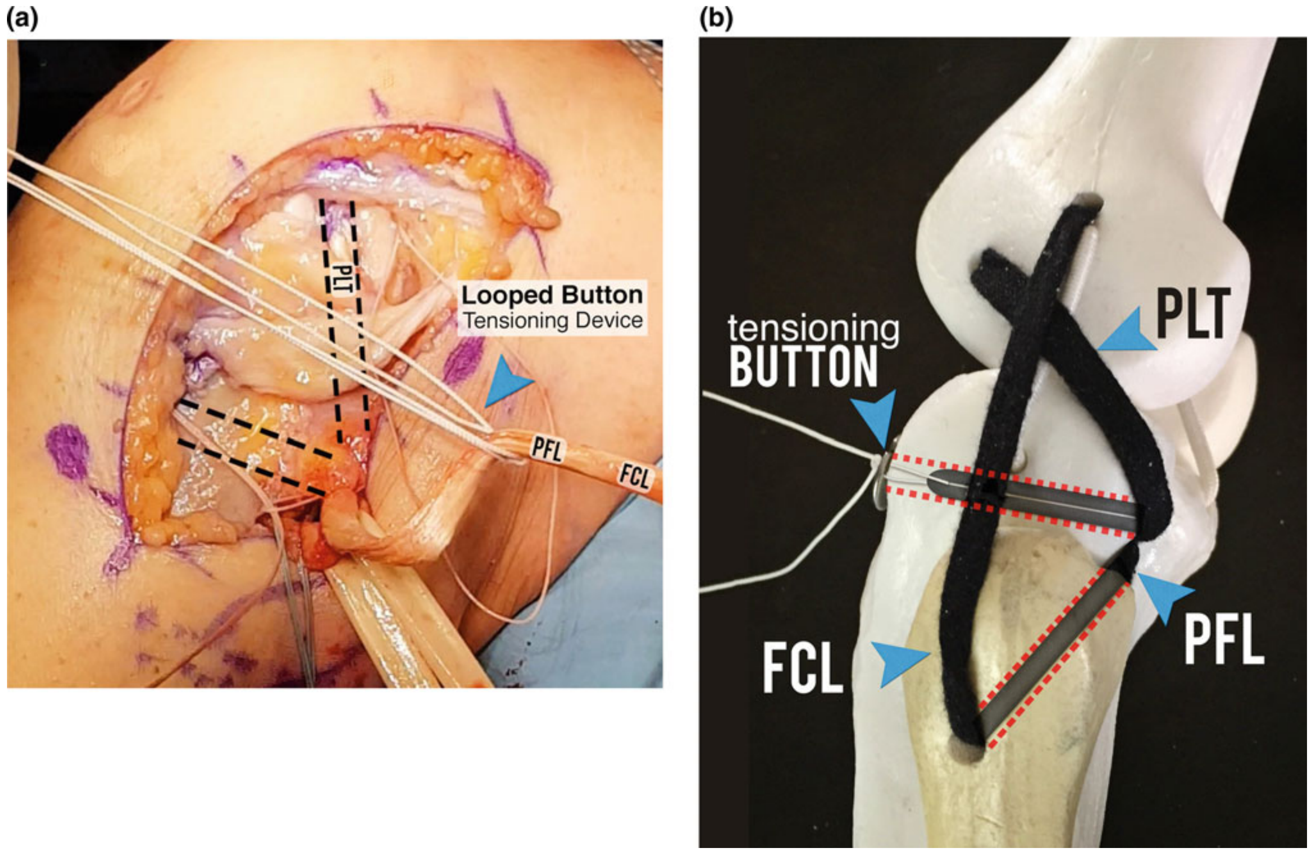

Fig. 15.18 **a** The graft has been secured in the popliteus femoral tunnel, passed along the course of the popliteus, and the variable loop fixation device is attached. The free end of the graft will then be passed through the fibula and along the course of the FCL to create the PFL and FCL portions of the construct. **b** Saw bone model demonstrating the single graft variable loop button re-tensioning technique for PLC reconstruction

following the course of the native popliteus tendon. A curved hemostat can be used to retrieve the graft from posterior to anterior in the interval between the tibia and the LHG. The graft must remain deep to biceps femoris and the IT band. Next, the graft is passed through a variable loop tensioning device and shuttled from posterior to anterior through the tibial tunnel. The fixation button is attached to the device but importantly is not tensioned at this time. The graft is then passed through the fibular tunnel from posterior to anterior, thereby creating the PFL portion of the construct. Lastly, the graft is passed along the course of the native FCL, deep to the IT band and superficial to the popliteus portion of the graft. It is secured in the FCL femoral tunnel with an interference screw (6 × 25 mm). It is important to confirm that there is sufficient slack in the construct for delivery and tensioning of the graft in the tibial tunnel. This is performed by inspecting the looped portion of the graft at the entrance of the tibial tunnel on the posterior cortex of the tibia. There must be a minimum of 1.5 cm of looped graft (3 cm in total) to allow for adequate fixation within the tibial tunnel. Note: If the graft is too long (greater than 4 cm looped or 8 cm in total), it can bottom out in the tibial tunnel and prevent tensioning of the construct. If this is the case, the graft should be shortened prior to femoral fixation of the FCL (Fig. 15.18).

15.8.2.7 Graft Tensioning

The graft is tensioned via the variable loop fixation device with the knee in 30° of flexion, internal rotation, and with a valgus force applied. The knee is then cycled through flexion and extension and sequential tensioning is performed. The PCL can be re-tensioned at this stage as well. Once all three components of the PLC are taught, an interference screw can be used to secure the FCL portion of the graft in the fibular tunnel. Re-tensioning of the PFL and popliteus components of the graft can then be performed.

15.8.2.8 Posterolateral Capsular Plication and Closure

Imbrication of the posterolateral capsular structures is important for a successful PLC reconstruction. This is performed by advancing the posterolateral capsule proximally

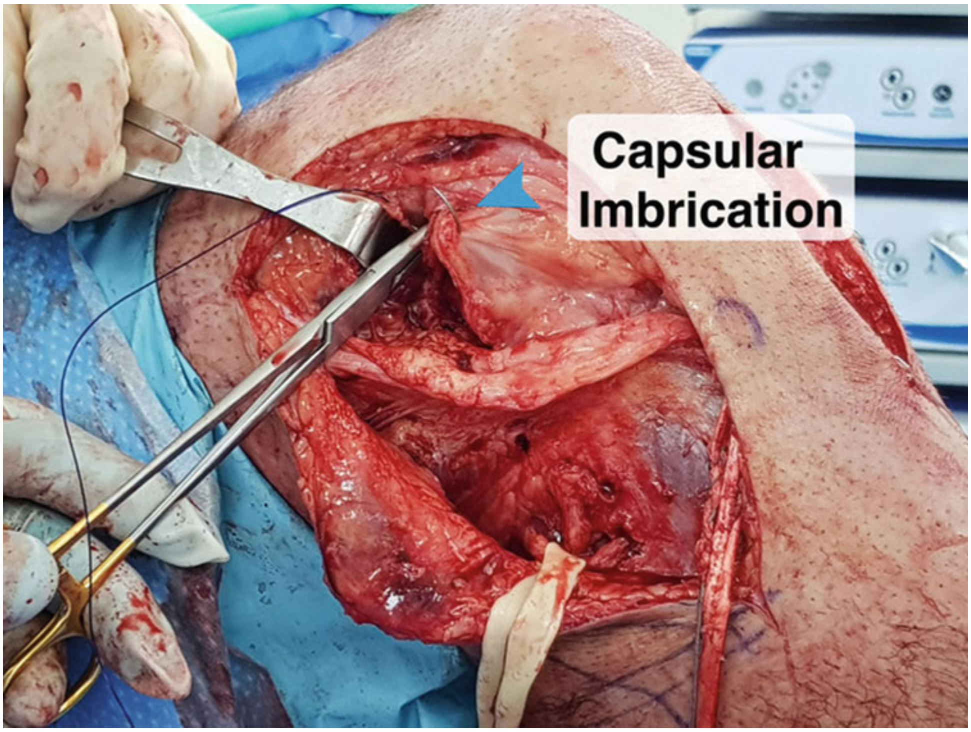

Fig. 15.19 Repair of the posterolateral capsulotomy. This can be further reinforced with heavy nonabsorbable sutures

and anteriorly—incorporating the capsular flap that was taken down to expose the femoral insertions of the FCL and popliteus. Nonabsorbable sutures can be placed through the capsular repair as well as the PLC graft to further reinforce the reconstruction [55] (Fig. 15.19). The IT band can then be closed in a running fashion. The stability of the repair should be tested with a posterior drawer, varus stress, and posterolateral drawer test. If necessary, the knee can be cycled once more and the final tensioning can be performed. The sutures should be tied over the fixation button. The peroneal nerve and interval between the lateral head of gastrocnemius and tibia can be left to heal on their own. The subcutaneous tissue and skin should be closed in a layered fashion. A Hemovac drain may be necessary depending on the extent of bleeding.

15.8.3 Osteotomy for Chronic PCL and PLC Injuries

There is no tool more powerful for the knee reconstructive surgeon than an osteotomy. Awareness of alignment in both the sagittal and coronal planes is critical in the management of a multi-ligament injured knee. Although osteotomy is covered extensively elsewhere in this textbook, it is worthwhile to briefly mention the role of anteromedial opening wedge high tibial osteotomy (HTO) in the management of a chronic combined PCL and PLC-deficient knee [56, 57]. There are four key objectives of this osteotomy. First, it increases the slope of the proximal tibia in the sagittal plane, thereby maintaining the anterior reduction of the tibia on the femur and consequently decreasing the force on the PCL graft. Giffin et al. [57] have demonstrated that a slope-correcting osteotomy can reduce posterior translation of the tibia on the femur in the absence of a PCL reconstruction. Second, increasing the tibial slope serves to flex the tibia with respect to the femur, thus decreasing knee recurvatum and eliminating the posterolateral thrust that frequently gives patients a sense of instability. Third, an anteromedial opening wedge HTO corrects varus deformity in the coronal plane which reduces the forces on the FCL and other PLC structures. This serves to protect PLC graft integrity and can eliminate the need for a soft tissue reconstruction. A prospective cohort study by Arthur et al. [58] followed 21 patients with chronic PLC deficiency and varus alignment treated with medial opening wedge HTO. At mean follow-up of 37 months, 38% of the entire cohort and 67% of those with isolated PLC injury did not require second-stage soft tissue reconstruction. Lastly, an anteromedial opening wedge HTO serves a chondro-protective role by bringing the tibia into valgus and thus decreasing medial tibiofemoral compartment stresses [57]. Additionally, reducing the tibia anteriorly decreases the fulcrum of the knee and reduces patellofemoral (PF) pressures. However, if the osteotomy is performed proximal to the tibial tubercle, there is a risk of creating a patella Baja which may *increase*

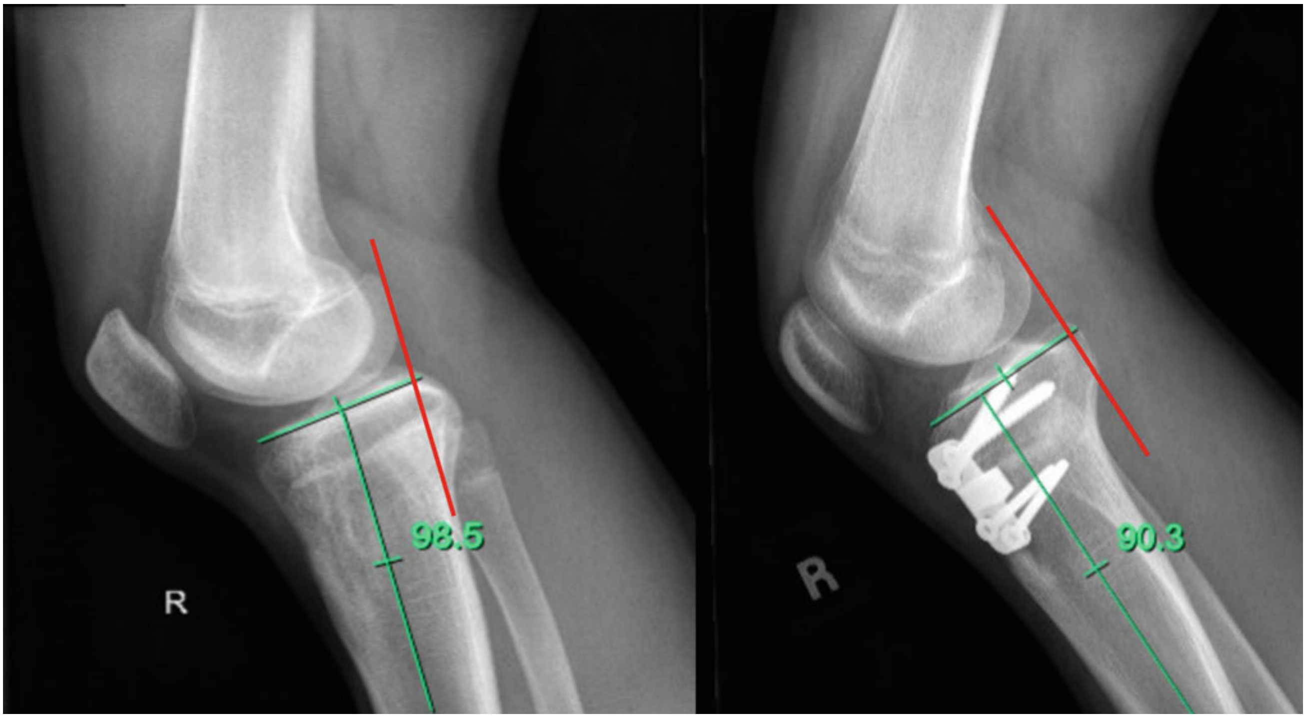

Fig. 15.20 Pre- and postoperative lateral X-ray views demonstrating an anteromedial opening wedge osteotomy to increase the tibial slope in a PCL deficient knee with hyperextension deformity due to anterior growth plate arrest. The slope has been corrected from −8.5° to +0.3° (*green lines*), and the tibia has been translated anteriorly (*red line*) relative to the posterior border of the femoral condyles

PF pressures. Preoperative assessment of patellar height may thus encourage the surgeon to shift the tubercle proximally if a patella Baja is identified.

There are several indications for performing an HTO in a chronic PCL/PLC-deficient knee. The most common clinical scenario is the patient with chronic PCL/PLC deficiency that presents with medial knee pain, swelling, and signs of medial tibiofemoral and PF osteoarthritis. These patients often present many years following their initial injury and seek help due to pain and *not* instability. Positive outcomes can be achieved with an HTO with or without a staged soft tissue reconstruction. In fact, surgeons should be cautious of performing isolated PCL and PLC reconstructions in these patients as this strategy may not provide adequate pain relief. Another important scenario is the patient with a varus knee with recurvatum and a varus thrust (the “triple varus” knee). In this setting, an isolated soft tissue PCL and PLC reconstruction will often deteriorate over time leading to persistent instability (particularly in the hyperextended position). Correcting varus alignment and increasing tibial slope improves both varus thrust and recurvatum and often negates the need for a soft tissue reconstruction. Another important clinical picture worthy of consideration of an HTO is that of a partial tear of the PCL and/or PLC. Given that augmentation of a PCL or PLC is technically challenging, an osteotomy may be the preferred treatment choice in this setting—particularly if there are other factors contributing to instability such as alignment and slope abnormalities (Fig. 15.20).

In summary alignment in both the sagittal and coronal planes must be considered in a chronic combined PCL and PLC-deficient knee, and if necessary, can be addressed with an HTO prior to or concurrently with a soft tissue ligament reconstruction.

15.9 Postoperative Rehabilitation

Rehabilitation following reconstruction of combined PCL and PLC injuries remains a point of significant controversy among knee ligament surgeons. The main issues of debate include the period of immobilization and restriction of weight-bearing. Historically, a more conservative approach was recommended due to the increased stresses that pass through the grafts—particularly the PCL—with functional motion and weight-bearing [41, 59, 60]. However, the risk of arthrofibrosis as well as experience with anterior cruciate ligament reconstruction has prompted some surgeons to consider more aggressive protocols that encourage early motion [61, 62]. It is important to assess each case individually and determine the appropriate balance between protecting graft integrity and preventing arthrofibrosis.

The frequently used rehabilitation protocol developed by Edson et al. [63] recommends immobilization in extension in a hinged knee brace as well as non-weight-bearing for the first four weeks postoperatively. The brace is then unlocked and progressive range of motion (ROM) is initiated at 4–6 weeks. Weight-bearing is progressed from 7 to 10 weeks, increasing by 25% body weight per week. Strengthening and proprioception are gradually incorporated with a goal of return to work and activity between 6 and 9 months post-operatively [10, 55, 63, 64].

Recent evidence suggests that early motion has no deleterious effect on long-term knee stability. A systematic review by Mook et al. [65] assessed the timing of operative intervention along with postoperative rehabilitation in multi-ligament knee injuries. The authors demonstrated that, in the setting of early surgery, immediate motion (greater than 30° in the first 3 weeks) resulted in less posterior instability, varus and valgus laxity, extension and flexion contracture (greater than 10° and 5°, respectively), and higher outcomes scores than delayed motion. The same authors performed a biomechanical study evaluating laxity of common PCL grafts in simulated ROM, partial, and full weight-bearing. They found no acquired graft laxity with partial weight-bearing and early ROM, but significant acquired graft laxity with full weight-bearing [66]. Accordingly, newer protocols recommend early motion and delayed weight-bearing. Passive ROM from 0° to 90° in a hinged knee brace begins immediately post-surgery and active ROM is initiated at 2 weeks. Non-weight-bearing is maintained for a full 6 weeks postoperative. Hamstring activation is also restricted for up to 4 months post-surgery to minimize additional forces on the PCL graft. Return to sport is permitted once equal ROM, strength, and stability are achieved (typically around 12 months) [62, 67].

The risk of arthrofibrosis following multi-ligament knee reconstruction ranges from 8 to 57% in the literature, with a correspondingly high rate of manipulation under anesthesia (MUA) [61, 65, 68]. The systematic review by Mook et al. [65] reported that the incidence of flexion loss greater than 10° and extension loss greater than 5° in patients treated acutely was as high as 47.8 and 14.8%, respectively. In general, early intervention in the setting of motion loss is recommended to maximize recovery while limiting damage to the reconstructed tissues. MUA with concurrent arthroscopic debridement is recommended if significant extension loss is present as early as 6 weeks post-surgery.

15.10 Summary

Combined PCL and PLC injuries are both a complex and rewarding clinical problem for the knee ligament surgeon. A thorough understanding of the anatomy and biomechanics is critical in the evaluation and management of these injuries. Reconstruction of the PCL and PLC is generally recommended and several techniques have been described in the literature. In reconstructing the PCL, achieving a distal tibial tunnel is critical to restore the anatomy and biomechanics of the ligament. The most important structures in PLC reconstruction include the FCL, popliteus, and popliteofibular ligament. The use of a single graft with a variable loop suspensory button allows for reconstruction of all three key elements of the PLC while permitting sequential re-tensioning of the construct and thereby improving graft stability. Anteromedial opening wedge HTO is an important consideration in all chronic combined PCL/PLC injuries. Postoperative rehabilitation is focused on protecting graft integrity while progressing knee motion, and generally involves protected weight-bearing with early ROM. Despite recent advances in the understanding of combined PCL/PLC injuries, this remains a fascinating area in multi-ligament knee surgery. Continued research, evolution of reconstructive techniques, and evaluation of short- and long-term patient results will be essential to optimize patient outcomes in the coming years.

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Surgical Treatment of Combined PCL Medial Side Injuries: Acute and Chronic

16

Jeffrey M. Tuman and Mark D. Miller

16.1 Introduction

Multi-ligament knee injuries are relatively uncommon; however, an early and accurate diagnosis remains critical for optimal patient outcome [1]. Maintaining a high index of suspicion is critical to the correct diagnoses and management of these knee injuries, which is frequently present as spontaneously reduced knee dislocations with unremarkable plain radiographs [2]. The management of multi-ligament knee injuries continues to evolve with increased awareness of important anatomic structures and their relationships to knee stability, as well as with advancements in surgical technique. However, management of a combined injury to the posterior cruciate ligament (PCL) and the medial knee complex, consisting of both the medial collateral ligament (MCL) and posteromedial corner (PMC), remains a hotly debated topic. Specifically, which injuries should be addressed surgically, optimal surgical timing, and what types of repair or reconstructions are most favorable remains unclear. This chapter will discuss these issues with regard to combined PCL, MCL, and PMC injuries in both the acute and chronic setting. Pertinent anatomy, clinical evaluation, treatment consideration, and surgical technique in the acute and chronic injury setting will be discussed.

16.2 Anatomy

16.2.1 Posterior Cruciate Ligament

The anatomy of the PCL has been well described in the previous literature. The PCL is the primary static restraint to posterior tibial translation [3]. It is located near the center of rotation of the knee [4], originating from the anterolateral aspect of the medial femoral condyle, approximately 1 cm proximal to the articular surface. The PCL inserts within a central sulcus located on the posterior aspect of the tibia, approximately 1–1.5 cm distal to the posterior edge of the tibial plateau. The PCL is functionally and anatomically divided into two bundles. The anterolateral (AL) bundle provides the primary restraint and is taught in flexion, while the posteromedial (PM) bundle is taught in extension (Fig. 16.1). Previous anatomic studies have confirmed the important contributing stability that the PM bundle provides [5–8].

16.2.2 Medial Collateral Ligament

The MCL is the primary static stabilizer on the medial side of the knee, contributing up to 78% of the force resistance to valgus stress, especially at 30° of knee flexion. In addition, the MCL acts to secondarily resist abnormal external tibial rotation [9]. It is composed of a superficial MCL, deep MCL, and the posterior oblique ligament which is formed by the capsular attachments from the semimembranosus tendon (Fig. 16.2) [10].

The superficial MCL, the largest and thickest component of the MCL complex, has one femoral and two tibial attachments. The femoral attachment is on average 3.2 mm proximal and 4.8 mm posterior to the medial femoral condyle. The two distinct tibial attachments include one directly over the anterior arm of the semimembranosus (soft tissue attachment) and one slightly anterior to the posteromedial

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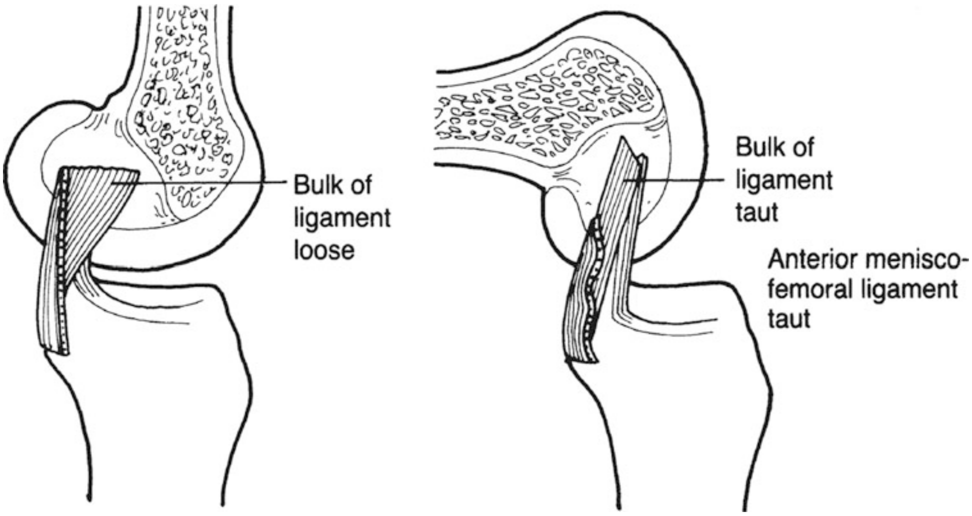

Fig. 16.1 The anterolateral bundle of the PCL provides the primary restraint and is taught in flexion, while the posteromedial bundle is taught in extension. Reprinted with permission from Blevins et al. [25]

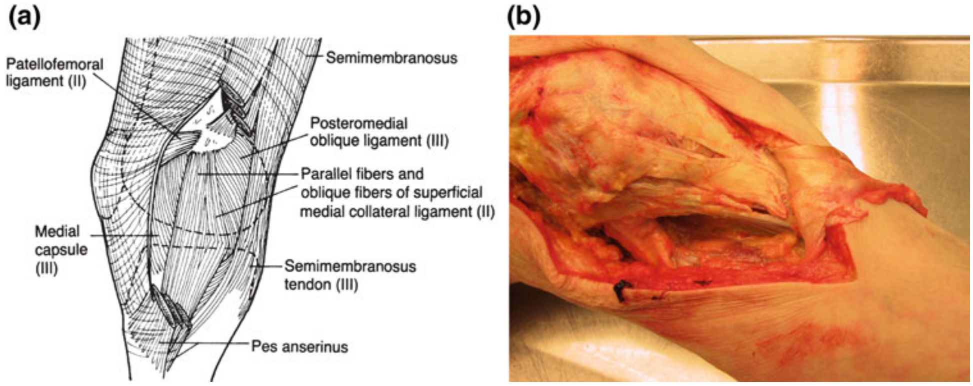

Fig. 16.2 Anatomy of the medial knee. **a** Schematic drawing. **b** Photograph. Reprinted with permission from Blevins et al. [25]

crest of the tibia (bony attachment). The tibial attachment of the superficial MCL is 4–5 cm distal to the joint, located within the pes anserine bursa, forming a large portion of the posterior floor of the bursa. The anterior portion tightens primarily in flexion, while the posterior portion tightens primarily in extension. Knowledge and recognition of the origin and insertional sites of the superficial MCL are critical to anatomic primary repair of the MCL, when possible.

The deep MCL is typically recognized as a thickening of the medial joint capsule which is often indistinguishable from the posterior oblique ligament. The deep MCL tightens in knee flexion and is lax in full knee extension. In addition, the meniscotibial and meniscofemoral ligaments are distinct structural components of the deep MCL. The medial meniscus is thus firmly attached to the deep portion of the MCL.

16.2.3 Posteromedial Corner

Similar to the posterolateral corner complex of the knee, the PMC consists of a series of capsular and tendinous attachments in addition to the anatomic components of the MCL described above. Specifically, distinct anatomic structures composing the PMC include the pes anserine tendon attachments, posteromedial capsule, superficial MCL, posterior oblique ligament, semimembranosus tendon, deep MCL, and the medial gastrocnemius tendon. Like the posterolateral corner, the PMC plays a key role in preventing pathological rotation.

The posterior oblique ligament (POL) is particularly crucial to the stability of the medial side of the knee. Historically this ligament was described as consisting of three capsular arms (superficial, tibial/central, and capsular). Anatomically, these fascial attachments originate from the semimembranosus tendon at the knee with subsequently separate sites of insertion as described by LaPrade et al. [10]. The central arm of the POL is the thickest and most significant contributor to stability, forming the main portion of the femoral attachment of the posterior oblique ligament. It stabilizes both the meniscofemoral and meniscotibial ligaments and attaches directly onto the posteromedial aspect of the medial meniscus. It also merges with and thus reinforces the posteromedial capsule. For these reasons, the central arm of the posterior oblique ligament is the most important anatomic structure to consider for repair, or more typically for reconstruction, following injury to the PMC of the knee.

16.3 Clinical Evaluation

16.3.1 History and Physical Examination

Immediate diagnosis of a multi-ligament knee injury remains important, secondary to the potential associated morbidities, including neurovascular injury. Clinical assessment of the knee is critical to an expeditious recognition of these injuries, particularly in the polytraumatized patient. Such injuries due to acute knee dislocations are often missed on initial assessment since knee dislocations often spontaneously reduce prior to presentation to the acute care center. In general, obvious deformity, medial skin dimpling, avascular or aneural distal extremity, and ligamentous instability on knee examination are all indications of a knee dislocation and potential multi-ligament injury. A complete vascular assessment is extremely important in the initial evaluation of these injuries [11].

For the PCL and medial knee complex, specific examination tests help to reveal injuries to these structures. A positive posterior drawer test, in which a posterior force is applied to the proximal tibia with the knee flexed to 90°, resulting in posterior tibial translation relative to the distal femur, is indicative of PCL injury (Fig. 16.3). Normal tibial station is 1 cm anterior to the femoral condyles. A grade III posterior drawer test, in which the tibia is translated 1 cm posterior to the femoral condyles, is indicative of a likely combined PCL and posterolateral corner (PLC) injury [12]. Visualized posterior sag of the tibia with ipsilateral hip and knee flexion to 90° while supporting the heel is also suggestive of PCL injury (Fig. 16.4). Valgus stress testing of the knee is used for assessment of the medial side of the knee. Instability at 30° of flexion indicates MCL injury (Fig. 16.5). If instability is also present in full extension, a combined MCL/cruciate injury is likely. A Slocum test is used for assessment of the PMC complex. In the Slocum test, the tibia is translated anteriorly in drawer testing with the foot externally rotated to 15° [13].

Fig. 16.4 The posterior sag sign is indicative of a high-grade PCL injury

16.3.2 Radiographic Evaluation

Initial radiographs may be normal in the setting of multi-ligament knee injuries. Stress radiographs, however, may be obtained to elucidate the extent of injury. Lateral

Fig. 16.3 The posterior drawer test is used in the clinical diagnoses of a PCL injury

Fig. 16.5 Valgus instability at 30° of knee flexion indicates MCL injury

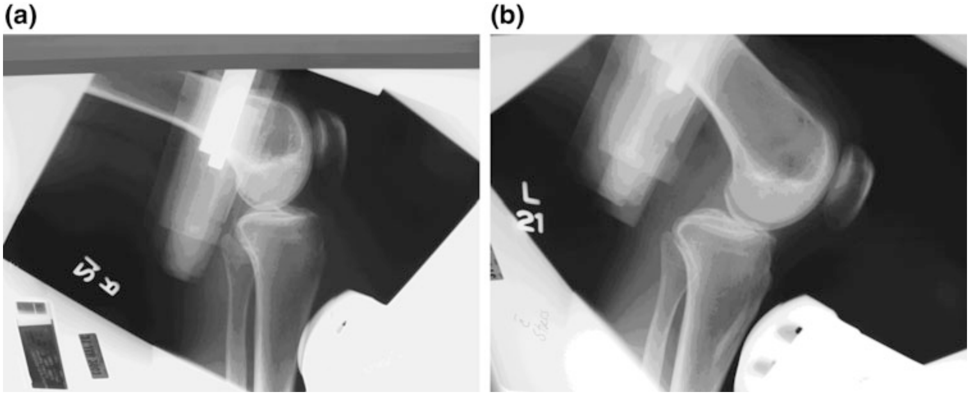

Fig. 16.6 Instrumented stress radiography with a posterior-directed force. **a** Normal relationship between the distal femur and tibial plateau. **b** A PCL-injured knee with obvious posterior tibial translation of >10 mm

Fig. 16.7 Valgus stress radiograph of an MCL injury showing pathologic widening of the medial joint space

Fig. 16.8 Coronal T2-weighted MR image of the knee demonstrating an MCL avulsion injury off of the tibia. Such an injury may be amenable to primary repair of the MCL without the necessity for reconstruction

X-rays of the knee showing a side-to-side difference of >10–12 mm of posterior tibial displacement is indicative of combined PCL/PLC injury (Fig. 16.6) [12]. A side-to-side difference of medial joint space opening >3.2 mm with valgus stress is indicative of MCL injury (Fig. 16.7) [14]. Magnetic resonance imaging (MRI) is frequently obtained for complete evaluation of knee and for preoperative planning purposes (Fig. 16.8). Associated injuries to the meniscus and chondral surfaces are often discovered on MRI.

16.4 Treatment Considerations: Nonoperative Management for Combined PCL/Medial Knee Complex Injuries

Historically, isolated partial PCL or partial MCL injuries are initially managed nonoperatively. Indications for nonoperative management of combined injuries, however, are less well defined. Typically, these injuries are a result of high-energy mechanisms such as motor vehicle accidents or athletic injuries, and combined low-grade injuries of the PCL and MCL/PMC are unusual. However, low-grade PCL injuries combined with low-grade MCL tears may undergo a trial of conservative treatment with hinged bracing, progressive weight bearing and range of motion exercises, and physical therapy. Frequent clinical assessment of improved knee stability is important. Nonsurgical management of these low-grade combined injuries may vary in their treatment algorithms. Typically, initial treatment involves immobilization in full extension with a posterior calf bolster, with protected weight bearing for 2 weeks. The range of motion exercises are then advanced with the use of a hinged knee brace, and strengthening is focused on the quadriceps muscles. Once 90° of knee flexion is obtained with good quadriceps motor control, full weight bearing is allowed. Advanced strengthening and activity level such as closed-chain exercises and jogging is encouraged with improvement in range of motion and quadriceps strength. Full return to sports activities is dependent upon repeated assessment of clinical stability, return of range of motion, and improvement in strength.

16.5 Considerations for Operative Management of Combined PCL/Medial Knee Complex Injuries

The majority of combined PCL/medial knee complex ligamentous injuries require operative intervention to prevent persistent acute and potentially chronic functional instability and degenerative changes. Many controversies exist regarding treatment algorithms for these injuries. Timing of surgery, delayed repair of cruciate injuries in a staged manner, and specific surgical techniques in both the acute and chronic injury setting are frequently debated.

Timing of surgery and whether staged procedures are completed for multi-ligament knee injuries, including combined PCL/medial knee complex injuries, are controversial. Based upon a literature review and author experience, The Knee Dislocation Study Group recommended acute surgical management of all damaged ligamentous structures [15]. A similar conclusion was made in a recent evidence-based systematic review of multi-ligament injured knees [16]. The senior author of this chapter (MDM) favors early single-stage surgical intervention when there are a combined PCL and medial corner injury. Optimally this is completed within 2 weeks of injury which helps avoid the formation of scar tissue, maintains tissue planes, and facilitates primary repair in certain circumstances. Often the status of the medial corner dictates the timing of surgery. In cases of high-grade PCL injuries and MCL injuries that could be treated nonoperatively in isolation (i.e., grade 1 or 2 MCL sprains), delayed surgical intervention is recommended by the senior author until some normalization of knee range of motion is obtained. This is also the case in chronic PCL/MCL/PMC injuries >3 weeks from injury, at which time abundant scar tissue is typically present and primary repair is no longer possible. In this case, good preoperative knee range of motion becomes extremely important in addition to other factors such as proper limb alignment.

16.6 Surgical Techniques of Combined PCL/MCL/PMC Injuries: Acute Setting

Acute surgical intervention for combined PCL/MCL/PMC injuries is typically defined as within 2 weeks of injury. The specific injury pattern can dictate the surgical technique that is completed. Surgical techniques addressing cruciate and collateral/medial complex injuries often vary from surgeon to surgeon due to training, experience, and comfort level. Many differences in acute surgical technique exist when addressing the PCL, MCL, and PMC in combined injuries.

Whether direct repair or reconstruction of the PCL is completed should be determined by the injury pattern. The vast majority of these PCL injuries is mid-substance tears and is not amenable to direct repair [17]. Those, however, that occur in a “peel back” pattern or avulsion of the tibial attachment may be primarily repaired [18]. In doing so, the patient is placed supine on a radiolucent table. The skin incision and dissection may be completed in a similar fashion to the tibial inlay technique described below. Using a vertical arthrotomy, the avulsed tibial fragment and attached PCL are identified and reduced. Reduction is then secured, typically with a 4.0 mm cortical or a 6.5 mm cancellous screw and spiked washer. Reduction is then confirmed using intraoperative fluoroscopy. Alternatively, nonabsorbable sutures may be used for very small avulsed bone fragments, passed through small drill holes tied over a cortical bridge of bone on the outer cortex of the femur.

In most complete PCL injury patterns, reconstruction of the PCL, rather than primary repair, is recommended. Indeed, different surgical techniques exist when reconstruction of the PCL is undertaken in the setting of a combined medial-sided injury. Some have expressed concerns for extravasation of arthroscopic fluid through capsular rents associated with medial-sided knee injuries [11]. This subsequently led to recommendations for staged cruciate reconstruction or use of a dry arthroscopic procedure [2]. However, this concern may be addressed with the placement of an egress arthrotomy incision that allows fluid to drain freely from the knee.

Many surgeons prefer the classic transtibial tunnel technique although a more recently described tibial inlay technique is also an option. These variables in technique are discussed below.

The classic transtibial tunnel technique for PCL reconstruction is well documented (Fig. 16.9) [19]. Advocates of this technique for PCL reconstruction in multi-ligament knee injuries state that such an approach is safer regarding the risk of vascular injury and requires less extensive soft tissue dissection [1]. A recent review article by Fanelli et al. discusses the surgical technique and results of double-bundle PCL reconstruction via the transtibial tunnel approach [19]. Highlighted is the importance of graft selection, tunnel placement, graft tensioning, graft fixation, as well as a discussion of single-bundle versus double-bundle techniques.

Allografts are ideal for PCL reconstructions of multi-ligament knee injuries since they avoid the morbidity of autograft harvest. A hamstring autograft should be reserved for its use in MCL/PMC reconstruction. Bone–patellar tendon–bone and Achilles tendon allografts are frequently used for PCL reconstruction. Multiple studies have shown good outcomes with both single- and double-bundle PCL reconstruction [19–22]. The single-bundle technique typically reconstructs the anterolateral bundle of the PCL. However, as discussed previously, the PCL does consist of two distinct bundles that function at different degrees of knee flexion, and reconstructing these bundles using the double-bundle technique may produce more normal knee function. Of primary concern regarding the classic transtibial tunnel technique are the reported rates of graft abrasion and subsequent failure secondary to the "killer curve," the acute angle that the graft must make to round the posterior lip of the tibia when exiting the tibial tunnel. A clinical study by MacGillivray et al. has shown no difference in outcome between the transtibial and inlay techniques [23]. A biomechanical study, however, demonstrated increased failure rates following cyclic testing, as well as increased graft thinning and elongation using the transtibial tunnel technique. Long-term cadaveric and clinical studies are required for further understanding of potential differences in outcome using these two reconstruction techniques.

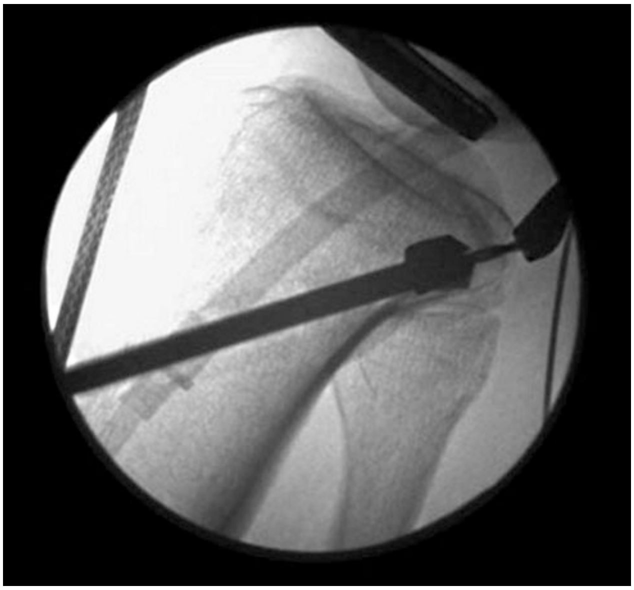

Fig. 16.9 Appropriate tibial tunnel placement for the transtibial tunnel technique during PCL reconstruction

The senior author of this chapter (MDM) prefers a single-bundle anatomic reconstruction of the PCL using the tibial inlay technique. The preferred graft for reconstruction is patella tendon allograft or, in some circumstances, contralateral patella tendon autograft. Tibial graft fixation is achieved with bicortical cannulated screw fixation and the femoral graft fixation with interference screws (Fig. 16.10). PCL reconstruction is typically achieved prior to addressing injured extracapsular structures such as the MCL/PMC. The patient is placed supine on the operating table with a tourniquet in place. The knee is evaluated using standard arthroscopy portals. The residual PCL stump is debrided. The PCL femoral tunnel is prepared by outside-in technique using a PCL guide and guide pin. Placement of the guide pin within the PCL footprint in the medial femoral notch is confirmed arthroscopically. The guide pin is placed near the 1:30 position (right knee), 6–8 mm from the articular margin. The PCL tunnel is then drilled over the guide pin, and a looped 18-G smooth wire is placed through the tunnel and into the back of the knee for graft passage. This technique reproduces the anterolateral bundle of the PCL. Attention is then turned to the tibial inlay open posterior approach assuming an ipsilateral ACL injury is not present. A transverse incision within the popliteal crease is made, and blunt dissection is used to identify the lateral aspect of the medial head of the gastrocnemius muscle. This is then mobilized medially, protecting the neurovascular structures. Smooth Steinmann pins drilled into the posterior tibial cortex may be used for soft tissue retraction. Electrocautery is used to clear the PCL sulcus, and a trough in the posterior tibia is made with a high-speed burr. This trough is made to fit the bone plug of the PCL graft. The bone plug for the tibial inlay is then secured with two 4.5 mm cannulated bicortical screws. The graft is then pulled into the joint using the looped 18-G smooth wire previously placed through a vertical arthrotomy at the proximal margin of the inlay (Fig. 16.11). A generous arthrotomy at this point facilitates easier graft passage. The PCL inlay is secured on the tibial side; however, tensioning and femoral fixation are held until collateral/corner graft passage or primary repair is completed, as discussed below. Once this occurs, the PCL is tensioned and secured on the femoral side at 90° of knee flexion. A Schantz pin connected to a T-handle chuck can be drilled into the anterior tibia which allows an anterior drawer force to be exerted

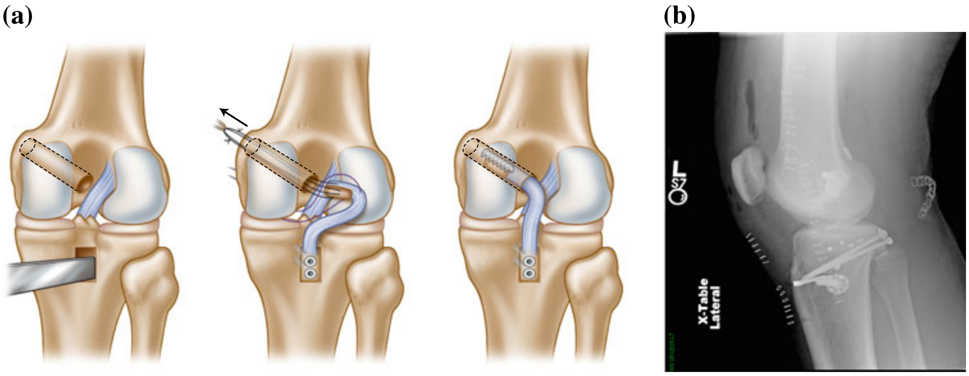

Fig. 16.10 PCL reconstruction using the tibial inlay technique. **a** Schematic. **b** Radiograph demonstrating how tibial graft fixation is achieved with bicortical cannulated screw fixation, and the femoral graft fixation with interference screws

during PCL tensioning. Attention is then turned toward isometry testing, tensioning, and securing the MCL/PMC.

As discussed previously, acute surgical intervention for high-grade MCL/PMC injuries is preferred. In the acute setting, MCL avulsion injuries may be primarily repaired to a prepared bone bed with suture anchors or a screw and spiked washer (Fig. 16.12). An incision is centered over the medial joint line. The underlying sartorius fascia is split longitudinally, exposing the superficial MCL. A vertical incision is then made along the interval between the posterior border of the MCL and anterior border of POL, exposing the deep MCL. A plane between the superficial MCL and deep MCL can then typically be developed, allowing for repair of the deep MCL against the POL, facilitating tension of the POL. Developing the plane also facilitates exposure of the medial tibial plateau and subsequent repair of the deep MCL at the level of the joint line. A screw and spiked washer or suture anchors are then used for femoral and tibial fixation based upon surgeon preference. Acute mid-substance tears require reconstruction in addition to primary repair. The modified Bosworth technique is the preferred reconstruction approach of the senior author of this chapter. With this technique, the native ipsilateral semitendinosus tendon is harvested, leaving its tibial insertion intact. This tendon is then looped around a screw and spiked washer that has been placed at the medial femoral epicondyle. It is then secured distally with a second screw and spiked washer (Fig. 16.13). Semitendinosus allograft may be used if autograft is unavailable. For PMC injuries, reestablishment of the POL function is important for knee stability. This is achieved by looping the posterior limb of the MCL graft around the semimembranosus tendon.

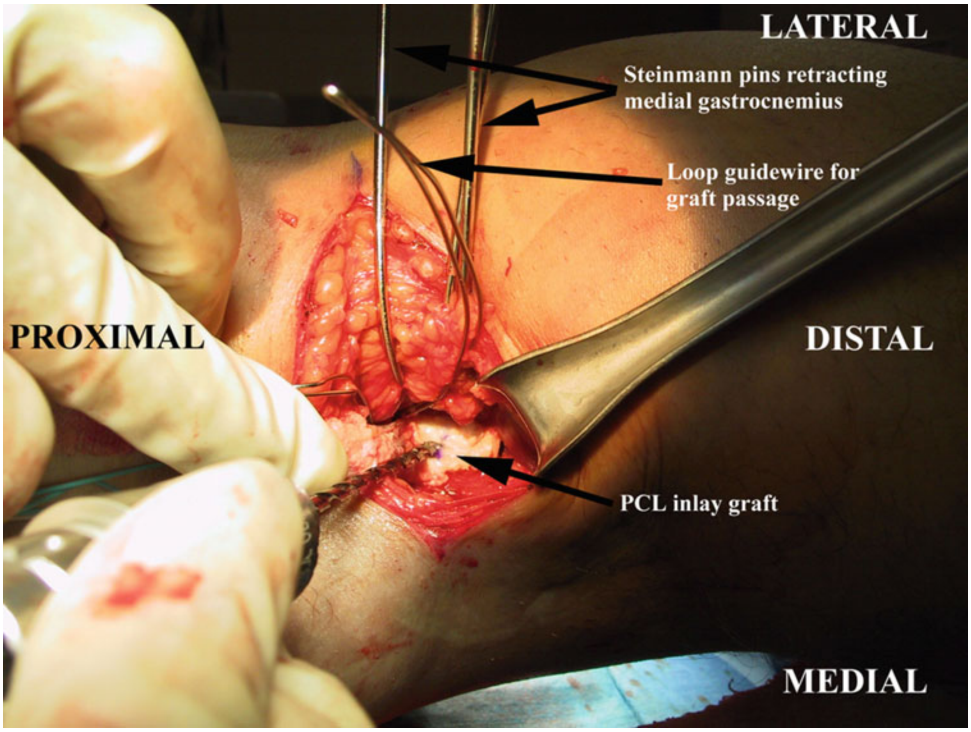

Fig. 16.11 During the tibial inlay technique for PCL reconstruction, Steinmann pins may be used for soft tissue retraction of the medial gastrocnemius, protecting the neurovascular bundle. This provides adequate exposure of the posterior tibial sulcus for positioning of a tibial trough and subsequent graft passage using a looped 18-gauge guidewire

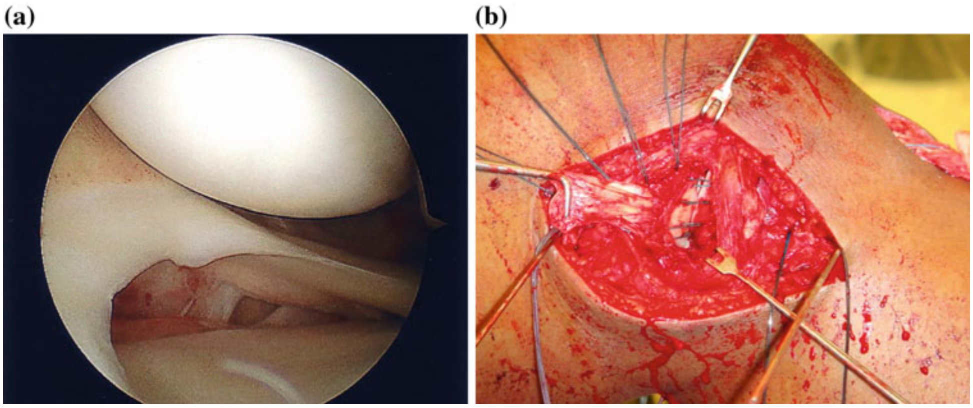

Fig. 16.12 MCL avulsion injuries. **a** Arthroscopic view demonstrating a tibial-sided meniscocapsular injury as the meniscus “stays with” the femur on valgus stress. **b** Suture anchors for primary repair of the medial meniscus, capsule, and MCL

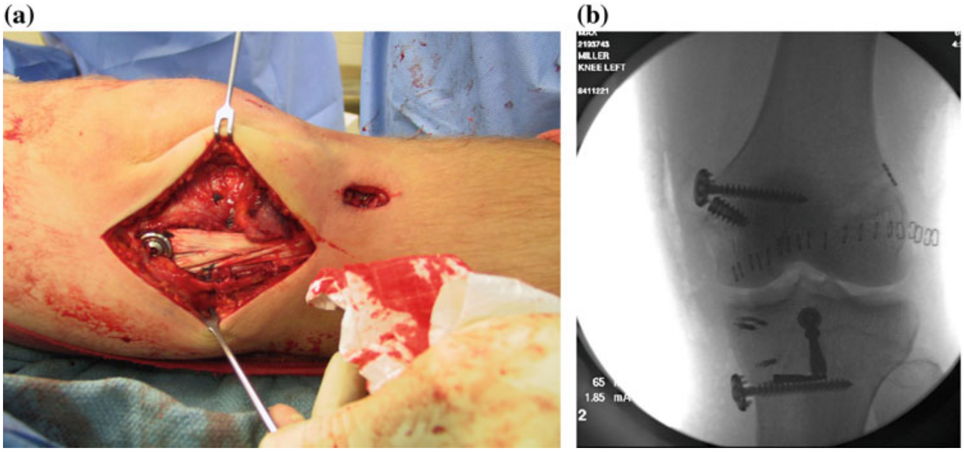

Fig. 16.13 MCL reconstruction using the modified Bosworth technique. **a** The native semitendinosus tendon, with its tibial insertion intact, is looped around a screw and spike washer at the medial femoral condyle. **b** Proximal and distal ends of the MCL reconstruction are secured using a screw and spiked washer. Also demonstrated is femoral and tibial fixation of a PCL reconstruction using the tibial inlay technique

A similar procedure for reconstruction of the MCL and POL for medial instability of the knee has been described by Kim et al. with good results [24].

The MCL/PMC repair or reconstructions are tested for isometry using guide pins placed at respective femoral fixation points. This occurs prior to securing the graft with a screw/spiked washer. With knee flexion and extension, no excursion of the graft relative to the guide pin should be observed. The medial reconstruction is then secured in slight varus stress at 30° of knee flexion.

16.7 Surgical Techniques of Combined PCL/MCL/PMC Injuries: Chronic Setting

Reconstruction of the PCL when >2 weeks out from injury in the setting of a combined PCL/MCL/PMC injury is similar to that of an acute reconstruction described above. Most critical to an acceptable surgical outcome in the chronic setting is a good preoperative range of motion. This is achieved with aggressive range of motion physical therapy prior to surgery.

When addressing an MCL/PMC knee injury in a chronic setting, reconstruction as described above is mandatory. Tissue planes are scarred and less distinct, and primary repair is significantly more difficult and less reliable. The modified Bosworth technique provides an excellent reconstruction option in this scenario.

16.8 Postoperative Management

Various protocols exist regarding postoperative care and rehabilitation for multi-ligament knee injuries. Often this needs to be individualized based upon the injury pattern, medical comorbidities, and patient compliance issues.

Duration of perioperative antibiotics vary, but often involve 24 h IV antibiotics postoperatively, followed by a less uniform duration of oral antibiotic coverage. Mechanical deep vein thrombosis (DVT) prophylaxis using sequential compression devices and/or TED stockings should be used. Patient-specific postoperative and outpatient DVT chemoprophylaxis is used based upon the extent of surgery and associated risk factors.

Postoperatively, preserving range of motion without compromising ligament reconstructions is critical to a successful outcome. Rehabilitation protocols vary from surgeon to surgeon. The preferred protocol of the senior author of this chapter is as follows. Weight bearing in extension is limited to 50% for 6 weeks. Within 2 days postoperatively, supervised passive prone range of motion exercises are initiated. The knee is otherwise locked in knee extension with a hinged knee brace. Quadriceps strength training in locked extension is also started. At 2 weeks out from surgery, the brace is unlocked and set 0°–90°, and at home, exercises are initiated. At 6 weeks, full weight bearing is initiated. Subsequent rehabilitation focuses on strengthening, proprioception training, and range of motion exercises. This process is always individualized, but typically treadmill jogging is allowed at 3 months, and sport-specific activities begin at 4–5 months postoperatively. Full return to sports usually takes anywhere from 6 to 9 months after surgery.

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Surgical Treatment of Combined PCL Medial and Lateral Side Injuries: Acute and Chronic

17

James P. Stannard and Daniel Deasis

17.1 Classification

The Schenk anatomic classification (Table 17.1) [1] is widely accepted and is based on the ligaments and structures injured rather than the direction of the dislocation. For example, a KD I injury describes a knee dislocation in which one or both of the cruciate ligaments are intact, and where collateral ligament injuries have variable degrees of injury. A knee dislocation that has an intact ACL with injury to the PCL, medial, and lateral corners can be classified as a KD I injury, but in our experience, these types of dislocations are quite rare compared to KD III injuries.

17.2 Mechanism of Injury

Multiple knee ligament injuries can result from various types of injuries, but the vast majority result from high-energy trauma such as motor vehicle accidents (52%) [2]. Other high energy causes include motorcycle collisions (17%) and motor vehicle versus pedestrian accidents (16%). However, low energy sports injuries can also result in knee dislocations, with mechanisms typically involving hyperextension of the knee. Football and equestrian injuries are the two most common causes of low energy knee dislocations [2].

17.3 Initial Evaluation

Since the majority of knee dislocations are the result of high-energy trauma, patients often present with multiple injuries that may be life-threatening and frequently involve the ipsilateral extremity. Because of the possibility of other distracting injuries, the diagnosis of a spontaneously reduced knee dislocation in the emergency room is difficult. If the knee remains dislocated, a closed reduction under complete sedation should be performed as soon as the patient's condition allows. Typically, gentle longitudinal traction is sufficient for reduction. However, occasionally, soft tissue interposition can prevent complete reduction. If this is the case, the patient should be taken to the operating room and an open reduction must be performed. Following reduction, a complete neurovascular examination is the single most important step to perform. Postreduction, the knee should be immobilized in slight flexion in a knee immobilizer, splint, or hinged knee brace. If the knee will not stay reduced, is an open KD, or has a significant vascular injury, a spanning external fixator should be applied.

An open knee dislocation should be suspected when there is an open wound around the knee. The most common location of the open wound is in the popliteal fossa. Open knee dislocations should undergo a debridement and irrigation in the operating room as soon as the patient's condition permits. In most cases, a spanning external fixator should be used to stabilize, temporize, and stage the knee, until soft tissues allow for definitive repair.

It is important to document the pulses of both the involved and uninvolved extremities to evaluate for any arterial injury. Pedal pulses at both the dorsalis pedis and posterior tibial arteries are examined and must be compared to the contralateral side. Subtle signs such as skin temperature, color, and capillary refill are also noted but not nearly as important as the pulses. Following reduction, the neurovascular structures should be reassessed and documented thoroughly. All patients with a knee dislocation should be admitted for careful observation and have serial neurovascular examinations for at least 48 h. The pedal pulse should be checked and compared to the contralateral side before and after reduction, between 4 and 6 h, at 24 h, and at 48 h following reduction [2, 3]. If there is any decrease in the pulse, or if the pulse is absent, emergent angiography should

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Table 17.1 Schenk anatomic knee dislocation classification

KD I	One cruciate ligament torn with one or both collaterals torn
KD II	Both ACL and PCL torn; collateral ligaments intact (rare)
KD III-M	ACL, PCL, and MCL torn
KD III-L	ACL, PCL, and LCL torn
KD IV	ACL, PCL, MCL and LCL torn
KD V	Fracture—dislocation
C (added to above)	Associated arterial injury
N (added to above	Associate nerve injury

This is a widely accepted classification based on the ligaments and structures injured rather than the direction of the dislocation

be performed, and vascular surgery should be consulted. This "selective arteriography" protocol has been proven reliable and safe for the diagnosis of popliteal artery injuries [2]. A complete neurologic exam is also performed with the focus on the common peroneal nerve due to the high frequency of injury.

A ligament exam is often difficult in the acute setting due to pain, swelling, and distracting ipsilateral extremity injuries. Accurate diagnosis of instability patterns becomes crucial later in order to allow definitive ligament repair or reconstruction, and should be established with a careful examination under anesthesia (Table 17.2). Careful documentation of the ligament examination findings at the end of operative fixation of ipsilateral fractures (e.g., tibial plateau, distal femur, and acetabulum) is also very important for future ligament reconstructions.

17.4 Imaging Studies

Anteroposterior and lateral radiographs of the knee are obtained before and after reduction in order to assess the direction of dislocation, concomitant periarticular fractures,

Table 17.2 Special tests for examination of ligamentous structures of the knee

Ligament	Diagnostic tests	Positive finding: interpretation
MCL and PMC	Valgus stress at 30° and 0° flexion	Medial joint opening Positive only at 30°: isolated MCL injury Positive at both 30° and 0°: MCL + PMC + cruciate injury
	Tibial external rotation at 90° flexion	Anterior subluxation of the medial tibial plateau from under the femoral condyle MCL + PMC injury
FCL and PLC	Varus stress at 30° and 0° flexion	Lateral joint opening Positive only at 30°: isolated FCL injury Positive at both 30° and 0°: FCL + PLC + cruciate injury
	Dial test at 30° and 90° flexion	External rotation increase >10° compared to normal side Positive only at 30°: FCL + PLC injury Positive at both 30° and 90°: FCL + PLC + cruciate injury
	External rotation recurvatum test	Knee recurvatum and varus + tibial external rotation FCL + PLC injury
ACL	Lachman test	Anterior subluxation of tibia at 30° flexion ACL injury
	Anterior drawer	Anterior subluxation of tibia at 90° flexion ACL injury
	Pivot-shift test	Sudden reduction of anteriorly subluxated tibia at 20°–40° flexion Small subluxation: ACL injury Greater subluxation: ACL + PLC injury
PCL	Posterior drawer test	Posterior subluxation of tibia at 90° flexion PCL injury
	Quadriceps active test/posterior sag sign	Anterior movement of posteriorly subluxated tibia with active quadriceps contraction at 90° flexion PCL injury

MCL medial collateral ligament, *PMC* posteromedial corner, *FCL* fibular collateral ligament, *PLC* posterolateral corner, *ACL* anterior cruciate ligament, *PCL* posterior cruciate ligament foreign bodies, avulsion fractures, malalignment of the knee, and joint incongruity. A quick stress view radiograph at the end of an ipsilateral fracture fixation is very helpful in determining future ligament injury management. It is important to obtain an MRI of the knee before the application of any metal hardware when there is high suspicion of a knee dislocation. An MRI is an important roadmap to the assessment of a ligamentous injury pattern, particularly when there are ipsilateral extremity injuries. MRI is also useful for assessing meniscal injuries, osteochondral lesions, and occult tibial plateau fractures. However, examination under anesthesia remains the gold standard for the ultimate diagnosis of the ligament injury pattern, which determines the final treatment strategy.

17.5 Surgical Indications and Timing

The vast majority of patients who have sustained knee dislocations should undergo surgical reconstruction, which allows early mobilization of the knee. With the exception of patients who are extremely sedentary, uncooperative, or critically ill with chronic medical conditions, ligament reconstruction with early mobilization benefits nearly all patients following knee dislocations. The results of nonoperative treatment (e.g., cast, knee brace, and external fixation) in the patients who were poor candidates for reconstructive surgery are invariably poor with residual instability and stiffness. External fixation should be used as a temporary treatment prior to reconstruction in patients with open knee dislocations, severe soft tissue injuries, grossly unstable dislocations, and initial vascular surgery due to a popliteal artery injury. If it is inevitable to use external fixation as a definitive immobilization method, the external fixator is maintained for 6–8 weeks, and manipulation under anesthesia or arthroscopic lysis can be attempted to regain the knee motion afterward.

Definitive surgical treatment is typically performed within 4 weeks following the injury. If there are associated fractures, these are fixed surgically within the first week. Ligament reconstruction is typically performed between 2 and 4 weeks following the initial injury. This is to allow enough soft tissue recovery and to restore the watertight joint capsule for arthroscopic reconstruction procedures. For knee dislocations with posterior cruciate ligament (PCL), posterolateral corner (PLC), and posteromedial corner (PMC) injuries, the injured ligament structures can be reconstructed all at once. If there is an associated tibial plateau fracture, the surgical timing is changed. Fixation of the plateau fracture is performed within the first week, and this is followed by reconstruction of the PCL and PMC along with the application of a Compass Knee Hinge external fixator (Smith & Nephew, Memphis, TN, USA) for 2–4 weeks after the initial trauma. Finally, reconstruction of the PLC is performed 3–4 months later. The reason for delaying the PLC reconstruction in the presence of a tibial plateau fracture is that the tibial bone tunnel for fixation of the PLC graft inevitably passes through the fractured plateau, which was found to be a cause of reconstruction failure. A period of 3–4 months is usually required for fracture healing before drilling the tibial tunnel.

17.6 Surgical Technique

Reconstruction is preferred over repair in the majority of patients with knee dislocation. This is based on our previous study findings that reconstructions have a significantly lower failure rate than repairs of the PLC. The only exception to this would be a dislocation with a large avulsion fracture, which can be repaired with open reduction and internal fixation (ORIF) of the bony fragment. Similar data have been published regarding the reconstruction of the PMC in patients with knee dislocations. For dislocations with combined injuries to the PCL and both corners, the reconstruction procedure should start with the PCL followed by the reconstruction of the PMC and PLC. The final tensioning and fixation of the PCL graft is delayed, until after the grafts of both of the corners are in place.

The PCL is composed of two bundles, the larger anterolateral bundle and the smaller posteromedial bundle. One cause of PCL failure is the "killer turn," which is the sharp angle that is created by a transtibial approach that exits too proximally near the articular surface. The PCL inlay technique was developed to resolve this, by placing a bone block on the posterior aspect of the tibia which decreases the killer turn. A new technique using a transtibial approach that exits the back of the tibia more distally in the same location as the bone block on the inlay technique also eliminates the killer turn. This technique combines the aspects of both inlay and transtibial PCL reconstruction with a more distal insertion point on the tibia to replicate the anatomy of the PCL (Fig. 17.1).

In the past, I have used screws and washers for graft fixation. I have however converted to the use of suspensory fixation, which allows repetitive tensioning after stressing and ranging the knee intraoperatively. Furthermore, all creep can be removed from the grafts, fixation is not dependent on the quality of the cancellous bone of the patient, and there is less hardware prominence compared to the screws that have required removal in the past. The final benefit is that each graft can be tensioned when it is placed, and then tensioned again as additional grafts are placed completing the reconstruction.

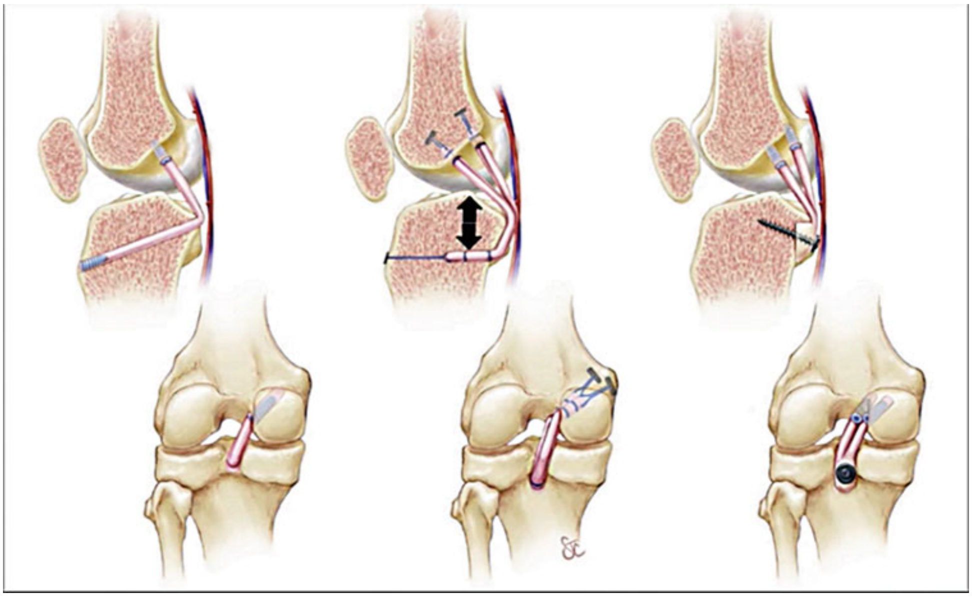


Fig. 17.1 PCL reconstruction techniques. The traditional PCL reconstruction is shown on the left and also demonstrates the "killer turn" and sharp angle associated with PCL reconstruction failure. The center images demonstrate the new PCL reconstruction with suspensory fixation. The images on the right show the PCL inlay technique. ©2018 The Curators of the University of Missouri, reprinted with permission

17.6.1 PCL: Anatomic Posterior Cruciate Ligament Reconstruction with Suspensory Fixation of a Double-Bundle Achilles Tendon Allograft

17.6.1.1 Examination Under Anesthesia and Diagnostic Arthroscopy

The "gold standard" for determining the extent of an injury in a knee dislocation patient is a thorough examination under anesthesia. The instability pattern is reassessed and compared to the preoperative diagnosis. It is important to compare the affected extremity to the contralateral extremity because of the variability of normal laxity among individuals. This is followed by a diagnostic arthroscopy to confirm the diagnosis. The patient is placed supine on the operating table so that the operative leg can hang off the side of the table during the arthroscopic portion of the procedure. A simple lateral post without a circumferential leg holder is positioned at the level of the tourniquet to facilitate intraoperative valgus stress (Fig. 17.2). A #11 blade is used to make an anterolateral portal and an 18-gauge needle is used for localization followed by a #11 blade to make an anteromedial portal under direct visualization. Arthroscopic evaluation of the knee should view the suprapatellar pouch, medial gutter, and lateral gutter, followed by the patellofemoral joint, the medial compartment, notch, and the lateral compartment. The articular surfaces are checked in addition to the menisci, and the ACL and PCL are visualized in the notch. Any meniscal or chondral injuries are addressed. Easy widening of a compartment confirms an injury to the corner on that side. The torn PCL or remnant is debrided in the notch using an aggressive shaver. Care should be taken to note the natural attachment of the PCL on the femur.

17.6.1.2 Preparation of Allograft for PCL Suspensory Technique

A graft is prepared using an Achilles tendon allograft. The tendon portion of the graft is split into two bundles using a #10 blade. One bundle is approximately 60% of the width of the tendon for the lateral side and the other is 40% for the medial side. This normally creates a larger anterolateral bundle and a smaller posteromedial bundle. It must be ensured that the larger AL bundle is made on the lateral

Fig. 17.2 Basic set up for multi-ligament reconstruction knee surgery. The patient is placed in supine position and the operating table is left flat so that the operative leg can hang off the side of the table. A pneumatic tourniquet is applied to the upper thigh but not inflated until the latter part of the procedure. A simple lateral leg post without a circumferential leg holder is positioned at the level of the tourniquet

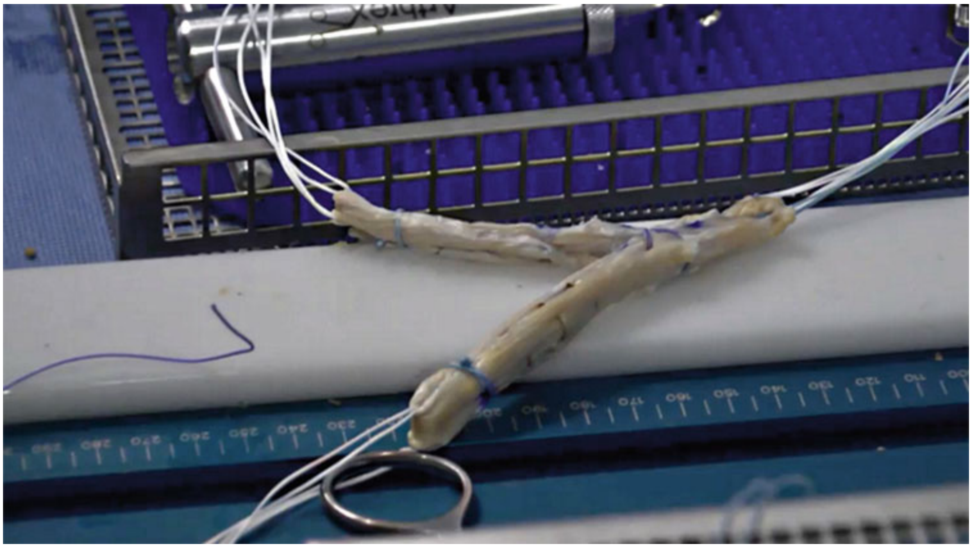


Fig. 17.3 Preparation of the Achilles tendon allograft. The tendon portion of the graft is split into two bundles using a #10 blade. One bundle is approximately 60% of the width of the tendon for the lateral side and the other is 40% for the medial side. The limbs are measured and prepared with locking Krakow stitches with #2 Fiberwire and then attached to Fiberlink buttons. Two different colored sutures are used for accurate and quick identification of the AL and PM bundles. The common bundle that goes into the tibia is usually 12 mm and the sizes for the limbs are a 10.5 mm size for the anterolateral bundle and 7.5 mm size for the posteromedial bundle

aspect of the graft. The graft is trimmed in line with the fibers. The limbs are measured and prepared with locking Krakow stitches with #2 Fiberwire. Two different colored sutures are used for accurate and quick identification of the AL and PM bundles. The common bundle that goes into the tibia is usually 12 mm and the sizes for the limbs are a 10.5 mm size for the anterolateral bundle and 7.5 mm size for the posteromedial bundle (Fig. 17.3).

17.6.1.3 PCL with Suspensory Fixation

A bump is then placed under the knee, and the leg hangs off the side of the table with the knee flexed to approximately 90°. The anterolateral bundle is addressed first. This is created by placing the PCL guide (Arthrex, Inc. Naples, FL, USA) through the anteromedial portal proximally in the notch and 10 mm posterior to the articular cartilage. It is usually located at an 11 o'clock position of a left knee and a 1 o'clock position of a right knee (Fig. 17.4). An incision is made through the skin of the superomedial aspect of the knee, and a Kelly clamp is used to spread the soft tissues. A flip cutter is drilled across the medial femoral condyle in the desired position. The guide is tamped in and the rubber grommet is placed down the guide for measurement. The flip cutter is flipped and a socket is reamed to a depth of

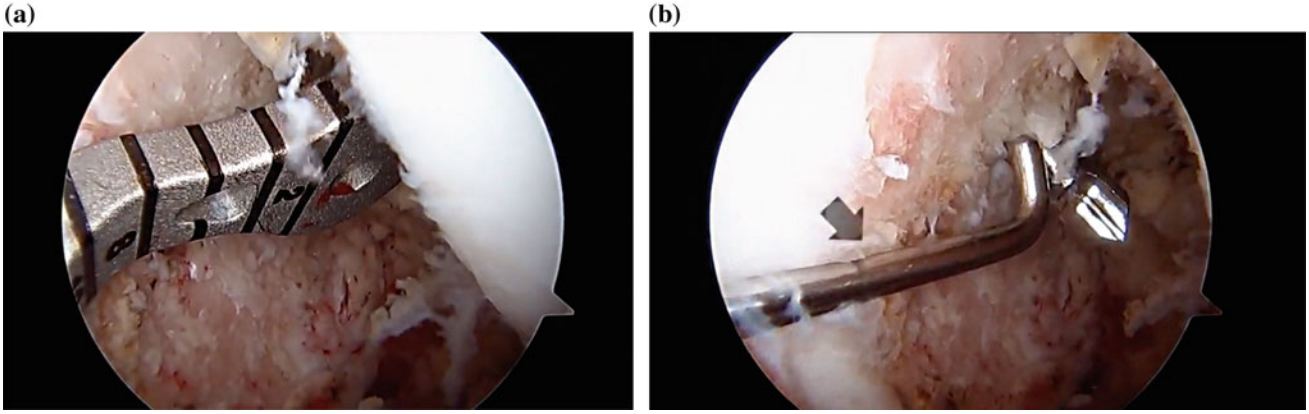


Fig. 17.4 Positioning of the PCL guide for the anterolateral bundle of the PCL. **a** The guide is placed as proximal as possible in the notch and 10 mm posterior to the articular cartilage. It is usually located at an 11 o'clock position of a left knee and 1 o'clock position of a right knee. The flip cutter is drilled into the knee and the position is checked. **b**. If the position is acceptable, the flip cutter is flipped and a socket of about 25 mm is drilled

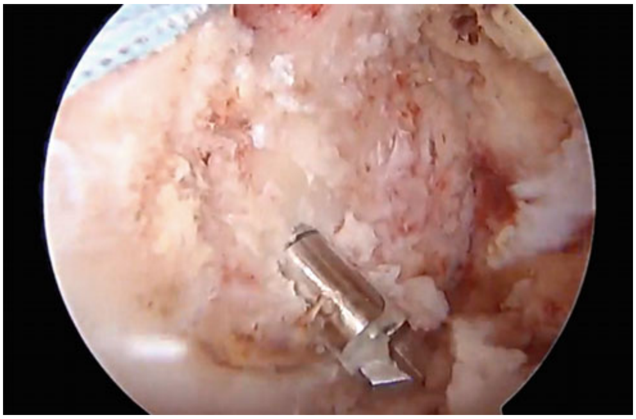


Fig. 17.5 Drilling the posteromedial bundle of the PCL. The posteromedial bundle is drilled just inferior to the tunnel for the anterolateral bundle (above the flip cutter in the picture) and is approximately 8 mm posterior to the articular surface

approximately 25 mm. The flip cutter is then returned to the notch, flipped, and removed. A fiber stick is then placed into the knee and grasped with a looped grasper out the lateral portal and clamped to itself.

The posteromedial bundle is created by placing the guide immediately below the anterolateral bundle, which is usually about 8 mm from the articular cartilage (Fig. 17.5). The tunnels shoulder be slightly divergent. Similarly, the flip cutter is used to create a socket of approximately 25 mm. A fiber stick is then passed and pulled out the medial portal. The socket technique spares bone and allows for a less painful reconstruction (Fig. 17.6).

A posteromedial portal is established by using a spinal needle to localize the position under direct visualization. An incision is made for the portal on the posterior medial skin. A switching stick is used to gain access to the posterior aspect of the knee, followed by a dilator and a cannula to use as a working portal for instrument use (Fig. 17.7). After the

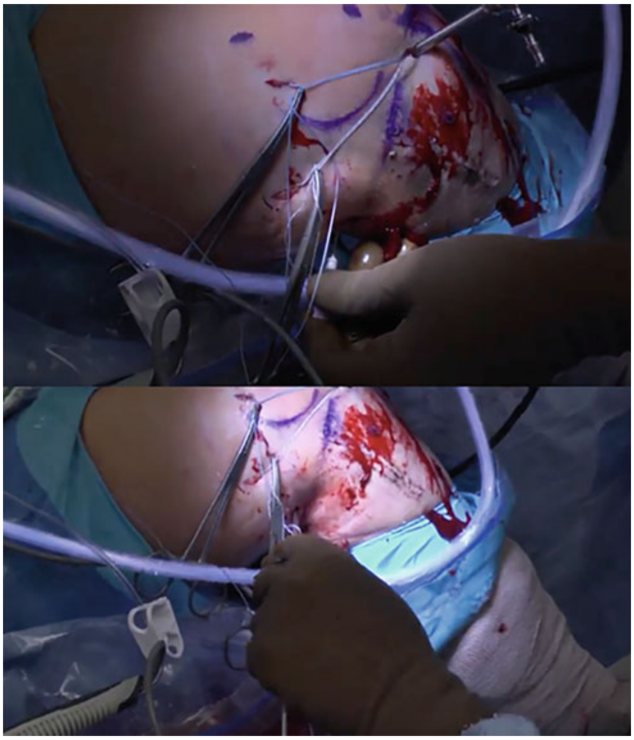
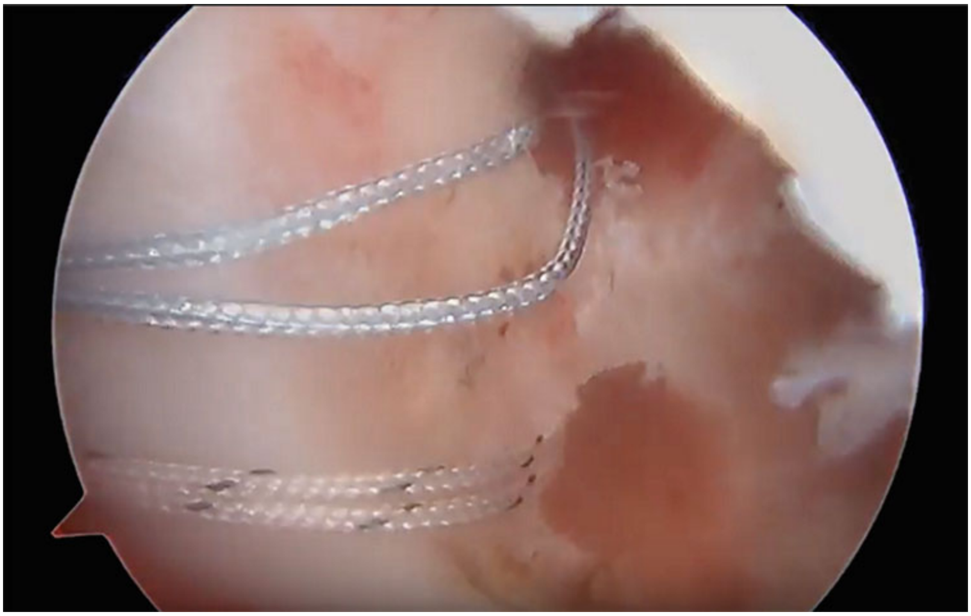


Fig. 17.7 Establishing the posteromedial portal to prepare the posterior aspect of the tibia. A spinal needle is used to find an appropriate position for the posteromedial portal under direct visualization. Once the preferred position is found, a skin incision is made and a switching stick is used to gain access to the joint. A dilator is then used followed by insertion of a cannula. This allows easier access for preparation of the posterior tibia

Fig. 17.6 The tunnels for the anterolateral and posteromedial bundles of the PCL in the femur. Once the tunnels are drilled, fiber stick sutures are shuttled through the tunnels and then attention is turned to preparation of the tibia



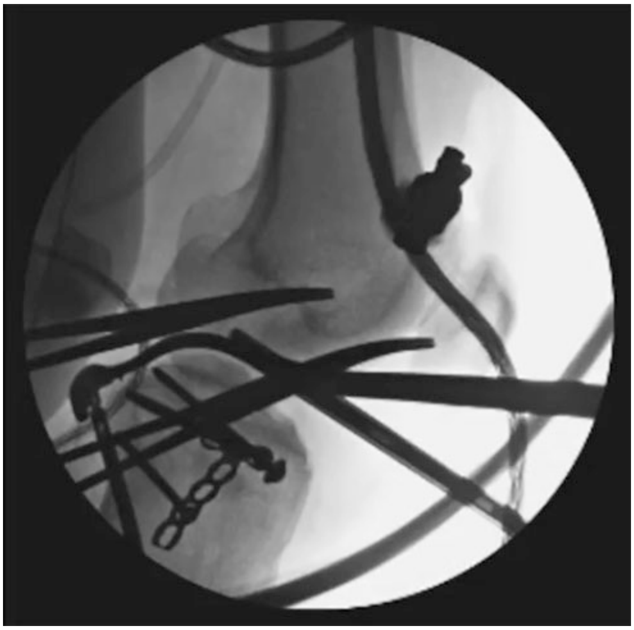


Fig. 17.8 Placing the PCL drill guide for the tibial tunnel. The arthroscopic PCL guide (Arthrex, Inc., Naples, FL) is placed into the knee and should sit in the back of the tibia. Intraoperative fluoroscopic images can be used to confirm this as shown. A 12-mm flip cutter is drilled across the knee, flipped, and a 50-mm deep socket is made. A fiber stick is passed through that socket and out through the medial portal coming through the notch to allow for passage of the graft

portal is established, a combination of a thermal tool and an aggressive shaver are used to debride the remnant of the PCL off the back of the tibia. This is safe as long as one stays on the bone, the blades face anteriorly, and tools do not drift posteriorly. A rasp and curette can also be used to help speed the process of debridement in the posterior aspect of the tibia. Once this is complete, the arthroscopic PCL guide (Arthrex, Inc., Naples, FL, USA) is placed into the anteromedial portal of the knee and should sit in the back of the tibia (Fig. 17.8). A 12-mm flip cutter is drilled across the knee, flipped, and a 50-mm deep socket is made. A shaver is used to debride away the excess bone. A fiber stick is passed through that socket and out through the medial portal coming through the notch. After using a looped grasper to make certain there were no soft tissue bridges, the PCL graft is pulled into the knee and into its tibial socket. The posterior medial bundle is pulled into its socket, the button is flipped, and the graft pulled approximately 15 mm deep. The same process is repeated to pull the anterolateral bundle into its socket. The tibial side is tensioned first in flexion. A removable button is pulled down to the tibia. The anterolateral bundle is tensioned in 90° of flexion. The posteromedial bundle is tensioned in about full extension. The knee is stressed and ranged and the grafts are all retightened again. The grafts are checked with a probe and grafts are again retightened. If the medial or lateral corners are also being reconstructed, these will be performed and the PCL bundles can be retightened again after the completion of those reconstructions (Fig. 17.9).

17.6.2 PCL: Anatomic Posterior Cruciate Ligament Reconstruction with a Double-Bundle Inlay Technique Using Achilles Tendon-Bone Allograft

A PCL inlay technique was developed to avoid the “killer turn” associated with conventional transtibial PCL

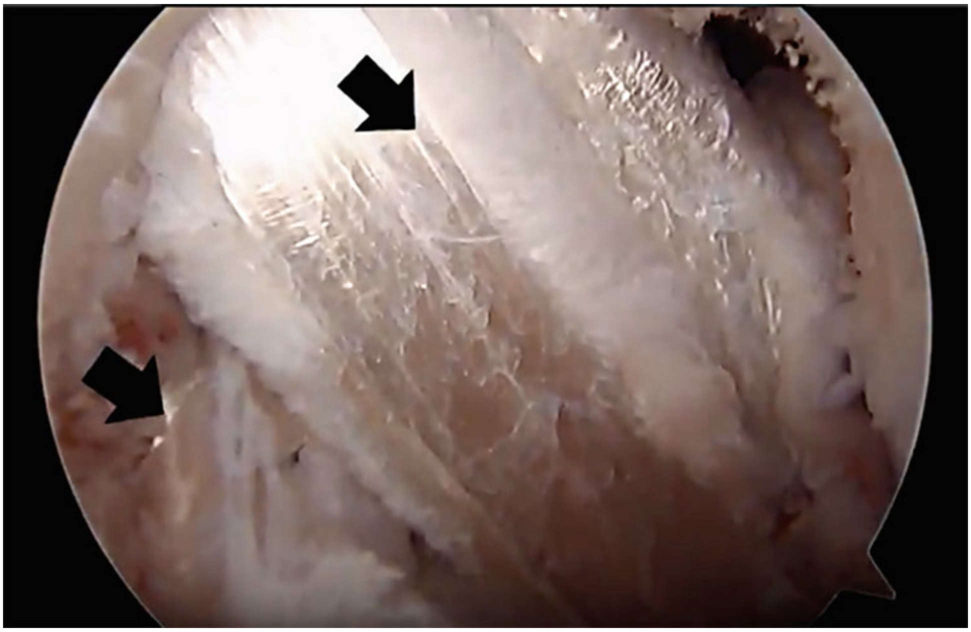


Fig. 17.9 Final intraoperative images of the larger anterolateral bundle (right arrow) and posteromedial bundle (left arrow)

reconstructions. Although technique modifications and fixation methods have led us to use a modified transtibial technique for most PCL reconstructions, the inlay technique will still be useful in cases where tunnel crowding is an issue (e.g., cases where the previous fixation of tibial plateau fractures has been performed).

17.6.2.1 Preparation of Allograft for PCL Inlay Technique

The graft is prepared as a double bundle using Achilles tendon allograft. The graft is split using a #10 blade, with about 60% for the lateral side and 40% for the medial side. The graft is trimmed in line with the fibers and tapered at the ends. The limbs are measured and prepared with locking Krakow stitches and with #2 Fiberwire. The sizes for the limbs are approximately 10.5 mm for the anterolateral bundle and 7.5 mm for the posteromedial bundle.

The bone block is then prepared. A proposed block is drawn with the marker on the graft and an oscillating saw is used to cut the excess bone. The graft should be no less than 15 mm long by 10 mm wide and 10 mm thick (Fig. 17.10). Care should be taken to ensure that the graft is 10 mm thick to minimize the risk of fracture of the bone block when the fixation screw is tightened. The edges are beveled with the oscillating saw. The bone block is drilled with a 4.5 mm drill bit in the center, which allows the 4.5 mm screw to function as a lag screw.

17.6.2.2 PCL Inlay Technique

After examination under anesthesia and diagnostic arthroscopy, the anterolateral and posteromedial tunnels are prepared in a manner similar to that described in the previous section for PCL reconstruction with suspensory fixation technique. The drill guide is placed as proximal as possible in the notch and 10 mm posterior to the articular cartilage. An incision is made through the skin and a Kelly clamp is used to spread the soft tissues. A flip cutter is drilled across the medial femoral condyle in the desired position. The guide is tamped in and the rubber grommet is placed down the guide for measurement. The flip cutter is flipped and a socket is reamed to a depth of 25 mm. The flip cutter is then returned to the notch, flipped, and removed. A fiber stick is then placed into the knee and grabbed with a looped grasper out the medial portal and clamped to itself. The posteromedial bundle is created by placing the guide immediately inferior to the anterolateral bundle, which is usually about 8 mm from the articular cartilage. Similarly, the flip cutter is used to create a socket of approximately 25 mm. Again, a fiber stick is then passed and pulled out the medial portal as well.

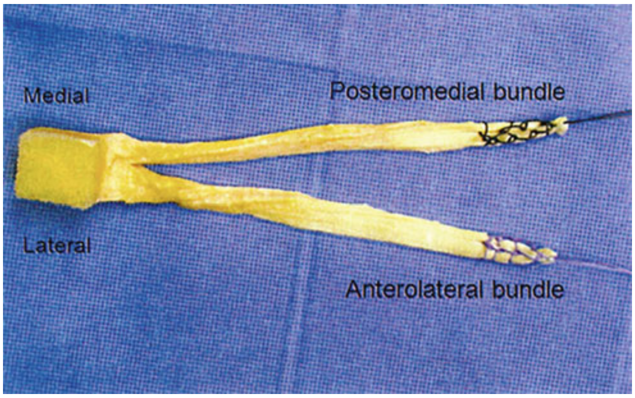


Fig. 17.10 Achilles bone-tendon allograft for anatomic double-bundle inlay PCL reconstruction. The tendon part of the graft is split longitudinally to make the larger anterolateral (AL) bundle and a smaller (PM) bundle. The larger AL bundle must be made at the lateral side of the graft with the cancellous portion of the bone block facing anterior. This graft is prepared for a left knee PCL reconstruction. We use two different colored sutures for accurate and quick identification of the AL and PM bundles during the procedure

The patient's leg is placed in a figure-of-four position for the open approach. I normally do not use a tourniquet, but it is an option if visualization is difficult due to bleeding. A straight-line incision approximately 8–10 cm in length is used along the posteromedial edge of the tibia. The knee should be flexed with deeper dissection to avoid the neurovascular structures. Electrocautery dissection is used to dissect down through the superficial tissues and then finger dissection is performed to the posterior edge of the tibia. The inferior border of the approach is the semitendinosus tendon. Right above this tendon and anterior to the medial head of the gastrocnemius, a Cobb elevator is used to release the attachments to the posterior edge of the tibia, taking care to keep the instrument right against bone and elevate up the popliteus muscle. The medial head of the gastrocnemius can be released to aid in exposure. A blunt Hohmann retractor is placed across the back of the tibia to keep the popliteus and gastrocnemius muscles between the surgeon and the neurovascular structures (Fig. 17.11). The foot is externally rotated to facilitate the visualization of the posterior tibial surface.

Once this is exposed, the trough is ready to be prepared. A 1/2-inch-curved osteotome is used to make the superior, then medial, lateral, and inferior edges of the rectangular trough on the back of the tibia. The insertion of the PCL starts approximately 10 mm inferior to the articular surface of the tibia in the midline. The trough is then enlarged using the 1/4 inch osteotome, rongeur, or burr to meet the size of the graft. The graft is then placed within the trough and impacted. The graft should be flush or slightly prominent and should not be countersunk. The bone block should be held in place and a guidewire for a 4.5 mm cannulated screw can be drilled into place. This should be horizontal with the knee joint and should be directed toward the tibial tubercle. This screw is frequently directed slightly from posteromedial

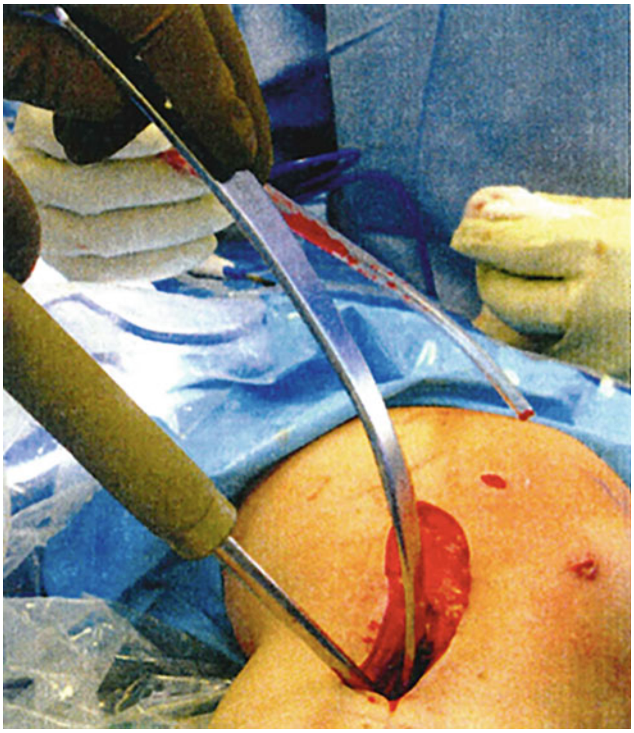


Fig. 17.11 Posteromedial knee approach for PCL reconstruction with inlay technique. The same approach is used for PMC reconstruction. A Cobb elevator is placed to elevate the popliteus muscle off of the entire posterior surface of the tibia, and a blunt Hohmann retractor is placed to keep the popliteus and gastrocnemius muscles between the surgeon and neurovascular structures

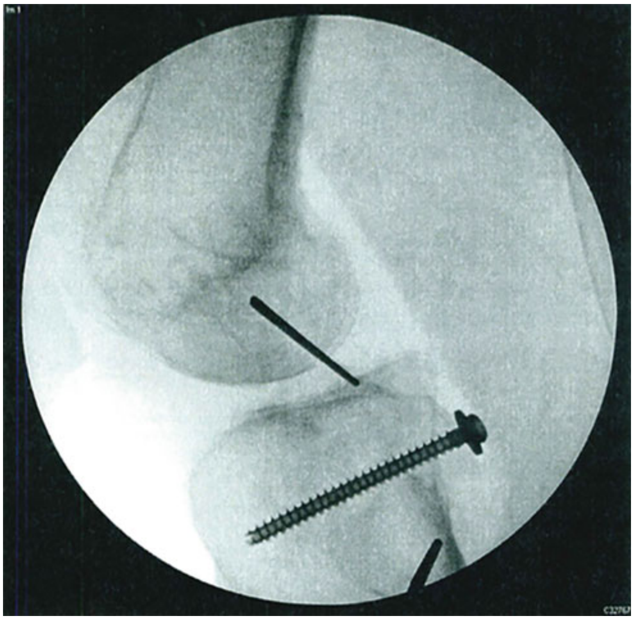


Fig. 17.12 Intraoperative fluoroscopic image showing the placement of a 4.5 mm fully threaded cannulated screw with a washer to secure the PCL allograft bone block. Note that, the bone block is placed in a trough that starts approximately 5–10 mm inferior to the articular surface of the tibia. Care needs to be taken not to have a long screw that is prominent out of the anterior cortex

to anterolateral. Fluoroscopy is then used to check the position of the guidewire. This is measured for the appropriate length, and a screw and washer can be placed (Fig. 17.12). It may be beneficial to take a 6 mm to 8 mm off of the measured length to avoid soft tissue irritation with the screw anteriorly. The guide wire can be tapped out anteriorly and removed to avoid losing any fixation with the cancellous screw.

A hole then should be made in the posterior capsule using a Kelly clamp, and a suture passer can be inserted through the anteromedial portal and posterior joint capsule opening. Care should be taken to ensure that the suture passer travels between the ACL and medial femoral condyle. The suture of the posterior medial bundle can be pulled into the knee. The arthroscope is then reinserted and that bundle is then pulled into its tunnel with a grasper and with the assistance of a probe. The button is then flipped on the cortex and the graft is pulled to the depth of about 15 mm. The process is then repeated with the anterolateral bundle. It is pulled into the knee with the suture passer on the lateral side of the posterior medial bundle, and then is pulled into its socket. The button is again flipped on the cortex with the knee in flexion. The posteromedial bundle is tensioned in full extension and the anterolateral bundle is tensioned in about 90° of flexion. At the time of final fixation, the PCL grafts are pretensioned by ranging the knee 20 times and then tightening the fixation again.

17.6.3 Posteromedial Corner Reconstruction

A torn PMC is different from a torn medial collateral ligament (MCL) due to rotatory instability from a torn posterior oblique ligament (POL) and/or capsule. This can be differentiated by performing an anterior drawer test with the foot placed in external rotation. A PMC reconstruction addresses both the superficial MCL and the POL.

17.6.3.1 Allograft for PMC Reconstruction

A semitendinosus or split tibialis posterior or anterior tendon allograft is used. The graft is divided into two 5–7 mm diameter grafts. Locking stitches are placed at each end of the graft to facilitate passage. FiberTapes (Arthrex, Inc., Naples, FL, USA) is used to create loops in the graft for the graft-link suspensory fixation. Approximately, 20 mm of graft is marked out at the limbs—this is the length of graft to be pulled into the tunnel. The two arms of the graft are each stabilized to the FiberTape and tied with suture. The limbs are measured to check for size and are usually around 7 mm (Fig. 17.13).

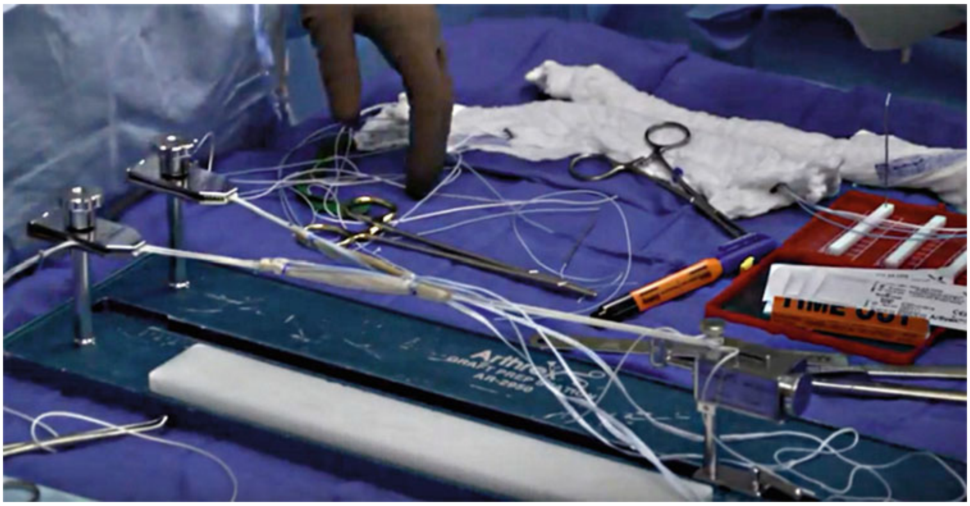


Fig. 17.13 Final graft preparation for the PMC. A semitendinosus or split tibialis posterior or anterior tendon allograft is used. The graft is divided into two 5–7 mm diameter grafts. Locking stitches are placed at each end of the graft to facilitate passage. FiberTapes are used to create loops in the graft for the graft-link suspensory fixation. Approximately, 20 mm of graft is marked out at the limbs—this is the length of graft that is pulled into the tunnel

17.6.3.2 PMC Reconstruction

A straight-line incision with a #10 blade is used to make a skin incision along the posteromedial edge of the tibia. This incision and approach are similar to that used for the superficial portion of the PCL inlay technique described earlier. Sharp dissection is used to dissect down and expose the insertion of semitendinosus and gracilis tendons (Fig. 17.14). One can mark the insertion of the superficial MCL just proximal to the semitendinosus with electrocautery.

The isometric point on the femur is then identified with a perfect lateral fluoroscopic X-ray. This is found at the intersection of the line along the posterior aspect of the posterior femoral cortex with Blumensaat's line (Fig. 17.15). Once that point is identified, a spade-tipped guidewire is drilled across the femur. This should be aimed slightly anterior and proximal to avoid other potential tunnels in a multi-ligament knee reconstruction. A 9-mm reamer is then drilled approximately 60 mm in length to create a socket for the femur based on the size of the graft and a passing suture is passed through the femur.

The distance of the superficial MCL is measured. Another spade-tipped guidewire is drilled across the tibia at that point just proximal to the insertion of the semitendinosus and gracilis, and then reamed with a 70 mm reamer to the far cortex. A suture is pulled through that socket as well for passage of the graft later (Fig. 17.16).

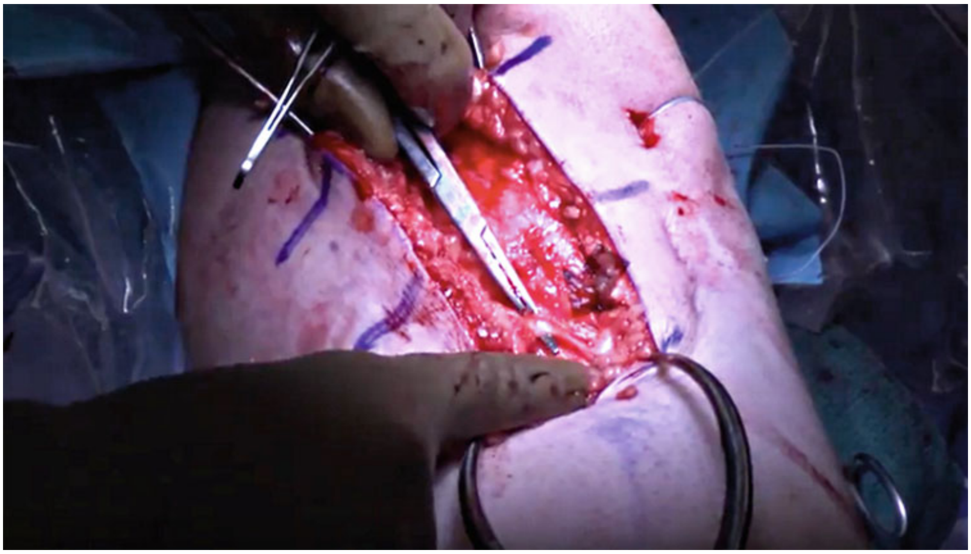


Fig. 17.14 A straight-line incision with a #10 blade is used to make a skin incision along the posteromedial edge of the tibia. Sharp dissection is used to dissect down and expose the insertion of semitendinosus and gracilis tendons as seen isolated by the tonsil clamp in the figure. One can mark the insertion of the superficial MCL just proximal to the distal portion of the semitendinosus tendon with electrocautery

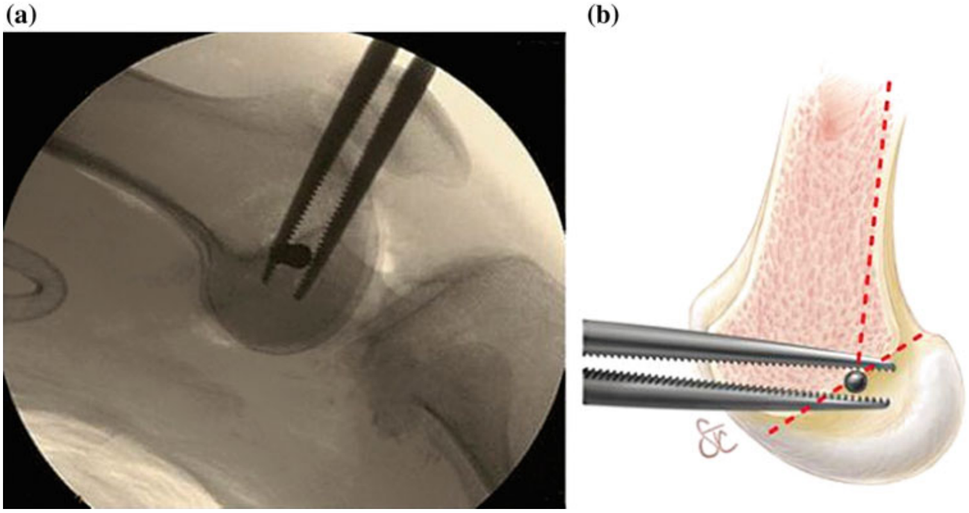


Fig. 17.15 The isometric point on the femur is then identified with a perfect lateral fluoroscopic X-ray. This is found at the intersection of the line along the posterior aspect of the posterior femoral cortex with Blumensaat's line. A spade-tipped guidewire is drilled across the femur, aimed slightly anterior and proximal. **a** An intraoperative photograph and **b** an artist's depiction. **a** From [10]. Reprinted with permission from Thieme New York. **b** ©2018 The Curators of the University of Missouri, reprinted with permission

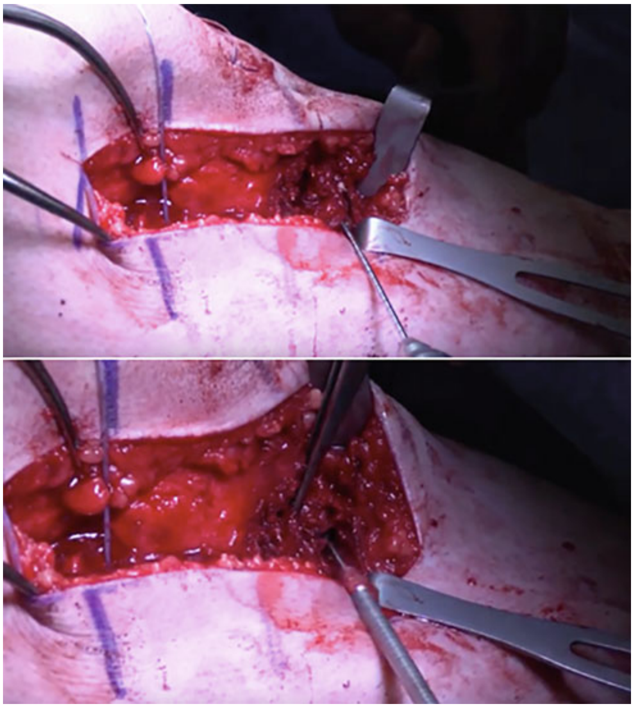


Fig. 17.16 The insertion point of the superficial MCL identified during the approach is again addressed. Another spade-tipped guidewire is drilled across the tibia at that point just proximal to the insertion of the semitendinosus and gracilis, and then reamed with a 70 mm reamer to the far cortex. A suture is pulled through that socket as well for passage of the graft limb for the superficial MCL later in the procedure

Fluoroscopy is used combined with anatomy to find the appropriate insertion point for the POL (Fig. 17.17). A spade-tipped guidewire is drilled to the opposite cortex just posterior to the direct head of the semimembranosus muscle. A 7-mm reamer is then used and checked with fluoroscopy to ensure that the tunnel for the PCL reconstruction is not encountered. Again, another suture is pulled across there for graft passage.

The common bundle of the allograft is then pulled into the femur and the button is flipped on the lateral cortex. After confirming that position with fluoroscopy, the graft is pulled into the socket approximately 20 mm. The limb for the superficial medial collateral ligament is pulled in line with its fibers and then pulled across into the tibial socket. The button is flipped on the lateral cortex and the graft is pulled to a depth of 15 mm. The POL graft is then routed underneath the semimembranosus and pulled into its socket (Fig. 17.18). The button is flipped on the lateral cortex, and the graft is also pulled to a depth of 15 mm. The common bundle is then retightened. With the knee held in 20°–30° of flexion, the limb for the superficial MCL button is then tightened on the tibia. The knee is then placed in full extension and the POL button is tightened. After the knee is ranged and stressed, the buttons are then retightened one last time (Fig. 17.19).

17.6.4 Posterolateral Corner Reconstruction

Many surgeons use a two-tailed approach to PLC reconstruction: one tail is based in the tibia while the other is based in the fibula to address all three components of the PLC. Fanelli supports a fibula-based reconstruction with a capsular shift instead of the tibia-based tail [4]. However, there are deficiencies of the two-tailed techniques that should

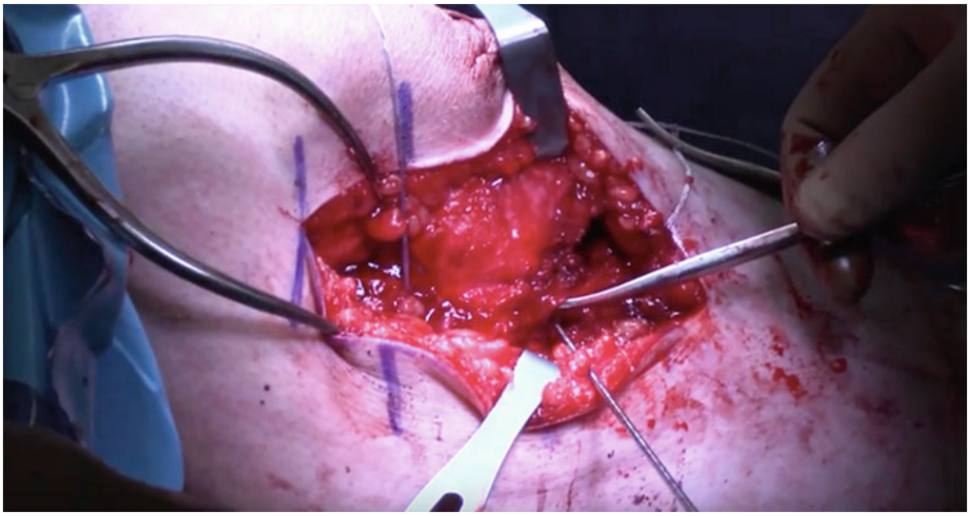


Fig. 17.17 The insertion point for the POL is identified using a combination of anatomy and fluoroscopy. A spade-tipped guidewire is drilled to the opposite cortex just posterior to the semimembranosus muscle, which is retracted in the picture by a tonsil clamp. A 7-mm reamer is then used and checked with fluoroscopy to ensure that the tunnel for the PCL reconstruction is not encountered

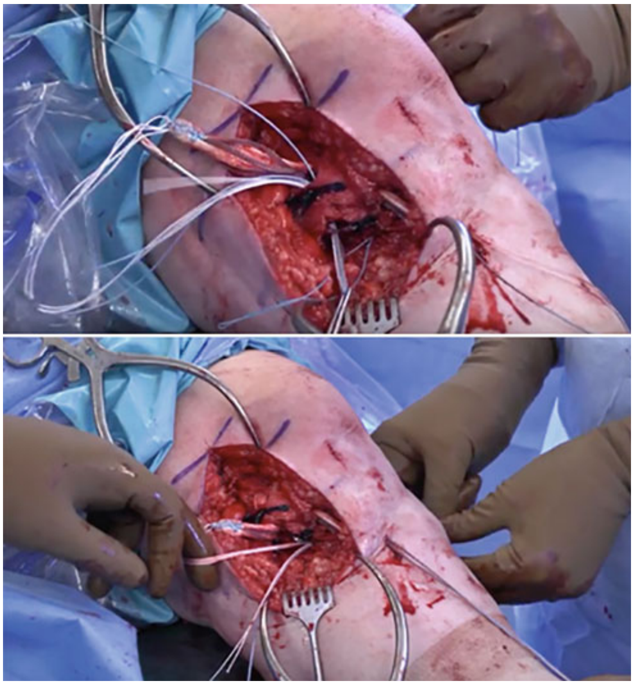


Fig. 17.18 The posterior oblique ligament graft is then routed underneath the semimembranosus (note the graft passing under the muscle marked by the purple pen) and pulled into its socket. The button is flipped on the lateral cortex, and the graft is also pulled to a depth of 15 mm

be addressed. A study by van der Wal et al. demonstrates that varus stability was improved but not restored to match that in the contralateral knee in 5-year follow-ups [5]. As stated previously, the use of a screw and washer in the femoral condyle can lead to complications such as hardware prominence. Helito et al. reported a 66% incidence of radiographic loosening and a 50% incidence of pain and irritation of the iliotibial band caused from the screw and washer [6]. Because of these limitations and improvements in fixation devices, a new two-tailed reconstruction method was devised and tested [7]. This technique uses cortical button suspensory fixation and interference screw fixation of the allografts in their respective sockets, and allows for individualized tensioning of the grafts in order to obtain optimal stability.

Two separate allograft tendons are used to create the FCL/popliteofibular and popliteus grafts. A semitendinosus, anterior tibialis, or gracilis allograft is used to create the FCL/popliteofibular limb. The allograft chosen should be 6.0–7.0 mm in diameter and at least 240 mm long. A piece of 36″ long, 2 mm wide FiberTape is looped over a cortical button suspensory fixation device at the mid portion of the FiberTape. The tendon allograft is then looped over the suspensory fixation device 20 mm from the end of the allograft (Fig. 17.20). A #2 FiberLoop suture (Arthrex, Inc., Naples, FL, USA) is passed through both arms of the allograft and incorporates both strands of the FiberTape, about 5 mm from the doubled-over end. The loop end of the FiberLoop is then passed through the suspensory fixation device and the needle end of the FiberLoop is passed through the loop end and back through both arms of the allograft to lock and secure the FiberLoop over the suspensory fixation. The two limbs of the allograft are then sutured together over the 20 mm overlap with a locking double whipstitch. The diameter of the doubled over part of the FCL graft should be 8–10 mm. The allograft is then cut to 220 mm in length from the doubled-over end. The FiberLoop suture is pulled taut to the free end of the tendon allograft and used to suture the end of the tendon allograft to both strands of the FiberTape using a locking double whipstitch pattern 15 mm from the free end of the graft. The

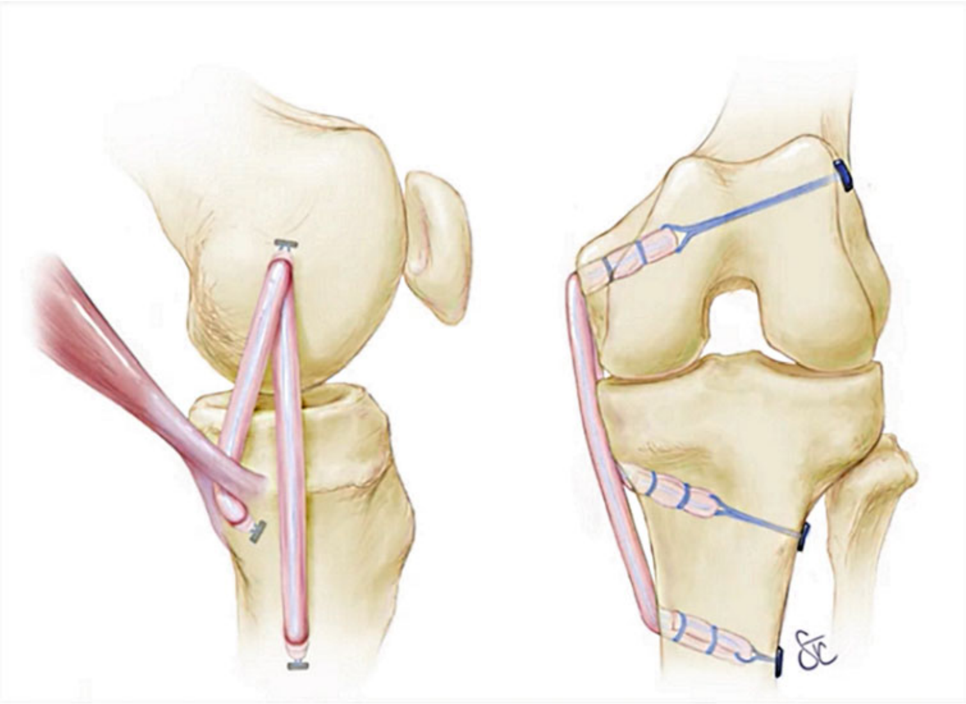


Fig. 17.19 A final schematic of the finished PMC reconstruction with suspensory fixation. ©2018 The Curators of the University of Missouri, reprinted with permission

needle is then removed. The diameter of the FCL portion should be no greater than 7 mm from the end of the doubled-over portion to the free end.

Again, a semitendinosus, anterior tibialis, or gracilis allograft is used to create the popliteal portion of the construct. The tendon allograft should be 5.5–6.5 mm in diameter and at least 130 mm long. A #2 FiberLoop suture is placed at each end of the graft using a locking double whipstitch pattern over 15 mm of the free end of the allograft.

A bump is placed underneath the knee, and the knee is dropped off the side of the table. The PLC is exposed through the posterolateral approach, allowing relaxation and protection of the peroneal nerve. A #10 blade can be used to make an incision in line with the middle of the fibular head. The biceps tendon, iliotibial band, and overlying fascia are identified. Sharp dissection is used to dissect down to the deeper fascia (Fig. 17.21). Using careful dissection, the peroneal nerve is identified. It can usually be palpated just posterior to the hamstrings in the groove below the head of the fibula. A Penrose drain can be placed around it to allow for gentle retraction and easy identification (Fig. 17.22). No clamps or other surgical instruments should be placed on the Penrose drain as permanent traction injuries can result. With sufficient dissection of the nerve, the entire proximal fibula is made readily accessible. Blunt dissection is carried out to define the plane anterior to the lateral head of the gastrocnemius. It is important to never stray posterior to the lateral head of the gastrocnemius as it places the popliteal neurovascular structures at risk. The interval between the biceps femoris tendon and iliotibial band is opened along the direction of their fibers to evaluate the FCL and popliteus tendon (Fig. 17.23). The popliteus runs deep to the FCL to attach to its femoral insertion that is 1–2 cm anterior and distal to the FCL attachment.

The isometric point is located approximately halfway between these two attachment sites and can be found in a similar fashion as in the PMC reconstruction isometric point. A perfect lateral view of the knee is obtained, and the isometric point is identified where a line extends from where the posterior femoral cortex intersects with Blumensaat's line. It is sometimes necessary to release the iliotibial band near the femoral attachment of the FCL to facilitate the graft placement. If the IT band is released, it should be repaired at the end of the procedure. The popliteofibular ligament traverses from the posterior aspect of the head of the fibula to the popliteus tendon. This normal anatomy is frequently disrupted in patients with knee dislocations. The isometric point is drilled with a spade-tipped guide wire and is reamed based on the size of the graft to create a tunnel of at least 50 mm. A suture is passed for future graft passage. The guide wire should be aimed anterior and proximal in order to avoid ACL femoral tunnel placement.

A tunnel is drilled through the head of the fibula from anterolateral to posteromedial, first with a 3.2 mm drill bit. It is followed by a 6-mm cannulated reamer and a manual 7-mm reamer. A 3.2-mm drill bit is then used to make a hole in the lateral tibia in an anterior to posterior direction. The drill enters the tibia directly medial and inferior to the anterolateral arthroscopic portal, at least 2 cm below the

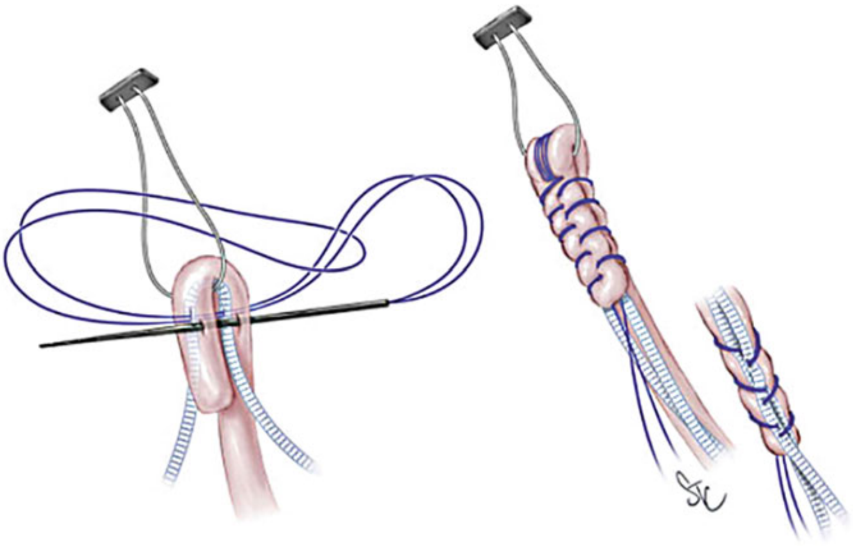


Fig. 17.20 Illustration depicting the preparation of the fibular collateral ligament/popliteofibular graft for the allograft reconstruction of the PLC using cortical button suspensory and interference screw fixation. ©2018 The Curators of the University of Missouri, reprinted with permission

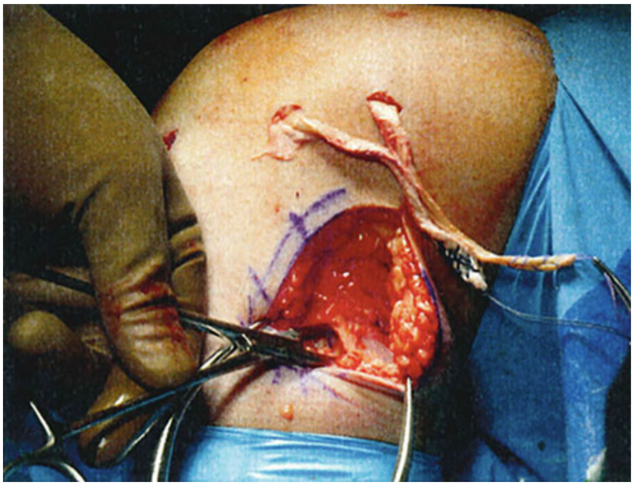


Fig. 17.21 Posterolateral approach of PLC reconstruction in a left knee. The skin incision is placed in line with the fibular head and carried in a straight line proximally and distally. The biceps tendon, iliotibial band, and the overlying fascia are identified. A pair of scissors is placed immediately posterior to the biceps tendon along the direction of the tendon to open the deep fascia, and the peroneal nerve is identified and dissected out from the fibular neck. *Note* The graft materials exiting the lateral femoral condyle in this image were for ACL reconstruction in this case

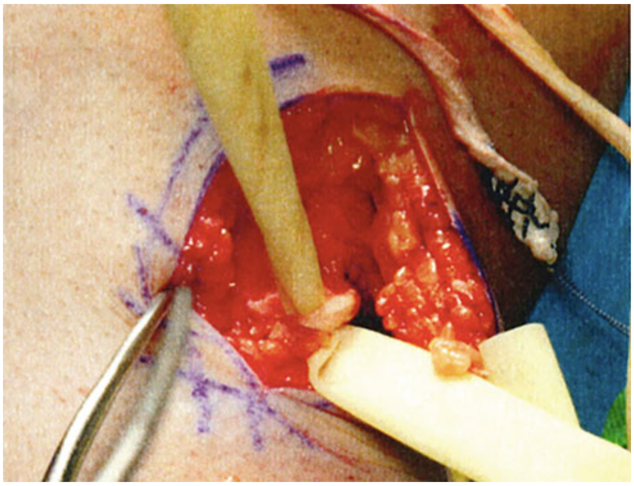


Fig. 17.22 A Penrose drain is placed around the peroneal nerve during the posterolateral approach of the knee

joint line, and exits on the posterolateral tibia just medial to the head of the fibula. A freehand technique is used for the drilling and involves positioning the index finger of the nondominant hand at the posterolateral edge of the tibia through the interval described above. The tibial tunnel is reamed to a diameter of 6 mm and tapped to a diameter of 7 mm. Another suture is passed through this tunnel.

The grafts are then passed and tensioned. The free end of the FCL graft is passed deep to the IT band proximal to distal and pulled through the fibular tunnel from anterior to posterior with the passing suture. The free end of the FCL/popliteofibular is then passed back to the socket at the isometric point and attached to a graftlink or other suspensory fixation device. This is then pulled into the socket and flipped on the medial cortex. The graft is pulled to an initial depth of 15 mm. The popliteal graft is passed together under the biceps tendon, IT band, and FCL graft toward the socket drilled at the proximal part of the popliteal hiatus. It is placed into the popliteal socket and fixed with an interference screw. The tibial end of the popliteal graft is pulled taut and the knee is cycled to take slack out of the graft. The knee is then placed in 30° of flexion and neutral rotation and a 7-mm interference screw are placed in the tibial tunnel in an anterior to posterior direction. Extra popliteal graft is then

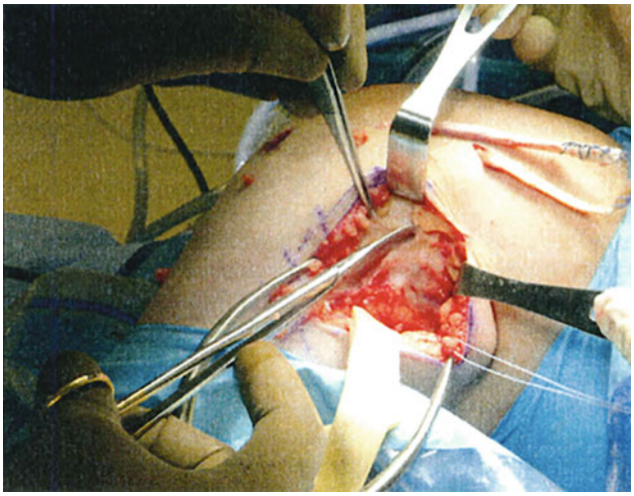


Fig. 17.23 The interval between the biceps femoris tendon and the iliotibial band is opened along the direction of their fibers. This allows for the evaluation of the status of the FCL and popliteus tendon, and facilitates graft passage underneath the biceps tendon and iliotibial band later

excised. The femoral suspensory fixation device is then tightened after cycling the knee to obtain the desired stability (Fig. 17.24).

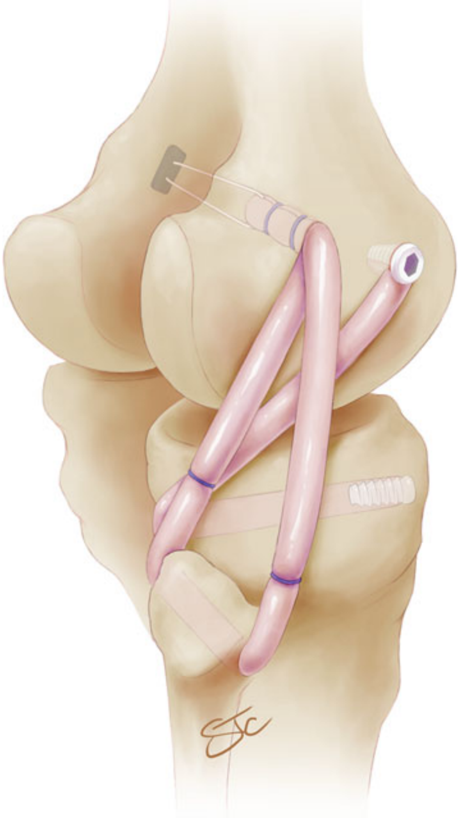


Fig. 17.24 New anatomic reconstruction of the posterolateral corner with suspensory fixation. ©2018 The Curators of the University of Missouri, reprinted with permission

17.6.5 Posterolateral Corner Reconstruction—Figure of Eight

If there is no rotational instability on examination under anesthesia, the popliteus does not need to be reconstruction and a figure-of-eight reconstruction can be performed. This procedure is identical to what is described above minus the popliteus reconstruction. The reconstruction is based on the isometric point and a tunnel through the head of the fibula from anterolateral to posteromedial. The suspensory fixation device is tightened to reconstruct the FCL and popliteofibular ligament. The knee is ranged and stressed and the buttons are retightened multiple times (Fig. 17.25). Final fluoroscopic images confirm the position of the button.

17.7 Postoperative Care

Most patients with multi-ligament reconstruction require several days of hospitalization following the procedure. Patients are given antibiotic prophylaxis initially, but it is discontinued before 24 h following surgery. For deep vein thrombosis (DVT) prophylaxis, patients are placed on both the mechanical prophylaxis such as thrombo-embolic deterrent (TED) hose compression stockings or sequential compression devices, as well as pharmacological prophylaxis during inpatient hospitalization. On discharge, they have prescribed one baby aspirin per day as DVT prophylaxis, until the patient resumes full normal weight bearing ambulation. If there is an immediate family history of symptomatic DVT or PE, pharmacologic prophylaxis is maintained for 6 weeks.

Following PCL and corner reconstructions, patients start weight bearing as tolerated with crutches with the knee locked in full extension in a hinged knee brace on the first postoperative day. Patients begin range of motion at 0°–30° on the first postoperative day and progress as tolerated. A continuous passive motion (CPM) machine can assist with this also. Care should be taken not to progress the motion too quickly in order to allow early graft healing into the tunnels and fixation points. At 3–4 weeks, the hinged knee brace is unlocked during weight-bearing activities. Physical therapy starts after the first 2 weeks. The main focus during the initial recovery period is to obtain and maintain knee motion. In this regard, patellar mobilization is another important exercise during this phase because the patella is frequently involved in arthrofibrosis following multi-ligament knee injuries. By 6 weeks, the patient should be expected to have 0°–90° of active and passive knee motion, good patellar mobility, and normal gait without any assistive device. Once

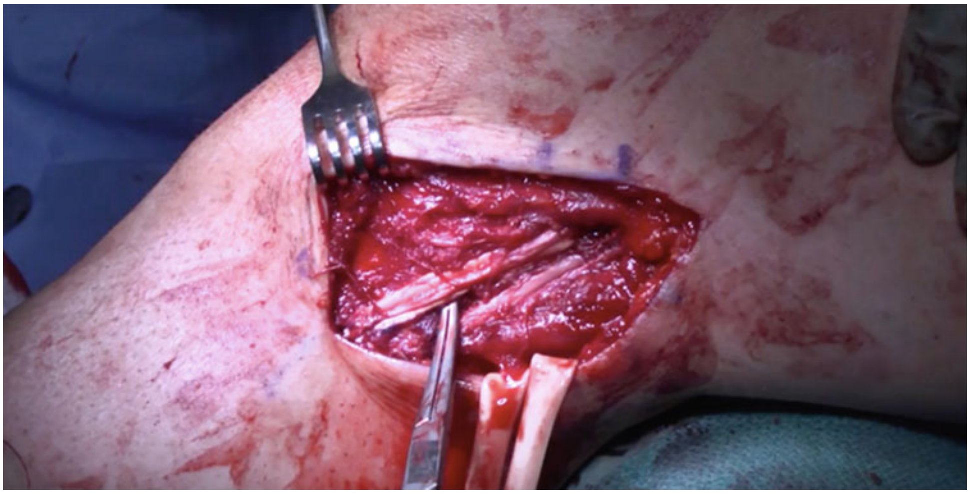


Fig. 17.25 Final figure-of-eight reconstruction. *From* Stannard et al. [7]. Reprinted with permission from Thieme New York

all these goals have been achieved, the patient can start the strengthening phase. The brace is discontinued anytime after 6–8 weeks once patients have achieved 0°–120° of active motion, 30 s of single leg balancing, and normal gait without extensor thrust. A custom-fit knee brace is recommended for therapy and athletic activities for the first 2 years following reconstruction of a knee dislocation.

Return to heavy work and sports are gradually allowed during the period of 9–12 months post-surgery. For patients who have sustained a multi-ligament injury, full recovery frequently involves a 12–18-month process. The criteria for return to heavy work and sports varies depending on the activity level that patients want to perform; but in general, patients return to strenuous activities when they have convincingly regained normal stability, motion, and strength of the knee.

17.8 Clinical Outcomes

The overall incidence of failure of our anatomic PCL reconstruction was 7% (4/54) [8] in a patient population with a mean follow-up of nearly 5 years. All remaining 50 patients had a negative posterior drawer test, with 44 (88%) having a 0 and 6 (12%) having 1+ posterior drawer. Excellent stability was found when knee stability was measured in the anteroposterior direction with KT-2000 arthrometer at 30° and 70°. The injured knee was 0.07 mm tighter at 30° and 1.08 mm looser at 70° than the uninjured knee. PLC failure rates in our published studies have been 7–8%. In our separate published study, the failure rate of PMC reconstruction was found to be 4% compared to 20% failure rate with PMC repair [9]. Following reconstruction of the PCL and other ligaments, 90% of patients were able to return to some type of work [8]. Seventy-six percent of patients returned to full-time work at the same job, while 8% returned to full-time employment at a different job. Six percent of patients returned to light duty only, and 10% were not able to return to work. Fifty percent of patients were able to return to their prior level of recreational activities and 25% returned to a lower level of activity.

17.9 Conclusions

Multiple-ligament-injured knees pose a formidable challenge to the orthopedic surgeon. The neurovascular structures may be injured and result in a limb-threatening situation. Concomitant injuries to the ipsilateral extremity further complicate the diagnosis and treatment. Clinical outcomes have often been discouraging, and complications are frequent. It is not uncommon for patients to have chronic pain, stiffness, residual instability, early post-traumatic arthritis, and so forth. Injuries to the PCL and both the PMC and PLC should be managed surgically with the reconstruction of each ligamentous structure. An anatomic double-bundle inlay technique using Achilles tendon allograft is a reliable and reproducible method for PCL reconstruction. This technique eliminates the killer turn, which has been shown to be associated with graft stretch and failure. The PMC is reconstructed with allograft by reconstruction the MCL and POL. The PLC is reconstructed with a modified two-tail technique which reconstructs all three critical components of the PLC—the FCL, popliteus, and popliteofibular ligament. With experience in patient evaluation and surgical technique, these clinical outcomes have shown a steady improvement in recent years.

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Surgical Treatment of Combined ACL PCL Medial Side Injuries: Acute and Chronic

18

Benjamin Freychet, Nicholas I. Kennedy, Bruce A. Levy,
and Michael J. Stuart

18.1 Introduction

The optimal strategies to treat the multiligament injured knee remain controversial. It is generally accepted that the central pivots, the anterior cruciate (ACL), and posterior cruciate (PCL) ligaments are best managed with reconstruction; however, treatment of the medial collateral ligament (MCL) is debatable. The pattern and location of the MCL injury may influence surgical timing and the decision to repair or reconstruct.

This chapter will focus on the ACL/PCL/MCL injured knee, including the pertinent anatomy, diagnosis, timing of surgery, operative techniques, rehabilitation protocol, and patient outcomes.

18.2 Classification

The modified Schenck classification is commonly used to describe specific injury patterns for the multiligament injured knee. Based on this system, an ACL/PCL/MCL injury falls into the Type III category [1].

18.3 Anatomy

The medial side of the knee is typically divided into three distinct layers. Layer one is comprised of the sartorius tendon and fascia. Layer two includes the superficial MCL, the posterior oblique ligament (POL), and the semimembranosus tendon. The gracilis and semitendinosus tendons are located between layer one and layer two. Layer three consists of the deep MCL and the posteromedial capsule. Layers one and two blend together anteriorly, and layers two and three blend posteriorly [2].

More recently LaPrade et al. described the distinct bony prominences on the medial distal femur and their relationships to the attachment sites of the key ligaments and tendons (Fig. 18.1). These prominences include the medial epicondyle, the gastrocnemius tubercle, and the adductor tubercle. The superficial MCL attaches on the femur just slightly proximal and posterior to the medial epicondyle. The POL attaches on the femur just slightly distal and anterior to the gastrocnemius tubercle [3]. More specifically, the superficial MCL has its origin 3.2 mm proximal and 4.8 mm posterior to the medial epicondyle. Its tibial insertion is 61.2 mm (approximately 6 cm) distal to the joint line. The deep MCL is attached through the meniscofemoral and meniscotibial ligaments. The tibial insertion is just distal to the articular cartilage on the tibial plateau. The POL has its femoral origin 7.7 mm distal and 6.4 mm posterior to the adductor tubercle (Fig. 18.2).

These ligament attachment sites have also been correlated with radiographic landmarks. Intraoperative fluoroscopy is a helpful tool during surgery to ensure anatomic repair or reconstruction. The intersection of a line drawn along the posterior border of the posterior femoral cortex (Line 1) with a line drawn perpendicular at the proximal extent of Blumensaat's line (Line 2) helps to identify the MCL and POL origins (Fig. 18.3) [4].

18.4 Diagnosis

The mechanism of a combined ACL, PCL, and MCL injury is typically a valgus stress to an extended knee. It is imperative to perform a detailed physical examination, knee radiographs, and MRI. Bilateral fluoroscopic radiographs or fluoroscopy, with or without anesthesia, can also be very helpful in making an accurate diagnosis. Standard physical

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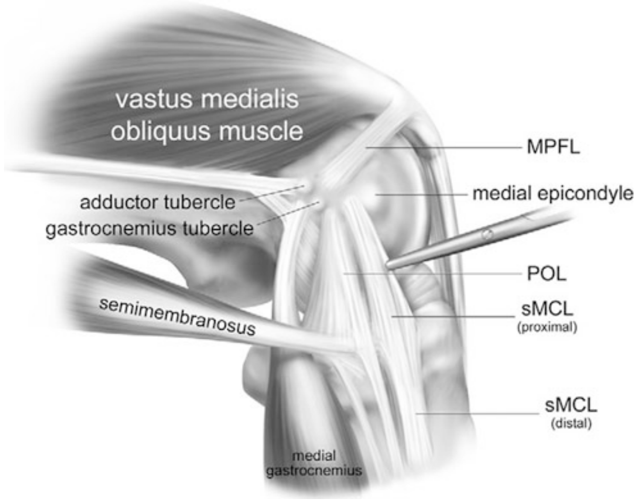


Fig. 18.1 Anatomic diagram of MCL and POL ligaments. From Wijdicks CA, Griffith CJ, LaPrade RF, et al. [4]. Reprinted with permission from Wolters Kluwer Health, Inc

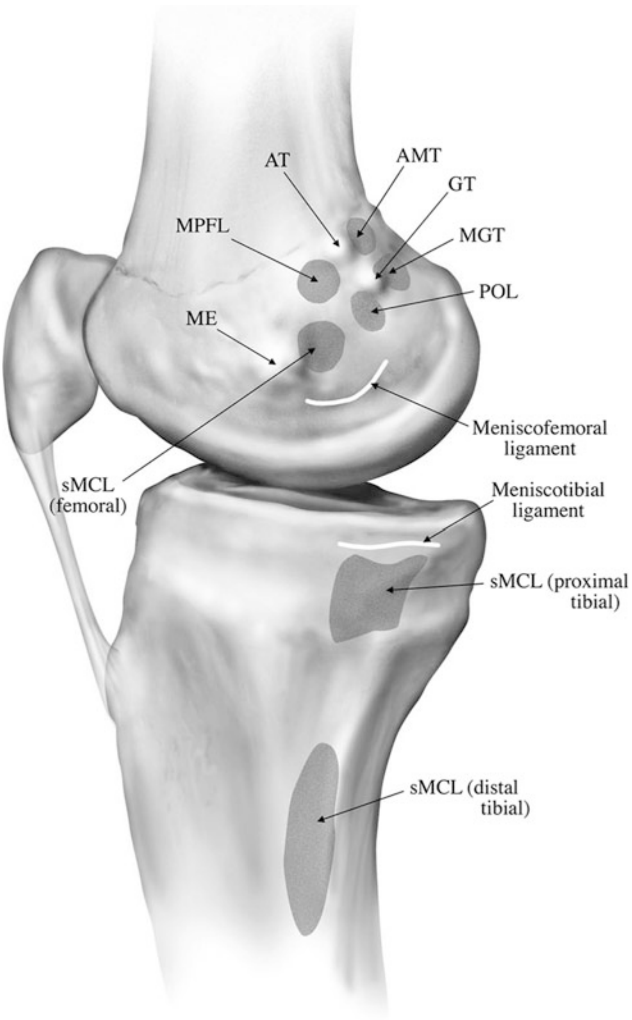


Fig. 18.2 Anatomic diagram of the insertion sites for medial-sided structures. From LaPrade RF, et al. [3]. Reprinted with permission from Wolters Kluwer Health, Inc

examination tests include Lachman and pivot shift for the ACL; posterior sag, posterior drawer, and quadriceps active tests for the PCL; and valgus stress in full extension and 30° of flexion for the MCL. Greater than 10 mm of medial joint space opening in full extension is consistent with disruptions of the MCL, ACL, PCL, and POL.

18.5 Radiographs

Radiographs are scrutinized for intra-articular loose bodies, medial or lateral joint space widening, and associated peri-articular fractures. Even subtle medial joint space widening may be a clue to a multiligament injury with an MCL disruption.

Stress fluoroscopy or radiography is also helpful to compare side-to-side differences in joint space opening.

18.6 Mri

MRI is the diagnostic imaging of choice because it can delineate both intra-articular and extra-articular injuries, including cartilage, menisci, bones, and ligaments. The precise images can identify the location and extent of the MCL tear, involvement of the meniscofemoral and meniscotibial ligaments, and the presence of a so-called MCL “Stener” lesion where the pes tendons are interposed between the superficial MCL and its tibial insertion site.

18.7 Surgical Timing

Surgical timing can be divided into three categories: emergent, acute (1–3 weeks), and delayed (>3 weeks).

18.7.1 Emergent

Emergent surgery is required in the presence of an arterial injury requiring repair or bypass graft, compartment syndrome, open knee dislocation, or an irreducible knee dislocation. If the patient is undergoing emergency surgery for any of these indications, an open medial side repair can be performed at the same time.

If none of the emergent clinical scenarios are present, the definitive ligament surgery can be performed in an acute or delayed fashion. Non-emergent surgery allows for monitoring of vascular status, reduction of limb swelling, and the time to perform advanced imaging, plan the surgical procedures, obtain the necessary allografts, and assemble an experienced team.

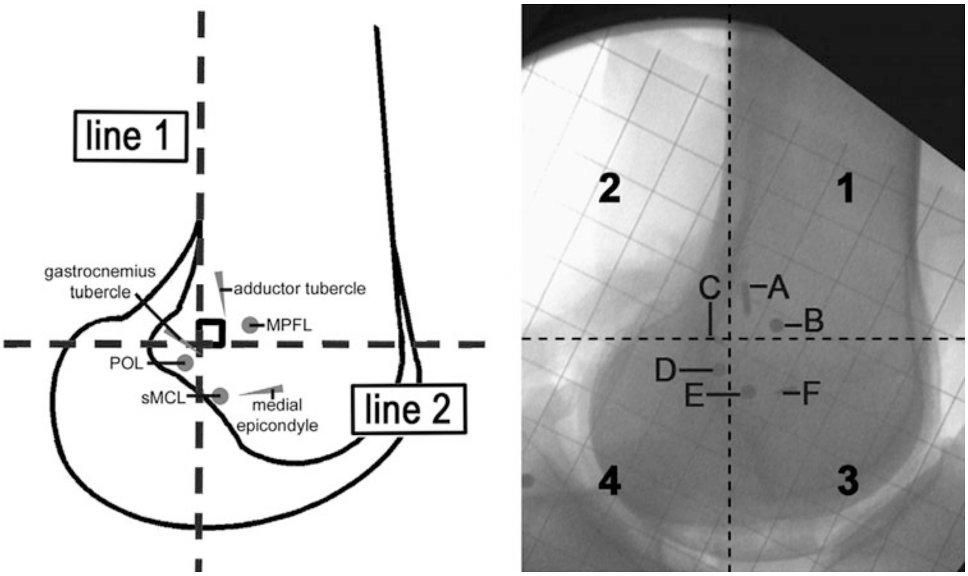


Fig. 18.3 Fluoroscopic and pictorial diagram for locating the MCL femoral insertion site. From Wijdicks CA, et al. [4]. Reprinted with permission from Wolters Kluwer Health, Inc

18.7.2 Acute (1–3 Weeks)

If the soft tissues are amenable, early surgical intervention can be considered for an extensive medial-sided disruption. Operative intervention within 3 weeks of the injury allows for easier identification and repair of the injured structures, with or without the augmentation of a graft. Acute surgery is advised for a displaced medial meniscus tear blocking motion or a "Stener" lesion where the distal MCL is flipped up over the pes tendons. Figure 18.4 is a coronal T-2 MRI image that depicts a "Stener" lesion. The superficial MCL is actually trapped within a medial tibial plateau rim fracture.

Fig. 18.4 Coronal T-2 MRI depicting the superficial MCL trapped within a medial tibial plateau rim fracture

18.7.3 Delayed (>3 Weeks)

Surgical delay greater than 3 weeks is required for patient and/or limb conditions that preclude operative intervention. Examples include significant associated injuries such as a cervical spine fracture, severe leg swelling with or without a deep venous thrombosis, a recent vascular repair that requires monitoring (Fig. 18.5), a degloving injury that necessitates multiple debridements and soft tissue coverage, or fractures of the ipsilateral lower extremity. The patient depicted in Fig. 18.6 sustained a knee dislocation in combination with a severe, open, proximal tibia fracture, proximal tibiofibular joint dislocation, and fibular neck fracture that required multiple debridements and open reduction internal fixation (ORIF). Delayed surgery is also an option for an MCL femoral avulsion because these low-grade femoral side injuries have a robust healing response. After a period of rehabilitation in a brace, repeat physical examination and stress radiographs are helpful. If the MCL has healed, delayed ACL and PCL reconstructions alone can be performed at 6–8 weeks following the injury.

Patients who meet the criteria for a delayed reconstruction are placed in a rehabilitation brace that allows controlled range of motion while maintaining joint reduction. Knee radiographs in the brace, including anteroposterior and oblique views, are necessary to ensure joint reduction.

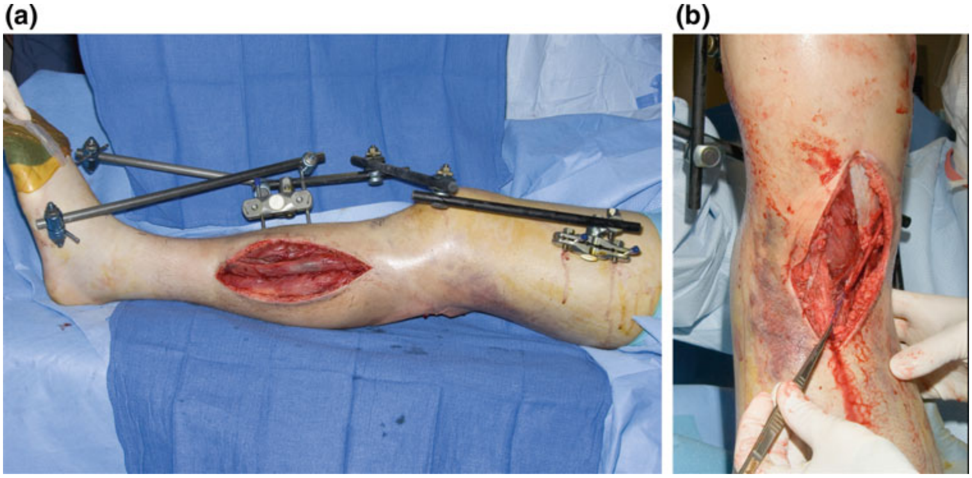


Fig. 18.5 Clinical photographs of lateral (**a**) and prone (**b**) views depicting severe soft tissue swelling following a knee dislocation requiring vascular repair and fasciotomies

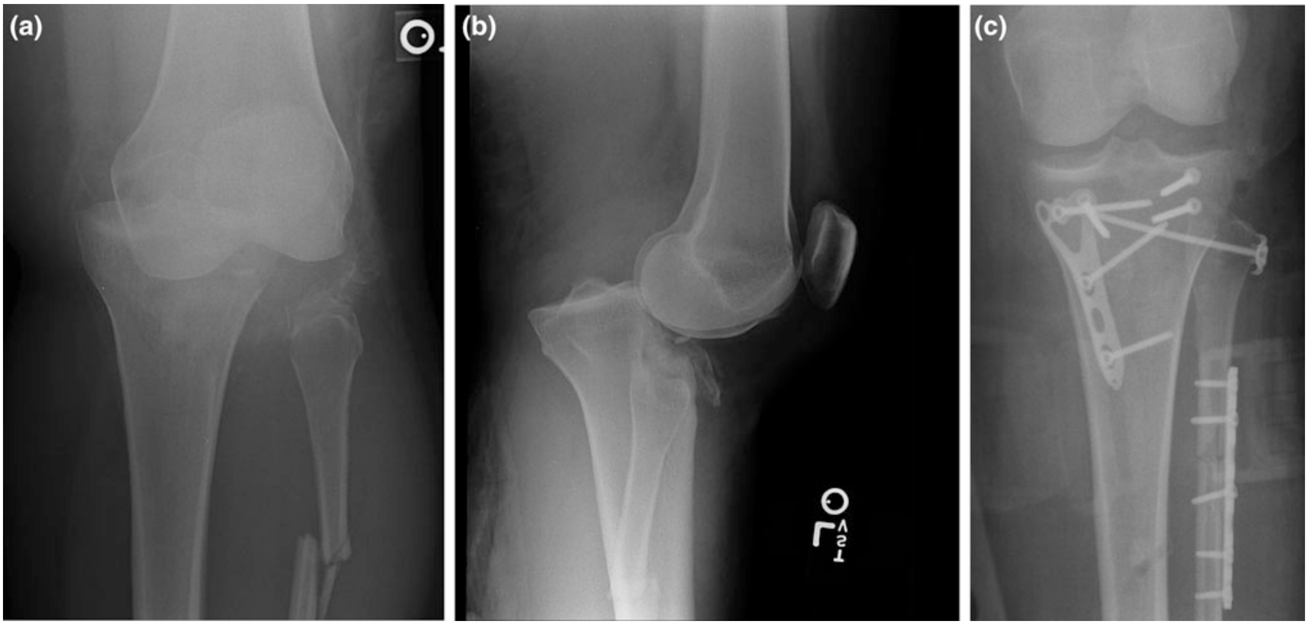


Fig. 18.6 **a** Anteroposterior (AP) and **b** lateral radiographs of open tibial plateau, proximal tibiofibular joint dislocation, and fibular neck fracture that required multiple debridements. **c** Open reduction and internal fixation (ORIF)

18.8 Surgical Technique

Multiligament knee reconstruction starts with fluoroscopic stress examinations of both knees under anesthesia. Position and prep the leg very carefully to prevent joint dislocation and neurovascular injury. A tourniquet is usually applied but not inflated. The arthroscope is first used to identify meniscus tears and osteochondral injuries, then to assist with meniscus repair and bone tunnel preparation for the ACL and PCL reconstructions. Our preferred technique for ACL reconstruction uses a patellar tendon allograft supplemented with a platelet-rich fibrin matrix and secured with femoral and tibial interference screws. The anterolateral bundle PCL reconstruction typically uses an all-inside graftlink technique using a quadruple-bundled tibialis anterior [5]. The graft is fixed with both tibial and femoral suspensory fixation.

Following completion of the ACL and PCL reconstructions, the anteromedial skin incision is extended proximally while maintaining full-thickness skin flaps. This exposure allows for MCL repair or reconstruction as well as repair of the menisci, medial patellofemoral ligament, and medial head of the gastrocnemius as indicated.

18.8.1 Medial-Sided Repair/Reconstruction (Acute)

In the case of an MCL femoral avulsion, we reattach the MCL to the anatomic femoral origin with a suture post and ligament washer construct as described by Schenck. In the presence of an MCL tibial avulsion and good quality tissue, reattach the deep MCL with suture anchors at the level of the joint and repair the superficial MCL with the suture post and ligament washer construct (Fig. 18.7). The construct is typically tensioned as 30° of flexion with a varus stress and slight external rotation. The deep MCL is reattached in full extension with suture anchors. If the medial meniscus is extruded, the coronary ligaments are repaired with suture anchors along the tibial plateau.

The posterior medial capsule is reattached with suture anchors to the posteromedial femur and/or tibia depending on the location of the injury. The posterior oblique ligament (POL) is repair if torn from the femur or tibia, then sutured to the posterior border of the MCL without imbrication and with the knee in full extension.

Inadequate knee stability due to poor tissue quality after repair is an indication for augmentation. A tendon graft or an internal brace can strengthen the repair and allow for early range of motion. This accelerated rehabilitation may prevent arthrofibrosis, which is the most common complication of acute medial-sided surgery in the setting of multiligamentous injury.

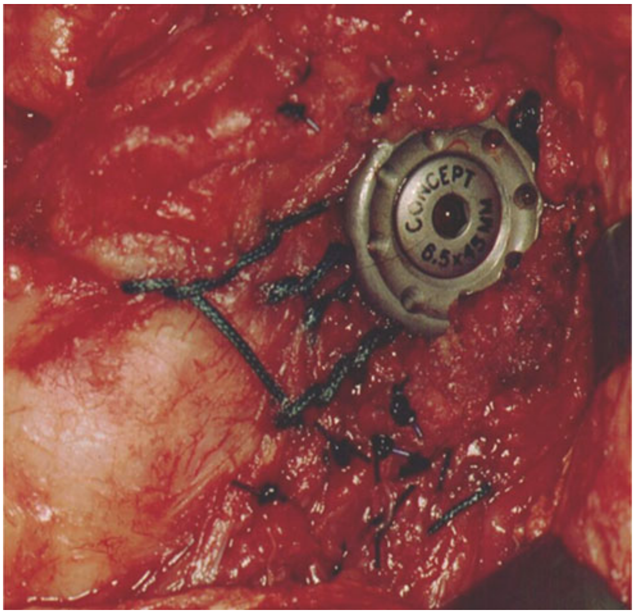


Fig. 18.7 Clinical photo of suture post and ligament washer construct

Augmentation is typically performed with a gracilis or semitendinous autograft or an Achilles tendon allograft [6–8]. The augmented repair technique with an Achilles tendon allograft involves drilling a socket at the MCL femoral insertion, inserting and securing the Achilles bone plug with a biocomposite interference screw, passing the tendon distally under the skin, and then fixing the graft 6 cm distal to the joint line at the superficial MCL tibial insertion site [9].

If the MCL repair is satisfactory but requires additional support, we utilize the internal brace augmentation technique published by Lubowitz et al. [10]. A knotless 4.75 mm anchor with a suture tape is placed at the MCL proximal origin. The internal brace is tensioned, and then the second anchor is introduced at the posterior aspect of the distal tibial superficial MCL insertion. The tibial periosteum is attached around the suture tape with a high strength suture at the level of the deep tibial MCL insertion,

Wijdick et al., in an in vitro biomechanical study, reported that both an anatomic sMCL augmented repair and an anatomic sMCL reconstruction provide equivalent joint stability [11].

18.8.2 MCL Reconstruction—Chronic

In the chronic setting, we typically recommend an Achilles tendon allograft or semitendinosus autograft. For the Achilles allograft technique, a K-wire is inserted at the MCL femoral origin by visual and fluoroscopic guidance [4]. The MCL tibial origin is identified by the remaining fibers beneath the semitendinosus and gracilis tendons. A looped suture or Mersilene tape is placed around the K-wires at the origin and insertion sites to check for isometry in flexion and extension. A femoral socket (9 mm diameter, 25 mm length) is drilled with a reamer. The bone block is inserted and secured with an 8 × 25 mm metal interference screw. Two suture anchors are placed at the medial tibial plateau margin and the sutures are passed through the graft, but not tied. A nonabsorbable, locking whip stitch is placed in the tibial end of the graft. The knee is placed in 30° of flexion with a varus and slight external rotation stress. The graft is then tensioned and fixed to the tibia with a bicortical screw/ligament washer, and the sutures are tied around the screw. This construct spreads out the tibial attachment site and provides secure, double fixation. The deep MCL sutures (suture anchors at the tibial plateau margin) are tied with the knee in full extension. Figures 18.8 and 18.9 depict case examples of ACL/PCL/MCL reconstructions using Achilles allograft for the MCL reconstruction.

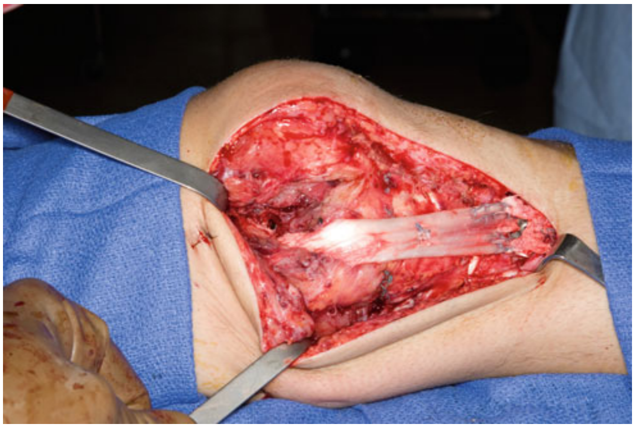


Fig. 18.8 Clinical photo of an Achilles MCL reconstruction

For the medial hamstring autograft technique, the semitendinosus and gracilis tendons are left attached distally. The isometric point on the femur is identified and a K-wire placed. The tendons are looped around the K-wire and isometry is verified (Fig. 18.10). The graft is fixed on the femur with a 3.5 mm bicortical screw and a spider washer. The graft is also secured on the tibial side with screw/ligament washer and suture/post construct.

The POL is repaired back to the femur or tibia according to the zone of injury. A vertical incision of the posteromedial capsule is made between the posterior border of the MCL and the anterior border of the POL. Redundancy is eliminated by imbricating the POL underneath the MCL with fanned-out mattress sutures. A lax capsular arm of the semimembranosus can also be sutured to the POL construct. Figures 18.11, 18.12, 18.13 and 18.14 depict a case example of ACL/PCL/MCL reconstructions with hamstring autograft MCL reconstruction and medial meniscal transplantation.

Summary of Our Current Strategy for Ligament Reconstruction Sequence in the Setting of ACL, PCL, and MCL Injury

(1) Diagnostic arthroscopy and meniscal and articular cartilage treatment
(2) PCL tibial tunnel
(3) PCL femoral tunnel
(4) ACL tibial tunnel
(5) ACL femoral tunnel
(6) PCL graft is tensioned in full extension, then fixed at 80 of flexion
(7) ACL graft is tensioned and fixed in full extension
(8) Repair, augment, or reconstruct the deep and superficial MCL
(9) Tension the MCL at 30° of flexion with varus stress and slight external rotation
(10) Repair the posterior oblique ligament and posterior medial capsule
(11) Tension the posterior oblique ligament and capsule near full extension

18.9 Postoperative Rehabilitation

We follow the rehabilitation protocol as described by Edson and Fanelli [12]. A rehabilitation brace with a varus mold is applied and locked in full extension for three weeks. The patient is instructed on touch weight-bearing with crutches, ankle pumps, quad sets, and straight leg lifts. After 3 weeks, partial weight-bearing and passive prone flexion up to 90°

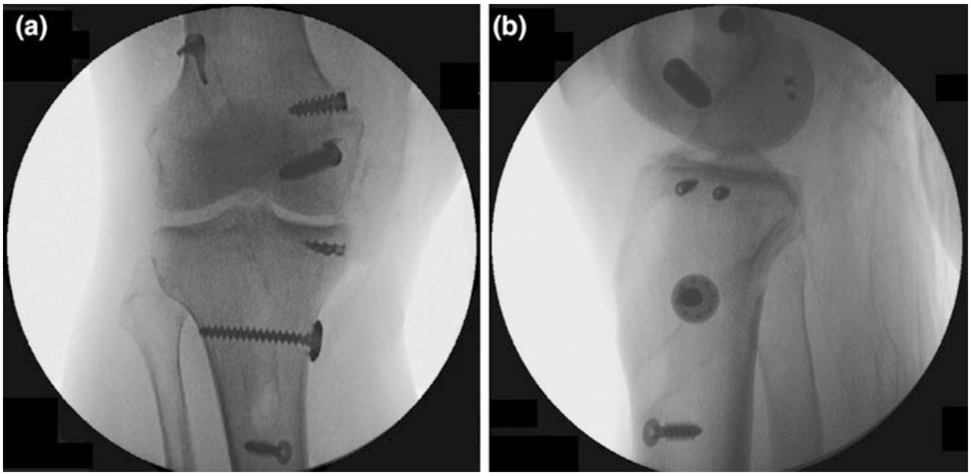


Fig. 18.9 Example of AP (**a**) and lateral (**b**) fluoroscopy after ACL/PCL/MCL reconstructions with Achilles allograft MCL reconstruction

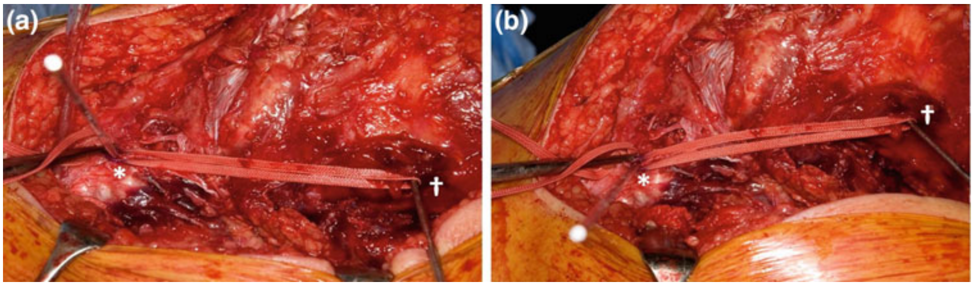


Fig. 18.10 Intraoperative images of medial side of right knee (anterior = up; distal = left). During medial collateral ligament reconstruction, isometry between the femoral (†) and distal tibial (*) attachments is confirmed in extension (**a**) and flexion (**b**) using Mersilene tape

Fig. 18.11 Intraoperative AP (**a**) and lateral (**b**) fluoroscopy of ACL/PCL/MCL/meniscus allograft reconstructions. Note the position of the trocars for the ACL and PCL tunnels and guide pin position for the medial meniscus posterior horn

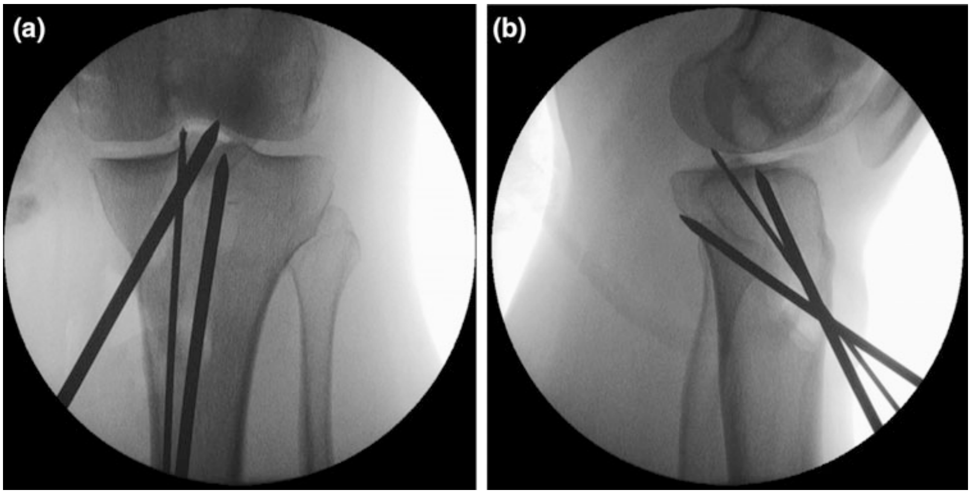
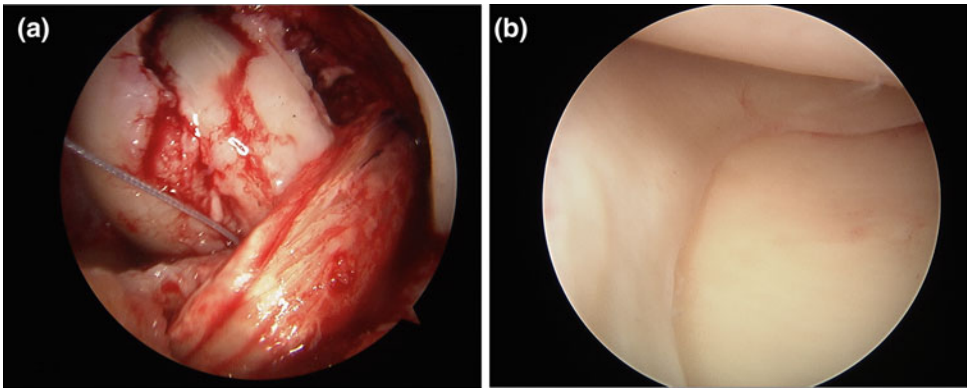


Fig. 18.12 Arthroscopic views of ACL/PCL single-bundle ligament reconstructions (**a**) and meniscus transplant (**b**)



are allowed. After 8 weeks, the patient may bear weight as tolerated with crutches, and a custom unloader brace with a varus mold is worn at all times except for bathing. Light resistance and closed kinetic chain strengthening are allowed, but open kinetic chain hamstring exercises are avoided. After 6 months, the patient may bear full weight, discontinue crutches, and perform full range of motion exercises and progressive resistance closed kinetic chain strengthening.

18.10 Current Literature

We performed an evidence-based, systematic review on the operative management of the MCL in the setting of the multiligament injured knee over a 30-year time period between 1978 and 2008. Only studies with outcome data on MCL repair or reconstruction in the setting of combined ligament injuries were included. We found 8 relevant

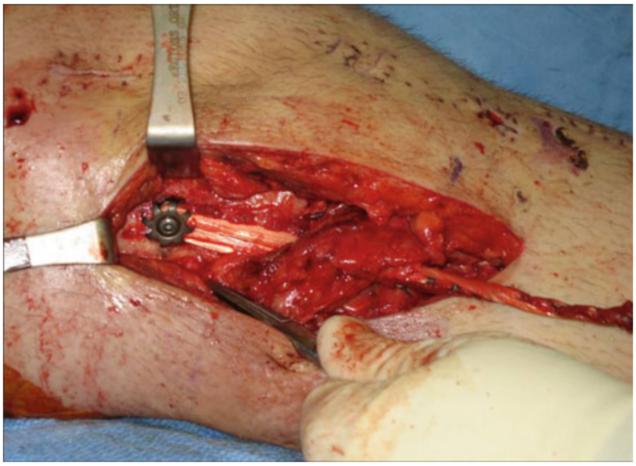


Fig. 18.13 Clinical photo of hamstring autograft MCL reconstruction

studies, all Level IV evidence including 5 on repair and 3 on reconstruction. Outcomes were deemed satisfactory with both *repair* and *reconstruction*, and we were unable to recommend one over the other. There were no prospective studies comparing MCL repair or reconstruction to nonoperative treatment and no prospective studies directly comparing MCL reconstruction to repair [13].

Of the studies that reported on *repair* of the MCL in the multiligament injured knee, we identified a combined cohort of 55 repairs with a mean Lysholm score of 84. Ibrahim et al. reported on 18 patients that underwent MCL repair with ACL and PCL reconstructions. Mean Lysholm score was 79, and 89% of the patients were deemed stable to valgus stress [14]. Owens reported on 11 patients that were treated with primary repair of all ligaments including ACL, PCL, and MCL. Although no patients demonstrated valgus instability, 27% of the patients who underwent MCL repair developed postoperative stiffness requiring arthroscopic lysis of adhesions and manipulation [15]. In a series of 10 knee dislocation patients treated with acute MCL repair followed by delayed ACL/PCL reconstructions, Bin et al. reported a mean Lysholm score of 89.6, and 70% of the patients demonstrated no valgus instability on stress radiography [16].

Repair plus augmentation has gained favor to avoid multiple tunnels and allow for more aggressive rehabilitation. Gorin et al. described a technique for a multiligamentous injury involving ACL and MCL, where augmented repair was performed utilizing gracilis tendon autograft in skeletally immature athlete achieving equal stability and range of motion when compared with the opposite limb [6]. Lubowitz et al. reported a technique with internal bracing without outcomes [10]. Cruz and Ferrari also reported on an augmented repair technique utilizing hamstring tendons with just one femoral tunnel and keeping the hamstring's tibial attachment intact [8].

Tunnel convergence can be a problem when performing multiple ligament reconstruction. Camarda et al. suggested that proximal orientation from 20 to 40° of the sMCL tunnel can avoid convergence with the PCL tunnel in single-bundle PCL reconstruction with concurrent MCL reconstruction [17]. Bonadio et al. demonstrated how to avoid convergence with excellent outcome using a single femoral tunnel for Achilles tendon allograft MCL reconstruction in a PCL-MCL combined injury [18].

Of the studies that reported on *reconstruction* of the MCL in the multiligament injured knee, only five studies met our inclusion criteria. Yoshiya et al. published their series of 22 patients that sustained a combined knee ligament injury including the MCL. They reconstructed the MCL with semitendinosus and gracilis autografts. Only three of the 22

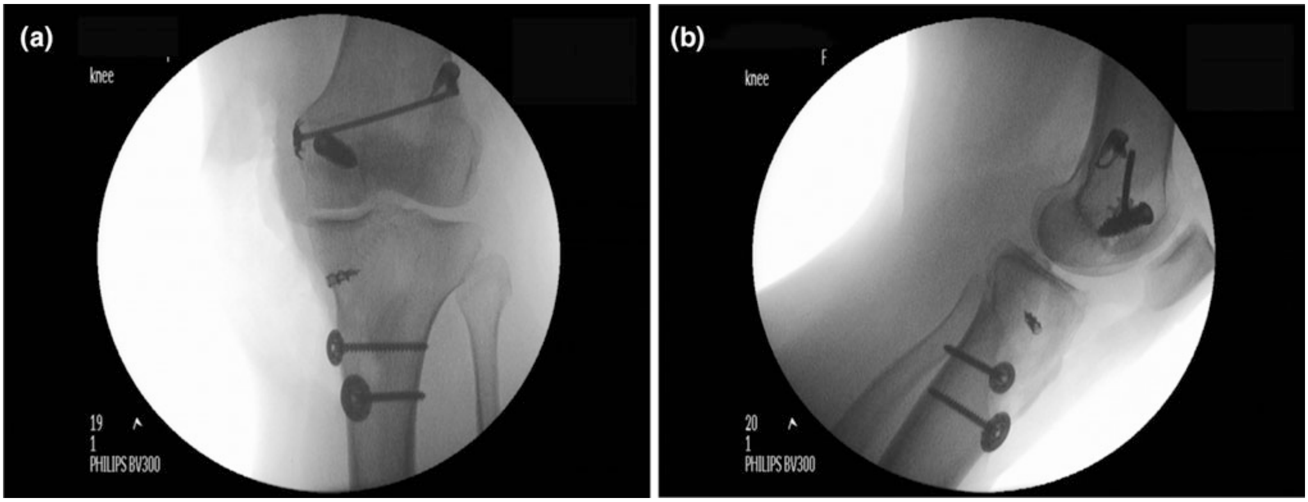


Fig. 18.14 AP (**a**) and lateral (**b**) fluoroscopy after ACL/PCL/MCL reconstructions with hamstring autograft MCL reconstruction

patients sustained a bicruciate injury with MCL disruption, all of whom reported near-normal knee function at final follow-up [19]. Ibrahim et al. reported their results of 15 patients treated with multiligament knee reconstruction using an artificial ligament to reconstruct the MCL. Using comparison clinical stress examination, 93% of the patients were deemed stable to valgus stress [20]. More recently, Liu et al. published their series of 19 patients with multiligament injured knees including a superficial medial collateral ligament tear with a mean follow-up of 34 months. They reconstructed the MCL using Achilles allografts and found both Lysholm and IKDC scores to be significantly improved postoperatively [21]. A systematic review by DeLong et al. concluded that anatomic reconstruction had better clinical and objective outcomes than nonanatomic reconstruction [22]. Lind et al. described an anatomical reconstruction of the MCL and posteromedial corner of the knee in 14 patients with chronic MCL instability using semitendinosus autograft left attached distally to reconstruct the MCL and POL. They noted acceptable clinical results based on IKDC, KOOS, and patient satisfaction scores [23].

We did identify one retrospective study that compared MCL *reconstruction* to nonoperative treatment of the MCL in the multiligament injured knee. Fanelli et al. reported on 35 patients, of whom 15 had injuries to the MCL. Of these 15 patients, 8 were treated with reconstruction using either semitendinosus autograft or allograft, and the remaining 7 patients were treated nonoperatively. No difference was found between the two groups. The major limitation of this study was its retrospective design and the absence of randomization [24].

More recent studies have compared anatomic repair to reconstruction. Stannard et al. reported on 73 dislocated knees with MCL/posteromedial corner (PMC) injuries with a mean follow-up of 43 months and mean age of 36 years. There were 25 patients who underwent MCL repair, 27 patients who underwent autograft reconstruction, and 21 patients who underwent allograft reconstruction. The repair failure rate was 20%, autograft failure rate 3.7%, and allograft failure rate 4.8%. This was statistically significant with a P value of 0.04. The authors concluded that MCL/PMC repair was felt to be inferior to reconstruction in the setting of the multiligament injured knee [25]. Dong et al. compared anatomic MCL repair and anatomic triangular reconstruction combined with ACL reconstruction. They found no statistical difference in IKDC scores and medial opening evaluations with a mean follow-up of 34 months [26]. Wijdick et al., in an in vitro biomechanical study, reported that both an anatomic sMCL augmented repair and an anatomic sMCL reconstruction provide equivalent joint stability [11].

Staged treatment for a multiligament knee injury remains controversial. We identified three systematic reviews that compared acute management to staged surgery. Mook et al. reported 396 patients over a 60-year period in 24 studies with only KDIII or IV MLKI [27]. They demonstrated that staged and acute repair of MLKI produced equivalent results. Mook and Jiang reported that staged treatment yielded the highest percentage of excellent and good subjective outcomes [27, 28]. The systematic review by Barfield et al. cited insufficient evidence to suggest superiority of outcomes for acute or staged treatment of MLKI [29].

Concerning the results between lateral and medial side injuries in MLKI, we found two comparative studies. King et al. compared 24 patients with the KDIII-M injury pattern and 32 patients with the KDIII-L injury patients with a mean follow-up of 6,5 years. They reported that medial side injuries had significant worse Lysholm scores, IKDC scores, and range of motion than lateral side injuries. In contrast, Tardy et al. compared 19 patients with posteromedial corner repair or reconstruction and 9 patients with posterolateral corner reconstruction in acute one stage MLKI treatment. They did not find a significant difference for functional scores between acute posteromedial and posterolateral corner groups [30].

Only two studies examined the association between MLKI outcomes and arthritis with long-term follow-up. Moatsche et al. reported results of 65 patients with a multiple ligament knee injury after minimum 10-year follow-up. 42% of patients had radiologic evidence of arthritis in the injured group compared to 6% on the non-injured knee. No statistical difference was found between medial and lateral side injuries [31]. With minimum 5-year follow-up and a mean of 10 years, Fanelli et al. reported that 24% of 44 patients had radiologic osteoarthritis after MLKI but didn't compare injury patterns [32].

Although no clinical data is currently available, "anatomic" reconstructions for the medial side of the knee are being developed. Coobs et al. performed an in vitro analysis of an MCL and POL reconstruction technique using 10 cadaver knees. Comparison of MCL intact, ligament-sectioned, and reconstructed knees revealed restoration of near-normal stability and avoidance of overconstraint with the reconstructed ligament grafts [33].

18.11 Conclusions

Successful management of the ACL/PCL/MCL injured knee requires an accurate anatomic diagnosis; a safe and appropriate time for surgical intervention; allograft reconstruction of the ACL and PCL; and repair, augmentation, or reconstruction of the MCL and posterior medial structures along with a guided, controlled rehabilitation program. We recommend individualized treatment of the ACL/PCL/MCL injured knee tailored to the specific injury pattern and demands of the patient.

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Surgical Management of ACL, PCL, and Lateral-Sided Injuries: Acute and Chronic

19

Peter B. MacDonald and Scott W. Mollison

Abbreviations

ACL	Anterior cruciate ligament
PCL	Posterior cruciate ligament
PLC	Posterolateral corner
PM	Posteromedial
PL	Posterolateral
AL	Anterolateral
AM	Anteromedial
ALL	Anterolateral ligament
IT	Iliotibial band
PL	Popliteus muscle
PFL	Popliteo-fibular ligament

19.1 Introduction

Although rare, multi-ligament injuries to the knee pose great challenges to both patients and treating surgeons. They represent <0.02% of all orthopedic injuries, but are commonly associated with neurologic and vascular injuries that may result in limb-threatening situations [1, 2]. Missed injuries to the posterolateral corner (PLC) of the knee result in chronic instability, gait abnormalities, and medial compartment arthritis. Missed lateral-sided injuries or varus alignment may also be causes of failed cruciate ligament reconstructions [3, 4]. The complex anatomy of the PLC of the knee, in addition to the heterogeneity of injuries and reconstruction techniques, has resulted in a lack of consensus regarding specific treatment and rehabilitation algorithms. Historically, these injuries were treated non-operatively with bracing and gradual rehabilitation to regain motion once the knee had become stiff and stable. Higher patient and surgeon expectations, together with advancing reconstruction techniques and a high failure rate with surgical repair alone, have led a shift toward surgical management with ligament reconstruction [5]. Most surgeons now recommend early acute reconstruction within 3 weeks after injury [6–9]. The goals of surgical intervention are to provide the patient with a stable, well-aligned knee that allows for ambulation. Although most patients return to a satisfactory level of function, the expectation of returning to high-level sport is generally considered unrealistic. Long-term studies on pain relief and prevention of arthritis are lacking [5]. In the treatment of these complex injuries involving the ACL, PCL, and lateral structures, many unanswered questions still remain. The optimal timing of surgery, repair versus reconstruction, alignment, and graft choice will be addressed briefly in this chapter; however, the goal of this section will be to focus on surgical technique for repairing and reconstructing the knee with an acute and chronic combined ACL, PCL, and PLC injury.

19.2 Initial Treatment

Following an acute injury, the patient's knee is immobilized with either an extension splint, hinged knee brace locked at full extension, or an external fixator if the knee remains unstable despite bracing. Occasionally an external fixator may be indicated to protect a vascular repair or reconstruction. Definitive surgery is usually delayed until 2–3 weeks post-injury. This allows for a period of neurovascular monitoring and to some degree, capsular healing for ease of arthroscopy. It also provides time for the acute inflammation to subside, facilitating surgical dissection and identification of structures on the lateral side of the knee, in addition to minimizing problems with wound closure.

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19.3 Early Versus Delayed Surgery

Although it is clear that surgical intervention is generally warranted, what has not been well established is the ideal timing of surgery. Due to lack of quality randomized controlled trials comparing early and late surgical intervention, timing of surgery remains controversial. “Early” surgery typically refers to operative intervention under 3 weeks of injury, although some authors extend this to 6 weeks. “Delayed” surgery occurs beyond 3 weeks after injury.

Potential benefits and risks are present with early intervention. The benefit of early repair is relative ease of performing primary repair due to the lack of scar tissue formation, resulting in more readily identifiable tissue planes [7]. The primary concern with early intervention is unacceptable rates of arthrofibrosis and subsequent knee stiffness [10–12]. Studies comparing early versus delayed surgery report higher Lysholm scores and higher sports activity scores on the Knee Outcome Survey in the early treatment groups [13–17]. Although there was no difference between groups in most other parameters, including final knee range of motion, this has led authors to suggest early surgical treatment within 3 weeks of injury [7]. The rates of arthrofibrosis and limited knee motion following early reconstruction of isolated ACL injury have led some authors to delay the ACL reconstruction in the setting of combined ligament injuries. Following PCL or PLC reconstruction, the patient will start therapy. Once they have regained full range of motion and improved muscle strength, the ACL is reconstructed. However, many surgeons now opt to reconstruct all ligaments at one once, as ACL deficiency may place higher stresses on the PLC grafts, resulting in higher failure rates [18]. Finally, early surgery poses a theoretic risk of causing an iatrogenic compartment syndrome from fluid extravasation through an acutely torn capsule. Presumably this risk diminishes after 2 weeks post-injury as the capsule heals.

19.4 Authors’ Preferred Technique

We prefer to perform a single-stage reconstruction of ACL, PCL and PLC around 3 weeks after injury. If surgery is delayed longer than 3 weeks, acute repair of damaged structures and suture fixation of avulsion fractures of the fibular head may no longer be possible due to scarring and contracture. If we are unable to surgically address the injury within 3 weeks, the patient is fitted with a hinged knee brace and surgery is delayed until full range of motion is restored in an attempt to minimize postoperative arthrofibrosis [19, 20]. If at that point the patient complains of persistent pain or instability, a delayed reconstruction is offered, usually at 12 weeks post-injury.

19.5 Historical Perspective

Historically, the definitive surgical management of multi-ligament injured knees was to repair all damaged tissue. However, work by Stannard has demonstrated that acute repair alone of lateral structures produces significantly higher rates of PLC failure when compared to reconstruction using a modified “two-tailed” technique [21]. Critics of this study highlight that the patients were subjected to an early aggressive rehabilitation protocol, which may have put more stress on the repair-only group. However, most authors now agree that acute reconstruction is superior to repair [5, 7, 8].

19.6 Graft Selection

A variety of options exist when choosing graft material for multiple ligament reconstruction. The first consideration is graft type. Standard of care dictates use of allograft tissue, although options include using the patient’s own tissue as autograft or even synthetic graft material. In the acute setting, tissues around the knee have been traumatized and further dissection to harvest autograft tissue may be technically challenging, cause increased morbidity, and increase total tourniquet time [13, 17, 22–24]. Harvesting three autografts may only be possible if considering using the contralateral knee. In contrast, allograft allows for decreased donor morbidity. Additionally, allograft tissue allows for choice of graft type, thickness, and length. However, with any transplanted tissue comes a small risk of viral or bacterial transmission. There may also be a higher risk of graft failure as reported in the ACL literature [25–27]. Use of synthetic grafts has fallen out of favour over time due to high rates of synovitis, infection, and lack of incorporation [28, 29]. In some countries, allograft may not be available, necessitating use of autograft which usually is both ipsilateral and contralateral.

19.7 Authors’ Preferred Choice of Grafts

We prefer using a tibialis posterior or anterior allograft for the PCL, and a tibialis posterior or anterior allograft or bone-patellar-tendon-bone (BTB) allograft for the ACL reconstruction. These are robust grafts that are readily available in a variety of lengths. The optimal graft for the lateral structures is dependent on the type of reconstruction performed. We prefer either a tibialis anterior allograft or an Achilles allograft with a calcaneal bone block, which we divide into a two-tailed graft with two bone blocks. Ultimately, the choice of graft is dependent on the availability of quality allografts or autografts, the number of grafts needed, the type of reconstruction being performed, the cost of allograft, and both surgeon and patient preferences. The degree of instability of the posterolateral corner may be a factor as to whether a tibial and fibular based reconstruction is chosen or just a fibular. Where possible, minimal or no irradiation to the graft is preferred.

19.8 Dealing with Fractures

A significant number of patients with multi-ligament injured knees present with fractures involving the tibial plateau, distal femur, tibia, or fibula [19]. If open reduction and internal fixation of these fractures is necessary, it is advisable to address the fractures first and definitively reconstruct the disrupted ligaments at least six weeks post-fixation. The hardware often must be removed once the fractures are healed in order to allow for appropriate tunnel placement. Plain radiographs of the knee are essential for identification of fractures and to assess the overall alignment of the knee. They are also useful to monitor for residual subluxation following reduction of a dislocation. Avulsion fractures of the anterior tibial spine may indicate ACL injury. Avulsions from the posterior aspect of the proximal tibia may reflect PCL injuries. Avulsions off the fibular head or lateral epicondyle can be the result of LCL injury. These are important to recognize in the acute setting, as the surgeon may consider primary repair. A Segond fracture, resulting from avulsion of the anterolateral capsule, or ‘anterolateral ligament’ (ALL), off the tibia may also be apparent. In the case of chronic or failed ACL reconstructions associated with Segond fracture, some surgeons have advocated performing ALL reconstruction, or lateral extra-articular tenodesis using a strip of the tensor-fascia. Early results appear promising, though concerns about over-constraint remain [30].

19.9 Dealing with Varus Alignment

Long-leg standing radiographs should be obtained to assess bony varus malalignment, which may affect surgical management (Fig. 19.1). This is especially true for patients presenting with chronic PLC injuries or those with failed reconstructions or persistent instability. Potential causes of varus alignment include congenital deformity and medial tibial plateau fracture that was unrecognized or insufficiently elevated and fixed. Varus of more than 3° along the mechanical axis increases the stress on lateral-sided grafts and should be addressed prior to considering ligamentous reconstruction. Unaddressed bony varus alignment through the knee has been shown to result in higher rates of PLC graft failure following surgery [18]. We recommend treating varus malalignment of greater than 3° with a medial opening wedge high tibial osteotomy with or without bone grafting and allowing it to heal prior to ligamentous reconstruction (Fig. 19.2). Some low-demand patients may be satisfied with knee stability and function following osteotomy, and therefore may not require ligament reconstruction.

19.10 Non-anatomic Posterolateral Corner Reconstruction Techniques

A wide variety of reconstructions have been described for the lateral side of the knee. These can be broadly divided into anatomic and non-anatomic procedures based on how accurately they recreate the normal anatomy of the PLC. Dr. Noyes described anatomical reconstructions as those where “a graft was placed in anatomical ligament attachment sites with secure internal fixation” [18]. In contrast to anatomic reconstructions, procedures such as capsular advancement, suture repair with or without suture anchors, extra-articular IT band augmentation, and biceps tendon rerouting are all considered non-anatomic. Historically these have resulted in unacceptably high failure rates [5].

19.11 Anatomic Posterolateral Corner Reconstruction Techniques

Anatomic reconstructions recreate the fibular collateral ligament (FCL) also known as the lateral collateral ligament (LCL), the popliteus muscle (PL), and the popliteo-fibular ligament (PFL). Various combinations have been described. Fibular sling techniques attempt recreate the FCL and the PFL. These involve a single graft that runs through a fibular tunnel and attaches to the femur. This is performed with either one or two femoral attachment sites. If using a single femoral attachment site, an isometric point is chosen, and a screw and washer construct may be used. Alternatively, two independent femoral tunnels may be drilled in order to affix one end of the graft to the anatomic femoral attachment of the LCL, and the other at the popliteus insertion site, an average of 18.5 mm apart [31]. Adding to the complexity of the reconstruction, another graft may be placed through the fibular tunnel with one strand recreating the popliteus tendon, and one strand overlying the anterior tibio-fibular joint. Finally, Dr. LaPrade’s technique involves drilling a tibial tunnel as well as a fibular tunnel. One graft passes through the tibial tunnel and affixes to the femur to recreate the popliteus tendon, and the other graft passes through both tunnels, recreating the FCL and PFL. Interference screws are utilized for fixation [32].

Fig. 19.1 Three-foot standing X-ray of a failed ACL reconstruction from varus malalignment

Fig. 19.2 Opening wedge high tibial osteotomy

19.12 Acute Reconstruction of ACL, PCL and PLC

19.12.1 Introduction

If an external fixator was initially applied, it is removed one week prior to definitive surgery. Irrigation and debridement of the pin sites is performed. This usually takes place two weeks post-injury, at which time the knee has stiffened enough to remain reduced in an extension splint. The pin sites are dressed and left open to heal, reducing the risk of postoperative infection. Our preference is to avoid external fixation if possible due to potential pin site complications.

19.12.2 Positioning, EUA, and Preparation

Documentation of the status of the peroneal nerve is essential prior to starting the case, as well as examination of gait to check for lateral thrust. Preoperative antibiotics are given 30 min prior to tourniquet inflation [33]. If the patient had a vascular reconstruction, we do not use a tourniquet, as there is an increased risk of occluding the bypass graft. No preoperative nerve block is used to minimize the risk of postoperative quadriceps weakness. We prefer to reconstruct the PCL first, followed by the ACL, and finally the lateral structures. Our preference is to drill both the PCL and ACL tunnels prior to passing any graft material in order to avoid inadvertently damaging the graft material. Although many surgeons reconstruct isolated cruciate ligament injuries with a double bundle technique, we prefer single bundle cruciate reconstruction in this setting. Reason for this is to reduce the risk of complications with multiple tunnels. Converging or overlapping tunnels may result in iatrogenic fracture, and this has been reported in the literature [34].

19.12.3 Positioning and Exam Under Anesthesia (EUA)

Once in the operating room, general anesthesia is induced, and the patient is placed supine. A careful examination under anesthesia is performed. This provides clinical correlation to the MRI findings and helps plan the reconstruction. Exam under anesthesia should test both knees to check for side-to-side differences in varus, external rotation, and recurvatum laxity. Specific tests to document include Lachman, anterior drawer, and pivot shift test for ACL. Reverse pivot shift, and posterior drawer test for PCL laxity. For the posterolateral corner, testing varus stress at 0° and 30° should be performed. In addition, determining rotational stability by using the “dial test” at 30° and 90° of knee flexion also helps to gauge amount of pre-operative laxity. The external rotation recurvatum test as described by Dr. LaPrade may also be of use to describe in the setting of combined ACL and PCL injuries [35].

19.12.4 Arthroscopy Portals

We prefer to break the bed and free drape the limb with a stockinette, cling wrap, and iodine-impregnated incision drape just proximal to the stockinette to prevent fluid egress from underneath the stockinette. No stress positioner is used to allow easier access to both sides of the knee. The knee surface anatomy is marked, including the patella, patellar tendon, joint lines, Gerdy’s tubercle, and fibular head (Fig. 19.3). Three portals are created using an 11-blade scalpel, staying above the meniscus and keeping the blade up. A low anterolateral arthroscopy portal and a high antero-medial arthroscopy portal are created to perform basic arthroscopy visualization. Outflow is created by utilizing a supero-medial sub-vastus outflow cannula placed under direct visualization, 1 cm proximal to the proximal pole of the patella. This is connected to gravity outflow suction tubing. The ACL and PCL remnants are debrided using a 5.5 mm shaver. Meniscal tears are addressed with either debridement or repair if indicated.

19.13 Acute PCL Technique

19.13.1 Arthroscopy and Portal Placement

We perform a single bundle, arthroscopically-assisted, tibial tunnel PCL reconstruction with tibialis posterior allograft. A postero-medial (PM) arthroscopy portal is made to visualize the posterior proximal tibia for drilling the tibial tunnel and to facilitate posterior capsular release. An 18-gauge spinal needle is placed in the soft spot just superior to the hamstrings tendons with the knee flexed to 90°. It is visualized arthroscopically, and once appropriate position is confirmed, an 11-blade scalpel is used to make a skin incision and an 8-mm arthroscopic cannula is inserted. This allows fluid egress from the knee and potentially reduces the risk of iatrogenic compartment syndrome. The outflow cannula can be turned off at this point to aid in dilating to posterior capsule. A shaver is inserted into the PM portal, and 2–3 cm of posterior capsule is debrided from the proximal tibia using a shaver and radio-frequency device pointed anteriorly, away from the neurovascular bundle. This takes place directly between the mammillary bodies of the knee, allowing the neurovascular bundle to retract posteriorly. Other landmarks include the midline septum medially, and the posterior horn of the lateral meniscus laterally. Distal dissection stops at the upper border of the popliteus muscle belly. If additional visualization is required, a 70° arthroscope may be introduced. Release of the capsule is often necessary to reduce the knee if it is chronically subluxated, and this also allows for direct visualization of the tibial tunnel drilling. In the setting of a prior vascular reconstruction, a postero-lateral (PL) portal can be used to avoid a medial bypass graft. The PL portal is made with the knee in 90° of flexion, to allow the peroneal nerve to drape posteriorly. The portal is created by introducing the spinal needle directly posterior to the lateral femoral condyle, and immediately anterior to the biceps femoris tendon.

Fig. 19.3 Location of right knee arthroscopy portals, with arthroscope placed in the PM portal. This aids in debridement of the tibial remnant of the PCL

19.13.2 Tibial Tunnel Drilling

The PCL tibial drill guide (Arthrex Naples, Florida) is inserted through the AL portal and placed in the footprint of the PCL over the most distal and lateral fibers. This is approximately 1–1.5 cm below the articular surface and in the midline of the tibia. The most common error is for the tunnel to exit too medially and too proximally putting excessive stress on the graft. The position of the guide is confirmed with the arthroscope in the PM portal. Anteriorly, the guide is positioned slightly lateral to the tibial tubercle to decrease the “killer turn” of the graft. The guide pin or FlipCutter (Arthrex) is inserted through the guide and advanced posteriorly until the tip is visualized through the posterior cortex. A curved curette can be placed through the AM portal to protect the neurovascular structures during pin and drill perforation through the posterior tibia. We place the pin and drill under power, but we perforate the posterior cortex by hand. Finally, intra-operative fluoroscopy may be used to confirm pin placement prior to drilling. This should localize the pin to the superior aspect of the ‘champagne-glass drop-off’ of the posterior tibia on a lateral radiograph. If repositioning of the pin is required, parallel guide pins may be useful. The FlipCutter (Arthrex) of appropriate diameter is passed and flipped, reaming a retrograde tunnel to 20–35 mm, depending on graft length. A FiberStick (Arthrex) is passed antegrade through the tibial tunnel and grasped inside the knee to establish a shuttle suture.

19.13.3 Femoral Tunnel Drilling

Early literature vaguely described femoral tunnel placement as “the anatomic location of the PCL” [36, 37]. However, more recent work has suggested the tunnel be drilled in the distal and anterior portion of the femoral footprint to reconstruct the stronger anterolateral bundle [38]. For the femoral tunnel, we use an outside-in technique to reduce the “killer turn” of the graft on the femoral side. The guide is placed on the medial femoral condyle 6–8 mm from the articular surface at the junction of the medial wall and the roof of the notch. The 2.4 mm guide pin (Arthrex) is inserted through the medial condyle midway between the medial epicondyle and the articular surface. Once appropriate pin position is confirmed, the femoral tunnel is drilled to a length of 25 mm and appropriate diameter. This is followed by a similarly sized dilator passed to the same depth. A passing suture is then placed within the tunnel and the guide pin removed. Care must be taken to drill anatomically placed tunnels, which may be difficult in a posteriorly subluxed knee.

19.13.4 Graft Passage

The tibial side of the PCL graft is passed first and pulled into the tibial socket. Next, the TightRope ABS sutures, attached to the tibial side of the graft, are held tightly while the femoral sutures are pulled into the femoral socket. The TightRope RT button can be visualized through the arthroscope as it passes beyond the femoral cortex. Marking the graft at the measured tunnel length can be used as a double-check before flipping the button. The TightRope RT is then tensioned to dock the femoral end of the graft.

19.14 Acute ACL Reconstruction Technique

19.14.1 Femoral Tunnel Drilling

We perform an arthroscopically-assisted single-bundle ACL reconstruction using a tibialis anterior allograft. A lateral condyle notchplasty is not routinely performed unless there will be obvious impingement on the ACL. A low AM accessory portal is made to drill the femoral tunnel. The guide pin is inserted through this portal and placed at the ten o'clock position on the femoral footprint of the ACL. Using the bull's-eye anatomic reconstruction system (ConMed Linvatec, Largo, FL) with the knee in 120° of flexion, with the foot in a sterile basin, the pin is advanced through the lateral condyle up to the lateral cortex. The depth of the tunnel is measured off the guide pin prior to perforating the lateral cortex and passing the pin through the soft tissues and out the lateral side of the thigh. We use GraftMax adjustable loop button (ConMed Linvatec, Largo, FL) fixation of the ACL graft on the femoral side, therefore 15–20 mm of lateral bone is left intact when drilling the 8–9-mm femoral tunnel to a length of 20 mm. When passing the reamer through the knee, care must be taken to avoid damage to articular cartilage on the medial femoral condyle, by pulling the guide pin anteriorly and avoidance of spinning the drill when passing the condyle.

19.14.2 Tibial Tunnel Drilling

The Howell tibial guide (Arthrotek, Warsaw, IN) is set at 65° and placed on the antero-medial subcutaneous border of the proximal tibia. This is usually 2 cm medial to the tibial tubercle. A longitudinal incision is made and carried down to bone. The guide is passed through the AM portal and placed on the tibial plateau at the level of the posterior aspect of the anterior horn of the lateral meniscus and at the medial tibial spine. This should be approximately 7 mm anterior to the PCL. The guide pin is then inserted through the tibia and is visualized from the AL portal as it enters the knee. Fluoroscopy can be used to assess pin position prior to tibial tunnel drilling. The appropriate size tibial tunnel is then drilled with a curved curette placed on top of the guide pin to protect the femoral articular cartilage while the drill tip enters the knee. Residual debris is cleared using a shaver to ensure smooth graft passage.

19.14.3 Graft Passage and Fixation

The edges of all tunnels are smoothed with a rasp prior to passing graft material. If using an Achilles allograft, the calcaneal bone plug is trimmed to accommodate the femoral PCL tunnel. The Achilles allograft is pulled through the femoral tunnel and then through the tibial tunnel, leaving the calcaneal bone plug in the femoral tunnel. The femoral side is affixed with a metal interference screw. If using button fixation, the loop and button are affixed to the tripled tibialis anterior allograft, and they are pulled through the tibial tunnel and then through the femoral tunnel. The button is flipped to provide femoral fixation. The tibial fixation for the ACL and PCL grafts is not undertaken until completion of the lateral reconstruction.

19.15 Acute Posterolateral Corner Reconstruction Technique

19.15.1 Incision and Dissection

With the knee in 90° of flexion, a curved skin incision is made. The incision begins midway between Gerdy's tubercle and the fibular head, and extends proximally over the lateral epicondyle paralleling the posterior border of the IT band (Fig. 19.4). Subcutaneous dissection is taken through to the deep fascia which is carefully incised with Metzenbaum scissors. The peroneal nerve can be palpated posterior to the biceps femoris tendon as it courses distally toward the fibular neck. It is best isolated proximally, gently retracted with a latex tube drain, and followed distally. Identification and protection of the peroneal nerve are mandatory as iatrogenic nerve injury has been reported and can be devastating to patient outcomes. If a peroneal nerve deficit existed from the time of injury, exploration and release of the nerve should be undertaken. Most injuries are axonotmesis resulting from a traction injury. However, if the nerve is transected, the ends should be tagged with suture for repair or nerve grafting by a plastic surgeon [39].

The plane anterior to the lateral head of gastrocnemius and the posterior tibia is developed with blunt dissection. Straying posterior to the gastrocnemius may put the neurovascular structures behind the knee at risk. The fibular attachment of the LCL is identified and is followed proximally and posteriorly to its attachment on the femur. The femoral insertion of popliteus is identified anterior to the LCL, and the posterolateral capsule is visualized. Although the PFL plays an important role in knee biomechanics and is well described in the anatomic literature, it is rarely visualized following a lateral-sided injury.

19.15.2 Fibular Tunnel Drilling

In the acute situation, we reconstruct the lateral side of the knee with a fibular sling technique and independent femoral tunnels. A 7-mm diameter tunnel is drilled through the head of fibula in an anterolateral to postero-medial direction, aiming slightly proximal (Fig. 19.5). In a chronic situation, a LaPrade-type reconstruction may be used.

Fig. 19.4 Lateral skin incision on a right knee. Proximally the incision begins at the lateral epicondyle and carries distally to between the fibular head (marked) and Gerdy's tubercle

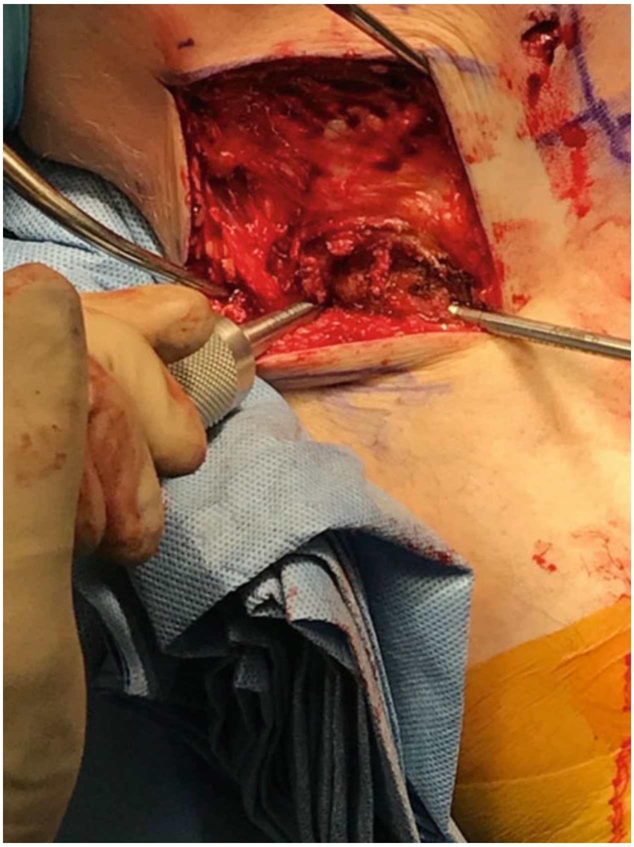

Fig. 19.5 Location and direction of fibular tunnel. Cobb instrument inserted proximally to prevent drill penetration

19.15.3 Femoral Tunnel Drilling

The femoral insertions points for the FCL and popliteus tendons are located. A guide wire is inserted at each insertion point, followed by reaming a 7 mm diameter socket to a depth of 25–30 mm. These are placed 18.5 mm away from each other. The graft is placed through the fibular tunnel, and passes proximally underneath the IT band (Fig. 19.6).

19.15.4 ACL and PCL Tensioning and Fixation

The grafts are tensioned after all ligaments have been reconstructed. The ACL is tensioned first with the knee in full extension, and a bio-absorbable interference screw is used for tibial fixation. The PCL is tensioned with the knee in 90° of flexion while manually translating the tibia anteriorly to recreate a normal anterior step-off of the medial plateau in relation to the medial femoral condyle. Tibial fixation of the PCL graft is achieved with an ABS button (Arthrex) attached to the TightRope.

19.15.5 PLC Tensioning and Fixation

Once the ACL and PCL are tensioned, attention can be paid to the lateral reconstruction. If using the fibular sling technique, the lateral-sided graft is tensioned with the knee in 60° of flexion with slight internal rotation of the tibia. Care should be taken not to over-constrain the graft with excessive internal rotation. The graft is affixed to the fibula with a 7-mm bioabsorbable interference screw. Femoral fixation is achieved with two 8 mm × 25 mm Genesys Matryx (ConMed) interference screws, one in each socket after the graft is crossed over to recreate the LCL and PL. If using Dr. LaPrade's technique, the LCL component of the graft is tensioned with the knee in 30° of flexion, neutral rotation, and a slight valgus force.

19.15.6 Augmented Repair and Conclusion

Once all grafts are tensioned and affixed appropriately, range of motion of the knee is tested to ensure the knee is not over-constrained. The posterolateral capsule is repaired and advanced if possible, which is particularly important in acute

Fig. 19.6 Allograft passing under IT band, and affixed to the femur in two independent sockets

reconstructions. All acutely damaged structures are repaired with sutures. This may include the popliteus tendon, the PFL, the LCL, the biceps femoris, and the IT band. Any redundant lateral-sided graft material is sutured to itself to augment the reconstruction prior to closure of the deep fascia and the skin. We place the patient into a hinged knee brace postoperatively, unlocked at 0°–90°. The patient is instructed to be non-weightbearing for the first 6 weeks.

19.16 Chronic Reconstruction of ACL, PCL and PLC

19.16.1 Introduction

We encourage patients to regain a full range of motion of the knee and improve quadriceps and hamstrings strength prior to undergoing delayed ligament reconstruction. Full-length standing films of the legs are used to assess for bony varus alignment from either a congenital etiology or a depressed medial tibial plateau fracture. If more than 3° of bony varus is present, we perform a medial opening wedge high tibial osteotomy prior to considering ligament reconstruction, as stated previously. In addition to bony varus being a known cause of failure of lateral reconstruction, some patients describe resolution of their instability following osteotomy and do not ultimately require ligament reconstruction [18]. Osteotomy alone may be particularly effective in low-demand patients.

19.16.2 Chronic PLC Reconstruction Technique

For chronic symptomatic lateral-sided injuries requiring reconstruction, we use the technique described by LaPrade with an Achilles allograft [40, 41]. This is often described as the most anatomically accurate reconstruction. The fibular tunnel is drilled as previously described. An additional tibial tunnel is drilled. Anteriorly, the tunnel begins at the flat spot slightly lateral to the tibial tubercle. The tibial tunnel exists posteriorly at the popliteus musculotendinous junction, approximately 1 cm medial and 1 cm proximal to the exit of the fibular tunnel [31]. The Achilles allograft is split longitudinally, and the bone plugs trimmed to accommodate the femoral tunnels. Passing sutures are placed through the bone plugs and they are pulled into the femoral tunnels where they are affixed with 7 mm interference screws. The graft in the popliteus sulcus is passed posteriorly and distally through the popliteus hiatus and to the posterior tibia to recreate the static function of the popliteus tendon. The graft in the LCL attachment site is passed distally and deep to the IT band, into the anterior aspect of the fibular head to reconstruct the LCL. It is then passed anterior to posterior through the fibular tunnel and wrapped medially toward the tibia to reconstruct the PFL. Both grafts are then passed together from posterior to anterior through the tibial tunnel.

19.16.3 Graft Tensioning

The grafts are tensioned after all ligaments have been reconstructed, in the same manner as for an acute reconstruction. The LCL component of the graft is tensioned with the knee in 30° of flexion, neutral rotation, and a slight valgus force. The graft is affixed through the fibula with a 7-mm bioabsorbable interference screw. The popliteus and PFLs are then tensioned with the knee in 60° of flexion and neutral rotation while applying an anterior translation force on the tibia. Tibial fixation of the two grafts is achieved with a 9-mm bioabsorbable interference screw.

19.16.4 Repair Augmentation

Once all grafts are tensioned and affixed appropriately, range of motion of the knee is tested to ensure the knee is not over-constrained. The posterolateral capsule is repaired and advanced if possible, which is particularly important in acute reconstructions. All acutely damaged structures are repaired with sutures. This may include the popliteus tendon, the PFL, the LCL, the biceps femoris, and the IT band. Any redundant lateral-sided graft material is sutured to itself to augment the reconstruction prior to closure of the deep fascia and the skin.

19.17 Summary and Conclusions

Multi-ligament knee injuries involving the lateral side are a particularly challenging problem to manage. They are often associated with knee dislocations, and limb-threatening conditions must be addressed urgently upon initial presentation. External fixators are only used in select cases if indicated, and we prefer to remove them 1 week prior to definitive surgery. Early reconstruction at 3 weeks post-injury tends to yield the best results. If early surgery is not possible, bony varus malalignment should be addressed prior to delayed reconstruction. Many anatomical reconstruction techniques have been described, and none have been shown to be superior. A conservative rehabilitation protocol is instituted postoperatively, and most patients regain a satisfactory level of function, but many are unable to return to high level sports.

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Surgical Treatment of Combined PCL-ACL Medial and Lateral Side Injuries (Global Laxity): Acute and Chronic

20

Gregory C. Fanelli

20.1 Introduction

The multiple ligament injured knee is a severe injury that may also involve neurovascular injuries and fractures [1]. Surgical treatment offers good functional results documented in the literature by physical examination, arthrometer testing, stress radiography, and knee ligament rating scales. Mechanical tensioning devices are helpful with cruciate ligament-tensioning. Some low-grade medial collateral ligament complex injuries may be amenable to brace treatment, while high-grade medial side injuries require repair-reconstruction. Lateral posterolateral injuries are most successfully treated with surgical repair-reconstruction. Surgical timing in acute multiple ligament injured knee cases depends upon the ligaments injured, injured extremity vascular status, skin condition of the extremity, degree of instability, and the patients overall health. Allograft tissue is preferred for these complex surgical procedures. Delayed reconstruction of 2–3 weeks may decrease the incidence of arthrofibrosis, and it is important to address all components of the instability. Currently, there is no conclusive evidence that double-bundle PCL reconstruction provides superior results to single-bundle PCL reconstruction in the multiple ligament injured knee.

The purpose of this chapter is to discuss my surgical technique for combined posterior and anterior cruciate ligament, medial, and lateral side reconstructions in acute and chronic multiple ligament injured knees with global laxity [1–6]. This chapter will focus on recognizing and defining the instability pattern, the use of external fixation, surgical timing, graft selection and preparation, the author's preferred surgical technique, mechanical graft tensioning, perioperative antibiotics, specialized operating teams, postoperative rehabilitation, and our results of treatment in these complex surgical cases.

20.2 Surgical Timing

Surgical timing in the acute bi-cruciate multiple ligament injured knee is dependent upon the vascular status of the involved extremity, the collateral ligament injury severity, the degree of instability, and the post-reduction stability. Delayed or staged reconstruction of 2 to 3 weeks post injury has demonstrated a lower incidence of arthrofibrosis in our experience [7, 8].

Surgical timing in acute ACL-PCL-lateral side injuries is dependent upon the lateral side classification [9, 10]. Arthroscopic combined ACL-PCL reconstruction with lateral side repair and reconstruction with allograft tissue is performed within 2 to 3 weeks post injury in knees with types A and B lateral posterolateral instability. Type C lateral posterolateral instability combined with ACL-PCL tears is often treated with staged reconstruction. The lateral posterolateral repair and reconstruction with allograft tissue is performed within the first week after injury, followed by arthroscopic combined ACL-PCL reconstruction 3 to 6 weeks later.

Surgical timing in acute ACL-PCL-medial side injuries is also dependent on the medial side classification. Some medial side injuries will heal with 4 to 6 weeks of brace treatment, provided that the tibiofemoral joint is reduced in all planes. Other medial side injuries require surgical intervention. Types A and B medial side injuries are repaired-reconstructed as a single-stage procedure with combined arthroscopic ACL-PCL reconstruction. Type C medial side injuries combined with ACL-PCL tears are often treated with staged reconstruction. The medial posteromedial repair-reconstruction augmented with allograft tissue is performed within the first two weeks after injury, followed by arthroscopic combined ACL-PCL reconstruction 3 to 6 weeks later [7, 8, 10–13].

Surgical timing may be affected by modifiers beyond the surgeon's control and may cause the surgical treatment to be performed either earlier or later than desired. The surgical

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timing modifiers include the injured extremity vascular status, open wounds, reduction stability, skin conditions, multiple system injuries, other orthopedic injuries, and meniscus and articular surface injuries [10, 11]. When delayed or staged reconstruction techniques are used, it is very important to document maintained reduction of the tibiofemoral and patellofemoral articulations with radiographs.

Chronic bi-cruciate multiple ligament knee injuries often present to the orthopedic surgeon with functional instability, and possibly, some degree of post traumatic arthrosis. Considerations for treatment require the determination of all structural injuries. These structural injuries may include various ligament injuries, meniscus injuries, bony malalignment, articular surface injuries, and gait abnormalities. Surgical procedures under consideration may include proximal tibial or distal femoral osteotomy, ligament reconstruction, meniscus transplant, and osteochondral grafting.

20.3 Graft Selection

My preferred graft for the posterior cruciate ligament reconstruction is the Achilles tendon allograft for single-bundle PCL reconstructions, and Achilles tendon and tibialis anterior allografts for double-bundle PCL reconstructions. We prefer Achilles tendon allograft or other allograft for the ACL reconstruction. The preferred graft material for the lateral posterolateral reconstruction is allograft tissue combined with a primary repair, and posterolateral capsular shift procedure. My preferred method for medial side injuries is a primary repair of all injured structures combined with posteromedial capsular shift and allograft tissue supplementation-augmentation as needed.

20.4 Combined PCL-ACL Reconstruction Surgical Technique

The principles of reconstruction in the multiple ligament injured knee are to identify and treat all pathology, accurate tunnel placement, anatomic graft insertion sites, utilize strong graft material, mechanical graft tensioning, secure graft fixation, and a deliberate postoperative rehabilitation program [1, 2, 6, 14–20].

The patient is placed on the operating room table in the supine position, and after satisfactory induction of anesthesia, the operative and nonoperative lower extremities are carefully examined [6]. A tourniquet is applied to the upper thigh of the operative extremity, and that extremity is prepped and draped in a sterile fashion. The well leg is supported by the fully extended operating room table which also supports the surgical leg during medial and lateral side surgery. A lateral post is used to control the surgical extremity. An arthroscopic leg holder is not used (Fig. 20.1). Preoperative and postoperative antibiotics are given, and antibiotics are routinely used to help prevent infection in these time consuming, difficult, and complex cases. Allograft tissue is prepared prior to bringing the patient into the operating room. Autograft tissue is harvested prior to beginning the arthroscopic portion of the procedure.

The arthroscopic instruments are inserted with the inflow through the superolateral patellar portal. Instrumentation and visualization are positioned through inferomedial and inferolateral patellar portals, and can be interchanged as necessary. Additional portals are established as necessary. Exploration of the joint consists of evaluation of the patellofemoral joint, the medial and lateral compartments, medial and lateral menisci, and the intercondylar notch. The residual stumps of both the anterior and posterior cruciate ligaments are debrided; however, the posterior and anterior cruciate ligament anatomic insertion sites are preserved to serve as tunnel reference points. The notchplasty for the anterior cruciate ligament portion of the procedure is performed at this time.

An extracapsular extra-articular posteromedial safety incision is made by creating an incision approximately 1.5–2 cm long starting at the posteromedial border of the tibia approximately one inch below the level of the joint line and extending distally (Fig. 20.2). Dissection is carried down to the crural fascia, which is incised longitudinally. An interval is developed between the medial head of the gastrocnemius muscle and the nerves and vessels posterior to the surgeon's finger, and the capsule of the knee joint anterior to the surgeon's finger (Fig. 20.3). The posteromedial safety incision enables the surgeon to protect the neurovascular structures, confirm the accuracy of the PCL tibial tunnel, and to facilitate the flow of the surgical procedure.

The curved over-the-top PCL instruments (Biomet Sports Medicine, Warsaw, Indiana) are used to sequentially lyse adhesions in the posterior aspect of the knee, and elevate the capsule from the posterior tibial ridge. This will allow accurate placement of the PCL/ACL drill guide, and correct placement of the tibial tunnel (Fig. 20.4).

The arm of the PCL/ACL guide (Biomet Sports Medicine, Warsaw, Indiana) is inserted through the inferior medial patellar portal. The tip of the guide is positioned at the inferior lateral aspect of the PCL anatomic insertion site. This is below the tibial ridge posterior and in the lateral aspect of the PCL anatomic insertion site. The bullet portion of the guide contacts the anteromedial surface of the proximal tibia at a point midway between the posteromedial border of the tibia, and the tibial crest anterior at or just below the level of the tibial tubercle (Fig. 20.5). This will provide an angle of graft orientation such that the graft will turn two very smooth 45° angles on the posterior aspect of

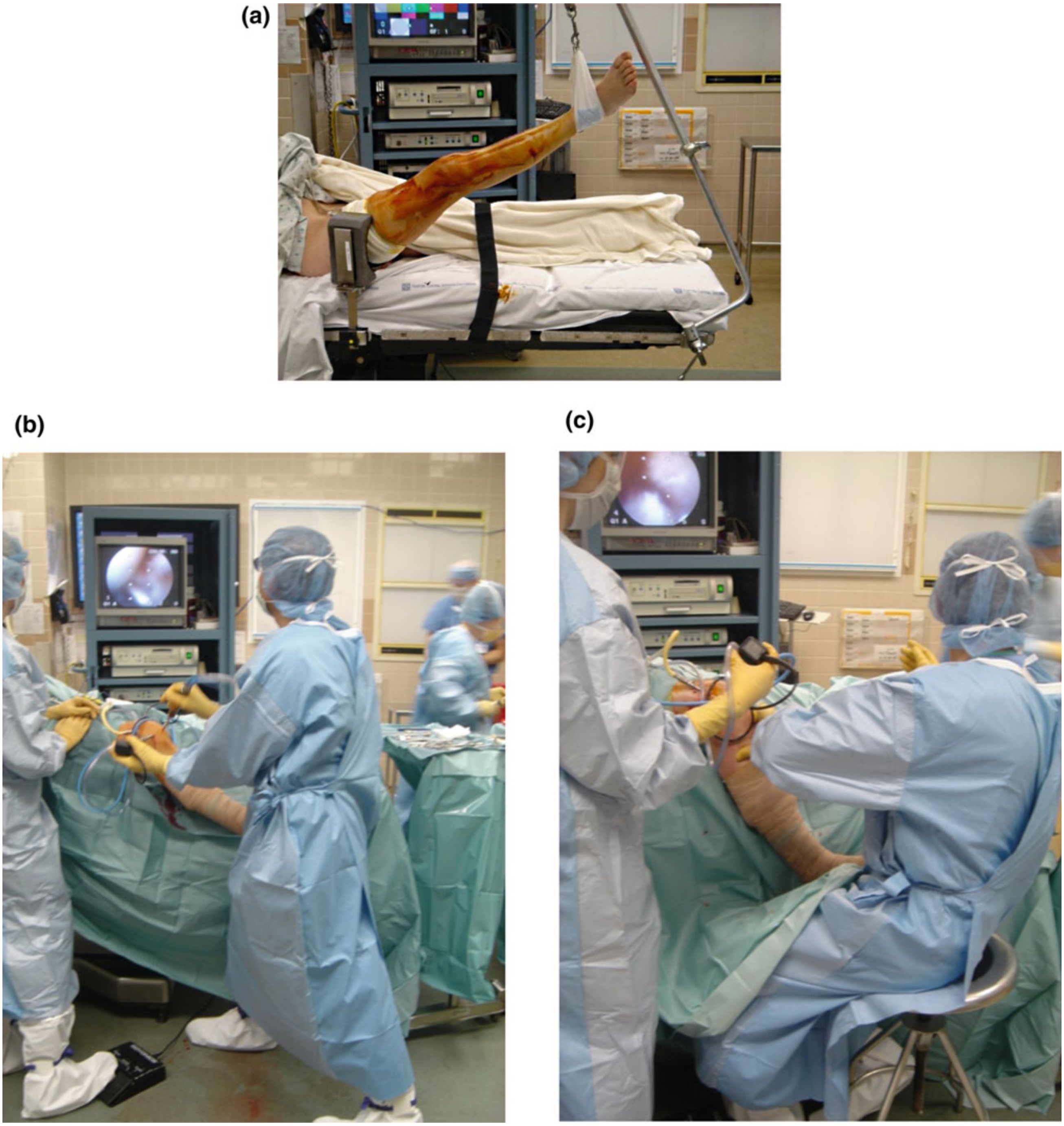


Fig. 20.1 Patient positioning. **a** The patient is positioned on the fully extended operating room table with a lateral post used for control of the surgical extremity. The surgeon stands during the basic arthroscopic portion of the procedure (**b**), and the surgeon is seated during the PCL, ACL, and lateral side reconstruction (**c**)

the tibia (Fig. 20.6). The tip of the guide, in the posterior aspect of the tibia is confirmed with the surgeon's finger through the extra capsular extra-articular posteromedial safety incision. Intraoperative AP and lateral X-ray may also be used; however, I do not routinely use intraoperative X-ray. When the PCL/ACL guide is positioned in the desired area, a blunt spade-tipped guide wire is drilled from anterior to posterior. The surgeon's finger confirms the position of the guide wire through the posterior medial safety incision.

The appropriately sized standard cannulated reamer is used to create the tibial tunnel. The surgeon's finger through the extracapsular extra-articular posteromedial incision is monitoring the position of the guide wire. When the drill is

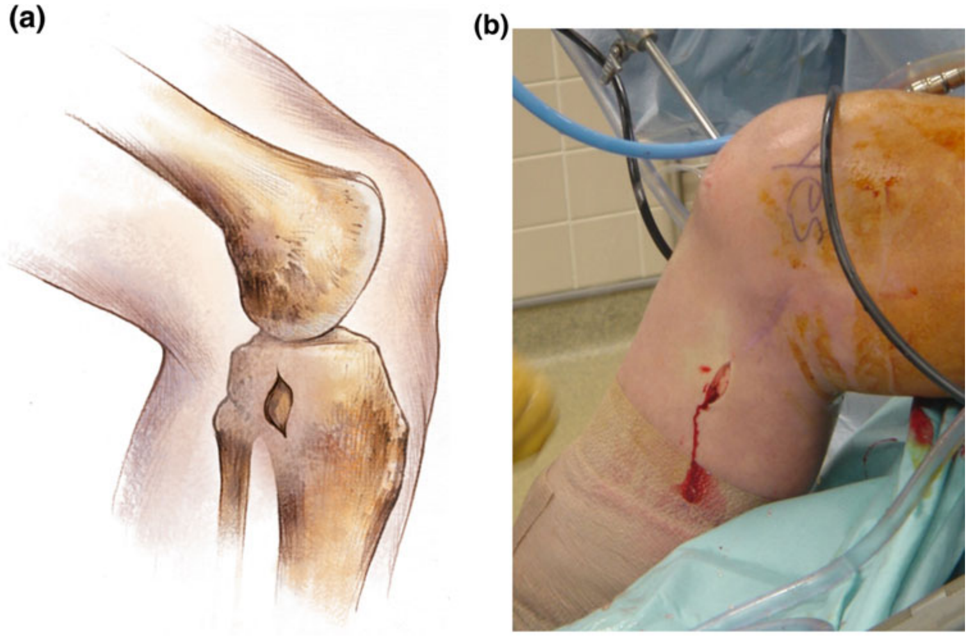


Fig. 20.2 **a** Posteromedial extra-articular extracapsular safety incision (from Fanelli GC [6]. Reprinted with permission from Zimmer Biomet). **b** Intraoperative photograph of the posteromedial safety incision

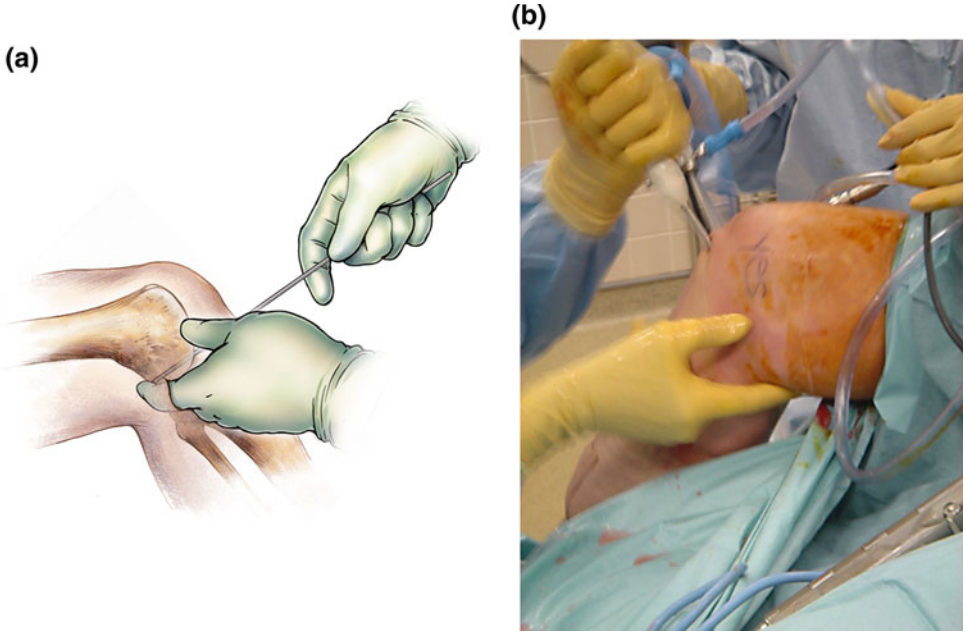


Fig. 20.3 **a** The surgeon is able to palpate the posterior aspect of the tibia through the extracapsular extra-articular posteromedial safety incision. This enables the surgeon to accurately position guide wires, create the tibial tunnel, and to protect the neurovascular structures (from Fanelli GC [6]. Reprinted with permission from Zimmer Biomet). **b** Intraoperative photograph of posterior instrumentation with the surgeon's finger in the posteromedial safety incision

engaged in bone, the guide wire is reversed, blunt end pointing posterior, for additional patient safety. The drill is advanced until it comes to the posterior cortex of the tibia. The chuck is disengaged from the drill, and completion of the tibial tunnel is performed by hand (Fig. 20.7).

The PCL single-bundle- or double-bundle femoral tunnels are made from inside out using the double-bundle aimers, or an endoscopic reamer can be used as an aiming device (Biomet Sports Medicine, Warsaw, Indiana). The appropriately sized double-bundle aimer or endoscopic reamer is inserted through a low anterior lateral patellar arthroscopic portal to create the posterior cruciate ligament anterior lateral-bundle femoral tunnel. The double-bundle aimer or endoscopic reamer is positioned directly on the footprint of the femoral anterior lateral-bundle posterior cruciate ligament insertion site (Fig. 20.8). The appropriately sized guidewire is drilled through the aimer or endoscopic reamer, through the bone, and out a small skin incision. Care is taken to prevent any compromise of the articular surface. The double-bundle aimer is removed, and the endoscopic reamer is used to drill the anterior lateral posterior cruciate ligament femoral tunnel from inside to outside (Fig. 20.9). When the

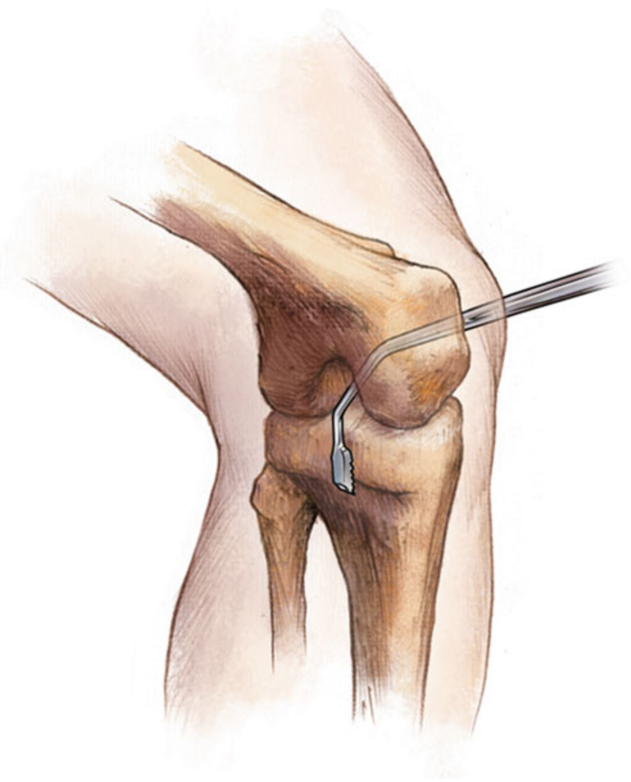


Fig. 20.4 Posterior capsular elevation (from Fanelli GC [6]. Reprinted with permission from Zimmer Biomet)

surgeon chooses to perform a double-bundle double-femoral tunnel PCL reconstruction, the same process is repeated for the posterior medial-bundle of the PCL (Fig. 20.10). Care must be taken to ensure that there will be an adequate bone bridge (approximately 5 mm) between the two femoral tunnels prior to drilling. This is accomplished using the calibrated probe, and direct arthroscopic visualization of the posterior cruciate ligament femoral anatomic insertion sites (Fig. 20.11).

My preferred surgical technique of posterior cruciate ligament femoral tunnel creation from inside to outside is for two reasons. There is a greater distance and margin of safety between the posterior cruciate ligament femoral tunnels and the medial femoral condyle articular surface using the inside-to-outside method (Fig. 20.12). Additionally, a more accurate placement of the posterior cruciate ligament femoral tunnels is possible, in my opinion, because I can place the double-bundle aimer or endoscopic reamer on the anatomic foot print of the anterior lateral or posterior medial posterior cruciate ligament insertion site under direct visualization (Fig. 20.13).

A Magellan suture retriever (Biomet Sports Medicine, Warsaw, Indiana) is introduced through the tibial tunnel into the joint, and retrieved through the femoral tunnel (Fig. 20.14). The traction sutures of the graft material are attached to the loop of the Magellan suture retriever, and the graft is pulled into position. The graft material is secured on the femoral side using a bioabsorbable interference screw for primary aperture opening fixation, and a polyethylene ligament fixation button for back-up fixation.

The cyclic dynamic method of graft tensioning using the Biomet graft-tensioning boot is used to tension the posterior and anterior cruciate ligament grafts [21, 22]. This tensioning method is discussed in Chap. 22 of this book. Tension is placed on the PCL graft distally using the Biomet graft-tensioning boot (Biomet Sports Medicine, Warsaw, Indiana) (Fig. 20.15).

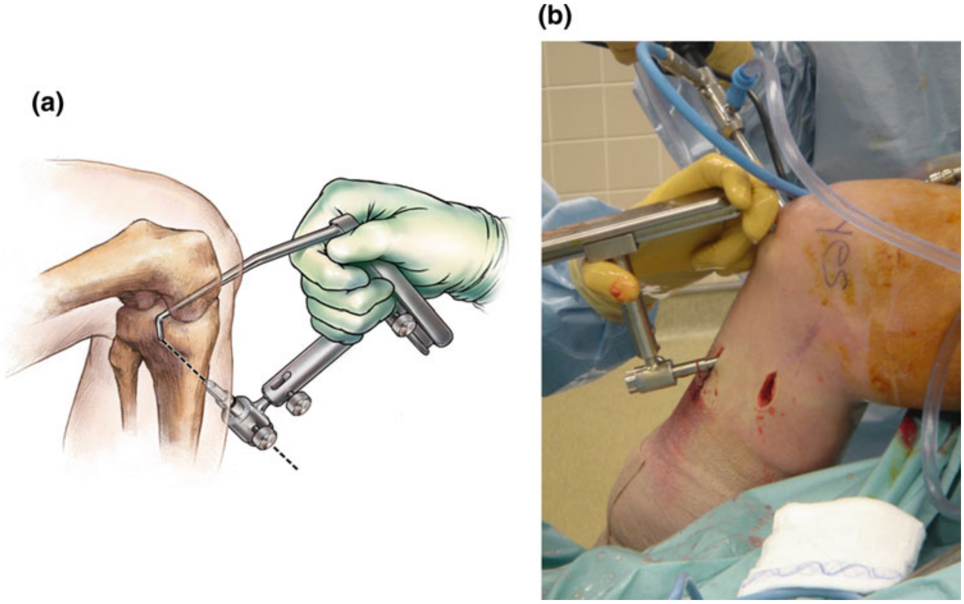


Fig. 20.5 **a** PCL-ACL drill guide positioned to place guide wire in preparation for creation of the Transtibial PCL tibial tunnel (from Fanelli GC [6]. Reprinted with permission from Zimmer Biomet). **b** Intraoperative photograph of the drill guide positioned to create the PCL tibial tunnel

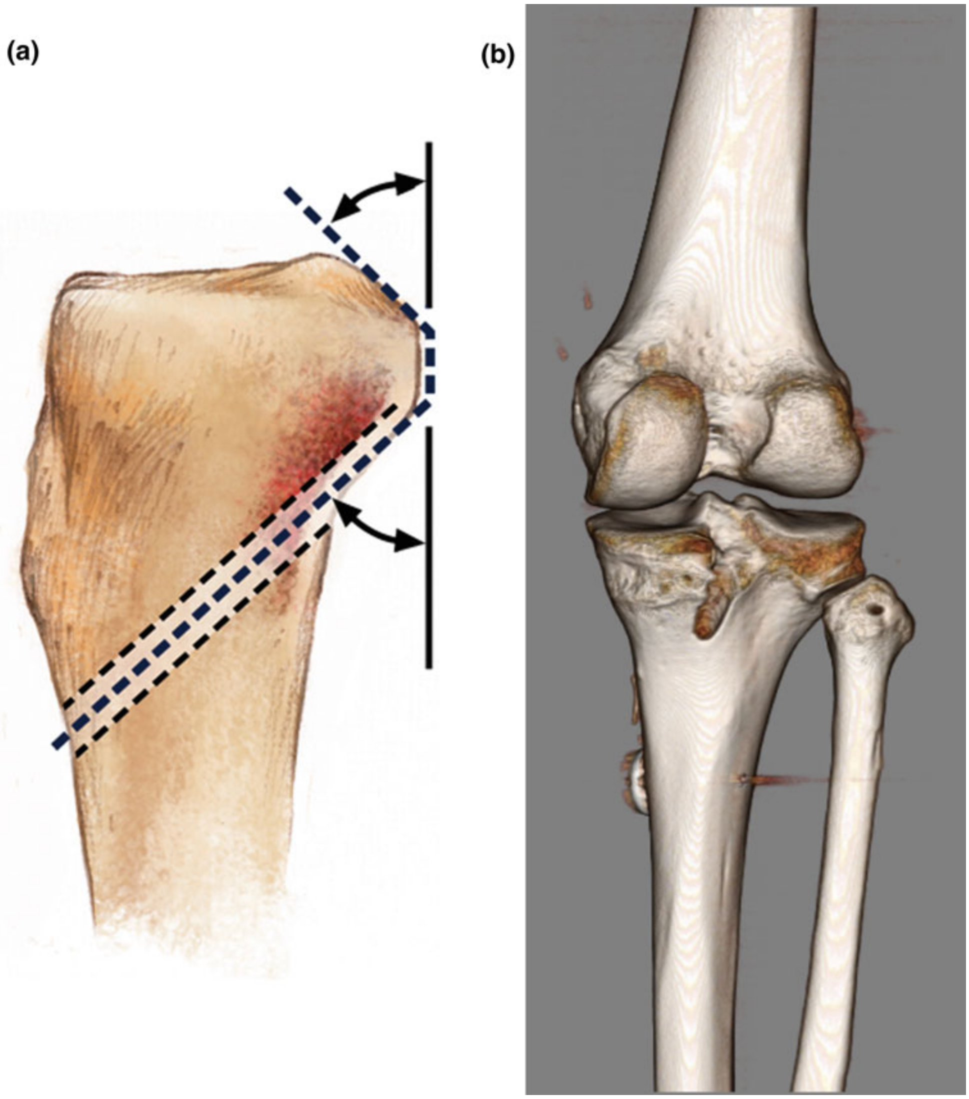


Fig. 20.6 **a** Drawing demonstrating the desired turning angles the PCL graft will make after the creation of the tibial tunnel (from Fanelli GC [6]. Reprinted with permission from Zimmer Biomet). **b** Three dimensional CT scan demonstrating the position of a well placed PCL tibial tunnel. Note the smooth turning angles the PCL graft will take

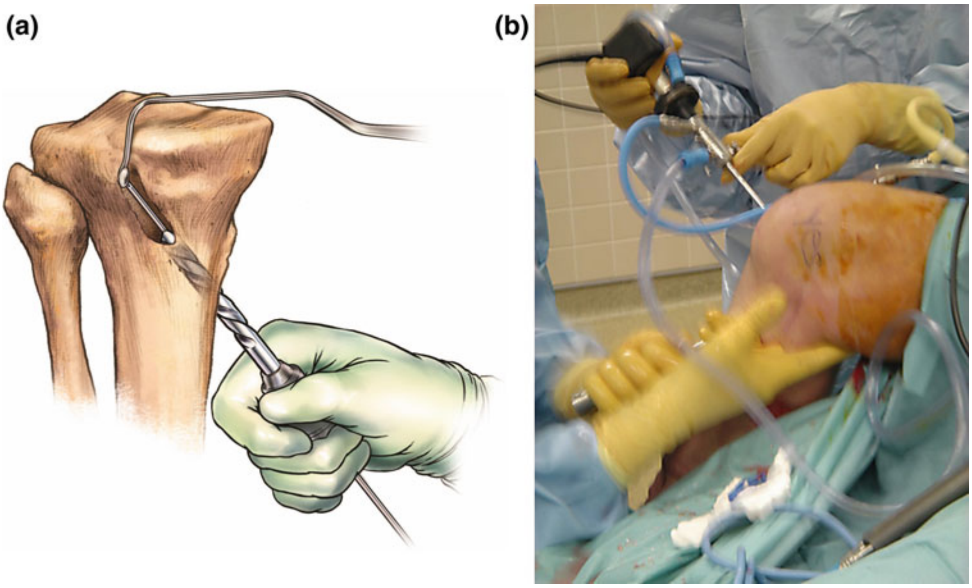


Fig. 20.7 **a** Final PCL tibial tunnel reaming by hand for an additional margin of safety (from Fanelli GC [6]. Reprinted with permission from Zimmer Biomet). **b** Intraoperative photograph of hand finishing of the PCL tibial tunnel

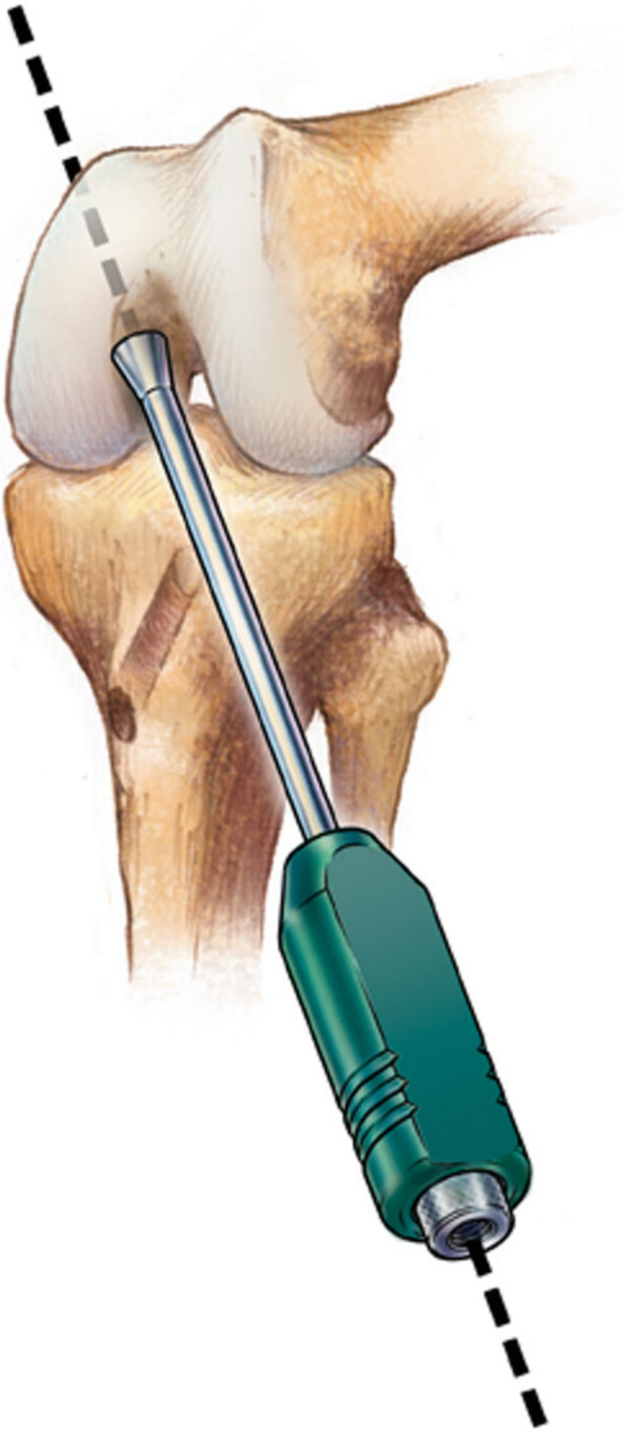


Fig. 20.8 Double-bundle aimer positioned to drill a guide wire for creation of the PCL anterolateral bundle tunnel (from Fanelli GC [6]. Reprinted with permission from Zimmer Biomet)

Tension is gradually applied with the knee in zero degrees of flexion (full extension) reducing the tibia on the femur. This restores the anatomic tibial step-off. The knee is cycled through a full range of motion multiple times to allow pre-tensioning and settling of the graft. The process is repeated until there is no further change in the torque setting on the graft tensioner. The knee is placed in 70°–90° of flexion, and fixation is achieved on the tibial side of the PCL graft with a bioabsorbable interference screw, and back-up fixation with a bicortical screw and spiked ligament washer or polyethylene ligament fixation button (Fig. 20.16).

With the knee in approximately 90° of flexion, the anterior cruciate ligament tibial tunnel is created using a drill guide. My preferred method of anterior cruciate ligament reconstruction is the transtibial femoral tunnel endoscopic surgical technique. The arm of the drill guide enters the knee joint through the inferior medial patellar portal (Fig. 20.17). The bullet of the drill guide contacts the anterior medial proximal tibia externally at a point midway between the posterior medial border of the tibia, and the anterior tibial crest just above the level of the tibial tubercle. A one centimeter bone bridge or greater exists between the PCL and ACL tibial tunnels. The guide wire is drilled through the guide and positioned so that after creating the anterior cruciate ligament tibial tunnel, the graft will approximate the tibial anatomic insertion site of the anterior cruciate ligament. A standard cannulated reamer is used to create the tibial tunnel.

With the knee in approximately ninety to one hundred degrees of flexion, an over-the-top femoral aimer is introduced through the tibial tunnel, and used to position a guide wire on the medial wall of the lateral femoral condyle to create a femoral tunnel approximating the anatomic insertion site of the anterior cruciate ligament (Fig. 20.18). The anterior cruciate ligament graft is positioned, and fixation achieved on the femoral side using a bioabsorbable interference screw, and cortical suspensory back-up fixation with a polyethylene ligament fixation button.

The cyclic dynamic method of tensioning of the anterior cruciate ligament graft is performed using the Biomet graft-tensioning boot [21, 22] (Biomet Sports Medicine, Warsaw, Indiana). Traction is placed on the anterior cruciate ligament graft sutures with the knee in zero degrees of flexion, and tension is gradually applied reducing the tibia on the femur. The knee is then cycled through multiple full flexion and extension cycles to allow settling of the graft. The process is repeated until there is no further change in the torque setting on the graft tensioner, and the Lachman and pivot shift tests are negative. The knee is placed in approximately thirty degrees of flexion, and fixation is achieved on the tibial side of the anterior cruciate ligament graft with a bioabsorbable interference screw, and back-up fixation with a polyethylene ligament fixation button (Fig. 20.19).

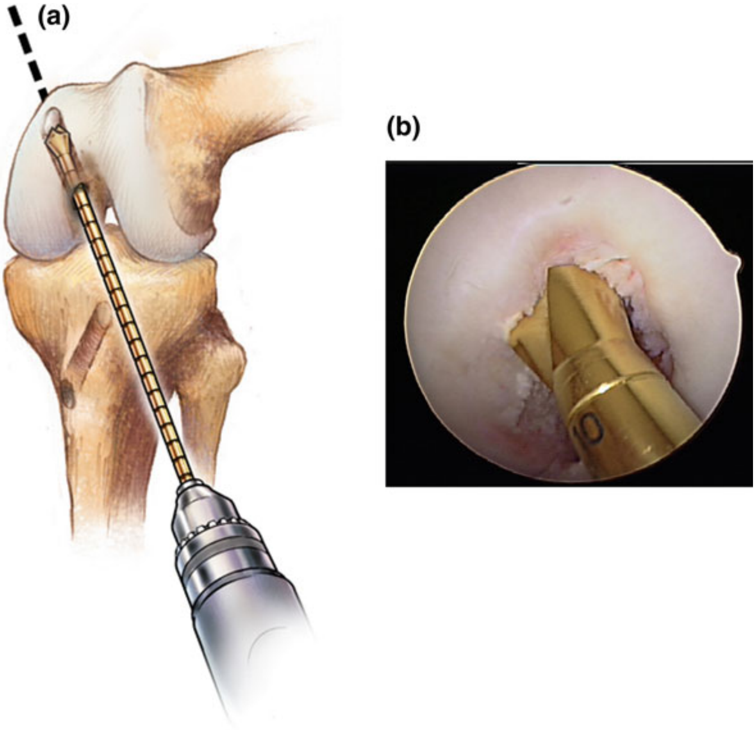


Fig. 20.9 **a** Endoscopic acorn reamer is used to create the PCL anterolateral bundle femoral tunnel through the low anterolateral patellar portal (from Fanelli GC [6]. Reprinted with permission from Zimmer Biomet). **b** Intraoperative view of an endoscopic acorn reamer is positioned to create the PCL anterolateral bundle femoral tunnel

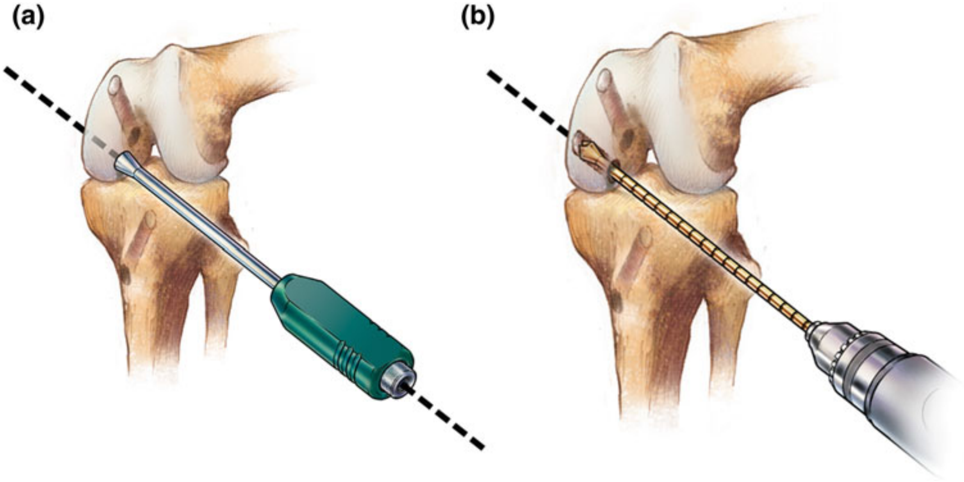


Fig. 20.10 **a** Double-bundle aimer positioned to drill a guide wire for creation of the PCL posteromedial bundle femoral tunnel through the low anterolateral patellar portal. **b** Endoscopic acorn reamer is used to create the PCL posteromedial bundle femoral tunnel. A five millimeter bone bridge is maintained between tunnels (from Fanelli GC [6]. Reprinted with permission from Zimmer Biomet)

20.5 Lateral Posterolateral Reconstruction

My most commonly utilized surgical technique for posterolateral reconstruction is the free graft figure of eight technique utilizing semitentinosus allograft, or other soft tissue allograft material (Fig. 20.20). This procedure requires an intact proximal tibiofibular joint, and the absence of a severe hyperextension external rotation recurvatum deformity. This technique combined with capsular repair and posterolateral capsular shift procedures, mimics the function of the popliteofibular ligament and lateral collateral ligament, tightens the posterolateral capsule, and provides a post of strong allograft tissue to reinforce the posterolateral

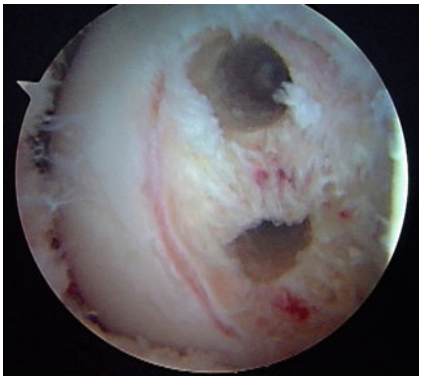


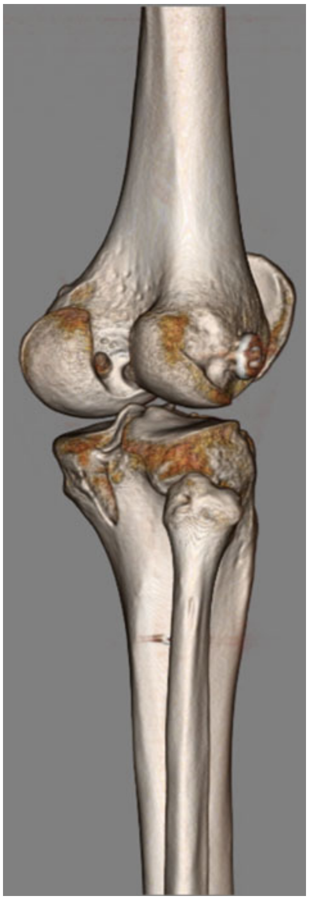
Fig. 20.11 Completed PCL anterolateral and posteromedial bundle tunnels fill the anatomic foot print of the posterior cruciate ligament. Five millimeter bone bridge is maintained between the tunnels

Fig. 20.12 Three dimensional CT scan showing properly positioned PCL femoral tunnel exit points after inside-to-outside PCL femoral tunnel creation. Note the distance between the femoral tunnel exit points and the distal medial femoral condyle articular surface

corner. When there is a disrupted proximal tibiofibular joint or severe hyperextension external rotation recurvatum deformity, a two-tailed (fibular head, proximal tibia) posterior lateral reconstruction is performed in addition to the posterolateral capsular shift procedure (Fig. 20.21).

In acute cases, primary repair of all lateral side injured structures is performed with suture anchors, screws and washers, and permanent sutures through drill holes as indicated (Fig. 20.22). The primary repair is then augmented with an allograft tissue reconstruction. Posterolateral reconstruction with the free graft figure of eight technique utilizes semitentinosus or other soft tissue allograft. A curvilinear incision is made in the lateral aspect of the knee extending from the interval between Gerdy's tubercle and the fibular head to the lateral epicondyle and then proximal following the course of the iliotibial band. A peroneal nerve neurolysis is performed, and the peroneal nerve is protected throughout the procedure. The fibular head is identified and a tunnel is created in an anterior to posterior direction at the area of maximal fibular head diameter. The tunnel is created by passing a guide pin followed by a standard cannulated drill 7 mm in diameter. The peroneal nerve is protected during tunnel creation, and throughout the procedure. The free tendon graft is passed through the fibular head drill hole. An incision is made in the iliotibial band in line with the fibers exposing the lateral femoral epicondyle area of the distal femur. The graft material is passed medial to the iliotibial band for the fibular collateral ligament limb, and medial to the common biceps tendon and iliotibial band for the popliteus tendon popliteofibular ligament limb. The limbs of the graft are crossed to form a figure of eight with the fibular collateral ligament component being lateral to the popliteus tendon component. A 3.2 mm drill hole is made to

Fig. 20.13 Three-dimensional CT scan showing properly positioned intra-articular PCL femoral tunnel position after inside-to-outside PCL femoral tunnel creation. A more accurate placement of the posterior cruciate ligament femoral tunnels is possible because I can place the double-bundle aimer or endoscopic reamer on the anatomic foot print of the anterior lateral or posterior medial posterior cruciate ligament insertion site under direct visualization



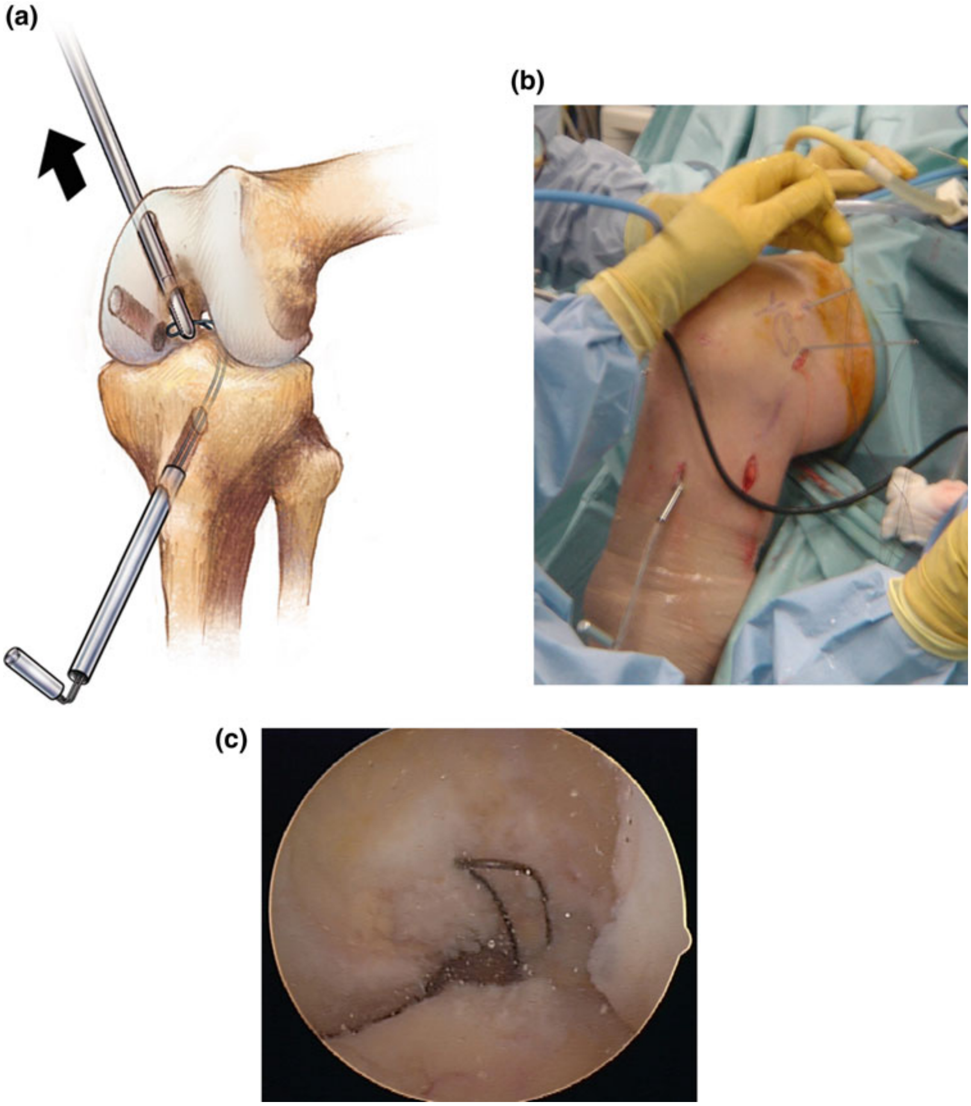


Fig. 20.14 **a** Magellan suture passing device (from Fanelli GC [6]. Reprinted with permission from Zimmer Biomet). **b**, **c** Intraoperative external and arthroscopic views demonstrating the positioning of the Magellan suture and graft passing device

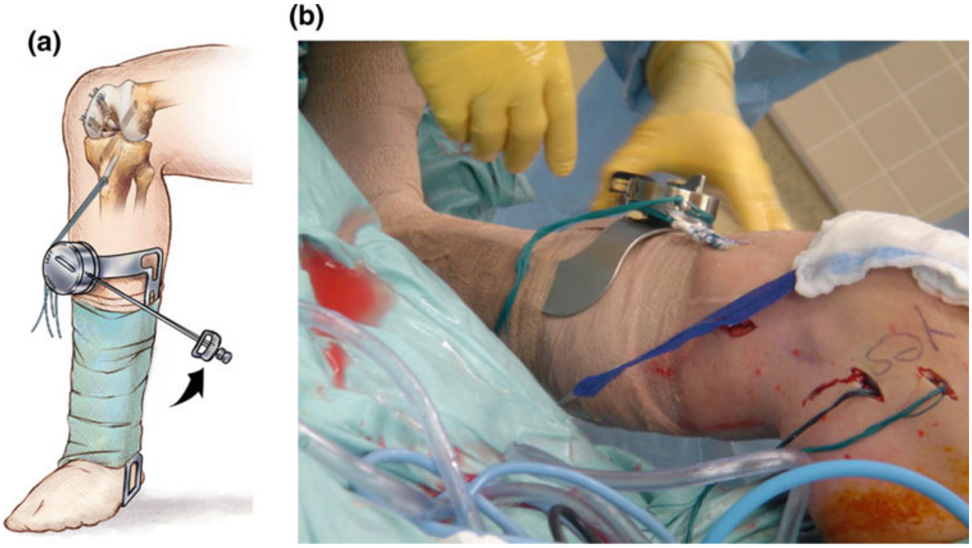


Fig. 20.15 **a** Knee ligament graft-tensioning boot is used to tension the PCL graft. This mechanical tensioning device uses a ratcheted torque wrench device to assist the surgeon during graft tensioning. (from Fanelli GC [6]. Reprinted with permission from Zimmer Biomet). **b** Intraoperative photograph of Biomet tensioning boot applied to the tibia to tension the PCL reconstruction graft

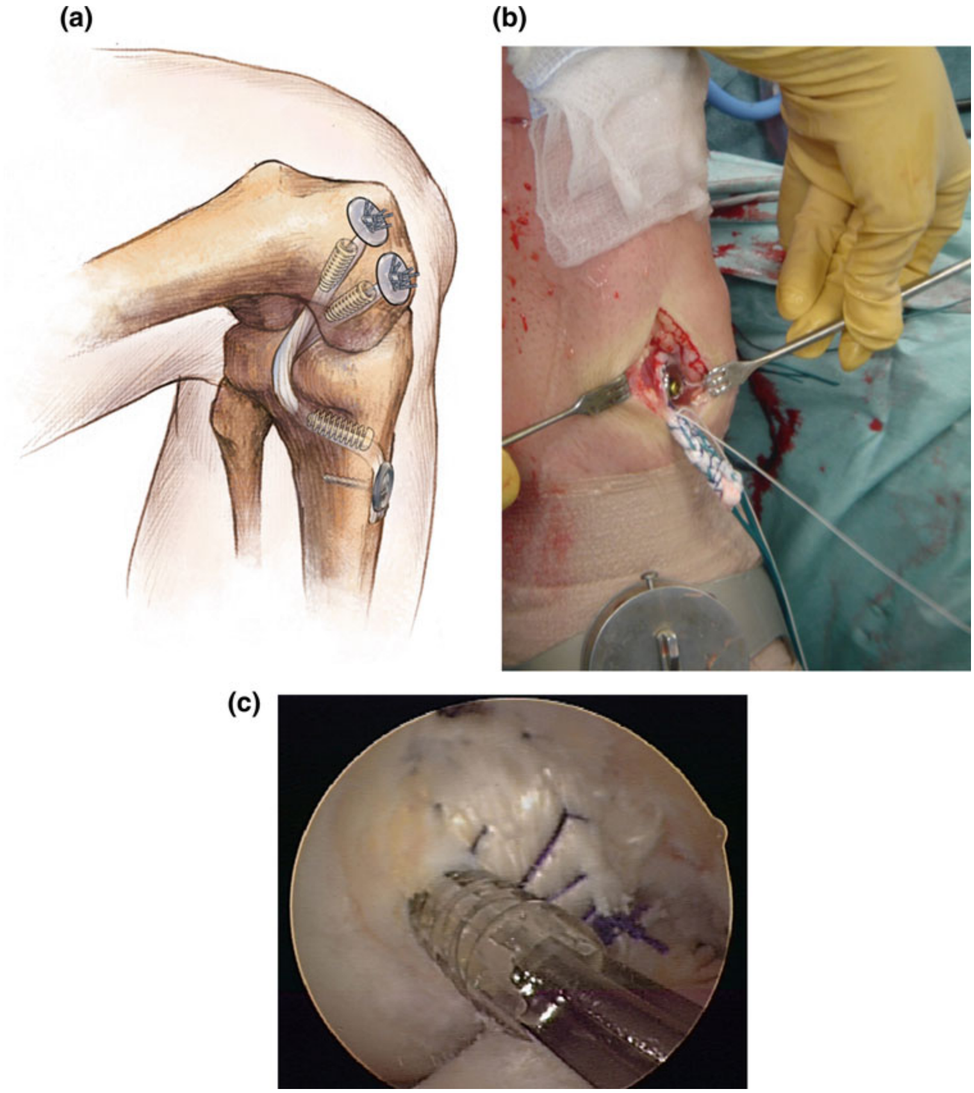


Fig. 20.16 **a** PCL final graft fixation using primary and back-up fixation (from Fanelli GC [6]. Reprinted with permission from Zimmer Biomet). **b** PCL final tibial fixation. **c** Interference fit fixation of PCL graft in femoral tunnel

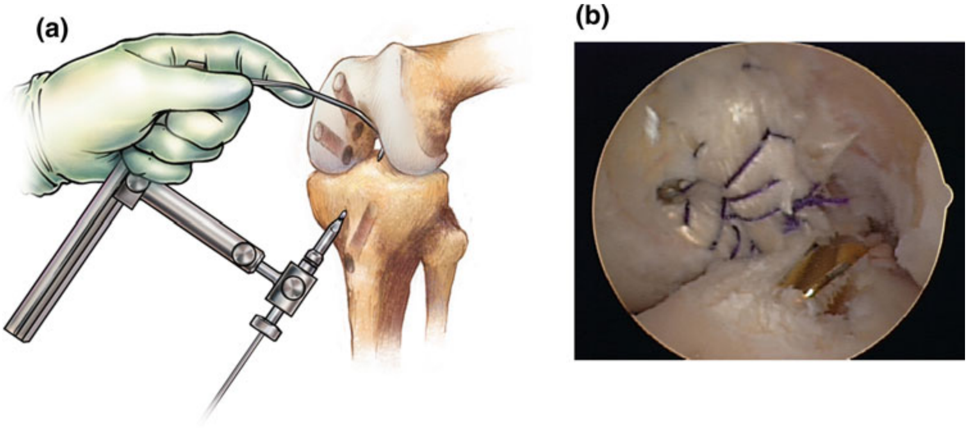


Fig. 20.17 **a** The PCL-ACL drill guide is positioned to create ACL tibial tunnel (from Fanelli GC [6]. Reprinted with permission from Zimmer Biomet). **b** ACL tibial tunnel orientation and position to approximate the tibial and femoral anatomic insertion sites of the anterior cruciate ligament

accommodate a 6.5 mm diameter fully threaded cancellous screw that is approximately 30–35 mm in length. The drill hole is positioned in the lateral epicondylar region of the distal lateral femur so that after seating a 17–20 mm washer with the above-mentioned screw, the washer will precisely secure the two limbs of the allograft tissue at the respective anatomic insertion sites of the fibular collateral ligament and popliteus tendon on the distal lateral femoral condyle. This

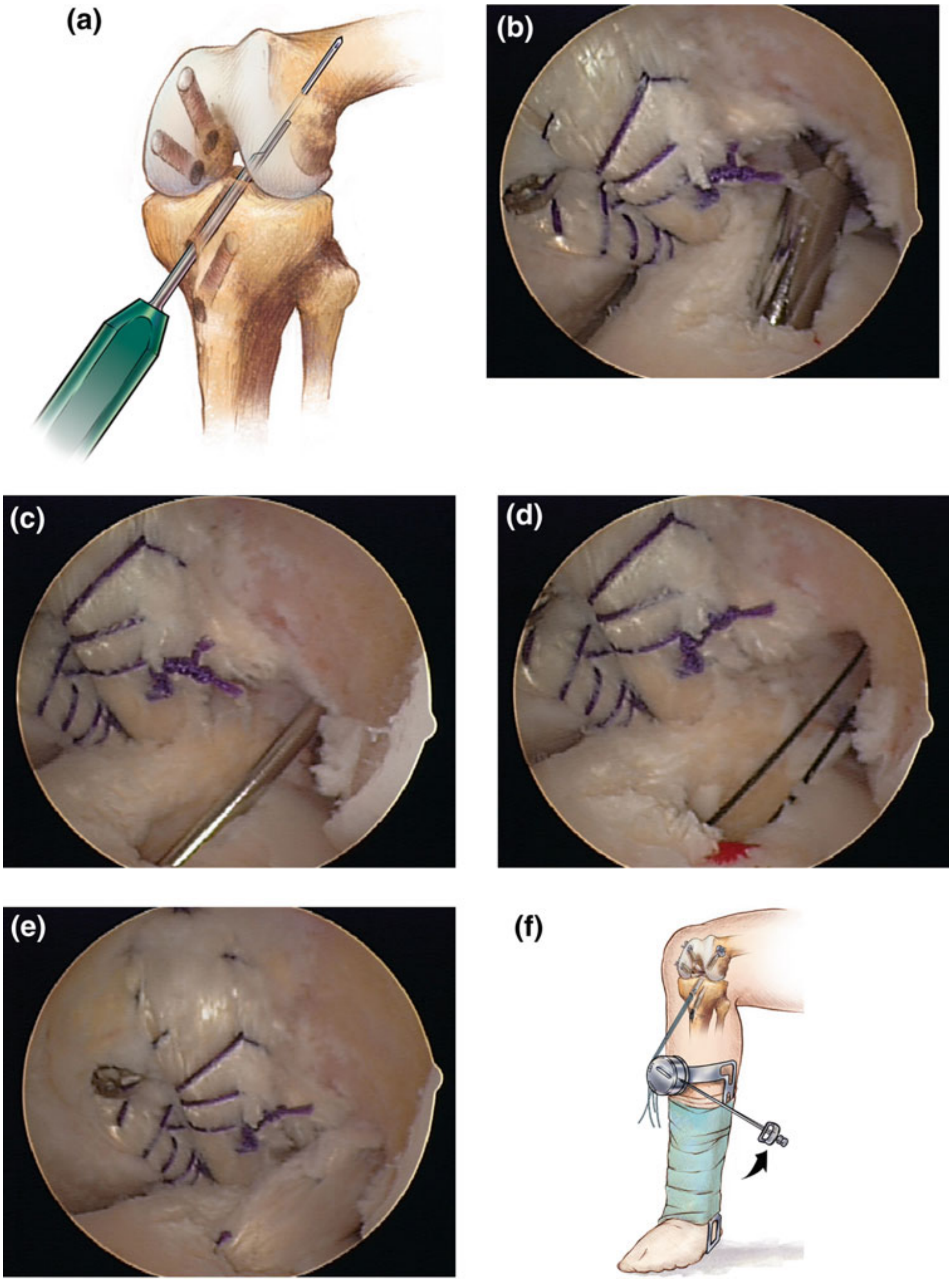


Fig. 20.18 **a** Transtibial ACL femoral tunnel is created with the help of an over-the-top femoral aimer to approximate the ACL femoral insertion site (from Fanelli GC [6]. Reprinted with permission from Zimmer Biomet). **b** Arthroscopic view of an over the top femoral aimer positioning a guide wire for ACL femoral tunnel creation. **c** Guide wire positioned for ACL femoral tunnel creation. **d** ACL femoral tunnel positioned to approximate the anatomic insertion of the anterior cruciate ligament. **e** Anterior cruciate ligament graft in final. **f** Final tensioning of the ACL graft using the Biomet graft-tensioning graft (from Fanelli GC [6]. Reprinted with permission from Zimmer Biomet)

drill hole is approximately 1 cm anterior to the fibular collateral ligament femoral insertion. A longitudinal incision is made in the lateral capsule just posterior to the fibular collateral ligament. The graft material is tensioned at approximately 30°–40° of knee flexion, secured to the lateral femoral epicondylar region with a screw and spiked ligament washer at the above-mentioned point. The posterolateral capsule that had been previously incised is then shifted and sewn into the strut of figure of eight graft tissue material to eliminate posterolateral capsular redundancy (Fig. 20.23). The anterior and posterior limbs of the figure of eight graft material are sewn to each other to reinforce and tighten the construct. The final graft-tensioning position is approximately 30°–40° of knee flexion with a slight valgus force applied and slight internal tibial rotation. The iliotibial band incision is closed. The procedures described are designed to eliminate posterolateral axial rotation and varus rotational instability. Number two Ethibond suture is used to sew the tails of the graft together proximal to the washer to prevent slipping, and also to sew the allograft to the deep capsular layers for additional reinforcement.

When there is a disrupted proximal tibiofibular joint, or hyperextension external rotation recurvatum deformity, a two-tailed (fibular head, proximal tibia) posterior lateral

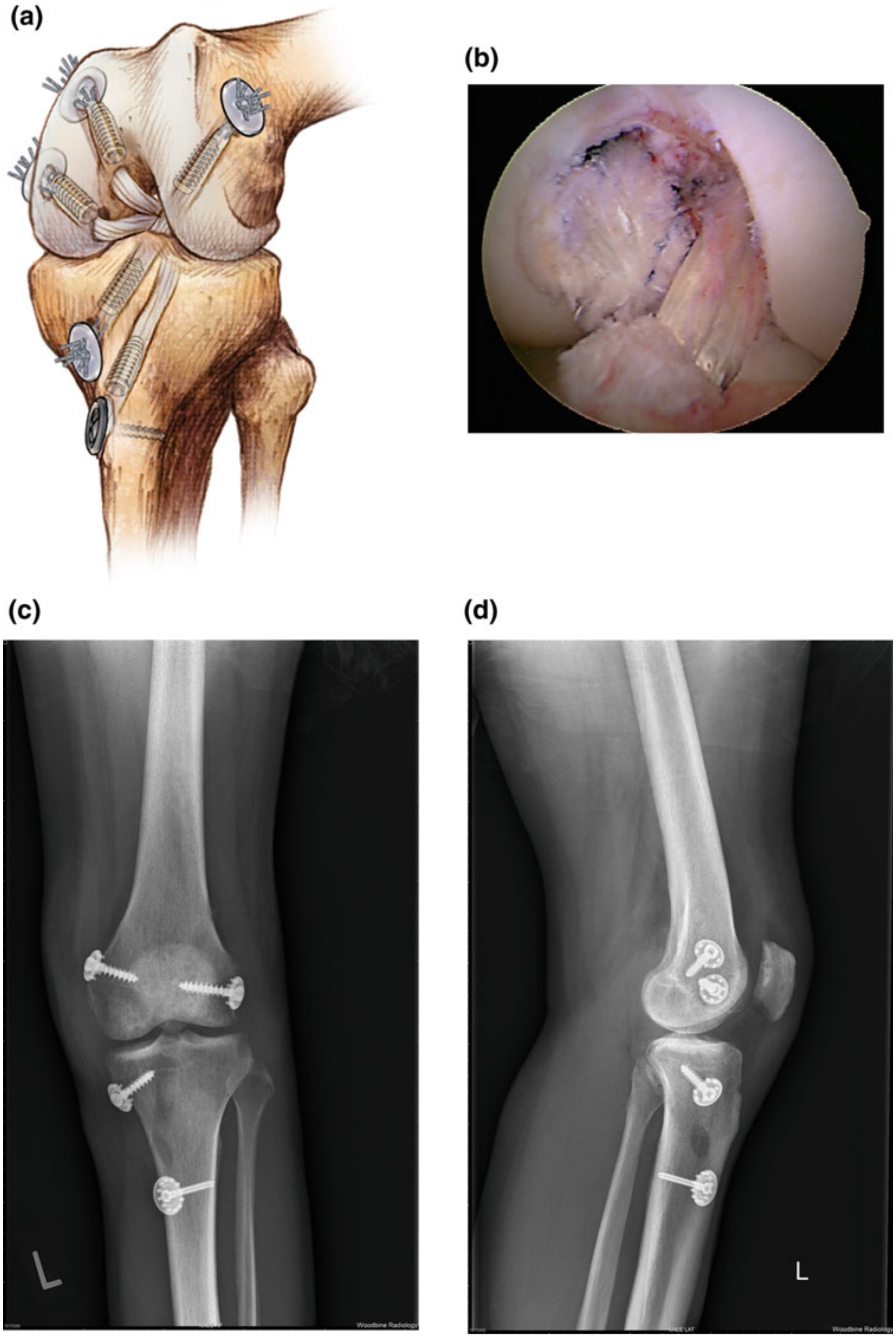


Fig. 20.19 **a** Drawing of final fixation of PCL and ACL grafts. Note primary and back-up fixation of each graft (from Fanelli GC [6]. Reprinted with permission from Zimmer Biomet). **b** Arthroscopic view of completed PCL-ACL reconstruction. **c**, **d** Postoperative anterior posterior and lateral radiographs of completed combined PCL, ACL, lateral, and medial side reconstructions

reconstruction is utilized combined with a posterolateral capsular shift. A 7 or 8 mm drill hole is made over a guide wire approximately 2cm below the lateral tibial plateau. A tibialis anterior or other soft tissue allograft is passed through this tibial drill hole and follows the course of the popliteus tendon to its anatomic insertion site on the lateral femoral epicondylar region. Nerves and blood vessels must be protected. The tibialis anterior or other soft tissue allograft is secured with a suture anchor, and multiple number two braided non-absorbable sutures at the popliteus tendon anatomic femoral insertion site. The knee is cycled through multiple sets of full flexion and extension cycles, placed in ninety degrees of flexion, the tibia slightly internally rotated, slight valgus force applied to the knee, and the

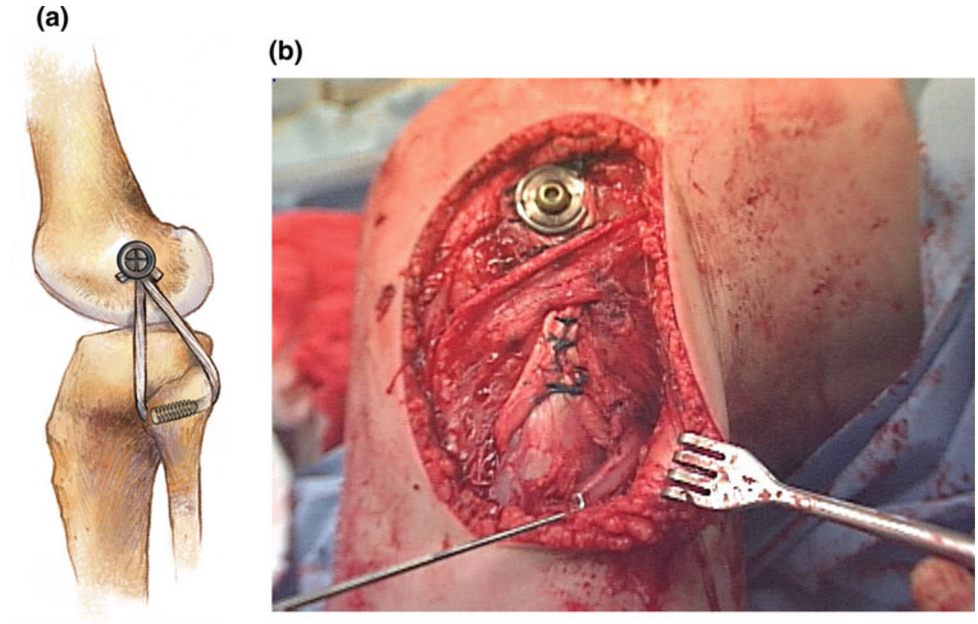


Fig. 20.20 **a** Posterolateral reconstruction using fibular head based figure of eight allograft tissue (from Fanelli GC [6]. Reprinted with permission from Zimmer Biomet). **b** Intraoperative photograph of fibular head based posterolateral reconstruction using semitendinosus allograft. Probe is pointing to peroneal nerve neurolysis, a very important part of the procedure

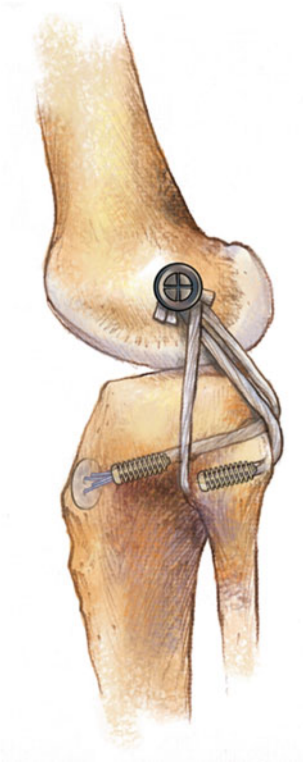


Fig. 20.21 Posterolateral reconstruction using fibular head based figure of eight allograft tissue combined with tibial based popliteus tendon allograft reconstruction (from Fanelli GC [6]. Reprinted with permission from Zimmer Biomet)

graft tensioned, and secured in the tibial tunnel with a bioabsorbable interference screw, and polyethylene ligament fixation button. The fibular head based reconstruction and posterolateral capsular shift procedures are then carried out as described above. Number two ethibond suture is used to sew the tails of the graft together proximal to the washer to prevent slipping, and also to sew the allograft to the deep capsular layers for additional reinforcement.

20.6 Medial Posteromedial Reconstruction

The surgical leg positioned on the extended operating room table in a supported flexed knee position, posteromedial and medial reconstructions are performed through a medial curved incision taking care to maintain adequate skin bridges between incisions. In acute cases, primary repair of all medial side injured structures is performed with suture anchors, screws and washers, and permanent sutures through drill holes as indicated. The primary repair is then augmented with an allograft tissue reconstruction (Fig. 20.24). In chronic cases of posteromedial reconstruction, the Sartorius fascia is incised and retracted exposing the superficial medial collateral ligament and the posterior medial capsule. Nerves and blood vessels are protected throughout the procedure. A longitudinal incision is made just posterior to the posterior border of the superficial medial collateral ligament (Fig. 20.25). Care is taken not to damage the medial meniscus during the capsular incision. Avulsed capsular structures are primarily repaired using bioabsorbable suture anchors and permanent braided number two ethibond sutures. The interval between the posteromedial capsule and medial meniscus is developed. The posteromedial capsule is shifted in an anterior and superior direction. The medial meniscus is repaired to the new capsular position, and the shifted capsule is sewn into the medial collateral ligament using three number two permanent braided ethibond sutures in horizontal mattress fashion, and that suture line is reinforced using a running number two ethibond suture.

When superficial medial collateral ligament reconstruction is indicated, this is performed using allograft tissue after

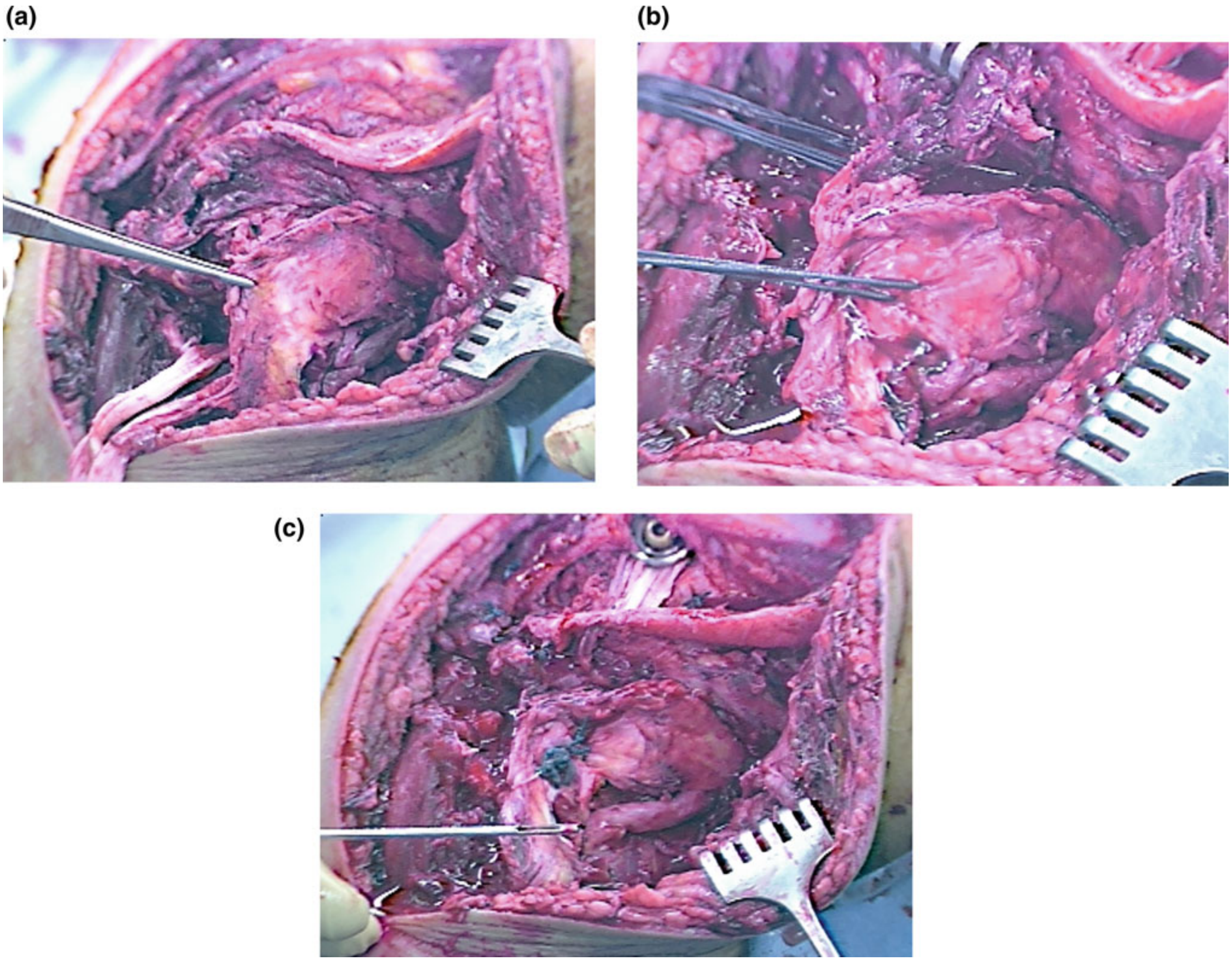


Fig. 20.22 **a** Acute severe lateral side injury. **b** Lateral posterolateral primary repair with a combination of suture anchors and transosseous sutures. **c** Augmentation of acute lateral posterolateral primary repair with fibular head based figure of eight allograft semitendinosus lateral posterolateral reconstruction. Probe is pointing to peroneal nerve neurolysis, a very important part of the procedure

completion of the primary capsular repair, and posteromedial capsular shift procedures are performed as outlined above (Fig. 20.26). This graft material is attached at the anatomic insertion sites of the superficial medial collateral ligament on the femur and tibia using a screw and spiked ligament washer, or suture anchors. The final graft-tensioning position is approximately 30°–40° of knee flexion. It is my preference to secure the tibial insertion site first, and to perform the final tensioning and fixation of the allograft tissue on the femoral side. Number two ethibond suture is used to sew the tails of the graft together proximal to the washer to prevent slipping, and also to sew the allograft to the deep capsular layers for additional reinforcement.

20.7 Graft Tensioning and Fixation

The posterior cruciate ligament is reconstructed first followed by the anterior cruciate ligament reconstruction followed by the lateral posterolateral reconstruction, and finally the medial posteromedial reconstruction. Final fixation has been performed on the femoral side of the posterior and anterior cruciate ligament reconstruction grafts. Tension is placed on the posterior cruciate ligament graft distally using the Biomet knee ligament-tensioning device (Biomet Sports Medicine, Warsaw, Indiana). This reduces the tibia on the femur in full extension, and restores the anatomic tibial

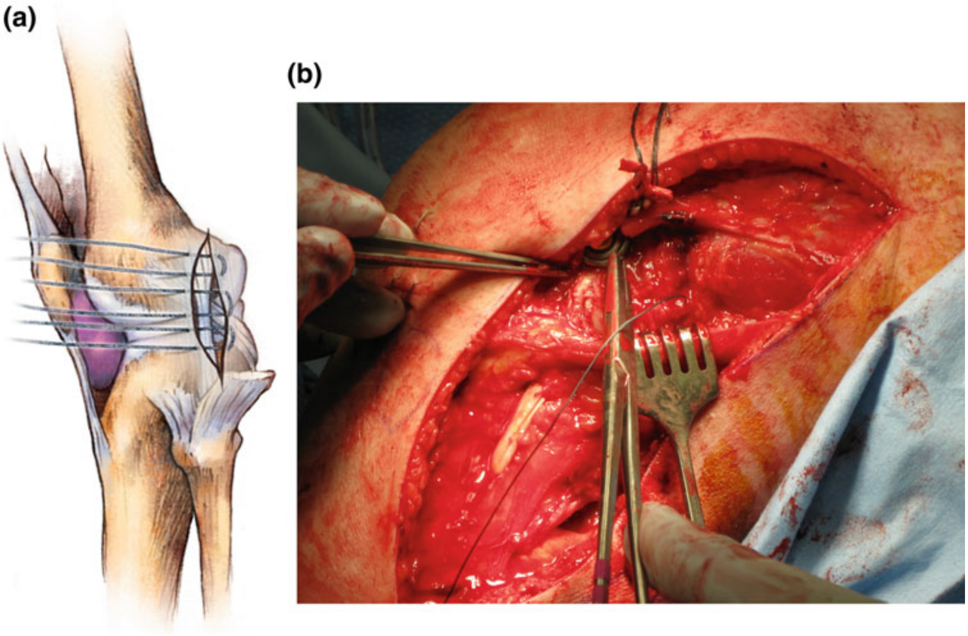


Fig. 20.23 **a** Posterolateral capsular shift is used to decrease redundant posterolateral capsular volume in combination with posterolateral allograft reconstruction (from Fanelli GC [6]. Reprinted with permission from Zimmer Biomet). **b** Intraoperative photograph of posterolateral shift using number two Ethibond suture material

step-off. The knee is cycled through a full range of motion multiple times to allow pre-tensioning and settling of the graft. The knee is placed in 70°–90° of flexion, and fixation is achieved on the tibial side of the posterior cruciate ligament graft with a bioabsorbable interference screw, and screw and spiked ligament washer or polyethylene ligament fixation button. The Biomet knee ligament-tensioning device (Biomet Sports Medicine, Warsaw, Indiana) is next applied to the anterior cruciate ligament graft, and tension is gradually applied at full extension reducing the tibia on the femur. The knee is cycled through a full range of motion multiple times to allow pre-tensioning and settling of the graft. The knee is placed in 30° of flexion, and final fixation is achieved of the anterior cruciate ligament graft with a bioabsorbable interference screw, and polyethylene ligament fixation button. The posterior and anterior cruciate ligament incisions are thoroughly irrigated and closed in layers. Attention is now turned to the lateral side of the knee where lateral posterolateral reconstruction, tensioning, and fixation are performed as outlined above. The lateral side incision is thoroughly irrigated and closed in layers. Finally, the medial posteromedial reconstruction, tensioning, and fixation are performed as outlined above. Full range of motion is confirmed on the operating table to assure the knee is not "captured" by the reconstructions.

20.8 Additional Technical Ideas

The posteromedial safety incision protects the neurovascular structures, confirms the accuracy of the posterior cruciate ligament tibial tunnel placement, and enhances the flow of the surgical procedure. It is important to be aware of femoral and tibial tunnel directions, and to have adequate bone bridges between tunnels. This will reduce the possibility of tibial fracture. We have found it very important to use primary and back-up fixation. During cruciate ligament reconstruction, primary aperture fixation is achieved with bioabsorbable interference screws, and back-up fixation is performed with a screw and spiked ligament washer, and ligament fixation buttons. Secure fixation is critical to the success of this surgical procedure. The medial and lateral side reconstruction primary fixation is achieved with screws and spiked ligament washers, and back-up fixation is achieved with multiple number two ethibond reinforcing sutures. Mechanical tensioning of the cruciates at zero degrees of knee flexion (full extension), and restoration of the normal anatomic tibial step-off at 70°–90° of flexion has provided the most reproducible method of establishing the neutral point of the tibia-femoral relationship in our experience in PCL reconstruction. ACL final fixation is at approximately 30° of knee flexion. Full range of motion is confirmed on the operating table to assure the knee is not "captured" by the reconstruction.

20.9 Postoperative Rehabilitation

The knee is maintained in full extension for five weeks non-weight bearing. Progressive range of motion occurs during postoperative weeks six through ten. Progressive weight bearing occurs at the beginning of postoperative week six progressing at a rate of twenty percent body weight per week during postoperative weeks six through ten.

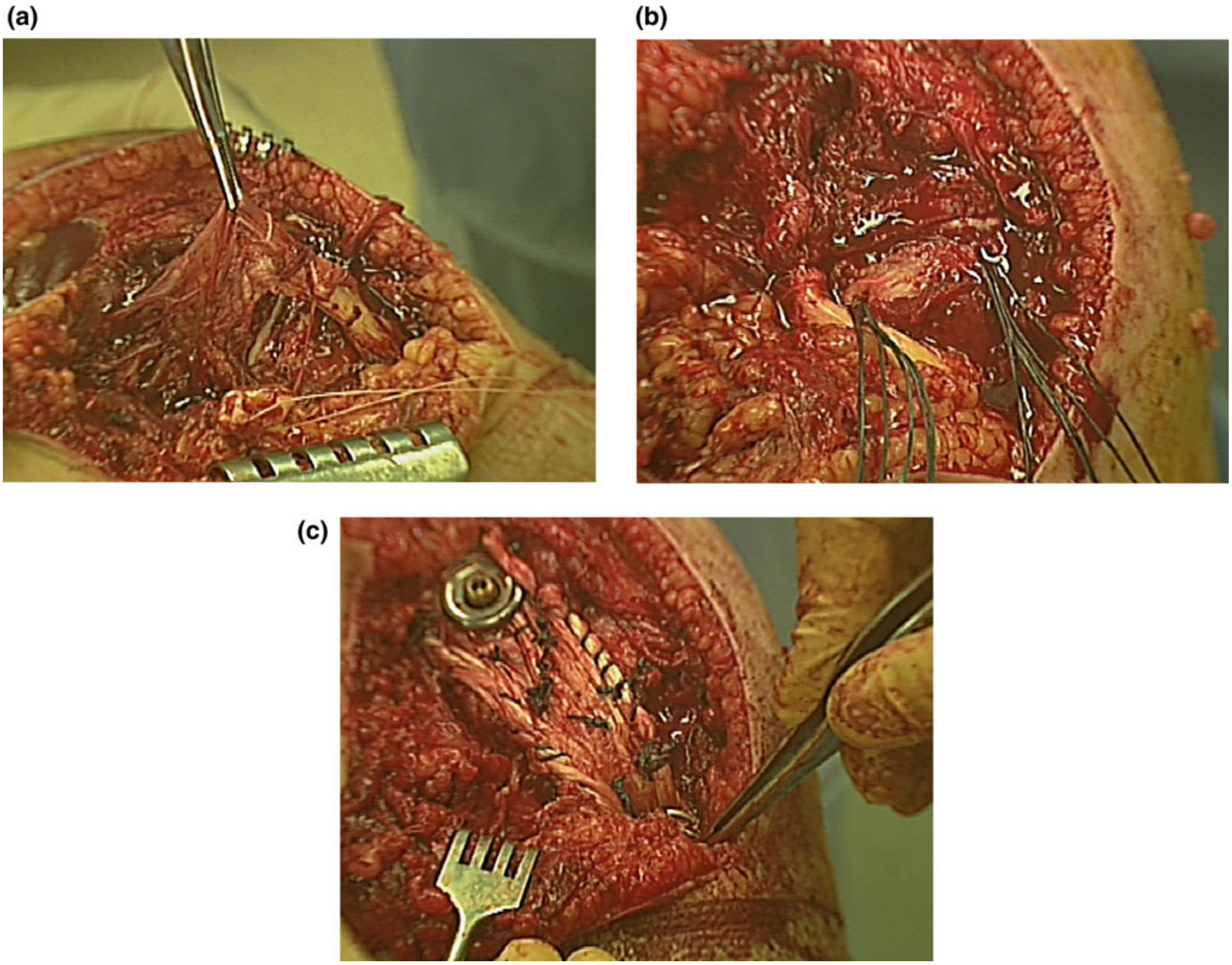


Fig. 20.24 **a** Acute severe medial side injury. **b** Medial posteromedial primary repair with a combination of suture anchors and transosseous sutures. **c** Augmentation of acute medial posteromedial primary repair with allograft medial posteromedial reconstruction

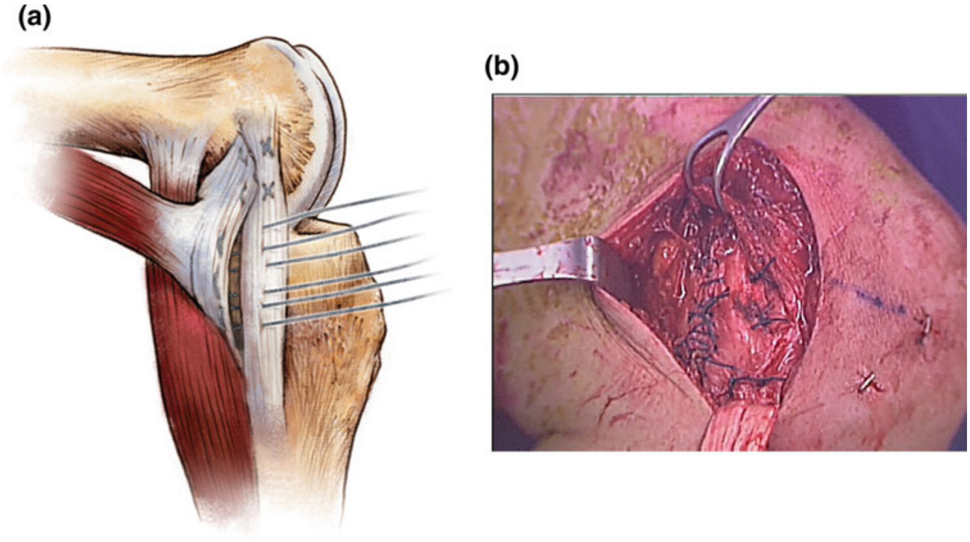


Fig. 20.25 **a** Posteromedial capsular shift utilized in medial posteromedial reconstruction (from Fanelli GC [6]. Reprinted with permission from Zimmer Biomet). **b** Intraoperative photograph of posteromedial capsular shift procedure using number two Ethibond

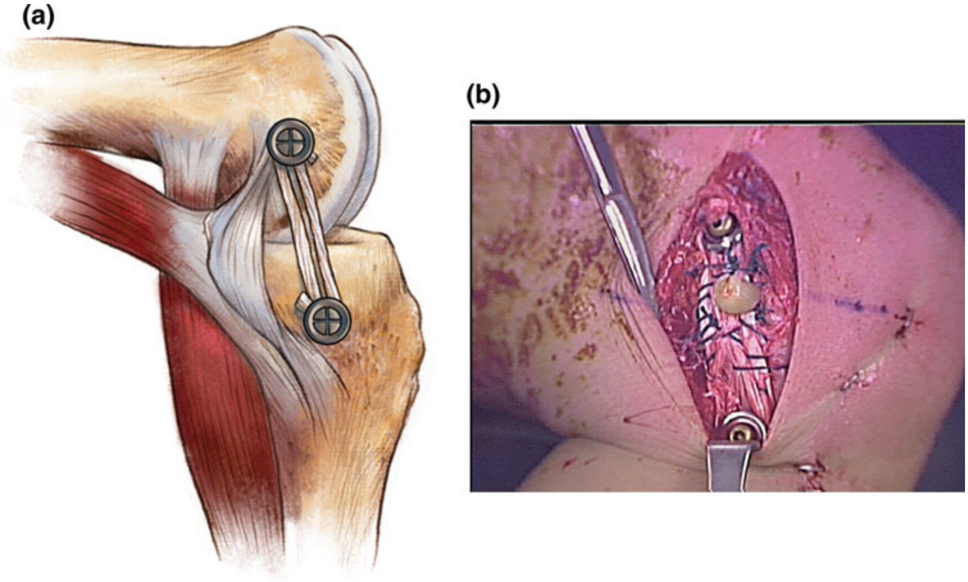


Fig. 20.26 **a** Allograft medial side reconstruction is used in combination with posteromedial capsular shift procedures for severe medial posteromedial instability (from Fanelli GC [6]. Reprinted with permission from Zimmer Biomet). **b** Allograft reconstruction of superficial medial collateral ligament. This reconstruction combined with the posteromedial capsular shift procedure controls valgus and axial rotation instability

Progressive closed kinetic chain strength training, proprioceptive training, and continued motion exercises are initiated very slowly beginning at postoperative week eleven. The long leg range of motion brace is discontinued after the tenth week and the patient wears a global laxity functional brace for all activities for additional protection. Return to sports and heavy labor occurs after the ninth postoperative month when sufficient strength, range of motion, and proprioceptive skills have returned [4, 5, 23–27]. It is very important to carefully observe these complex knee ligament injury patients, and get a feel for the "personality of the knee". The surgeon may need to make adjustments and individualize the postoperative rehabilitation program as necessary. Careful and gentle range of motion under general anesthesia is a very useful tool in the treatment of these complex cases, and is utilized as necessary. Our postoperative rehabilitation program is discussed in more detail in Chap. 39 of this book.

20.10 Author's Results

Our results of multiple ligament injured knee treatment without mechanical graft tensioning are outlined below [8]. This study presented the 2–10 year (24–120 month) results of 35 arthroscopically assisted combined ACL/PCL reconstructions evaluated pre and postoperatively using Lysholm, Tegner, and Hospital for Special Surgery knee ligament rating scales, KT 1000 arthrometer testing, stress radiography, and physical examination.

This study population included 26 males, 9 females, 19 acute, and 16 chronic knee injuries. Ligament injuries included 19 ACL/PCL/posterolateral instabilities, 9 ACL/PCL/MCL instabilities, 6 ACL/PCL/posterolateral/MCL instabilities, and 1 ACL/PCL instability. All knees had grade III preoperative ACL/PCL laxity, and were assessed pre- and postoperatively with arthrometer testing, 3 different knee ligament rating scales, stress radiography, and physical examination. Arthroscopically assisted combined ACL/PCL reconstructions were performed using the single incision endoscopic ACL technique, and the single femoral tunnel-single-bundle transtibial tunnel PCL technique. PCL's were reconstructed with allograft Achilles tendon (26 knees), autograft BTB (7 knees), and autograft semitendinosus/gracilis (2 knees). ACL's were reconstructed with autograft BTB (16 knees), allograft BTB (12 knees), Achilles tendon allograft (6 knees), and autograft semitendinosus/gracilis (1 knee). MCL injuries were treated with bracing or open reconstruction. Posterolateral instability was treated with biceps femoris tendon transfer, with or without primary repair, and posterolateral capsular shift procedures as indicated. No Biomet Sports Medicine graft-tensioning boot was used in this series of patients Biomet Sports Medicine, Warsaw, Indiana).

Postoperative physical examination results revealed normal posterior drawer/tibial step-off in 16/35 (46%) of knees. Normal Lackman and pivot shift tests in 33/35 (94%) of knees. Posterolateral stability was restored to normal in 6/25 (24%) of knees, and tighter than the normal knee in 19/25 (76%) of knees evaluated with the external rotation thigh foot angle test. 30° varus stress testing was normal in 22/25 (88%) of knees, and grade 1 laxity in 3/25 (12%) of knees. 30° valgus stress testing was normal in 7/7 (100%) of surgically treated MCL tears, and normal in 7/8 (87.5%) of brace treated knees. Postoperative KT 1000 arthrometer testing mean side-to-side difference measurements were 2.7 mm (PCL screen), 2.6 mm (corrected posterior), and

1.0 mm (corrected anterior) measurements, a statistically significant improvement from preoperative status ($p = 0.001$). Postoperative stress radiographic side-to-side difference measurements measured at 90° of knee flexion, and 32 lb of posteriorly directed proximal force were 0–3 mm in 11/21 (52.3%), 4–5 mm in 5/21 (23.8%), and 6–10 mm in 4/21 (19%) of knees. Postoperative Lysholm, Tegner, and HSS knee ligament rating scale mean values were 91.2, 5.3, and 86.8 respectively demonstrating a statistically significant improvement from preoperative status ($p = 0.001$). No Biomet graft-tensioning boot was used in this series of patients.

The conclusions drawn from the study were that combined ACL/PCL instabilities could be successfully treated with arthroscopic reconstruction and the appropriate collateral ligament surgery. Statistically significant improvement was noted from the preoperative condition at 2–10 year follow-up using objective parameters of knee ligament rating scales, arthrometer testing, stress radiography, and physical examination.

Our results of multiple ligament injured knee treatment using mechanical graft tensioning are outlined below [11]. This data presents the 2-year follow-up of 15 arthroscopic assisted ACL-PCL reconstructions using the Biomet graft-tensioning boot (Biomet Sports Medicine, Warsaw, Indiana). This study group consists of 11 chronic and 4 acute injuries. These injury patterns included six ACL-PCL PLC injuries, four ACL-PCL MCL injuries, and five ACL-PCL PLC MCL injuries. The Biomet graft-tensioning boot was used during the procedures as in the surgical technique described above. All knees had grade III preoperative ACL/PCL laxity, and were assessed pre- and postoperatively using Lysholm, Tegner, and Hospital for Special Surgery knee ligament rating scales, KT 1000 arthrometer testing, stress radiography, and physical examination.

Arthroscopically assisted combined ACL/PCL reconstructions were performed using the single incision endoscopic ACL technique, and the single femoral tunnel-single-bundle transtibial tunnel PCL technique. PCL's were reconstructed with allograft Achilles tendon in all 15 knees. ACL's were reconstructed with Achilles tendon allograft in all 15 knees. MCL injuries were treated surgically using primary repair, posteromedial capsular shift, and allograft augmentation as indicated. Posterolateral instability was treated with allograft semitendinosus free graft, with or without primary repair, and posterolateral capsular shift procedures as indicated. The Biomet graft-tensioning boot was used in this series of patients.

Post-reconstruction physical examination results revealed normal posterior drawer/tibial step-off in 13/15 (86.6%) of knees. Normal Lackman test in 13/15 (86.6%) knees, and normal pivot shift tests in 14/15 (93.3%) knees. Posterolateral stability was restored to normal in all knees with posterolateral instability when evaluated with the external rotation thigh foot angle test (nine knees equal to the normal knee, and two knees tighter than the normal knee). Thirty degree varus stress testing was restored to normal in all 11 knees with posterolateral lateral instability. Thirty and zero degree valgus stress testing was restored to normal in all nine knees with medial side laxity. Postoperative KT-1000 arthrometer testing mean side-to-side difference measurements were 1.6 mm (range −3 to 7 mm) for the PCL screen, 1.6 mm (range −4.5 to 9 mm) for the corrected posterior, and 0.5 mm (range −2.5 to 6 mm) for the corrected anterior measurements, a significant improvement from preoperative status. Postoperative stress radiographic side-to-side difference measurements measured at 90° of knee flexion, and 32 lb of posteriorly directed proximal force using the Telos stress radiography device were 0–3 mm in 10/15 knees (66.7%), 0–4 mm in 14/15 (93.3%), 4 mm in 4/15 knees (26.7%), and 7 mm in 1/15 knees (6.67%). Postoperative Lysholm, Tegner, and HSS knee ligament rating scale mean values were 86.7 (range 69–95), 4.5 (range 2–7), and 85.3 (range 65–93) respectively, demonstrating a significant improvement from preoperative status. The study group demonstrates the efficacy and success of using a mechanical graft-tensioning device in posterior and anterior cruciate ligament reconstruction procedures.

Our comparison of single-bundle- and double-bundle posterior cruciate ligament reconstruction in the PCL based multiple ligament injured knee revealed the following [2, 3, 5, 28]. Ninety consecutive arthroscopic transtibial PCL reconstructions were performed by a single surgeon (GCF). Forty five single-bundle- and 45 double-bundle reconstructions were performed using fresh frozen Achilles tendon allograft for the anterolateral bundle, and tibialis anterior allograft for the posteromedial bundle. Postoperative comparative results were assessed using Telos stress radiography, KT 1000, Lysholm, Tegner, and HSS knee ligament rating scales. Postoperative period ranged from 15 months to 72 months.

Three groups of data were analyzed: Single and double bundle all; single-bundle PCL-collateral and PCL double-bundle-collateral; and single-bundle PCL-ACL-collateral and double-bundle PCL-ACL-collateral.

Mean postoperative side-to-side difference values for Telos, KT PCL screen, KT corrected posterior, and KT corrected anterior measurements for the overall single-bundle group in millimeters were 2.56, 1.91, 2.11, and 0.23, respectively. Mean postoperative side-to-side difference values for Telos, KT PCL screen, KT corrected posterior, and KT corrected anterior measurements for the overall double-bundle group in millimeters were 2.36, 2.46, 2.94, and 0.15, respectively. Mean postoperative values for Tegner, Lysholm, and Hospital for Special Surgery (HSS) knee ligament rating scales for the single-bundle group was 5.0, 90.3, and 86.2, respectively. Mean postoperative values for Tegner, Lysholm, and Hospital for Special Surgery (HSS) knee ligament rating scales for the double-bundle group was 4.6, 87.6, and 83.3, respectively.

Mean postoperative side-to-side difference values for Telos, KT PCL screen, KT corrected posterior, and KT corrected anterior measurements for the PCL-collateral single-bundle group in millimeters were 2.59, 1.63, 2.03, and 0.25, respectively. Mean postoperative side-to-side difference values for Telos, KT PCL screen, KT corrected posterior, and KT corrected anterior measurements for the PCL-collateral double-bundle group in millimeters were 1.85, 2.03, 2.83, and −0.17, respectively. Mean postoperative values for Tegner, Lysholm, and Hospital for Special Surgery (HSS) knee ligament rating scales for the single-bundle PCL-collateral group was 5.4, 90.9, and 87.7, respectively. Mean postoperative values for Tegner, Lysholm, and Hospital for Special Surgery (HSS) knee ligament rating scales for the double-bundle PCL-collateral group was 4.9, 89.0, and 86.5, respectively.

Mean postoperative side-to-side difference values for Telos, KT PCL screen, KT corrected posterior, and KT corrected anterior measurements for the PCL-ACL-collateral single-bundle group in millimeters were 2.53, 2.19, 2.19, and 0.22, respectively. Mean postoperative side-to-side difference values for Telos, KT PCL screen, KT corrected posterior, and KT corrected anterior measurements for the PCL-ACL-collateral double-bundle group in millimeters were 3.16, 2.86, 3.09, and 0.41, respectively. Mean postoperative values for Tegner, Lysholm, and Hospital for Special Surgery (HSS) knee ligament rating scales for the PCL-ACL-collateral single-bundle group was 4.7, 89.6, and 84.6, respectively. Mean postoperative values for Tegner, Lysholm, and Hospital for Special Surgery (HSS) knee ligament rating scales for the PCL-ACL-collateral double-bundle group was 4.3, 86.0, and 79.4, respectively. There was no statistically significant difference between the single-bundle- and the double-bundle PCL reconstruction in any of the groups compared ($p > 0.05$).

Return to pre-injury level of activity was evaluated between the single- and double-bundle posterior cruciate ligament reconstruction groups. The bi-cruciate single-bundle reconstruction group return to pre-injury level of activity was 73.3%, and the bi-cruciate double-bundle reconstruction group return to pre-injury level of activity was 84.0%. There was no statistically significant difference ($p = 0.572$) between the single-bundle- and double-bundle group in the posterior cruciate ligament based multiple ligament injured knee. Both single-bundle- and double-bundle arthroscopic transtibial tunnel posterior cruciate ligament reconstructions provide excellent results in these complex multiple ligaments injured knee instability patterns. Our results did not indicate that one posterior cruciate ligament reconstruction surgical procedure was clearly superior to the other.

Our 2–18 year postsurgical results in combined PCL, ACL, medial and lateral side knee injuries (global laxity) revealed the following information [29]. Forty combined PCL-ACL-lateral-medial side (global laxity reconstructions were performed by a single surgeon (GCF). 28 of 40 were available for 2–18 year follow-up (70% follow-up rate). The patients were evaluated postoperatively with three different knee ligament rating scales for physical examination and functional capacity (Hospital for Special Surgery, Lysholm, Tegner). Static stability was assessed postoperatively comparing the normal to the injured knee using the KT 1000 knee ligament arthrometer (PCL screen, corrected posterior, corrected anterior, and 30° posterior to anterior translation), and stress radiography at 90° of flexion to assess PCL static stability using the Telos device. All measurements are reported as a side-to-side difference in millimeters comparing the normal to the injured knee. Range of motion, varus and valgus stability, and axial rotation stability of the tibia relative to the femur using the dial test are reported comparing the injured to the normal knee. Incidence of degenerative joint disease, and return to pre-injury level of function are also reported.

Knee ligament rating scale mean scores were: Hospital for Special Surgery 79.3/100 (range 56–95), Lysholm 83.8/100 (range 58–100), and Tegner 4/10 (range 2–9). KT 1000 mean side-to-side difference measurements in millimeters were: PCL screen at 90° of knee flexion 2.02 mm (range 0–7 mm), corrected posterior at 70° of knee flexion 2.48 mm (range 0–9 mm), corrected anterior at 70° of knee flexion 0.28 mm (range −3 to 7 mm), and the 30° of knee flexion posterior to anterior translation 1.0 mm (range −6 to 6 mm). Telos stress radiography at 90° of knee flexion with a posterior displacement force applied to the area of the tibial tubercle mean side-to-side difference measurements in millimeters were 2.35 mm (range −2 to 8 mm).

Range of motion side-to-side difference mean flexion loss comparing the normal to the injured knee was 14.0° (range 0°–38°). There were no flexion contractures. Varus and valgus stability were evaluated on physical examination at hyperextension, zero, and 30° of knee flexion comparing the injured to the normal knee. Symmetrical varus stability was achieved in 93.3% of knees, and symmetrical valgus stability was achieved in 92.6% of knees. The dial test performed at 30° of knee flexion to evaluate axial rotation posterolateral stability comparing the injured to the normal knee was symmetrical in 85.2%, tighter than the normal knee (less external rotation) in 11.1%, and more lax (greater external rotation) in 3.7% of knees. Thus, posterior lateral axial rotation instability was corrected or over corrected in 96.3% of knees.

Radiographic post traumatic degenerative joint disease occurred in 29.6% of injured knees [30]. No degenerative joint disease was found in 70.4% of the injured knees. Postoperatively, patients were able to return to their pre-injury level of activity in 59.3% of cases, and returned to decreased level of postoperative activity in 40.7% of cases.

20.11 Summary

The multiple ligament injured knee is a severe injury that may also involve neurovascular injuries and fractures. Surgical treatment offers good functional results documented in the literature by physical examination, arthrometer testing, stress radiography, and knee ligament rating scales. Mechanical tensioning devices are helpful with cruciate ligament-tensioning. Some low-grade medial collateral ligament complex injuries may be amenable to brace treatment, while high-grade medial side injuries require repair and reconstruction. Lateral posterolateral injuries are most successfully treated with surgical repair and reconstruction. Surgical timing in acute multiple ligament injured knee cases depends upon the ligaments injured, the injured extremity vascular status, skin condition of the extremity, degree of instability, and the patients overall health. Allograft tissue is preferred for these complex surgical procedures. Delayed reconstruction of 2–3 weeks may decrease the incidence of arthrofibrosis, and it is important to address all components of the instability. Currently, there is no conclusive evidence that double-bundle posterior cruciate ligament reconstruction provides superior results to single-bundle posterior cruciate ligament reconstruction in the multiple ligament injured knee.

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Recommended Reading

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Revision Surgery in the Posterior Cruciate Ligament and Multiple-Ligament Injured Knee

21

Anthony D. Bratton, Christopher D. Harner, and Timothy L. Miller

21.1 Overview and Historical Treatment Techniques

The treatment of posterior cruciate and multiple-ligament knee injuries has evolved since the late nineteenth century. In the first half of the twentieth century, cast immobilization was the treatment of choice for the multiple-ligament injured knee, with most patients experiencing decreased function, decreased strength, recurrent instability, or severe stiffness. Beginning with the work of O'Donoghue in the 1950s [1], surgical treatment with primary ligamentous repair became recognized as a more reliable treatment option than conservative management [2, 3]. However, due to limited potential of cruciate ligaments to heal primarily, ligamentous reconstruction has been recognized as the treatment of choice for high-grade PCL and multiple-ligament knee injuries since the 1980s [4–8].

In the twenty-first century, the goal of revision PCL and multiple knee ligament surgery is to optimize patient functional outcomes. This is accomplished with the use of anatomic reconstruction and repair of all associated soft tissue injuries [9–14]. Combined correction of abnormalities of the bony architecture may also be necessary to support ligament reconstruction. Revision surgery includes arthroscopically assisted cruciate ligament reconstruction, collateral ligament repair or reconstruction, posterolateral corner reconstruction or repair, and meniscus repair or partial excision. Secondary procedures often necessary for revision reconstruction include staged procedures, bone grafting of suboptimal bone tunnels when present, and proximal tibial or distal femoral osteotomy in the setting of malalignment.

The failed PCL and multiple-ligament injured knee reconstruction are difficult problems that necessitate concise evaluation and treatment by an experienced knee surgeon [15]. This chapter is meant to present up-to-date treatment principles on injury classification, surgical treatment strategy and techniques, and prevention of complications associated with revision surgery for the PCL and MLI knee. These recommended treatment principles are based on current literature and clinical experience of the senior authors.

21.2 General Treatment Principles

The first step in revision knee ligament surgery is appropriate classification of the injury. This is done based on the cause of surgical failure, timing of the injury, ligaments injured, and associated injuries. All factors are intimately related to one another, but in the revision situation, establishing the cause of failure for the primary surgery is most important [16–18]. Cause of failure for primary PCL and multiple knee ligament reconstructions can most often be divided into one of three categories: iatrogenic, biologic, or traumatic. One of the most common causes for failure of primary surgery is a missed posterolateral corner injury. This may be due to overloading stress of the cruciate ligaments with deficient posterolateral structures [19]. Other common causes are listed below.

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Etiology of Failure of Primary PCL and Multiple Knee Ligament Reconstruction

- Iatrogenic
  - Untreated combined instabilities
  - Missed posterolateral corner injury
  - Nonanatomic tunnel placement
  - Incorrect graft tensioning/inadequate fixation
  - Untreated or unrecognized meniscal or articular cartilage pathology
- Biologic
  - Failure of graft incorporation (especially with allograft)
  - Soft tissue graft elongation
- Traumatic
  - "Aggressive" early rehab before adequate biological healing
  - Major trauma/reinjury
  - Patient noncompliance with rehabilitation protocols
- Malalignment
- Combined etiologies.

Determining the timing of the failure as acute or chronic is important not only for understanding the etiology of failure but also for determining the viability of primary repair of structures versus reconstruction [20–25]. Chronicity of the treatment failure hints to the possibility of further internal derangement to the meniscus and articular surfaces. In the case of the posterolateral structures, chronicity may make revision reconstruction impossible due to healing and excess scar formation [16–18].

Further classification of knee ligamentous injury includes precise diagnosis of which ligaments are insufficient and what associated injuries are present. This requires assessment of the cruciate ligaments, collateral ligaments, posterolateral structures, the meniscus, and articular cartilage. The two most common combined injury patterns after knee dislocations include the ACL, PCL, and MCL and the ACL, PCL, LCL, and PLC [8, 16–18, 26].

Associated injuries include damage to the patellar tendon, the IT band, popliteal vascular structures, and the common peroneal nerve as well as bony avulsion fractures [27, 28]. As with all knee injuries, appropriate diagnosis and classification are based on an accurate history, thorough physical exam, and appropriate timely imaging studies [29–33].

21.3 Preoperative Evaluation

21.3.1 Patient History and Review of Previous Records

The preoperative evaluation for failed PCL and multiple-ligament surgery begins with a thorough history including review of the patient's old records to determining what original procedure was performed. Often patients are unreliable sources of objective information, and therefore operative reports, clinic notes, arthroscopic photographs, and physical therapy reports will provide the revision surgeon with vital information for preoperative planning. Key information to glean from old records includes the timing of surgery, results of the examination under anesthesia, what structures were repaired or reconstructed, the status of intra-articular structures, and the type of fixation used [16–18].

Information to be obtained directly from the patient pertains more to current symptoms, the mechanism of injury or reinjury, and the circumstances of the surgical failure [16–18, 34]. The surgeon must be able to discern from the patient whether the chief complaint is knee pain or recurrent instability. This distinction alone often determines the course of treatment, with instability more often requiring surgical treatment and pain alone indicating conservative management. Finally, tobacco history, coagulopathy history, and level of patient compliance should be addressed in order to understand the factors related to treatment failure. While the patient is often the best source for describing the circumstances of injury, postoperative level of compliance may be best sought from clinic notes and physical therapy reports.

It is of vital importance to evaluate and address each injured structure in the failed multiligament knee injury. We propose the following classification as a way to organize and document the various components the treating surgeon may encounter.

Classification of Multiligament Knee Injury Failure

- Anatomic (grade of injury I–III)
  - ACL
  - PCL
  - MCL
  - LCL
  - Popliteus
  - Biceps femoris

  - Iliotibial band
  - MPFL
- Timing
  - Acute (<4 weeks)
  - Subacute (4–8 weeks)
  - Chronic (>8 weeks)
- Associated injuries
  - Meniscus
    - Medial or lateral
    - Body or root
  - Articular cartilage
    - Grade
    - Location
    - Size
    - Depth
- Alignment (evaluated with long-cassette film)
  - Neutral
  - Varus
  - Valgus
- Neurovascular status
  - Intact
  - Neurapraxia
  - Axonotmesis
  - Neurotmesis
  - Venous thrombosis
  - Arterial injury (A-V fistula)
- Soft tissue
  - Normal
  - Degloving
  - Prior or active infection
  - Deficiency requiring coverage.

21.3.2 Physical Exam

Once the patient's chief complaint and the circumstances of treatment failure have been established from history and review of records, a thorough physical examination of both lower extremities in their entirety should be performed [16–18]. Key physical exam findings to evaluate are as follows:

Key Physical Examination Tests for the Failed PCL and Multiple-Ligament Reconstructed Knee

- Global
  - Gait pattern
  - Varus thrust
  - Quadriceps atrophy
  - Soft tissue injury
  - Previous incisions
  - Neurovascular status
  - Active straight leg raise
  - Active and passive range of motion
- Patellofemoral joint
  - Medial and lateral patellar glide
  - Passive patellar tilt
  - Crepitation with range of motion
  - Medial and lateral facet tenderness
  - Lateral patellar apprehension
- Meniscus
  - Joint line tenderness
  - McMurray's test
- Ligamentous laxity exam
  - Lachman
  - Anterior drawer (internal, neutral, and external rotation)
  - Posterior drawer (internal, neutral, and external rotation)
  - Pivot shift (reverse and internal)
  - Posterolateral rotatory instability (30° and 90° of flexion)
  - Varus and valgus stress (0° and 30° of flexion).

In the initial portion of the evaluation, the examiner should pay close attention to gait pattern, varus thrust, the soft tissue envelope, atrophy of the quadriceps musculature, presence or absence of an effusion, ability to perform an active straight leg raise, neurovascular status, and active and passive ranges of motion [16–18, 28, 35–39]. More focused evaluation of the knee joint should include a detailed assessment of the patellofemoral joint for crepitation, tenderness to palpation, and the integrity of the medial patellofemoral ligament. Not uncommonly, an associated patellofemoral subluxation or dislocation may occur with a tibiofemoral dislocation and should be evaluated.

Joint line tenderness, as well as the flexion McMurray's test, is utilized to assess the status of the meniscus. Ligamentous laxity patterns are then evaluated using the Lachman, anterior and posterior drawer, pivot shift, quadriceps active, varus and valgus stress, and posterolateral rotatory instability tests [16–18, 40, 41]. It should be kept in mind that there are two laxity patterns involved with a posterolateral corner injury: varus (LCL) and rotation (PLC). They may occur separately or in combination [42]. These tests should be meticulously performed, graded, and then compared to the uninjured limb to determine asymmetry. In patients with an injury to the PCL, the knee must first be held in a reduced position prior to assessing posterolateral rotatory instability. When in question, fluoroscopic evaluation may be indicated.

21.3.3 Preoperative Imaging: Radiographs, MRI, and Vascular Studies

Complete and appropriate imaging studies serve as a road map for revision PCL and multiple-ligament knee surgery. In addition to the bones and soft tissue structures, imaging should also be used to evaluate arterial and venous structures prior to revision surgery [16–18].

21.3.3.1 Radiographs

For all failed knee ligament reconstruction patients, standard knee series X-rays should be obtained and ideally compared with the patient's original preoperative X-rays. In the senior author's practice, all patients receive a standing bilateral 45° PA flexion X-ray, a bilateral 30° merchant view X-ray, bilateral lateral views, and a standing bilateral long-cassette image (Fig. 21.1). Important information to be ascertained from this imaging series includes (1) patella height, (2) tunnel position and size, (3) degree of tibiofemoral subluxation, (4) mechanical and anatomic axes, (5) position of retained hardware, and (6) associated fractures and osteopenia. Stress radiographs may also be helpful to determine the presence of fixed subluxation or laxity difficult to discern on physical examination alone [43]. Figure 21.2 shows the preoperative bilateral AP radiographs after a failed MLI reconstruction.

Fig. 21.1 Bilateral long cassette demonstrating varus alignment of the left lower extremity

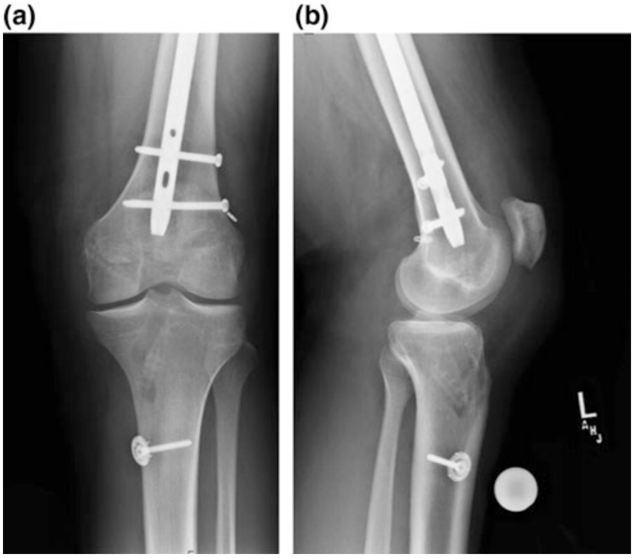

Fig. 21.2 AP (**a**) and lateral (**b**) X-rays of a 19-year-old male patient with recurrent instability after failed MLKI reconstruction of the ACL and PCL. The patient had also undergone intramedullary rod fixation of a femoral shaft fracture following a motor vehicle collision

21.3.3.2 MRI

A recent MRI should be obtained to evaluate the soft tissue structures prior to revision surgery. It should be borne in mind, however, that postsurgical changes and distortion metal implants from the previous procedure may confuse the injury pattern picture. All imaging series should be scrutinized by the surgeon and an experienced musculoskeletal radiologist to determine new injury from postsurgical changes. Care should be taken to evaluate all ligamentous structures, the patellar tendon, medial and lateral menisci, the articular cartilage, and posterolateral structures [16, 18, 19, 44, 45].

21.3.3.3 Arteriogram/CT-Angiogram

Though often more pertinent in the acute setting after knee dislocation and prior to primary reconstruction, an arteriogram or a CT-angiogram of the lower extremity should be obtained in any patient with suspected vascular injury [16–18, 28, 46]. Spasm, intimal injury, or complete tear may all alter vascular status of the injured limb and must be thoroughly evaluated prior to revision surgery [47–51]. It is strongly recommended that when there is any doubt regarding the vascular status of the extremity, a preoperative arteriogram should be obtained [16–18, 51–53]. Figure 21.3 demonstrates a preoperative CT-angiogram in a patient with popliteal artery occlusion after a knee dislocation.

21.3.3.4 Venous Duplex Doppler Ultrasound

We strongly recommend patients with combined ligamentous injuries and failed reconstructions undergo a venous duplex Doppler ultrasound to rule out deep vein thrombosis.

Fig. 21.3 Preoperative CT-angiogram demonstrating a popliteal arterial occlusion from an arterial thrombus

Given the decreased ambulatory status and limited range of motion of the traumatized knee, patients with multiple-ligament injuries are predisposed to clot formation [16–18]. It is recommended that bilateral Doppler ultrasounds be obtained after the initial office visit and 1 day prior to revision surgery.

21.3.4 Patient Counseling

Discussions with patients prior to revision posterior cruciate and multiple-ligament reconstructions should stress the importance of realistic expectations. Functional needs for activities of daily living and occupational requirements should take precedence over return to sporting activities. The lengthy recovery time, rehabilitation commitment, and increased risk of complications after revision knee ligament surgery should be thoroughly understood by the patient and family members before proceeding to surgery. Degenerative changes to the joint are likely no matter how great the technical ability of the surgeon. It should be further stressed that the use of tobacco products as well as poor diabetic control may further delay or inhibit the patient's healing ability postoperatively. Efforts should be made to discontinue tobacco use and maintain appropriate blood glucose levels.

21.4 Revision PCL and Multiple Knee Ligament Surgery

21.4.1 Indications and Contraindications

Indications for revision PCL or multiple-ligament reconstructions include a patient with a previous failed PCL or MLI reconstruction and continued symptoms of instability with or without pain. As previously noted, a thorough preoperative assessment of combined instabilities and associated injuries should be performed. Concomitant injuries should be addressed along with the revision reconstruction [54, 55]. Contraindications to revision reconstruction include significant loss of range of motion, fixed posterior subluxation, advanced osteoarthritis, and infection.

21.4.2 Preoperative Planning

21.4.2.1 Timing of Surgery

The appropriate timing of revision PCL and multiple knee ligament surgery is dependent on multiple factors. Key elements in determining ideal timing of surgery include patient-related factors, equipment availability, and qualified personnel. Patient-related factors affecting surgical timing pertain to the general health of the patient, availability of patient assistance after hospital discharge, and the presence of active infection. Available equipment must include desired allografts, necessary fixation devices, and intraoperative fluoroscopy [16–18, 27, 41]. Qualified personnel necessary for successful revision reconstruction includes an experienced knee surgeon, familiar operating room staff, and occasionally a vascular surgeon on standby. The procedure should be performed as the first and/or only case of the day when the reconstructive surgeon is well rested. Plans should be in place for the patient to be admitted to an inpatient orthopedic ward or ICU for the first 24 h postoperatively.

21.4.2.2 Graft Selection

Graft selection is dependent on autograft availability, surgeon experience, and patient age. Allografts may limit the amount of soft tissue disruption inflicted on an already traumatized soft tissue envelope. If autograft reconstruction is chosen, review of previous operative notes is essential for assuring graft availability and operative efficiency. Commonly used grafts for each ligament are as follows:

Graft Selection

- ACL
    - Autograft (ipsilateral or contralateral)
        - Bone–patellar tendon–bone
        - Quadriceps tendon with or without bone
        - Semitendinosus/gracilis
    - Allograft
        - Bone–patellar tendon–bone
        - Achilles tendon with bone
- PCL
    - Autograft (ipsilateral or contralateral) quadriceps tendon with bone block
    - Allograft Achilles tendon
- MCL
    - Allograft
        - Achilles tendon
        - Tibialis anterior
- PLC (LCL and popliteus tendon)
    - Allograft
        - Semitendinosus
        - Tibialis anterior.

Autograft tissue may be harvested from the ipsilateral or contralateral extremity and has the advantage of better graft incorporation and remodeling [16–18]. In recent years, quadriceps tendon autograft with a patellar bone plug has gained favor for younger patients. The advantages of using allograft tissue include decreased operative time and no donor site morbidity [16–18, 54–56]. Risks of allograft usage include an increase in cost, delay in incorporation, elongation of the soft tissue portion, and potential disease transmission [57]. Figure 21.4 illustrates commonly used allograft options.

21.4.2.3 Previous Skin Incisions

Prior to undertaking revision knee ligament surgery all previously used skin incisions should be known and marked with an indelible marker. When practical, previous incisions should be utilized to avoid further disruption to the soft tissue envelope. Patients should be aware, however, that previous incisions may need to be extended for adequate visualization and separate incisions may be necessary. Ideally, a discussion of incisions should be carried out with the patient in the clinic, and expected incisions should be drawn and demonstrated to the patient.

21.4.2.4 Staged Procedures

In the case of malpositioned or overly dilated bone tunnels, bone grafting and staging of revision reconstruction may be necessary [16–18]. Most modern digital imaging programs include a ruler tool allowing for more accurate measurement of tunnel width. Preoperative radiographs should be scrutinized and tunnel widths noted. These results should then be compared with operative notes and prior images if available from the primary surgery to determine the presence of tunnel dilation. Preparations should be made for harvesting bone graft or inserting prepackaged allograft bone dowels if poor bone stock or malpositioned tunnels are present. Regardless of results of preoperative X-rays, a diagnostic arthroscopy should be performed to determine the need for staged revision prior to proceeding with graft harvest. If excessive tunnel widening (16 mm or greater) or reabsorption is encountered, previous fixation hardware should be removed, the tunnels grafted, and adequate time allowed for healing and incorporation (usually 6 months) [16–18].

Proximal tibial and distal femoral osteotomies are indicated in the setting of varus or valgus malignment exceeding 5°. Biplanar opening wedge high tibial osteotomy may be indicated in patients who have failed prior cruciate or PLC repair or reconstruction when varus alignment is present [58–60]. With the ability to correct the coronal and sagittal planes, biplanar osteotomies reduce stress on the surrounding soft tissue protecting the reconstruction. In some cases, the osteotomy alone may resolve the instability. In the event that instability persists, soft tissue procedures should be performed 6–8 months after the malalignment is corrected.

21.4.2.5 Intraoperative Fluoroscopy

Intraoperative fluoroscopy has become an invaluable tool in primary as well as revision knee ligament reconstructions. The utility of readily available fluoroscopy lies in the ability to place precise anatomic tunnels in the femur and tibia and prevent the potential complication of tunnel convergence. Not only is fluoroscopy useful for guide pin and tunnel placement, but it also helps the surgeon to perform a more accurate preoperative examination under anesthesia [16–18]. With fluoroscopic examination under anesthesia, real-time evaluation can be made of ligamentous laxity. This is especially useful in evaluating fixed posterior tibial translation with PCL injuries [16–18]. Figure 21.5 shows an intraoperative lateral fluoroscopic knee X-ray showing posterior translation of the tibia.

21.4.3 Surgical Technique

(Section adapted and modified from Surgical Techniques in Sports Medicine, El Attrache, N., Harner, C. et al. 2007, Chaps. 47 and 49 with permission from Wolters Kluwer Health, Inc.)

21.4.3.1 Anesthesia

The choice of anesthesia is made in conjunction with the surgeon, the anesthesiologist, and the patient. The anesthesia

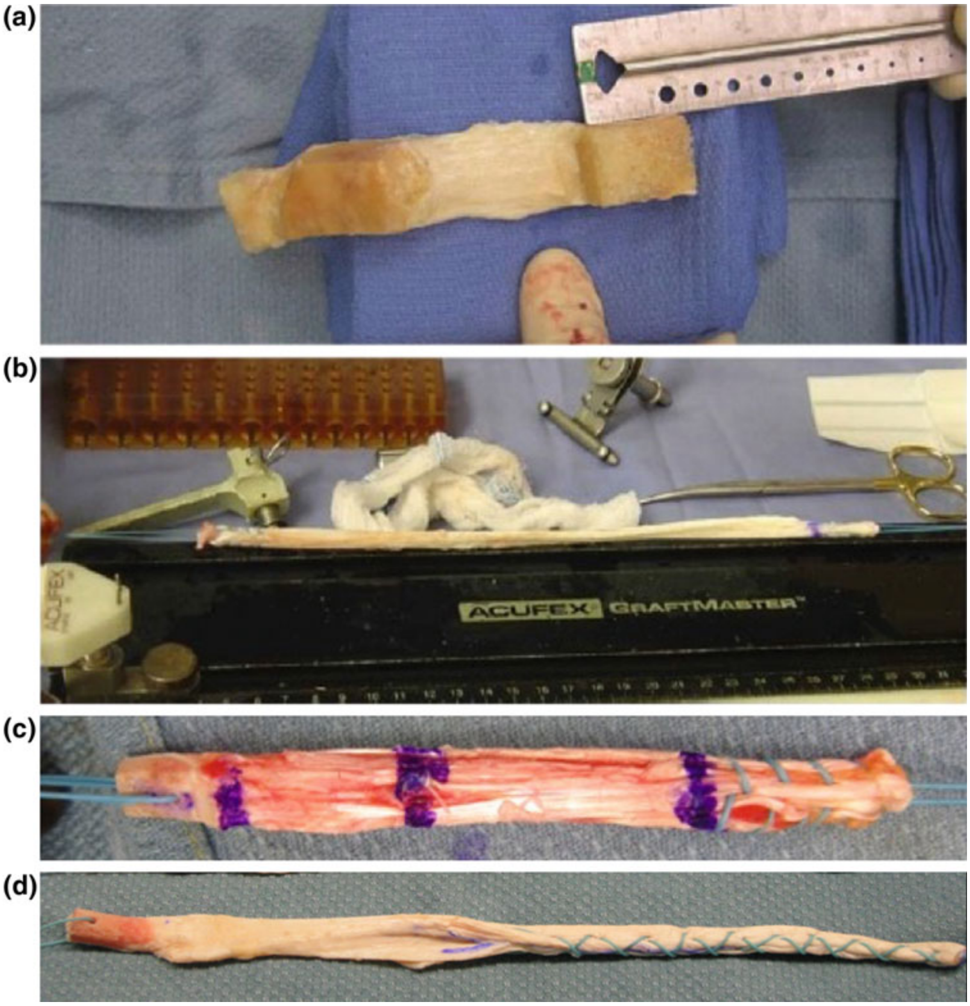

Fig. 21.4 Two commonly used allograft options for MLI reconstructions. From top to bottom: **a** bone–patellar tendon–bone and **b** anterior tibialis allografts **c** quadriceps tendon autograft with bone block **d** Achilles tendon allograft with bone block

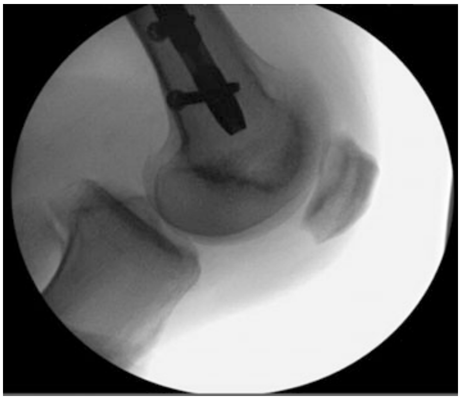

Fig. 21.5 Intraoperative fluoroscopic image showing posterior subluxation of the tibia with posterior drawer test under anesthesia

team typically chooses between general anesthesia and an epidural anesthetic with intravenous sedation. If the anesthesiologist is at all concerned regarding airway management, general anesthesia is performed. Nerve blocks can be considered for postoperative pain by an experienced anesthesiology. Our recommendation is to avoid femoral nerve blocks as they decrease quadriceps function in the postoperative period. A Foley catheter is placed for monitoring fluid status, and a vascular surgeon is on call in case a vascular injury occurs during the procedure.

21.4.3.2 Patient Positioning

The patient is placed in the supine position on a flat top table with the patient's heels at the end of the operative table. No arthroscopic leg holder, well leg holder, or tourniquet is used for the procedure given the potential extensive time of the procedure and risk of compartment syndrome. A sandbag or foot positioner is secured to the operative table to maintain the knee in a 90° flexed position. A side post is secured to the table at the level of the lesser trochanter, and a soft bump is placed under the hip of the injured limb. All limbs are well padded for the procedure, particularly the uninjured lower extremity. Figure 21.6 demonstrates the senior author's operative setup for limb positioning and available fluoroscopic imaging.

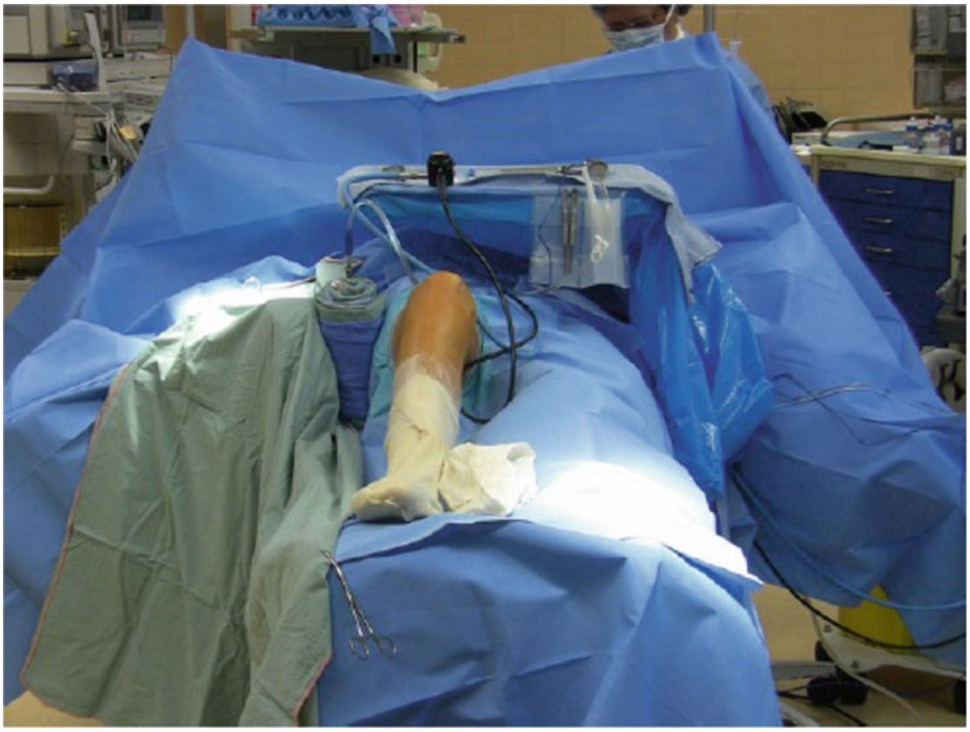

Fig. 21.6 OR setup. No tourniquet or leg holder is used. Fluoroscopy is available

21.4.3.3 Examination Under Anesthesia (EUA)

After successful induction of anesthesia in the operating room, a thorough examination under anesthesia is performed and correlated with clinical assessment and imaging findings. It is of utmost importance to examine the uninjured extremity and use it as a reference. Results of the EUA may alter the planned surgical procedure and all potentially needed grafts and equipment should be readily available. As previously stated, fluoroscopy can be very useful in evaluating combined injuries.

21.4.3.4 Surface Landmarks and Skin Incisions

An indelible marker is used to identify the surface anatomy and the incisions that will be utilized during the procedure. The osseous landmarks including the inferior pole of the patella, the tibial tubercle, Gerdy's tubercle, and the fibular head are identified and marked. The common peroneal nerve is then palpated and marked superficial to the fibular neck. The medial and lateral joint lines are then identified. All previous and potential skin incisions are then marked and utilized when appropriate. Prior incisions can be extended for adequate exposure if needed.

Standard incisions include a longitudinal 3-cm incision originating 2 cm distal to the joint line and 2 cm medial to the tibial tubercle on the anteromedial proximal tibia for the ACL and PCL tibial tunnels. A 2-cm incision is placed just medial to the medial trochlea articular surface and along the subvastus interval for the PCL femoral tunnel. The incision for the lateral and posterolateral structures is a curvilinear 12-cm incision that is drawn midway between Gerdy's tubercle and the fibular head. It is traced proximal to the lateral femoral epicondyle while the knee is in 90° of flexion [16–18]. If a medial injury is present, the distal incision for the tibial tunnels is traced proximally to the medial epicondyle in a curvilinear fashion.

21.4.3.5 Diagnostic Arthroscopy/Intra-articular Evaluation

An arthroscopic approach is advocated to assist in the planning of potential skin incisions needed for the procedure based on the pattern of injury. Gravity inflow or dry arthroscopy is recommended for the prevention of iatrogenic compartment syndrome. If inflow is used the posterior leg musculature should be palpated intermittently to assess for developing compartment syndrome. If excess fluid extravasation is noted, then the arthroscopic technique should be abandoned in favor of an open approach.

All compartments within the knee are assessed. The MCL and the meniscal attachment to the deep MCL are assessed to determine if tibial-sided injury is present. In the lateral compartment, the popliteus tendon is visualized and probed to discern if its function has been compromised. Both cruciate ligaments should be evaluated at their femoral and tibial insertion sites along with both menisci and the articular cartilage. If intra-articular pathology is present, any concomitant articular cartilage or meniscal injury must be addressed. Every effort should be made to preserve as much meniscus tissue as possible. Peripheral meniscus tears are repaired with an inside-out technique while irreparable tears may be debrided. If inside-out repair is performed, the sutures should be tied directly onto the joint capsule at 30° of flexion. If a meniscus root tear is present, repair via one or two tibial tunnels should be performed with care taken to avoid convergence with the tibial tunnels used for ligament reconstruction.

The necessary debridement of the joint is performed with a 4.5-mm arthroscopic shaver and basket forceps. This includes debridement of the notch while preserving any remaining intact PCL tissue. The tibial insertion site of the PCL is removed by inserting a shaver or a curette through a posteromedial portal and developing a plane between the PCL and the posterior capsule. Every attempt is made to debride the tibial insertion of the PCL to help with eventual placement of the guidewire for the tibial tunnel. In the senior author's practice, a notchplasty is rarely performed. The fat pad should be preserved if at all possible to prevent scarring and patellar fat pad entrapment syndrome.

21.4.3.6 Biplanar Opening Wedge High Tibial Osteotomy

When performing a high tibial osteotomy, preoperative templating using standing long-cassette radiographs is essential. The planned osteotomy should be drawn, and an estimate of the proximal tibial width and necessary plate size should be made. The width of the opening wedge osteotomy on the tibia is determined by the degree of desired correction.

The patient is placed in the supine position as described above. An incision is made midway between the tibial tubercle and the posterior border of the tibia. This incision begins 1 cm inferior to the joint line and extends approximately 5 cm distally. Exposure is made down to the superficial fibers of the medial collateral ligament. Subcutaneous flaps are created to allow exposure of the patellar tendon and the tibial tubercle. The patellar tendon is retracted laterally. An incision is then made in the sartorius fascia just superior to the gracilis tendon, and a subperiosteal dissection is carried out superiorly to release the superficial fibers of the MCL off of bone. Care must be taken to prevent violating the fibers of the MCL.

A tibial guidewire is placed from an anteromedial to a posterolateral direction angled 15° cephalad along the proposed osteotomy plane, and its position is confirmed with fluoroscopy. The line of osteotomy should be just superior to the tibial tubercle. The width of the proximal tibia should then be confirmed using a free K-wire to confirm that the actual tibial width at the osteotomy site matches the templated tibial width on preoperative radiographs. This allows confirmation of an adequate tibial osteotomy correction. A 1-in. osteotome is used to begin the osteotomy, using the K-wire as the directional guide. Once the osteotomy plane is established, the K-wire may be removed and the osteotomy completed with an oscillating saw or osteotome. Care must be taken to protect the lateral hinge of cortical bone. To safely complete the osteotomy across the posterior tibial cortex and protect the neurovascular structures, the osteotome must be angled to avoid excess perforation of the posterior cortex.

An opening wedge osteotomy system with a wedge device is then inserted into the osteotomy site to create the desired angle of correction. The appropriate plate is then selected and placed in the anteromedial aspect to the osteotomy for a biplanar effect. The alignment of the leg is again checked using an alignment rod and fluoroscopy, with the rod recreating the mechanical axis of the knee joint. The axis should be crossing lateral to the tibial spine. The plate is then secured in place with two cancellous screws proximally that are directed parallel to the joint line. The plate is fixed distally with 4.5-mm AO screws with purchase into the lateral tibial cortex. Wedge cuts of bone graft are then inserted into the osteotomy site. The superficial MCL is then repaired to the medial proximal tibial metaphysis with suture anchors. Figure 21.7 shows the AP and lateral X-rays after a high tibial osteotomy.

21.4.3.7 Graft Preparation

ACL—A bone–patellar tendon–bone allograft is preferred for our ACL revision reconstructions. We prefer 10-mm by 18-mm cylindrical bone plugs with a 10-mm tendon width. Two #5 nonabsorbable sutures are passed through drill holes placed in both bone plugs to allow for graft passage.

PCL—An Achilles tendon allograft is preferred for revision PCL reconstructions. This graft choice provides adequate length, a significant cross-sectional area, and a large calcaneal bone block. The central portion of the bone block is

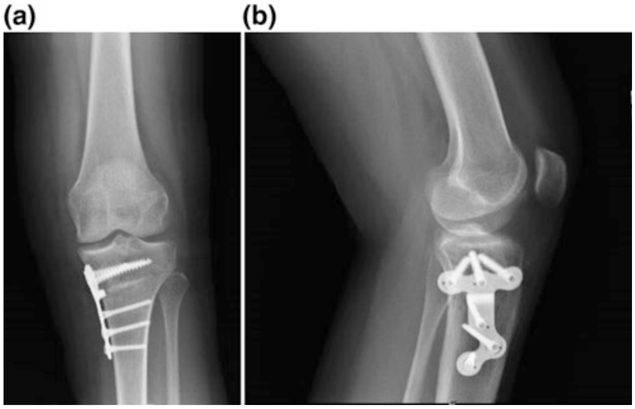

Fig. 21.7 Postoperative AP (**a**) and lateral (**b**) radiographs of a 20-year-old female who required high tibial osteotomy to correct varus malalignment and elevated tibial slope following failed anterior cruciate ligament reconstruction

fashioned to a 10-mm by 18-mm bone plug. Two #2 nonabsorbable sutures are passed through the bone plug, and the tendon is tubularized with a double-armed #5 nonabsorbable suture. Alternatively, a quadriceps tendon autograft with an 18-mm by 10-mm bone plug is harvested, and two #2 nonabsorbable sutures are passed through the bone plug. The proximal 20 mm of the tendinous portion is then baseball stitched with #5 nonabsorbable suture.

LCL—As with the PCL, an Achilles tendon allograft may be used for the lateral collateral ligament. The bone block is shaped to a 7- to 8-mm bone plug that may be fixed into the fibular head in a bone tunnel. Alternatively, an allograft semitendinosus graft may be used to reconstruct the lateral collateral ligament through an oblique tunnel in the fibular head.

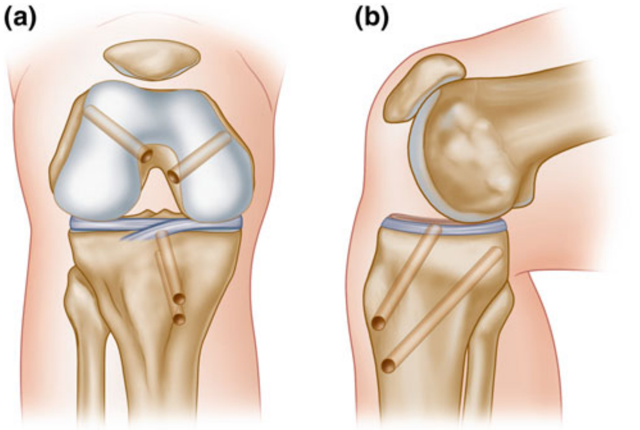

Fig. 21.8 Diagram AP (**a**) and lateral (**b**) projections of tibial and femoral tunnel positions for ACL and PCL reconstructions

21.4.3.8 Cruciate Tunnel Placement and Preparation

The PCL tibial tunnel is addressed first as this is the most dangerous and challenging portion of the procedure. We introduce a 15-mm offset PCL guide set at 50–55° through the anteromedial portal and place the tip of the guide at the distal and lateral third of the insertion site of the PCL on the tibia. The 3- to 4-cm medial proximal tibial skin incision is made, and the periosteum is sharply dissected from the bone. The starting point of the K-wire is approximately 3–4 cm distal to the joint line. The trajectory of the tibial PCL tunnel roughly parallels the angle of the proximal tibiofibular joint. We then pass a non-threaded guide pin into the desired position and perforate the posterior cortex of the tibia at the PCL insertion, and this is done under direct arthroscopic visualization with a hard-stop drill guide. Caution must be taken when passing the guidewire through the cortex of the tibial insertion of the PCL because of the close proximity of the neurovascular structures. Oftentimes, the PCL tibial insertion site has a cancellous feel when the far cortex is breeched and no hard cortex can be felt when the pin is advanced. The location of the pin placement is then confirmed with fluoroscopy on the true lateral projection of the knee. Occasionally, the wire is too proximal to the PCL tibial insertion site, and a 3- to 5-mm parallel pin guide will be used to obtain the ideal placement of the PCL tibial tunnel. The guide pin is left in place and attention is paid to the ACL tibial tunnel. The tibial guide set at 47.5° is introduced into the anteromedial portal and a guide pin is placed in the center of the ACL tibial footprint. This position should rest approximately 7 mm anterior to the PCL and should coincide with the posterior extent of the anterior horn of the lateral meniscus. The location of the ACL tibial tunnel is also confirmed on the full extension lateral fluoroscopy view. The guide pin should rest posterior to the Blumensaat line on the full extension lateral projection to ensure proper placement of the ACL tibial tunnel. The ACL tibial tunnel is proximal and anterior to the PCL tibial tunnel (Fig. 21.8).

After acceptable placement of the ACL and PCL tibial tunnel guide pins is confirmed, the PCL tunnel is drilled. A curette is placed directly on top of the guidewire over the area of the drill site. The 10-mm compaction drill bit or reamer is passed under direct arthroscopic visualization with a 30° arthroscope that is introduced through the posteromedial portal. The drill or reamer is initially passed through the tibia on power then completed by hand. The PCL tibial tunnel is then expanded to a diameter of 10–11 mm (the size of the graft) using dilators in 0.05-mm increments. The ACL tibial tunnel is then drilled in a similar manner. The ACL tibial tunnel is expanded to a diameter of 10 mm using the dilators in 0.5-mm increments. We prefer at least a 1- to 2-cm bone bridge between the ACL and PCL tibial tunnels.

The femoral tunnels for the ACL and PCL are now established. For a single bundle PCL reconstruction, the insertion for the PCL on the intercondylar notch is identified and the guide pin is placed from the anterolateral portal to a point approximately 7–10 mm from the articular margin within the anterior portion of the PCL femoral footprint. This is then overdrilled with a 10-mm compaction drill or reamer to a depth of approximately 24–35 mm. The tunnel is then dilated to the size of the graft by 0.5-mm increments. Next, the ACL femoral tunnel is established approximately 6 mm anterior to the back wall of the lateral femoral condyle. We prefer the medial portal technique or two-incision technique with inside-out drilling to the traditional transtibial technique due to the ability to place a more anatomically positioned insertion site on the femur. This tunnel is then expanded as before to a diameter of 10 mm with the dilators in 0.5-mm increments if the compaction drill is used.

21.4.4 Graft Passage

In the case of multiple-ligament reconstruction, the graft for the PCL is passed first. A looped 18-gage wire is passed retrograde into the PCL tibial tunnel and retrieved out the anterolateral arthroscopy portal with a pituitary rongeur. The nonabsorbable suture that has secured the tendon portion of the graft is shuttled into the joint with the looped 18-gage wire via the anterolateral portal and antegrade down the PCL tibial tunnel to exit on the anteromedial tibia. The bone plug portion of the graft is passed out the anteromedial femur via a Beath pin through the PCL femoral tunnel and out the anteromedial thigh. With arthroscopic assistance, a heavy right-angled clamp is used to direct the graft into the joint to allow passage of the graft. The ACL is passed in the usual fashion using the medial portal technique. The Beath pin with a #5 suture attached eyelet is passed through the femoral tunnel via the medial portal. An arthroscopic suture retriever device is passed retrograde through the tibial tunnel and the #5 suture is retrieved. The graft is then pulled through the tibial tunnel and into the femoral tunnel with arthroscopic visualization. A heavy right-angled clamp is again used to aid in positioning the bone plug for femoral tunnel passage. The femoral fixation of the cruciate grafts is done at this time using a suspensory implant secured on the femoral cortex. Fluoroscopic imaging is used to assure that the suspensory device is seated properly on the lateral femoral cortex. The grafts are not tensioned, however, until the end of the case.

21.4.4.1 LCL Reconstruction

The tendinous portion of a 7- or 8-mm Achilles tendon allograft is secured to the femoral insertion site of the LCL by drill holes or suture anchors. The remaining LCL is then imbricated to the tendinous portion of the allograft. The injured LCL is dissected free from its distal insertion on the fibular head and a bone tunnel is drilled along the longitudinal axis of the fibula. The allograft bone plug is inserted and secured into the tunnel using an interference screw. Alternatively, the bone plug can be fixed initially into the fibular tunnel and the tendinous portion is then recessed into the lateral femoral epicondyle through a bone tunnel and tied over a post or suspensory device on the medial femoral cortex.

21.4.4.2 Popliteofibular Ligament Reconstruction

The goal of reconstruction is reconstitution of the static portion of the posterolateral corner complex. The preferred grafts for this reconstruction include hamstring autograft or anterior tibialis allograft. The lateral epicondyle of the femur is exposed and the popliteus tendon is subperiosteally dissected off of its anatomic insertion. A whipstitch is placed in the popliteus tendon with a #2 nonabsorbable suture. A 6-mm femoral drill tunnel is then placed at the lateral epicondyle to a depth of 25–30 mm and the tunnel is expanded to 7 mm in diameter with the serial dilators. The posterior border of the fibula at the insertion of the PFL is exposed by incising horizontally just below the biceps insertion and proximal to the peroneal nerve. The anterior border of the fibula is also exposed from the anterior tibial musculature. A guide pin is then drilled from anterior to posterior across the fibular head. Care must be taken not to violate the LCL tunnel if one has been previously drilled. The PFL tunnel is then drilled over the guide pin medially in the fibular head and then dilated to a diameter of 7 mm. The graft is passed from posterior to anterior through the tunnel using a Hewson suture passer. The proximal end of the graft is then passed medial to the LCL and into the previously drilled femoral tunnel at the popliteus insertion site. Both the graft and the dissected popliteus tendon are pulled into the tunnel. Approximately 25 mm of graft and 10 mm of popliteus tendon are pulled into the femoral tunnel and secured with an AO screw post or a suspensory device. Incorporation and advancement of the popliteus tendon aid in rotational restraint. A diagram of the popliteofibular ligament reconstruction is shown in Fig. 21.9.

21.4.4.3 Graft Tensioning and Fixation

Once graft passage and femoral fixation are complete, final graft tensioning and distal fixation must be accomplished. Described below is a stepwise process of tensioning the PCL, ACL, lateral ligamentous structures, and the medial structures for revision reconstruction.

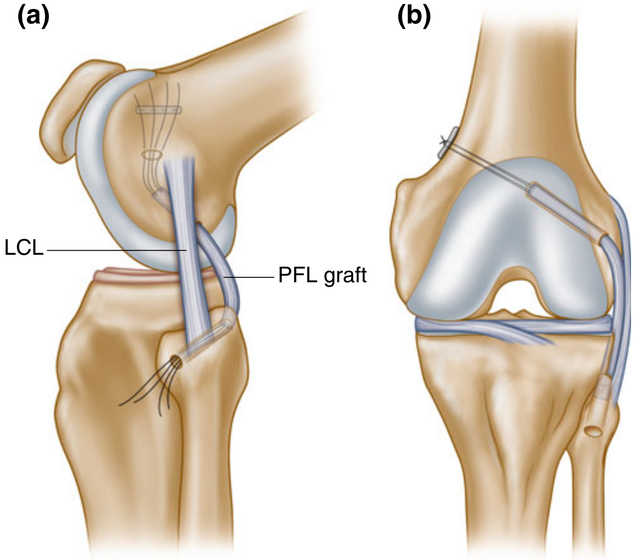

Fig. 21.9 **a**, **b** Popliteofibular ligament reconstruction

PCL—During tensioning of the PCL graft, the knee is maintained at 90° of flexion and a padded bump is applied posterior to the proximal tibia, preventing posterior tibial translation. The medial tibial plateau is held in an anteriorly overreduced position 10 mm anterior to the medial femoral condyle. Nonabsorbable sutures are tied over a 4.5-mm AO type screw with washer for tibial fixation.

ACL—The bone–patellar tendon–bone allograft is tensioned at 0 degrees of flexion. As with the PCL, nonabsorbable sutures of the graft are tied over a 4.5-mm AO screw with washer which serves as a post. Additional absorbable fixation devices are available for tibial fixation but at a higher cost.

LCL and PLC—The LCL and popliteofibular ligament are tensioned in 30° of flexion and the posterolateral corner (when timing of the revision reconstruction allows) with an internal rotation force on the tibia and fibula. The LCL graft is then fixed either in the fibular head with an interference screw or with bone tunnel passage and suture technique. The popliteofibular graft is passed through a bone tunnel in the proximal fibula and fixed either with an interference screw or suspensory device.

21.5 Medial Structures

The MCL is fixed at 15° of flexion, while the posterior oblique ligament is stabilized near full extension, preventing overconstraint of the knee. The repaired or reconstructed ligamentous complex is then fixed using either suture anchors or nonabsorbable sutures tied over an AO screw post with a washer.

21.6 Closure and Dressings

Prior to closure, it is pertinent to obtain an intraoperative X-ray imaging to establish that the joint is reduced in the AP and lateral planes and all hardware are in the appropriate position. After thorough irrigation of all wounds with antibiotic saline solution, deep fascia and periosteal layers are closed in a mattress fashion with #2 nonabsorbable sutures. The subcutaneous tissues are then closed with 2-*O* absorbable suture and the skin is reapproximated with either 4-*O* Monocryl suture in a subcuticular fashion or 3-*O* Nylon suture in a mattress fashion.

Prior to application of dressings, a vascular exam using either direct palpation or Doppler ultrasound is performed to ensure the presence and symmetry of a dorsalis pedis and posterior tibial pulses. The calf musculature is also palpated to assure that iatrogenic compartment syndrome has not occurred. Dressings consisting of Adaptic, sterile 4 × 4 gauze, ABDs, sterile Webril, and an ACE wrap are applied to the lower extremity. Finally, a hinged knee brace locked in full extension is applied to the knee (Fig. 21.10). Tight, constrictive braces, and dressings should be avoided to prevent patient discomfort and decrease the risk of compartment syndrome and peroneal nerve injury.

21.7 Immediate Postoperative Care

Given the need for general anesthesia, extended surgical time, and the risk of compartment syndrome, patients should be admitted for the first postoperative night. Appropriate preoperative and postoperative antibiotics are given. Prophylactic anticoagulation with subcutaneous enoxaparin should be used in all high-risk patients. Aspirin is indicated in low-risk patients. Tobacco use and the use of oral contraceptive pills are considered to be risk factors for thrombosis requiring more aggressive anticoagulation.

Particularly in the first 4 weeks postoperatively, the surgeon should anticipate potential problems and complications. It is recommended that patients be seen and evaluated in follow-up three times during the first month postoperatively. A high index of suspicion for infection and venous thrombosis should be maintained during the first 4 weeks post-op. Venous duplex Doppler ultrasound studies should be used liberally during this time frame to rule out DVT.

21.8 Rehabilitation Protocol

An appropriate and individualized postoperative rehabilitation program is integral to optimizing patient outcomes after revision surgery [38]. Immediately post-surgery, the limb is placed into a hinged knee brace locked in extension. A foot drop splint or molded ankle–foot orthosis may be required for patients with peroneal nerve injury. Initial postoperative rehabilitation should be focused on protecting healing bony and soft tissue structures and reestablishing full range of motion of the joint, specifically passive extension. Continuous passive motion machines are not recommended in this situation.

Passive flexion is typically initiated at 2 weeks postoperatively. Active flexion should be minimized during the first 6 weeks to prevent posterior translation of the tibia caused by hamstring contraction. Motion from 0° to 90° is promoted during this period, and at 6 weeks the brace is discontinued. Passive- and active-assisted ranges of motion exercises are then initiated to increase knee flexion beyond 90° with the goal of reaching symmetric motion to the uninjured knee by 12 weeks. A manipulation under anesthesia may be required between 8 and 12 weeks to reach 90° of flexion.

Fig. 21.10 A hinged knee brace locked in extension is applied immediately post-op and discontinued when quadriceps function returns

Active quadriceps exercises are progressed to open-chain knee extension exercises beginning at 4 weeks [61]. These exercises are performed in the 60°–75° arc of flexion in order to decrease stress on the healing grafts. Closed-chain hamstring contraction may begin at 6 weeks post-op. Open-chain hamstring exercises should be avoided for 3 months postoperatively to prevent stress on PCL grafts from posterior tibial translation.

Partial weight bearing with crutches is progressed to full weight bearing status over the first 4 weeks unless the patient has undergone a lateral reconstruction or meniscus repair. For these patients, full weight bearing is delayed for 6–8 weeks. After quadriceps control has been reestablished the hinged knee brace may be unlocked for gait training. By 6–8 weeks post-op, the brace may be discontinued.

Running is permitted at 12 weeks for patients undergoing PCL revision reconstruction alone while multiple-ligament injured patients should not be permitted for 4–6 months [61]. Patients performing sedentary occupations may often return to work after 2–4 weeks. Heavy laborers should not expect to return to work for 6–9 months. Return to sports activity should not be expected until 1-year postrevision surgery, if ever. Of note, maintaining close contact with the patient's physical therapist throughout the recovery period from revision knee ligament reconstruction can be vital for preventing reinjury or surgical failure due to overly aggressive rehab. Furthermore, knowing the patient's expected level of compliance and keeping the first 4 weeks of rehabilitation as simple as possible will help to prevent reinjury of the reconstructed knee. A team approach between surgeon, patient, family members, and physical therapists is vital for treatment success.

21.9 Complications

Complications of revision PCL and MLI reconstruction can be divided into three categories based on timing: preoperative, intraoperative, and postoperative. Most preoperative complications involve the neurovascular structures, including the popliteal artery and vein and the common peroneal nerve [9, 16–18, 62]. Intraoperative complications are typically related to technique, case setup, and poor preoperative planning. Finally, postoperative complications involve patient compliance, improper rehabilitation protocols, soft tissue management, infection, and thromboembolic events.

As with all revision procedures, the risk of complications of revision knee ligament reconstruction is significantly increased over primary reconstruction. When performing these procedures, the surgeon must be aware and prepared to treat these problems. The most common complications for revision PCL and MLI reconstruction procedures are as follows:

Common and Severe Complications of Revision PCL and Multiple Knee Ligament Reconstruction

- Preoperative
  - Vasculature
    - Arterial
      - Spasm
      - Intimal injury
      - Complete tear
      - A-V fistula
    - Venous (DVT)
  - Nerve (sensory, motor, complete)

Intraoperative
  Intraoperative vascular injury
  Iatrogenic compartment syndrome
  Intraoperative mortality
Postoperative
  Arthrofibrosis wound breakdown/skin slough
  Infection
  DVT/PE
  Recurrent instability
  Peroneal nerve neuropraxia
  Pain syndromes.

The key to treatment of these complications is prevention, which involves detailed preoperative planning, proper surgical technique, and a specific postoperative rehabilitation program. The senior author's top ten key points for prevention of complications with revision PCL and MLI knee reconstruction are as follows:

Top Ten Tips for Avoiding Complications of Revision PCL and Multiple-Ligament Knee Surgery

(1) Thorough history and physical exam
(2) Detailed preoperative planning (timing, equipment, graft choice, assistants, and vascular backup)
(3) Adequate imaging studies (X-rays, MRI, arteriogram/CT-angiogram, and venous duplex Doppler)
(4) Pad all extremities well, strongly consider not using a tourniquet, and place a Foley catheter
(5) Examination under anesthesia
(6) Intraoperative fluoroscopy
(7) Perform MLI reconstruction cases as first or only case of the day and when well rested
(8) Always admit the patient overnight
(9) DVT/PE prophylaxis
(10) Patient-specific rehab protocol and familiar, experienced physical therapists.

21.10 Outcomes

With appropriate patient selection, thorough preoperative workup and counseling setting realistic expectations, and comprehensive postoperative rehabilitation, favorable results can be expected from revision PCL and MLI reconstructions. Studies have demonstrated that revision PCL reconstruction results in improvement in pain, function, and stability [63, 64]. Although there is a relative paucity of studies reporting outcomes of revision MLI knee reconstruction due to the infrequent nature of the condition, a recent case series has demonstrated modest functional outcomes slightly decreased from primary MLI reconstruction [65]. Obtaining stability and a functional extremity should be the goal and is possible with the correct treatment algorithm.

21.11 Conclusions

Failed posterior cruciate ligament and multiple knee ligament reconstructions are a difficult problem for the knee surgeon. In order to effectively treat this problem, it is essential to classify the extent of the injury and determine the cause of the failure of the index procedure. Revision reconstruction for PCL and MLI knee injuries is fraught with complications, and clinical results are slightly less favorable for revision reconstruction than for primary reconstruction [16, 63–66].

With the treatment principles described in this chapter, the majority of our patients have been able to return to activities of daily living without difficulty. Ability to participate in sports after revision surgery, however, has been less predictable. To optimize patient outcomes, the need for detailed preoperative planning cannot be overemphasized. A thorough history and physical exam, adequate and optimal preoperative workup with imaging, proper surgical technique, careful soft tissue management, and an individualized postoperative rehabilitation program are essential for treatment success and prevention of complications.

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Part VIII

Other Considerations

22

Mechanical Graft Tensioning in Multiple Ligament Knee Surgery

Gregory C. Fanelli

22.1 Introduction

The principles of reconstruction in the multiple ligament-injured knee are to identify and treat all pathology, accurate tunnel placement, anatomic graft insertion sites, utilize strong graft material, mechanical graft tensioning, secure graft fixation, and a deliberate postoperative rehabilitation program [1]. This chapter will concentrate on my experience using a mechanical graft tensioning boot, the Biomet graft tensioning boot (Biomet Sports Medicine, Warsaw, Indiana), during posterior cruciate ligament reconstruction, and anterior cruciate ligament reconstruction, in the case of the multiple ligament-injured knee. The tensioning boot, the PCL and ACL reconstruction surgical techniques, the cyclic dynamic method of graft tensioning, and the comparative results using the graft tensioning boot will be presented in this chapter.

22.1.1 The Mechanical Graft Tensioning Device

The graft tensioning boot (Biomet Sports Medicine, Warsaw, Indiana) is a device used to tension posterior and anterior cruciate ligament grafts after graft preparation, and prior to final fixation during the PCL and/or ACL reconstruction surgical procedure. The graft tensioning boot consists of a frame that has a ratcheted torque wrench attached to the frame (Fig. 22.1). After completion of graft preparation, the allograft or autograft tissue is placed on the tensioning boot, and tension is gradually applied to pretension the graft tissue prior to implantation. The graft is wrapped in a damp sponge, and the tensioning boot graft assembly is protected on the back table, until it is time to implant the allograft or autograft tissue (Fig. 22.2). During the surgical procedure, the sterile tensioning boot is fitted over the surgical extremity foot and shin areas, and attached to the surgical leg with a sterile bandage (Fig. 22.3). The cyclic dynamic method of graft tensioning is the intraoperative process that is used, and this method is described in detail in the surgical technique section below.

22.2 Combined PCL–ACL Reconstruction Surgical Technique Using Mechanical Graft Tensioning

My surgical technique for posterior cruciate ligament reconstruction, and combined PCL–ACL medial- and lateral-side reconstruction are presented in Chaps. 9 and 15 of this textbook. This chapter specifically addresses the surgical technique for posterior and anterior cruciate ligament reconstruction using the Biomet graft tensioning boot.

The patient is placed on the operating room table in the supine position, and after satisfactory induction of anesthesia, the operative and nonoperative lower extremities are carefully examined [1–11]. A tourniquet is applied to the upper thigh of the operative extremity, and that extremity is prepped and draped in a sterile fashion. The well leg is supported by the fully extended operating room table which also supports the surgical leg during medial- and lateral-side surgery. A lateral post is used to control the surgical extremity. An arthroscopic leg holder is not used. Preoperative and postoperative antibiotics are given, and antibiotics are routinely used to help prevent infection in these time consuming, difficult, and complex cases. Allograft tissue is prepared prior to bringing the patient into the operating room. Autograft tissue is harvested prior to beginning the arthroscopic portion of the procedure.

The arthroscopic instruments are inserted with the inflow through the superolateral patellar portal. Instrumentation and visualization are positioned through inferomedial and inferolateral patellar portals, and can be interchanged as

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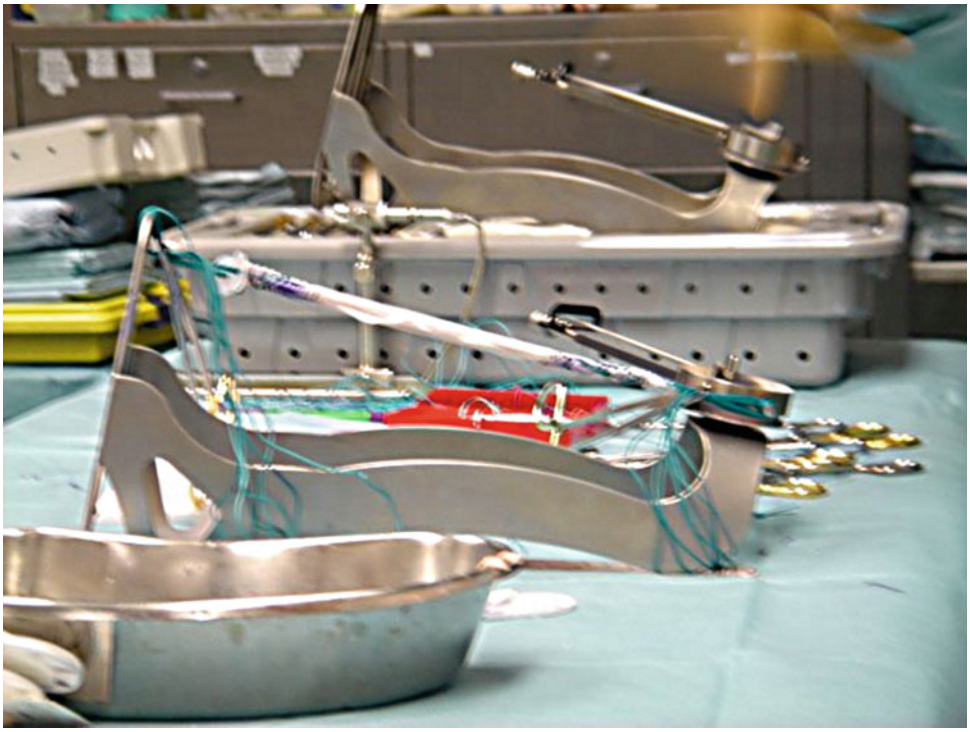
Fig. 22.1 The graft tensioning boot consists of a frame that has a ratcheted torque wrench attached to the frame. The device fits over the surgical foot and leg

Fig. 22.2 The graft tensioning device is used to pretension the prepared allograft or autograft tissue prior to implantation. After completion of graft preparation, the allograft or autograft tissue is placed on the tensioning boot, and tension is gradually applied to pretension the graft tissue prior to implantation. The graft is wrapped in a damp sponge, and the tensioning boot graft assembly is protected on the back table until it is time to implant the allograft or autograft tissue



necessary. Additional portals are established as necessary. Exploration of the joint consists of evaluation of the patellofemoral joint, the medial and lateral compartments, medial and lateral menisci, and the intercondylar notch. The residual stumps of both the anterior and posterior cruciate ligaments are debrided; however, the posterior and anterior cruciate ligament anatomic insertion sites are preserved to serve as tunnel reference points. The notchplasty for the anterior cruciate ligament portion of the procedure is performed at this time.

Fig. 22.3 During the surgical procedure, the sterile tensioning boot is fitted over the surgical extremity foot and shin areas, and attached to the surgical leg with a sterile bandage

An extracapsular extra-articular posteromedial safety incision is made by creating an incision approximately 1.5–2 cm long starting at the posteromedial border of the tibia approximately one inch below the level of the joint line and extending distally. Dissection is carried down to the crural fascia, which is incised longitudinally. An interval is developed between the medial head of the gastrocnemius muscle and the nerves and vessels posterior to the surgeon's finger, and the capsule of the knee joint anterior to the surgeon's finger. The posteromedial safety incision enables the surgeon to protect the neurovascular structures, confirm the accuracy of the PCL tibial tunnel, and to facilitate the flow of the surgical procedure.

The curved over-the-top PCL instruments (Biomet Sports Medicine, Warsaw, Indiana) are used to sequentially lyse adhesions in the posterior aspect of the knee, and elevate the capsule from the posterior tibial ridge. This will allow accurate placement of the PCL/ACL drill guide, and correct placement of the tibial tunnel.

The arm of the PCL/ACL guide (Biomet Sports Medicine, Warsaw, Indiana) is inserted through the inferior medial patellar portal. The tip of the guide is positioned at the inferior lateral aspect of the PCL anatomic insertion site. This is below the tibial ridge posterior and in the lateral aspect of the PCL anatomic insertion site. The bullet portion of the guide contacts the anteromedial surface of the proximal tibia at a point midway between the posteromedial border of the tibia, and the tibial crest anterior at or just below the level of the tibial tubercle. This will provide an angle of graft orientation such that the graft will turn two very smooth 45° angles on the posterior aspect of the tibia. The tip of the guide, in the posterior aspect of the tibia is confirmed with the surgeon's finger through the extracapsular extra-articular posteromedial safety incision. Intraoperative AP and lateral X-ray may also be used; however, I do not routinely use intraoperative X-ray. When the PCL/ACL guide is positioned in the desired area, a blunt spade-tipped guide wire is drilled from anterior to posterior. The surgeon's finger confirms the position of the guide wire through the posterior medial safety incision.

The appropriately sized standard cannulated reamer is used to create the tibial tunnel. The surgeon's finger through the extracapsular extra-articular posteromedial incision is monitoring the position of the guide wire. When the drill is engaged in bone, the guide wire is reversed, blunt end pointing posterior, for additional patient safety. The drill is advanced, until it comes to the posterior cortex of the tibia. The chuck is disengaged from the drill, and completion of the tibial tunnel is performed by hand.

The PCL single-bundle or double-bundle femoral tunnels are made from inside out using the double-bundle aimers, or an endoscopic reamer can be used as an aiming device (Biomet Sports Medicine, Warsaw, Indiana). The appropriately sized double-bundle aimer or endoscopic reamer is inserted through a low anterior lateral patellar arthroscopic portal to create the posterior cruciate ligament anterior lateral bundle femoral tunnel. The double-bundle aimer or endoscopic reamer is positioned directly on the footprint of the femoral anterior lateral bundle posterior cruciate ligament insertion site. The appropriately sized guide wire is drilled through the aimer or endoscopic reamer, through the bone, and out a small skin incision. Care is taken to prevent any compromise of the articular surface. The double-bundle aimer is removed, and the endoscopic reamer is used to drill the anterior lateral posterior cruciate ligament femoral tunnel from inside to outside. When the surgeon chooses to perform a double-bundle double femoral tunnel PCL reconstruction, the same process is repeated for the posterior medial bundle of the PCL. Care must be taken to ensure that there will be an adequate bone bridge (approximately 5 mm) between the two femoral tunnels prior to drilling. This is accomplished using the calibrated probe, and direct arthroscopic visualization of the posterior cruciate ligament femoral anatomic insertion sites.

My preferred surgical technique of posterior cruciate ligament femoral tunnel creation from inside to outside is for two reasons. There are a greater distance and margin of safety between the posterior cruciate ligament femoral tunnels and the medial femoral condyle articular surface using the inside-to-outside method. Additionally, a more accurate placement of the posterior cruciate ligament femoral tunnels is possible, in my opinion, because I can place the double-bundle aimer or endoscopic reamer on the anatomic footprint of the anterior lateral or posterior medial posterior cruciate ligament insertion site under direct visualization.

A Magellan suture retriever (Biomet Sports Medicine, Warsaw, Indiana) is introduced through the tibial tunnel into the joint, and retrieved through the femoral tunnel. The traction sutures of the graft material are attached to the loop of the Magellan suture retriever, and the graft is pulled into position. The graft material is secured on the femoral side using a bioabsorbable interference screw for primary aperture opening fixation, and a polyethylene ligament fixation button for back up fixation.

With the knee in approximately 90° of flexion, the anterior cruciate ligament tibial tunnel is created using a drill guide. My preferred method of anterior cruciate ligament reconstruction is the transtibial femoral tunnel endoscopic surgical technique. The arm of the drill guide enters the knee joint through the inferior medial patellar portal. The bullet of the drill guide contacts the anterior medial proximal tibia externally at a point midway between the posterior medial border of the tibia, and the anterior tibial crest just above the level of the tibial tubercle. A one-centimeter bone bridge or greater exists between the PCL and ACL tibial tunnels. The guide wire is drilled through the guide and positioned so that after creating the anterior cruciate ligament tibial tunnel, the graft will approximate the tibial anatomic insertion site of the anterior cruciate ligament. A standard cannulated reamer is used to create the tibial tunnel.

With the knee in approximately 90°–100° of flexion, an over-the-top femoral aimer is introduced through the tibial tunnel, and used to position a guide wire on the medial wall of the lateral femoral condyle to create a femoral tunnel approximating the anatomic insertion site of the anterior cruciate ligament. The anterior cruciate ligament graft is positioned, and fixation achieved on the femoral side using a bioabsorbable interference screw, and cortical suspensory back up fixation with a polyethylene ligament fixation button. Additional drawings and photographs of this surgical technique are presented in Chap. 20 of this textbook [9].

22.3 The Cyclic Dynamic Method of Cruciate Graft Tensioning

The cyclic dynamic method of graft tensioning using the Biomet graft tensioning boot is used to tension the posterior and anterior cruciate ligament grafts. During this surgical technique, the posterior and/or anterior cruciate ligament grafts are secured on the femoral side first with the surgeon's preferred fixation method. The technique described is a tibial sided tensioning method. I routinely use polyethylene ligament fixation buttons for cortical suspensory fixation, and aperture interference fixation with bioabsorbable interference screws for femoral side posterior and anterior cruciate ligament fixation. In combined PCL–ACL reconstructions, the posterior cruciate ligament graft is tensioned first, followed by final PCL graft(s) tibial fixation. The anterior cruciate ligament graft tensioning and fixation follows that of the PCL.

With the tensioning boot applied to the foot and leg of the surgical extremity, tension is placed on the PCL graft(s) distally using the Biomet graft tensioning boot (Biomet Sports Medicine, Warsaw, Indiana) (Fig. 22.4). Tension is gradually applied with the knee in 0° of flexion (full extension) reducing the tibia on the femur. This restores the anatomic tibial step off. Although there are numbers on the torque wrench dial, these numbers are not used to set the tension. The numbers on the torque wrench serve as a reference point during the cycling process, and readjustment process, and are not indicators of final tension in the graft. The tension is determined by reduction of the tibia on the femur in 0° of knee flexion (full extension), the restoration of the anatomic tibial step off, a negative posterior drawer on intraoperative examination of the knee, and full range of motion of the knee. The knee is cycled through a full range of motion multiple times to allow pretensioning and settling of the graft. The process is repeated until there is no further change on the torque setting on the graft tensioner with the knee at 0° of flexion (full extension). When there are no further changes or adjustments necessary in the tension

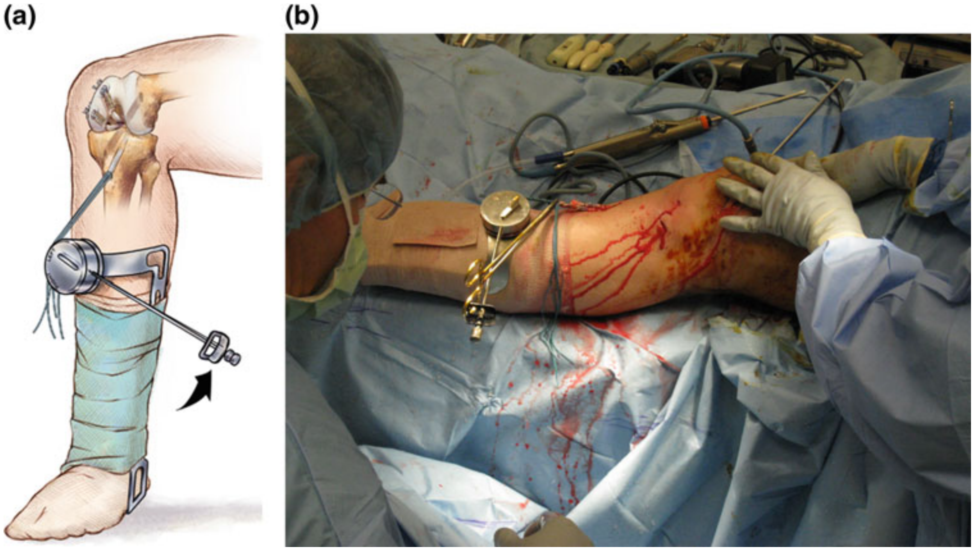


Fig. 22.4 **a** The graft tensioning boot is applied to the traction sutures of the posterior cruciate ligament graft (from Fanelli GC [2]. Reprinted with permission from Zimmer Biomet) **b** Tension is gradually applied with the knee in 0° of flexion (full extension) reducing the tibia on the femur. This restores the anatomic tibial step off. Although there are numbers on the torque wrench dial, these numbers are not used to set the tension. The numbers on the torque wrench serve as a reference point during the cycling process, and readjustment process, and are not indicators of final tension in the graft. The tension is determined by reduction of the tibia on the femur in 0° of knee flexion (full extension), the restoration of the anatomic tibial step off, a negative posterior drawer on intraoperative examination of the knee, and full range of motion of the knee

applied to the graft, the knee is placed in 70°–90° of flexion, and fixation is achieved on the tibial side of the PCL graft with a bioabsorbable interference screw for interference fit fixation, and back up cortical suspensory fixation with a bicortical screw and spiked ligament washer or polyethylene ligament fixation button (Fig. 22.5).

The cyclic dynamic method of tensioning of the anterior cruciate ligament graft is performed using the Biomet graft tensioning boot (Biomet Sports Medicine, Warsaw, Indiana) after tensioning and final fixation of the posterior cruciate ligament graft(s) has been performed (Fig. 22.6). Traction is placed on the anterior cruciate ligament graft sutures with the knee in 0° of flexion (full extension), and tension is gradually applied reducing the tibia on the femur. The knee is then cycled through multiple full flexion and extension cycles to allow settling of the graft. The Lachman and pivot-shift tests are performed. The process is repeated until there is no further change in the torque setting on the graft tensioner at full extension (0° of knee flexion), and the Lachman and pivot-shift tests are negative. Although there are numbers on the torque wrench dial, these numbers are not used to set the tension. The numbers on the torque wrench serve as a reference point during the cycling process, and readjustment process, and are not indicators of final tension in the graft. Final anterior cruciate ligament graft tension is determined by the Lachman and pivot shifts becoming negative, and achieving full range of motion of the knee. The knee is placed in approximately 30° of flexion, and fixation is achieved on the tibial side of the anterior cruciate ligament graft with a bioabsorbable interference screw, and back up fixation with a polyethylene ligament fixation button (Fig. 22.7).

22.4 Results

Fanelli and Edson, in 2004, published the 2–10-year (24–120 month) results of 41 chronic arthroscopically assisted combined PCL/posterolateral reconstructions evaluated pre and postoperatively using Lysholm, Tegner, and Hospital for Special Surgery knee ligament rating scales, KT-1000 arthrometer testing, stress radiography, and physical examination [12, 13]. PCL reconstructions were performed using the arthroscopically assisted single femoral tunnel–single-bundle transtibial tunnel posterior cruciate ligament reconstruction technique using fresh-frozen Achilles tendon allografts in all 41 cases. In all 41 cases, posterolateral instability reconstruction was performed with combined biceps femoris tendon tenodesis, and posterolateral capsular shift procedures. Postoperative physical exam revealed normal posterior drawer/tibial step off for the overall study group in 29/41 (70%) of knees. Normal posterior drawer and tibial step offs were achieved in 91.7% of the knees tensioned with the Biomet Sports Medicine mechanical graft tensioner. Posterolateral stability was restored to normal in 11/41 (27%) of knees, and tighter than the normal knee in

Fig. 22.5 When the tensioning sequence described in the chapter text is complete, the knee is placed in 70°–90° of flexion, and fixation is achieved on the tibial side of the PCL graft with a bioabsorbable interference screw for interference fit fixation, and back up cortical suspensory fixation with a bicortical screw and spiked ligament washer or polyethylene ligament fixation button

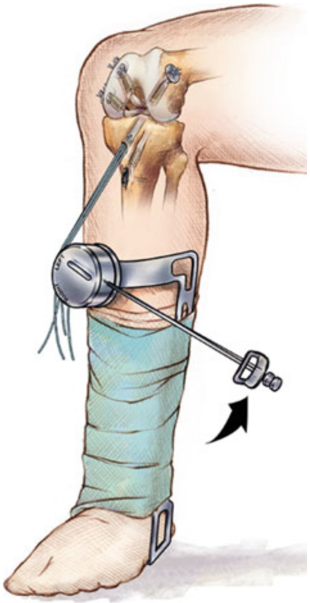


Fig. 22.6 This drawing depicts the graft tensioning boot applied to the traction sutures of the anterior cruciate ligament graft. From Fanelli GC [2]. Reprinted with permission from Zimmer Biomet

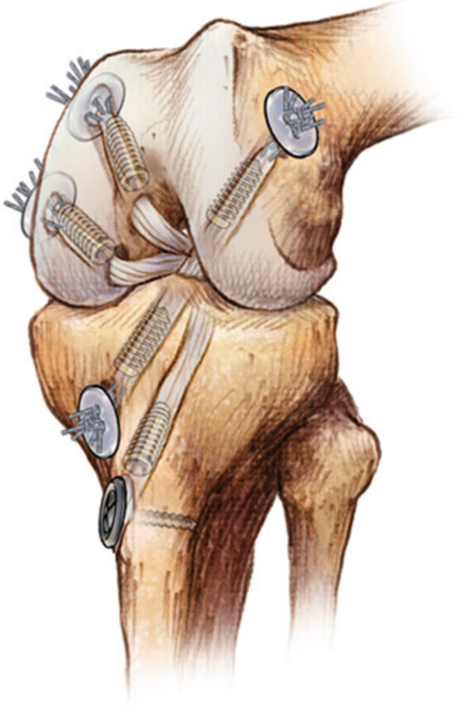


Fig. 22.7 This figure shows final fixation of the posterior and anterior cruciate ligament grafts. From Fanelli GC [2]. Reprinted with permission from Zimmer Biomet

29/41 (71%) of knees evaluated with the external rotation thigh-foot angle test. 30′ varus stress testing was normal in 40/41 (97%) of knees, and grade 1 laxity in 1/41 (3%) of knees. Postoperative KT-1000 arthrometer testing mean side-to-side difference measurements were 1.80 mm (PCL screen), 2.11 mm (corrected posterior), and 0.63 mm (corrected anterior) measurements. This is a statistically significant improvement from preoperative status for the PCL screen and the corrected posterior measurements ($p = 0.001$). The postoperative stress radiographic mean side to side difference measurement measured at 90′ of knee flexion, and 32 lb. of posterior directed force applied to the proximal tibia using the Telos device was 2.26 mm. This is a statistically significant improvement from preoperative measurements ($p = 0.001$). Postoperative Lysholm, Tegner, and Hospital for Special Surgery knee ligament rating scale mean values were 91.7, 4.92, and 88.7, respectively, demonstrating a statistically significant improvement from preoperative status ($p = 0.001$). The authors concluded that chronic combined PCL/posterolateral instabilities can be successfully treated with arthroscopic posterior cruciate ligament reconstruction using fresh-frozen Achilles tendon allograft combined with posterolateral corner reconstruction using biceps tendon tenodesis combined with posterolateral capsular shift procedure. Statistically significant improvement is noted ($p = 0.001$) from the preoperative condition at 2–10-year follow-up using objective parameters of knee ligament rating scales, arthrometer testing, stress radiography, and physical examination.

Two to 10-year results of combined ACL–PCL reconstructions without the Biomet Sports Medicine Graft Tensioning Boot have been published by Fanelli and Edson in 2002 [14]. This study presented the 2–10-year (24–120 months) results of 35 arthroscopically assisted combined ACL/PCL reconstructions evaluated pre and postoperatively using Lysholm, Tegner, and Hospital for Special Surgery knee ligament rating scales, KT-1000 arthrometer testing, stress radiography, and physical examination.

This study population included 26 males, 9 females, 19 acute, and 16 chronic knee injuries. Ligament injuries included 19 ACL/PCL/posterolateral instabilities, 9 ACL/PCL/MCL instabilities, 6 ACL/PCL/posterolateral/MCL instabilities, and 1 ACL/PCL instability. All knees had grade III preoperative ACL/PCL laxity, and were assessed pre and postoperatively with arthrometer testing, 3 different knee ligament rating scales, stress radiography, and physical examination. Arthroscopically assisted combined ACL/PCL reconstructions were performed using the single incision endoscopic ACL technique, and the single femoral tunnel–single-bundle transtibial tunnel PCL technique. PCLs were reconstructed with allograft Achilles tendon (26 knees), autograft BTB (7 knees), and autograft semitendinosus/gracilis (2 knees). ACLs were reconstructed with autograft BTB (16 knees), allograft BTB (12 knees), Achilles tendon allograft (6 knees), and autograft semitendinosus/gracilis (1 knee). MCL injuries were treated with bracing or open reconstruction. Posterolateral instability was treated with biceps femoris tendon transfer, with or without primary repair, and posterolateral capsular shift procedures as indicated. No Biomet graft tensioning boot was used in this series of patients.

Postoperative physical examination results revealed normal posterior drawer/tibial step off in 16/35 (46%) of knees. Normal Lachman and pivot-shift tests in 33/35 (94%) of knees. Posterolateral stability was restored to normal in 6/25 (24%) of knees, and tighter than the normal knee in 19/25 (76%) of knees evaluated with the external rotation thigh-foot angle test. 30° varus stress testing was normal in 22/25 (88%) of knees, and grade 1 laxity in 3/25 (12%) of knees. 30° valgus stress testing was normal in 7/7 (100%) of surgically treated MCL tears, and normal in 7/8 (87.5%) of brace treated knees. Postoperative KT-1000 arthrometer testing mean side-to-side difference measurements were 2.7 mm (PCL screen), 2.6 mm (corrected posterior), and 1.0 mm (corrected anterior) measurements, a statistically significant improvement from preoperative status ($p = 0.001$). Postoperative stress radiographic side-to-side difference measurements measured at 90° of knee flexion, and 32 lb of posteriorly directed proximal force were 0–3 mm in 11/21 (52.3%), 4–5 mm in 5/21 (23.8%), and 6–10 mm in 4/21 (19%) of knees. Postoperative Lysholm, Tegner, and HSS knee ligament rating scale mean values were 91.2, 5.3, and 86.8, respectively, demonstrating a statistically significant improvement from preoperative status ($p = 0.001$). No Biomet graft tensioning boot was used in this series of patients.

The conclusions drawn from the study were that combined ACL/PCL instabilities could be successfully treated with arthroscopic reconstruction and the appropriate collateral ligament surgery. Statistically significant improvement was noted from the preoperative condition at 2–10-year follow-up using objective parameters of knee ligament rating scales, arthrometer testing, stress radiography, and physical examination. Postoperatively, these knees are not normal, but they are functionally stable. Continuing technical improvements would most likely improve future results.

The results of allograft multiple ligament knee reconstructions using the Biomet Sports Medicine (Warsaw, IN) mechanical graft tensioning device were published by Fanelli, et al. in 2005 [13]. This data presents the 2-year follow-up results of 15 arthroscopic assisted ACL–PCL allograft reconstructions using the Biomet Sports Medicine graft tensioning boot. This study group consists of 11 chronic and 4 acute injuries. These injury patterns included 6 ACL–PCL–PLC injuries, 4 ACL–PCL–MCL injuries, and 5 ACL–PCL–PLC–MCL injuries. The Biomet Sports Medicine tensioning boot was used during the procedures as in the surgical technique described above. All knees had grade III preoperative ACL/PCL laxity, and were assessed pre and postoperatively using Lysholm, Tegner, and Hospital for Special Surgery knee ligament rating scales, KT-1000 arthrometer testing, stress radiography, and physical examination.

Arthroscopically assisted combined ACL/PCL reconstructions were performed using the single incision endoscopic ACL technique, and the single femoral tunnel–single-bundle transtibial tunnel PCL technique. PCLs was reconstructed with allograft Achilles tendon in all 15 knees. ACLs was reconstructed with Achilles tendon allograft in all

15 knees. MCL injuries were treated surgically using primary repair, posteromedial capsular shift, and allograft augmentation as indicated. Posterolateral instability was treated with allograft semitendinosus free graft, with or without primary repair, and posterolateral capsular shift procedures as indicated. The Biomet Sports Medicine graft tensioning boot was used in this series of patients.

Post-reconstruction physical examination results revealed normal posterior drawer/tibial step off in 13/15 (86.6%) of knees. Normal Lachman test in 13/15 (86.6%) knees and normal pivot-shift tests in 14/15 (93.3%) knees. Posterolateral stability was restored to normal in all knees. When evaluated with the external rotation thigh-foot angle test 9 knees were equal to the normal knee and 2 knees were tighter than the normal knee. 30° varus stress testing were restored to normal in all 11 knees with posterolateral lateral instability. 30° and 0° valgus stress testing was restored to normal in all 9 knees with medial side laxity. Postoperative KT-1000 arthrometer testing mean side-to-side difference measurements were 1.6 mm (range—3–7 mm) for the PCL screen, 1.6 mm (range—4.5–9 mm) for the corrected posterior, and 0.5 mm (range—2.5–6 mm) for the corrected anterior measurements, a significant improvement from preoperative status. Postoperative stress radiographic side-to-side difference measurements measured at 90° of knee flexion, and 32 lb of posteriorly directed proximal force using the Telos stress radiography device were 0–3 mm in 10/15 knees (66.7%), 4 mm in 4/15 knees (26.7%), and 7 mm in 1/15 knees (6.67%). Postoperative Lysholm, Tegner, and HSS knee ligament rating scale mean values were 86.7 (range 69–95), 4.5 (range 2–7), and 85.3 (range 65–93), respectively, demonstrating a significant improvement from preoperative status.

The authors concluded that the study group demonstrates the efficacy and success of using allograft tissue and a mechanical graft tensioning device (Biomet Sports Medicine graft tensioning boot) in single-bundle single femoral tunnel arthroscopic posterior cruciate ligament reconstruction in the multiple ligament-injured knee. Without the tensioning boot there were 46% normal posterior drawer and tibial step off examinations, and with the graft tensioning boot the normal tibial step offs and posterior drawer examinations improved to 86.6% of the PCL reconstructions in the study group.

22.5 Summary and Conclusions

The principles of reconstruction in the multiple ligament-injured knee are to identify and treat all pathology, accurate tunnel placement, anatomic graft insertion sites, utilize strong graft material, mechanical graft tensioning, secure graft fixation, and a deliberate postoperative rehabilitation program. This chapter has presented my experience using a mechanical graft tensioning boot during posterior cruciate ligament and anterior cruciate ligament reconstruction in the multiple ligament-injured knee. The cyclic dynamic method of posterior and anterior cruciate ligament graft tensioning pretensions the grafts, allows graft settling, and confirms knee range of motion and knee stability before final fixation of posterior and anterior cruciate ligament reconstruction. Our results demonstrate the efficacy and success of using allograft tissue and a mechanical graft tensioning device (Biomet Sports Medicine graft tensioning boot) in single-bundle single femoral tunnel arthroscopic posterior cruciate ligament reconstruction in the multiple ligament-injured knee. We have also found the graft tensioning boot to be equally effective in double-bundle posterior cruciate ligament reconstructions in the multiple ligament-injured knee, in patients with up to 18 year post-operative follow-up, in patients 18 years of age and younger, and revision PCL and multiple knee ligament reconstruction [2, 3, 15–26].

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23 Management of Arterial and Venous Injuries in the Dislocated Knee

Robert P. Garvin and Matthew C. Cindric

23.1 Introduction

Major popliteal artery or vein injury can accompany multi-ligamentous dislocation of the knee, and accounts for one of the most common reasons for medicolegal litigation with this entity. Only with a high clinical index of suspicion, rapid diagnosis, evaluation, and treatment can complications from vascular injury be avoided. Always present in the mind of the vascular surgeon is the very real possibility of a major vascular injury leading to irreversible ischemic injury and limb loss.

Knee dislocation itself is an infrequent injury. It accounts for less than 1% of all extremity injuries. Its rarity adds to the danger of underappreciation of the possibility of associated vascular injury. Modern diagnostic imaging, particularly MRI, has increased the ability to diagnose the ligamentous injuries. Knee dislocation was previously diagnosed on clinical grounds which were often unreliable. Two important practical diagnostic considerations must be appreciated. There is a high incidence of spontaneous reduction of the dislocation by the time orthopedic evaluation is performed which reduces the likelihood of recognizing the injury clinically as a dislocation. Second, knee MRI is generally not obtained at the time of initial injury and is therefore not a factor in the initial diagnostic algorithm.

Vascular injury is associated with knee dislocation in a significant minority of cases. Popliteal artery injury rates range from 7 to 100% in multiple series of knee dislocations [1–18]. In studies published since 1992, the range is 7–32% (Table 23.1) [9–18]. A frequently quoted average is 30%. Many injuries are minor and heal spontaneously without sequelae. Some are significant and present with ischemia or, less frequently, hemorrhage and require immediate treatment for a successful outcome. It is this subgroup with significant vascular injury that accounts for a disproportionate percentage of the serious morbidity, limb loss, and medicolegal exposure.

Recognition of the association of vascular injury with knee dislocation is a prerequisite to successful application of the management strategy. In this publication, the authors will review the mechanics of injury, vascular evaluation, vascular repair, and adjunctive measures as they apply to knee dislocation.

23.2 Mechanics of Knee Dislocations and the Causation of Vascular Injury

Multi-ligamentous disruption of the knee results in injury to the soft tissues in the region. Depending on the magnitude and mechanics of the disruption, neurovascular injury may occur. The mechanism of neurovascular injury is predominantly excessive stretching with some component of mechanical blunt force trauma is also possible. Due to an intrinsically poor collateral pathway bridging the popliteal region, severe ischemia is most often the result of acute popliteal artery occlusion. Without immediate recognition and rapid correction of perfusion, muscle and tissue necrosis occurs within hours, and above-knee amputation is the most likely outcome. A delay in correction of ischemia in excess of 8 h nearly always results in amputation. Better salvage results are seen with more rapid revascularization.

In the modern era, the majority of knee dislocations result from high energy trauma predominantly involving motor vehicles. Trauma to the legs may result from dashboard contact for vehicle occupants, vehicle contact for pedestrians, and environmental contact for motorcycle and all-terrain-vehicle riders. These mechanisms most commonly result in posterior dislocations. The next largest group of

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Table 23.1 Results of 18 studies of knee dislocation and the association with popliteal artery injury and amputation

Study	Knee dislocations	PA injuries	Amputations
Hoover [1]	14	7 (50%)	11 (92%)
Kennedy [2]	22	10 (33%)	5 (23%)
Green et al. [3]	245	78 (32%)	31 (13%)
Donnell et al. [4]	10	10 (100%)	2 (20%)
Jones et al. [5]	22	10 (45%)	1 (5%)
Sisto et al. [6]	20	2 (10%)	0 (0%)
Roman et al. [7]	30	10 (33%)	0 (0%)
Varnell et al. [8]	30	12 (40%)	2 (7%)
Treiman et al. [9]	115	23 (20%)	1 (<1%)
Kaufman et al. [10]	19	6 (32%)	0 (0%)
Dennis et al. [11]	38	9 (24%)	0 (0%)
Kendall et al. [12]	37	6 (16%)	1 (3%)
Wascher et al. [13]	47	11 (23%)	1 (2%)
Martinez et al. [14]	21	7 (33%)	0 (0%)
Abou-Sayed et al. [15]	53	13 (25%)	1 (2%)
Miranda et al. [16]	35	7 (20%)	0 (0%)
Mills et al. [17]	38	11 (29%)	1 (3%)
Stannard et al. [18]	138	138 (7%)	0 (0%)
Total	934	241 (26%)	57 (6%)

knee dislocations results from medium energy trauma, most commonly sporting events such as football, gymnastics, and trampoline activities. Some result from low energy trauma which includes falls and missteps particularly in the obese. Even low energy-induced knee dislocations are associated with a 15% incidence of vascular injury [19]. This incidence rises with the energy involved in the traumatic event and the severity of the orthopedic derangement.

Anatomically, the popliteal artery is secured superiorly at the tendinous attachment of the adductor magnus muscle within the adductor hiatus. Within the popliteal space, it has paired superior genicular arteries, an unpaired middle genicular artery, and then paired inferior genicular arteries. As it traverses the popliteal space, it has relatively little structural attachment before passing behind the fibrous arch of the soleus muscle where it is tightly bound to the posterior aspect of the tibia. Its tibial branches anchor it in place inferiorly as they penetrate the fascial planes in three distinct directions. When the dislocation injury occurs, the linear distance across the popliteal space acutely increases and stretch injury occurs to the vessels and nerves which span this region. Direct contusion of the vessels by the adjacent bone is also possible during the injury process. Contusion is presumed to be most likely to occur in posterior knee dislocations.

The arterial wall consists of three layers which differ in their elastic properties. The single cell layer of the intima is inelastic and requires relatively little linear stretching to disrupt its confluent monolayer structure. Intimal injury then exposes the subendothelial layer, which naturally activates its procoagulant properties. The multilayered smooth muscle cell and elastic fiber zone in the middle of the vessel wall is called the media. It has modest resistance to stretch injury. It is disrupted only after the endothelial layer, and therefore, medial injury exposes the intravascular contents to collagen and other components of the media which are potent thrombogenic substances (Figs. 23.1 and 23.2). The adventitia is the most resistant to stretch injury of the three layers of the arterial wall. It is often the only layer remaining intact following the injury event and maintains vascular integrity. If of extreme magnitude, the stretch injury can cause complete disruption of arterial continuity and the obvious symptoms of ischemia in addition to the consequences of hemorrhage. The latter is nearly always contained within the popliteal space unless the injury is of such severity that skin disruption occurs.

Knee dislocations are characterized by the relationship of the tibia to the femur in the dislocated position. Five categories are commonly described: anterior, posterior, lateral, medial, and rotatory. In 1963, Kennedy described, in the largest series at the time, 22 clinical cases of complete knee dislocation [2]. In addition, he performed and reported the results of an experimental design using human cadaver knee specimens mounted on a static stress machine capable of

Fig. 23.1 Intimal disruption resulting in popliteal artery thrombosis. Figure courtesy of Robert P. Garvin, MD

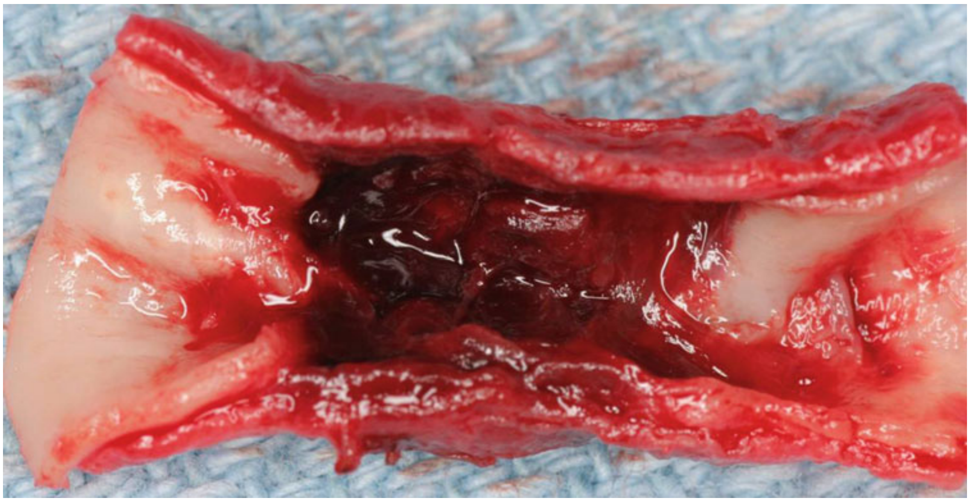

Fig. 23.2 Close-up of intimal injury. Figure courtesy of Robert P. Garvin, MD

reproducing traumatic knee dislocation and measuring the forces involved. He observed that only anterior dislocations could be reproducibly induced. The mechanism of induction involved hyperextension of the knee. This mechanism invariably resulted in stretching of the posterior capsule and cruciate ligaments until rupture occurred. The accompanying stretch injury to the popliteal artery resulted in complete disruption at 50° of hyperextension. He clinically postulated that popliteal injury occurs at a lesser degree of hyperextension, but his model was not sufficient to make a more precise estimate. His model was unable to satisfactorily reproduce posterior dislocations which required disruption of the patellar tendon in each of the few instances produced. Medial and lateral dislocations were generally associated with fracture of the tibial plateau and supracondylar femur and thus dissimilar to the injury seen clinically.

In his clinical series, anterior dislocations predominated (14 of 22) with only one posterior and one posterolateral dislocation. Eight of 22 experienced popliteal artery injury with 5 resulting in above-knee amputations. Three underwent immediate vascular repair with one uneventful recovery, one amputation, and the other developing claudication. In the presence of anatomic arterial injury, delayed exploration universally resulted in amputation. Two patients had popliteal spasm and recovered uneventfully from a vascular perspective. Anterior dislocation accounted for six of the eight vascular injuries. Anterior dislocation is the most commonly reported type of dislocation in older series [3].

Modern series report a predominance of posterior dislocations, thought to be due to the increasing frequency of dashboard trauma from motor vehicle accidents.

More recently, the Wascher modification of the Schenck Classification has been devised. It uses the abbreviation KD for knee dislocation. Increasing anatomic degree of injury is represented by five roman numeral classifications as seen below:

KD-I multi-ligamentous injury without injuring both cruciates
KD-II bicruciate injury only
KD-III bicruciate injury + either posteromedial or posterolateral corner
KD-IV bicruciate injury + both posteromedial and posterolateral corners
KD-V multi-ligamentous injury with periarticular fracture

Advanced imaging modalities have allowed this newer classification scheme where the older system preceded this technological advent and was based on mechanism and clinical exam primarily.

23.3 Vascular Evaluation

Since the majority of these injuries involve high energy trauma, the likelihood of life-threatening-associated injuries is high. Trauma protocols should be universally followed in every case of major traumatic injury. Knee dislocation is most often seen in association with additional serious injuries particularly when a popliteal vascular injury is present. Essentially, there is no systematic data reported for vein injuries in any of these series. In a study from the National Trauma Data Bank, the combination of arterial and venous injury as a result of blunt trauma resulted in the highest amputation rate of 27% [20].

The injured extremity mandates a careful and accurate clinical vascular examination in all situations. Because of the known association of knee dislocation with vascular injury, it is of even greater imperative when multiple ligament injuries are suspected, in particular, avulsion of the posterior cruciate ligament. Nonrecognition or delayed recognition of a significant vascular injury invariably results in an unfavorable outcome. The key to making the diagnosis is a high index of suspicion. Because the minority of multi-ligamentous injured knee dislocations will involve a significant vascular injury, it is important to follow a rigid protocol in their evaluation. A review of such an algorithm which includes a careful and accurate vascular physical exam, ankle–brachial index (ABI) testing, followed by selective duplex evaluation and, when necessary, catheter-based arteriography, will be presented.

23.4 Physical Examination

Pulse examination is the critical element of the physical exam. Reliability is of paramount importance. There is a well-described phenomenon whereby the examiner expects a pulse and therefore reports its detection when it is not actually present. This is most likely to occur when the examiner is inexperienced in vascular evaluation and results from feeling one's own pulse. Confirmation of the presence of a palpable pulse by the additional presence of a normal Doppler signal will reduce the frequency of this mistake. Other clues of vascular injury on the physical exam include coolness, delayed capillary refill, and pale, cyanotic, or mottled discoloration. None of these are entirely specific to vascular injury and may reflect systemic issues such as shock or hypothermia. Associated neurologic abnormalities indicate an increased but not certain risk of vascular injury. These are some of the soft signs of vascular injury and are less frequently absolute indicators.

The hard signs of vascular injury include absent or diminished distal pulses; a visible or expanding hematoma, usually in the popliteal fossa; palpable thrill; audible bruit; or visible pulsatile hemorrhage. The association of these signs with substantial vascular injury requiring repair is high enough to mandate surgical exploration based upon these findings alone. Thus, if on physical exam any hard signs of vascular injury are present after relocation of the knee, immediate surgical exploration or on-table arteriography should be performed. If no hard signs of vascular injury are present, many authorities recommend no further testing beyond a period of observation for 24 h with serial examinations at 4–6-h intervals [18]. One study of 134 knee dislocations in 126 patients resulted in 10 abnormal physical exam findings, and arteriography confirmed 9 arterial injuries and 1 false positive physical exam. No patient with a normal exam developed clinical findings of arterial injury in follow-up. Seventeen normal physical exam patients underwent arteriography due to surgeon preference, and none had an arterial injury. Another study of 35 knee dislocations revealed 6 arterial injuries, and all were identified by physical exam findings which selectively lead to arteriography [16]. Six retrospective studies with a total of 283 knee dislocations involving protocols of selective arteriography for abnormal physical exam have resulted in no reports to date of missed significant arterial injury [9–12, 14, 15]. Anecdotal reports of vascular complications despite a reportedly normal vascular physical exam do exist [6, 9, 20] and continue to fuel this decades-old controversy concerning mandatory versus selective use of arteriography. The majority opinion is that selective arteriography is the most appropriate protocol. Noninvasive arteriographic substitutes such as duplex ultrasound, computed tomographic arteriography (CTA), and magnetic resonance arteriography (MRA) have promise but have not been adequately studied to date to form a conclusive opinion.

23.5 Diagnostic Tests

23.5.1 Ankle–Brachial Index (Fig. 23.3)

ABI testing requires a continuous-wave handheld Doppler and appropriately sized blood pressure cuffs. Using the Doppler to detect resumption of arterial flow after blood pressure cuff inflation, the highest systolic blood pressure is recorded in all four extremities in the supine position. For arm pressures, the cuff is placed in the typical location, and Doppler interrogation is at the brachial artery at the antecubital fossa. In the lower extremities, cuffs are placed as close to the ankles as possible and pressures assessed in both the dorsalis pedis and posterior tibial locations bilaterally. The highest ankle pressure in each leg is then divided by the highest of the arm pressures. Many vascular laboratories today will also assess the peroneal arteries during this exam.

Lynch and Johansen pioneered the use of ABI in the evaluation of penetrating and blunt extremity trauma and compared its results to the findings on arteriography in a prospective study [21]. An ABI less than 0.90 had an 87% sensitivity and 97% specificity for arterial injury compared to arteriography. In a prospective study specific to knee dislocation, an ABI greater than 0.90 has been found to have a negative predictive value of 100% [17]. An ABI of less than 0.90 has reported sensitivities of 95–100% and specificities of 80–100% in detecting arterial injuries requiring operative management [15, 17, 21].

The combination of a careful vascular physical exam with ABI calculation is a standard tenet in the vascular clinic for evaluation of peripheral vascular disease. Many argue that it is mandatory in the evaluation of knee dislocation patients as well. In the study by Miranda et al., the combination of the physical exam with the ABI would not have identified any additional vascular injuries or avoided any complications, but it would have further reduced unnecessary (negative) arteriographic evaluations by an additional 25% [16]. The reduced exposure to iatrogenic risk from the invasive procedure and monetary expenditures would seem a worthy and worthwhile goal.

Fig. 23.3 Technician performing ankle–brachial index measurement of lower extremities. Figure courtesy of Robert P. Garvin, MD

Predominantly the few reported missed injuries of clinical importance after following a non-imaging algorithm have consisted of pseudoaneurysms. These have presented in delayed fashion (weeks to months) with rupture and have been successfully repaired without limb loss [22]. Though delayed recognition of a missed injury is not ideal, it is likely acceptable considering the potential for an equal or greater number of iatrogenic complications with a more liberal invasive arteriographic policy where the vast majority of the arteriograms would be normal or reveal clinically insignificant findings. We would propose that early imaging by noninvasive modalities would identify these lesions and facilitate their repair before the patient's dramatic representation with a delayed diagnosis of a vascular injury.

23.5.2 Catheter-Based Arteriography (Fig. 23.4)

Arteriography is still considered the gold standard for evaluation of arterial injury. The controversy as it applies in evaluation of knee dislocation involves whether to apply it in selective or routine fashion. The incidence of identifying a significant vascular injury in the absence of hard signs is very low. Thus, in the majority of patients, angiography will not provide information that will alter the overall management of the patient. Furthermore, angiography is not without risk, as potential complications such as iatrogenic arterial injury, access site complications, contrast-induced nephropathy, and radiation injury can complicate an already challenging case. Therefore, when hard signs of vascular injury are present, arteriography should be used to identify the exact location and nature of the injury and to help formulate an expeditious operative approach to correct the injury in a timely fashion.

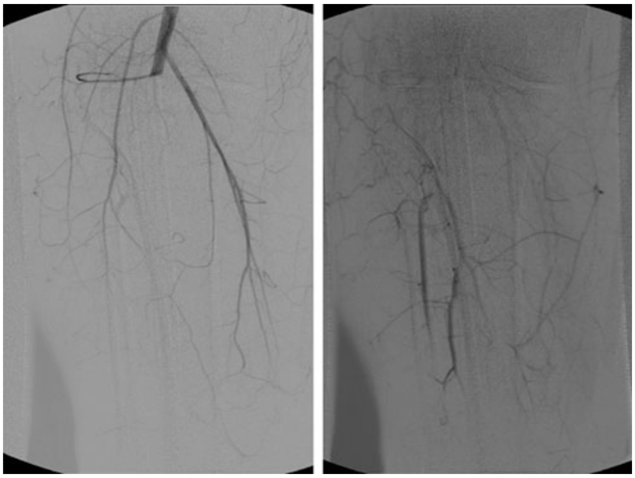

Fig. 23.4 Popliteal injury after knee dislocation: arteriogram showing popliteal artery occlusion (left image) at joint space with geniculates reconstituting proximal anterior tibial and peroneal arteries (right image). Figure courtesy of Robert P. Garvin, MD

Outcome is best when confirmation and correction of vascular injury are made rapidly [23]. Delays in excess of 6–8 h often end in tissue loss and/or amputation. To facilitate management, arteriography should ideally be performed in the operating room with the patient under anesthesia, with the affected extremity prepped and draped and ready for operative intervention. When arteriography is performed outside of the operating room, unnecessary delay is introduced into the treatment algorithm, and is best avoided altogether.

Depending on the severity and certainty of the clinical indicators of vascular injury, the arteriogram will obviate the need for vascular exploration and on occasion can provide correction of the abnormality. These are generally infrequent outcomes and are predictably more common as the clinical indicators are less certain and severe. Most of these patients could have been managed without arteriography with no clinically important complications. It must be reiterated that when hard signs of vascular injury occur, the patient should be taken to the operating room for vascular evaluation and management. An excellent and detailed review of this algorithm is presented by Nicandri et al. [24].

23.5.3 Duplex Ultrasound

Duplex evaluation of extremity arterial anatomy and hemodynamics is another standard vascular practice. Extremity duplex ultrasound is an ideal application of the technology because the vessels are in close proximity to the skin and the soft tissues transmit ultrasound frequencies well. In one series, arterial duplex identified all arterial injuries in a series of penetrating extremity trauma patients [25]. In anecdotal cases, it has been used in the evaluation of vascular injury after knee dislocation, but no randomized studies have been published. Despite not being rigorously studied in the trauma setting, there is an expectation that duplex technology would have excellent sensitivity in the detection or exclusion of significant vascular injury. Benefits of duplex imaging include its noninvasive nature, its portability, safety, and low expense compared to catheter-based arteriography, CT arteriography, or MR arteriography. One disadvantage is that an experienced sonographer may not always be readily available around the clock and on weekends, even in level 1 Trauma Centers. Duplex evaluation is also technician-dependent, which adds another limitation.

23.5.3.1 Computed Tomographic Arteriography (Fig. 23.5)

Advanced CT imaging is available 24/7 in nearly every facility and certainly at major trauma centers in the current era. Using modern CT scanners and intravenous contrast injection, CT arteriography (CTA) images with excellent resolution are rapidly acquired. Radiologic interpretation is

Fig. 23.5 CTA of popliteal artery occlusion of right lower extremity. Figure courtesy of Robert P. Garvin, MD

frequently available instantaneously or with minimal delay, and most vascular surgeons are facile with CTA interpretation even in the absence of radiologist support. Prompt evaluation of the concomitant orthopedic and vascular injuries can be made with a single examination. In a general study of extremity trauma patients with suspected vascular injury, CTA demonstrated sensitivity and specificity in excess of 90% [26]. CTA is routinely used to plan vascular surgical procedures for a wide range of pathologies and is readily used by vascular surgeons in the modern era. Its beneficial application to vascular injury after knee dislocation has been demonstrated and does not represent a major departure from its current routine use in the standard vascular patient. The requirement for a relatively large contrast bolus, expense, and radiation exposure are the main drawbacks.

23.5.3.2 Magnetic Resonance Arteriography

Magnetic resonance arteriography (MRA) has some disadvantages compared with CTA in the trauma population, including its lack of widespread acceptance, variable access around the clock in some centers, and its longtime of image acquisition. From an imaging perspective, MR technology provides exceptional orthopedic evaluation and is the study of choice for many orthopedic pathologies. It can offer vascular evaluation and images that are comparable to CTA and catheter-based arteriography, but in the severely injured patient, it has practical limitations and safety concerns because of the need to exclude metallic equipment from the scanner region and longer image acquisition times. It is best reserved for the elective orthopedic evaluation in the stable patient, a time when the vascular considerations have already declared themselves to be of no major clinical consequence. It may detect more subtle delayed vascular complications from incomplete healing of the initial injury such as pseudoaneurysm, intimal flap, hematoma, or deep vein thrombosis. Vascular imaging can be obtained without contrast administration but resolution suffers. Renal insufficiency (GFR <30 mg/dl) precludes the administration of current MRI contrast agents, but in the general trauma population, this concern is often not an issue (Fig. 23.6).

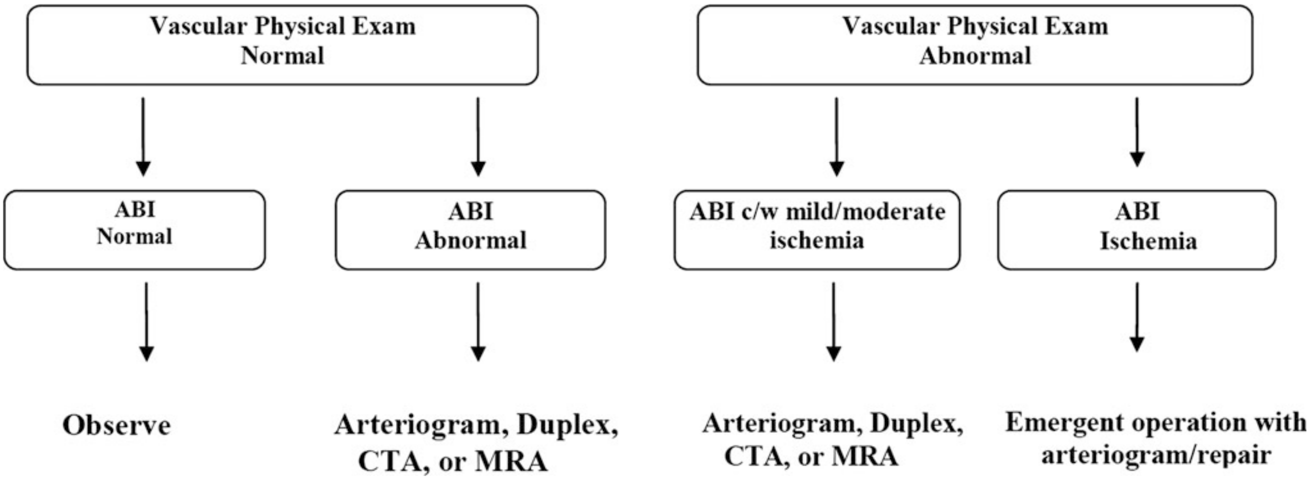

Fig. 23.6 Simplified management algorithm for vascular evaluation with knee dislocation. In hospitals with limited availability of vascular reconstructive services, routine arteriography and/or transfer to a higher level of care facility is recommended

23.6 Treatment

The injured patient with suspected popliteal arterial injury and an acutely ischemic lower extremity must first be thoroughly evaluated using standard Advanced Trauma Life Support protocols. Concomitant life-threatening injuries, if present, must be addressed first. Once satisfactory stabilization of the patient is achieved, expeditious management of the popliteal artery injury is indicated.

Systemic anticoagulation using 100 units/kg of unfractionated heparin should be performed, provided there are no contraindications such as intracranial hemorrhage or evidence of bleeding into pericardium, peritoneal cavity, retroperitoneum, or extremities. Early anticoagulation serves to mitigate secondary thrombosis of the microcirculation of the distal extremity, which otherwise may cause revascularization efforts to fail. When systemic use of heparin is contraindicated, regional use of heparinized saline is generally adequate once vessels are exposed and controlled, but obviously, there is a time delay in getting to this part of the care.

Unless there is a significant delay in the availability of orthopedic expertise, immobilization of the injured knee if it is substantially unstable using external fixation should ideally precede definitive arterial repair. In most scenarios, stabilization can be accomplished rapidly and will safeguard against limb instability consequences jeopardizing the integrity of the vascular repair. When feasible, the vascular surgeon should be present to assist with planning the placement of external fixation, as improperly located hardware may hamper surgical exposure during revascularization. The importance of clear physician-to-physician communication cannot be overemphasized in this situation.

There are two open surgical approaches to popliteal artery injuries, medial and posterior. In the medial approach, the patient is placed in the supine position with the injured lower extremity externally rotated and supported under the knee (the presence of external fixation limits the ability to simultaneously flex hip and knee). Exposure of the proximal popliteal vessels is obtained through a longitudinal medial distal thigh incision [27]. Once the subfascial plane is entered, the sartorius is retracted posteriorly, the popliteal fat pad is entered, and the vessels readily exposed. The distal popliteal artery is exposed through a separate longitudinal medial calf incision parallel and one fingerbreadth posterior to the proximal tibia. The medial head of the gastrocnemius muscle is retracted posteriorly. The popliteal fossa is entered and the distal popliteal vessels exposed. Care must be taken to avoid injury to the tibial nerve which is in intimate approximation to the vessels in this location.

The posterior approach requires prone positioning of the patient and for this reason is often not the preferred approach in the setting of concomitant orthopedic and vascular injuries, especially when external fixation is required to stabilize the orthopedic injury prior to vascular repair. It is imperative to first provide adequate cushioning for both lower extremities if this approach must be utilized. The presence of external fixation usually mandates a liberal stack of pillows or blankets to maintain a position that not only facilitates exposure but also prevents unintended injury. A “lazy S” incision is made medially along the distal thigh, horizontally across the skin crease, and laterally along the proximal calf. Subcutaneous flaps are created, and fascia is incised. Depending on the extent of soft tissue injury, the lesser saphenous vein may or may not be readily identified. Care is taken to avoid inadvertent neural injury while dissection of the neurovascular bundle is performed [28]. The mid portion of the popliteal artery is very nicely exposed through this approach, but often in the setting of a traumatic injury, local soft tissue edema and hematoma distorts the otherwise pristine anatomy that is appreciated only in the elective setting.

Each surgical approach has practical advantages and limitations. The medial approach permits supine position for the entire procedure (fixation, vein harvest, and reconstruction). Provided, there is a suitable length of autologous conduit, the medial approach may allow for expedient exposure in areas with less soft tissue injury and distortion by hematoma. The locations of incisions, inherently with less tension than the prone approach, facilitate successful wound healing. Additionally, fasciotomies of the superficial and deep compartments of the lower leg can be easily performed by mere extension of the distal incision. The posterior approach requires staging of the procedure: supine positioning for harvest of the contralateral thigh saphenous vein which is usually the best size match, followed by prone positioning for repair. The ischemic time, therefore, should be considered. Wound healing may be more problematic, owing to soft tissue swelling related to injuries as well as reperfusion. The posterior approach does provide excellent visualization of involved vessels, however. Through this approach, occasionally the popliteal artery can be repaired primarily after initial debridement; otherwise, posterior exposure allows for the minimal necessary length of arterial (and venous) reconstruction. In the setting where saphenous veins are not satisfactory and exhaustive search for other venous conduit is prohibited by time, a much shorter synthetic graft can be placed from the posterior approach, which improves patency relative to the medial approach.

Provided that it is of acceptable caliber (>3.5 mm), greater saphenous vein (GSV) remains the conduit of choice. With an endothelium that naturally elaborates a variety of antithrombotic factors, patency is strongly favored over synthetic conduit such as Dacron or expanded polytetrafluoroethylene (PTFE). Furthermore, the risk of infection in a traumatic operative field is reduced when using autologous vein. The most appropriately sized saphenous vein is most often located in the proximal thigh, and is exposed through an incision beginning 2 cm laterally and inferior to the pubic tubercle and carried distally as far on the thigh as necessary to obtain adequate length for reconstruction. Of paramount importance, both legs should be prepared for vein harvest. The contralateral leg should be explored for vein first, as preexisting deep venous injuries or subsequent deep vein thrombosis due to swelling and instrumentation may make the superficial venous system of the injured leg a critical collateral pathway for venous outflow that influences the durability of arterial repair.

An exception to proceeding in this order is if the ischemic period has already been long and the degree of ischemia severe. In this situation, repair should be done in the supine position with proximal and distal arterial exposure beyond the region of injury performed first. A temporary shunt is then placed and checked to confirm patency and distal flow. Once reperfusion is established, appropriate conduit for bypass can be harvested.

From a posterior approach, the popliteal artery is exposed, and proximal and distal control is obtained. The level of injury is identified and the popliteal artery is opened lengthwise and inspected; injured areas should be debrided and resected back to healthy artery. Antegrade and retrograde flow are next established, and commonly a Fogarty balloon catheter is helpful for this purpose. Instillation of heparinized saline prevents thrombosis while the repair is performed.

Infrequently, the injury is limited to an intimal flap or short arterial segment. Judicious use of tacking sutures and vein patch angioplasty may be all that is required to manage an intimal flap. A direct, end-to-end repair of the popliteal artery can occasionally be performed if the involved segment is short (~1 cm), but often this approach will require extensive mobilization of the popliteal artery with ligation and division of geniculate collateral vessels, making it less appealing. In any case, primary repairs are ill-advised if the remaining arterial ends cannot be brought together without tension or if tension-free repair could only be obtained by failing to debride injured artery.

Most often, an interposition graft using GSV is required. The choice of reversed or non-reversed vein is less important than an appropriate size match; if a non-reversed configuration is selected, valve lysis is mandatory, either initially or before completion of the distal anastomosis. Vessel ends are spatulated to prevent stenosis at the suture line. Intima-to-intima re-approximation is performed using 5–0 or 6–0 nonabsorbable monofilament suture in standard fashion (Fig. 23.7).

From a medial approach, the conduct of the operation differs in that the actual area of injury is often not visualized. Instead, the goal is to construct a bypass from the healthy above-knee popliteal artery to the healthy below-knee popliteal artery, thus bypassing the injured segment. If the injured segment was completely thrombosed, no effort is made to surgically remove the thrombus. Some authors even recommend suture ligating the popliteal artery on either side of the injury/thrombosis in order to prevent the possibility of distal embolization. In cases where there is clear evidence of

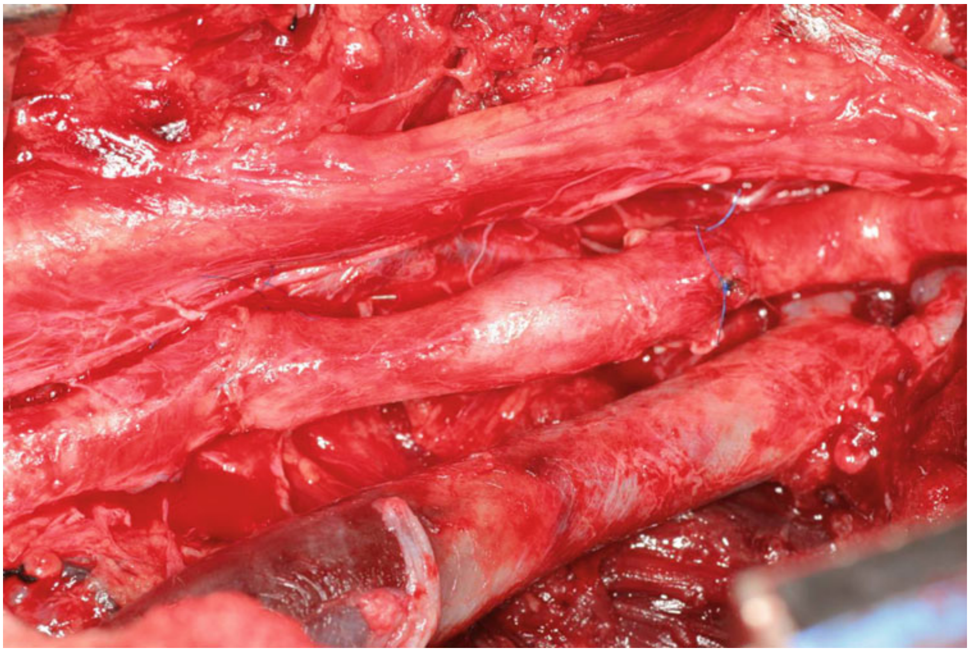

Fig. 23.7 Completed repair of popliteal artery with interposition saphenous vein graft. Figure courtesy of Robert P. Garvin, MD

complete popliteal artery transection, the popliteal artery should be suture ligated on either side of the injury to prevent hemorrhage following arterial reconstruction.

On completion of the reconstruction, whether it be from a posterior or a medial approach, adequacy of the distal circulation must be ascertained. Some surgeons routinely use angiography at this point, whereas others will only use it selectively when pedal pulses are not immediately palpable following repair. Either a small gauge (#20) butterfly needle or small caliber arterial catheter may be utilized for contrast injection. Digital subtraction angiography is preferred, and imaging should include not only the repair site but also the runoff vessels. If there is inadequate runoff to the foot, additional adjunctive surgical maneuvers may need to be employed by the vascular surgeon, the details of which are outside of the scope of this chapter, but the goal is to not leave the operating room until flow to the foot has been unequivocally reestablished.

Repair of popliteal venous injuries is less straightforward. Options include simple ligation, venorrhaphy, and interposition grafting. In the 1960s, the paradigm was to reconstruct all major venous injuries along with the arterial injuries. Proponents argued that the ensuing venous hypertension from venous ligation would compromise the patency of the arterial repair; furthermore, impaired venous outflow compounds the edema in the postoperative period, which already may be considerable due to reperfusion injury. However, several more contemporary series demonstrate similar long-term morbidity and outcomes between ligation and repair. Additionally, the majority of venous repairs or reconstructions ultimately go on to thrombose in the post-op period. Overall, the combined arterial and venous injury does have a worse outcome than arterial injury alone [20].

Accordingly, venous repairs should be undertaken selectively. In a hemodynamically stable patient with injuries amenable to lateral venorrhaphy or simple re-approximation, this approach is prudent. If the anatomic distribution of injury would require more extensive repair—synthetic or composite interposition grafts—or if the patient is unstable, simple ligation is preferable [29, 30]. The topic of vein repair versus ligation remains controversial, and available published data include penetrating traumatic mechanisms and dislocations associated with fractures. No definitive conclusions can be made; thus, it remains an unresolved issue. If ligation is chosen as the most prudent maneuver given the particular situation, effort should be made to ensure the ipsilateral greater saphenous vein is uninjured as it will serve as the primary collateral pathway for venous drainage of the leg. Postoperative leg compression and elevation help with management.

Four-compartment fasciotomy should be strongly considered at the time of arterial reconstruction based on the nuances of the case. Prophylactic fasciotomy is advised in the following circumstances: confirmation of compartment syndrome by direct pressure measurements, concomitant venous repair or ligation, prolonged ischemia, extensive injury or swelling, concomitant disabling neurologic injury in which physical assessment may be confounded, and institutions where rapid return to the operating room is compromised. In settings where the patient has multiple other injuries that require separate time-consuming diagnostic or therapeutic interventions, prophylactic fasciotomy should likewise be considered. Proponents of prophylactic fasciotomy cite avoidance of a second ischemic event as a critical determinant of limb salvage.

If fasciotomy is not performed at the time of reconstruction, bedside clinical assessment by experienced personnel is crucial to detect the development of compartment syndrome. Direct transduction of compartment pressures remains the most reliable method and in fact may be the only reliable method in sedated, intubated, or neurologically impaired patients. Otherwise, a complete neurovascular assessment, coupled with limb circumference measurements, is imperative. Caution is advised when using a palpable pulse as a determinant of compartment syndrome; loss of pulses is a late finding in the sequence of progressive tissue injury.

Primary amputations are not often indicated on a presentation based on ischemia alone. However, devastating injury of the tibial nerve, extensive associated crush or mangling injuries, and prolonged warm ischemic time (associated with rigor or capillary extravasation) forecast a dismal prognosis. In these selected circumstances, limb salvage efforts may not only be futile but place the patient at unnecessary risk of death or renal failure from myoglobinuria, and primary amputation may be indicated. It should be a unanimous decision by the vascular surgeon, orthopedic surgeon, and trauma surgeon to proceed with primary amputation, and compelling reasons for this approach should be well documented in the medical record.

Optimal outcomes after knee dislocation with arterial and venous injuries can be accomplished in the majority of cases. With a high index of suspicion for the presence of a vascular injury and a clear understanding of the management strategy, the disastrous consequences of the missed vascular injury can be avoided. It is our hope that the information provided in this review will be used to facilitate management and improve outcomes in patients who present with combined knee dislocations and vascular injuries.

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Tendon Transfers for Peroneal Nerve Injuries in the Multiple-Ligament-Injured Knee

24

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Abbreviations

CPN	Common Peroneal Nerve
PCL	Posterior cruciate ligament
PLC	Posterolateral corner
MRC	Medical Research Council
EMG	Electromyography
NCV	Nerve conduction velocity
NAP	Nerve action potential
MRI	Magnetic resonance imaging
AFO	Ankle foot orthosis
PTT	Posterior tibial tendon
FDL	Flexor digitorum longus

24.1 Introduction

Multiligament knee injuries due to knee dislocations are a complex injury often leading to concomitant neurovascular injury. The common peroneal nerve (CPN) is a common injury seen with knee dislocations. The CPN is vulnerable to injury due to its anatomic location and firm attachment to surrounding soft tissue structures about the lateral side of the knee [1, 2]. The reported incidence of injury to the CPN during knee dislocation varies between 4 and 50% [3–12]. Owens et al. concluded that CPN injury was found in 75% in patients with knee dislocations [13]. Multiple studies have demonstrated that CPN injuries are more prevalent with high-energy injury mechanisms (e.g., motor vehicle or industrial accidents), open dislocations, and knee dislocations associated with posterior cruciate ligament (PCL) and posterolateral corner (PLC) injuries, increased body mass index, and fibula fractures [1, 10, 14–16]. CPN injuries may range from incomplete, which often lead to paresthesias, to complete nerve palsy causing motor weakness in dorsiflexion of the ankle and toes, as well as foot eversion. This motor deficit often causes significant disturbances in the gait pattern leading to the need for an orthotic or surgical intervention.

Long-term outcome studies suggest that half of CPN injuries recover spontaneously [17]. Patients with injuries to multiple ligaments and persistent CPN palsy have worse functional outcomes [16, 18]. Surgical treatment is required for cases with irreversible nerve injury and/or persistent functional deficits. Controversy exists regarding the timing and type of surgical intervention. This chapter discusses the anatomy, pathophysiology, evaluation and treatment options for CPN injuries.

24.2 Anatomy

The CPN is a division of the sciatic nerve and is composed of nerve roots L4-S3. The sciatic nerve courses through the posterior thigh and divides into the tibial and common peroneal nerves just proximal to the popliteal fossa and deep to the biceps femoris. The CPN continues to track distally to the posterior lateral corner (PLC) deep to biceps tendon as the nerve makes its course to the lateral compartment of the leg [18] (Fig. 24.1). The CPN takes a turn to curve around the neck of the fibula, where it lies directly over fibular periosteum for approximately 6 cm. At this level, the nerve is protected solely by subcutaneous tissue and skin [19].

The CPN typically divides into three branches. The first branch, the lateral articular nerve, innervates the inferolateral

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Fig. 24.1 Anatomy of the lateral aspect of the knee. **a** Iliotibial band, **b** biceps femoris, **c** common peroneal nerve, **d** lateral head of the gastrocnemius, **e** location of the head of the fibula

portion of the knee joint capsule and the lateral collateral ligament. Between the peroneus longus muscle belly and the proximal fibula, the nerve divides into the two main branches: the superficial and deep peroneal nerves. The superficial branch passes through a tunnel formed by the origin of the peroneus longus muscle and the intermuscular septum. It travels between and innervates the peroneus longus and brevis muscle, which act to evert the foot. The superficial branch also provides sensory innervation to the anterolateral aspect calf and the dorsum of the foot.

The deep peroneal nerve passes through a second fibro-osseous tunnel formed by the origin of the extensor digitorum longus muscle, approximately 4 cm distal to the peroneal muscle tunnel. The deep peroneal nerve innervates the muscles of the anterior compartment of the leg: tibialis anterior, extensor hallucis longus, extensor digitorum longus, and peroneus tertius. The tibialis anterior is the main dorsiflexor of the ankle joint. Within the foot, the deep peroneal nerve innervates the intrinsic toe extensors, the extensor digitorum brevis, and the extensor hallucis brevis. The deep branch provides sensory innervation to the first web space [20].

24.3 Injury Mechanism and Pathoanatomy

Knee dislocations are classified by energy level of the injury or according to the anatomic location [21]. Kennedy described knee dislocations as anterior, posterior, medial, lateral, or rotatory, which refers to the position of the proximal tibia in relation to the distal femur [4]. Traction injuries to the CPN are associated with anterior and anteromedial dislocations which a result of a stress varus and hyperextension forces. These stretch injuries are attributed to the firm periosteal attachment of the CPN in the region of the fibular neck. Traction mechanism injuries can range from a mild stretch to complete rupture of the nerve. The posterior dislocation pattern has a higher rate incidence of injury to the neurovascular structures around the knee. According to some studies, CPN injuries are 100% correlated with concomitant PLC injuries following posterior knee dislocations [20]. Among all dislocations, posterolateral mechanism is most likely to cause permanent peroneal nerve injury [3, 22–24].

It is important to recognize the energy and mechanism associated with knee dislocation occurred. High-velocity mechanisms such as motor vehicle accidents, pedestrian versus motor vehicle, motorcycle accidents, and falls from a height, are more likely to have associated neurovascular injuries. An ipsilateral popliteal artery injury has a 44% association with CPN palsies [25]. Peroneal nerve injuries in traumatic knee dislocation are also common in sports injuries [26, 27]. A knee dislocation with a concomitant fibula head fracture is highly indicative of a posterolateral corner injury and therefore an injury to the CPN. Additionally, morbidly obese patients may sustain knee dislocations during daily activities which may result in CPN palsy after these ultra-low energy knee injuries [25, 27, 28].

Mechanism of nerve injury includes laceration, compression, traction, and focal ischemia [29]. An injury causing elongation 15% or greater than the length of the nerve can cause disruption to both the intraneural and extraneural microvasculature. This may result in a complete failure of its blood supply [30]. Tomaino et al. demonstrated that a stretch injury mechanism may result in a longer overall zone of injury compared to a complete rupture [31]. The length of trauma to an intact CPN is predictive of functional recovery [8].

Stretch injuries may also rupture the vaso nervorum, the nutrient vessels of the nerve. Damage to these vessels may result in ischemic changes from a compressive hematoma. This bleeding causes a gradual expanding hematoma, which delays the presentation of the nerve palsy. CPN function may be normal immediately post injury, but will then regresses over 24–48 h. As symptoms of paresthesia and/or motor weakness develop, immediate surgical intervention is indicated. For these delayed presentations, a surgical release will likely provide immediate relief, and possible full recovery [32].

The CPN is more susceptible to injury during knee dislocations than other neurologic structures for several anatomic and biologic reasons. These include the 4–6 cm-long subcutaneous course around the neck of the fibula where, the tethered anatomy of the deep and superficial branches below the knee, and the relatively thin epineurium. Epineural thickness refers to the ratio of epineurium to the fascicular area on cross-section [2, 32–35]. The decreased thickness is partially due to less adipose tissue being present compared to the tibial division. Additionally, the peroneal division of the sciatic nerve is composed of fewer and larger bundles compared to the tibial, leaving it more prone to injury [36].

The Seddon's or Sunderland's classification systems are widely used for classifying peripheral nerve injuries [36, 37] (Tables 24.1 and 24.2). Neuropraxia is defined by a localized conduction deficiency, usually secondary to compression. In this injury, axonal continuity is preserved. Axonotmesis is defined as the loss of continuity of axons, with preservation of the connective tissue elements of the nerve. Neurotmesis is the most severe injury, equivalent to physiologic disruption of the entire nerve. It may or may not include complete transection of a nerve.

24.4 Physical Examination

The diagnosis of neurological injury is made clinically. A complete history and physical examination should be obtained prior to any reduction. Crucial during the history is ascertaining the mechanism of injury. In the setting of an unconscious patient with a knee dislocation, a high energy mechanism, obese body habitus, fibula neck fracture and, an ipsilateral vascular injury should prompt suspicion for a peroneal nerve injury [20]. Examination of the ligaments and neurovascular structures should be obtained pre- and post-reduction. During the examination, care should be taken not to place further strain on neurovascular structures.

If a knee dislocation is reduced prior to presentation to the hospital it is crucial to have a high index of suspicion of neurovascular injury. Neurological examination should include an assessment of any muscle weakness and/or sensory deficit. Muscle weakness is graded on the Medical Research Council (MRC) scale and the individual muscles innervated by the common peroneal nerve should be assessed [38]. The MRC scale is a 0–5 graded scale (Table 24.3). Active foot eversion is tested to evaluate the motor function of the superficial peroneal nerve. Deep peroneal nerve motor function is tested by active dorsiflexion of the ankle and extension of the toes. A complete peroneal palsy results in loss of ankle dorsiflexion, foot eversion, and toe extension. In a chronic setting, an unopposed tibialis posterior muscle and Achilles presents as an equinovarus deformity. If considering tendon reconstruction a Silverskiold test should be performed in a patient with an equinous contracture to evaluate the etiology of the contracture for a potential release. Patient's gait will demonstrate a characteristic foot slap within the heel strike and a steppage gait pattern [39]. The careful sensory examination can assist with localization of a nerve injury. The deep peroneal nerve supplies cutaneous sensation to the web space between the first and second toes. The remainder of the dorsum of the foot is innervated by branches of the superficial peroneal nerve.

With the peroneal nerve injuries, sensation to the plantar aspect of the foot is spared. In cases of intraneural hematoma, numbness and foot drop may present hours to days after the initial reduction. Decreased sensation and paralysis in the extremity may also result from vascular injuries. Therefore, a delay in the diagnosis of nerve injury can be confused with an ischemic limb [40]. Sensory deficits secondary to compartment syndrome are typically in a stocking pattern and do not follow the standard dermatomal pattern. Intact sensation in the presence of an incomplete motor deficit is suggestive of an incomplete nerve injury [41].

The presence of Tinel's sign, which is defined as distal tingling in the sensory distribution of a nerve on proximal percussion of that nerve, is correlated with the regeneration of immature nerve fibers across a damaged section of nerve. It is commonly used as an indicator of sensory nerve regeneration and can appear 3 weeks after injury. Tinel's sign should be expected to progress distally at the same rate as nerve regeneration, approximately one millimeter per day

Table 24.1 Seddon classification of nerve injury

	Outcome
Neuropraxia	Full recovery is likely
Axonotmesis	Functional recovery is likely
Neurotmesis	Nerve will not recover without augmentation

Table 24.2 Sunderland classification of nerve injury

	Outcome
1	Full recovery is likely
2	Functional recovery is likely
3	Full recovery is not likely unless intrafascicular fibrosis is excised
4	Generally, surgical excision is needed
5	Nerve will not recover without augmentation

Table 24.3 Motor function grading scale

	Motor function grading scale
Grade 0	No movement
Grade 1	Trace of contraction
Grade 2	Active range of motioning when gravity is eliminated
Grade 3	Ability to perform range of motion against gravity only
Grade 4	Active range of motion against gravity as well as some resistance(mild weakness)
Grade 5	Normal strength

[1]. It is not always a reliable method, but can be useful in following the progress of nerve regeneration over a period of several months [42].

24.5 Diagnostic Studies

24.5.1 EMG

Electromyography (EMG) and nerve conduction velocity (NCV) testing are commonly used diagnostic tools. They can help determine the site and severity of peripheral nerve injuries, and to predict recovery [33] (Tables 24.4 and 24.5). When clinical evidence of nerve recovery exists on examination, electrodiagnostic studies are unnecessary. EMG findings that indicate nerve injury include positive sharp waves, fibrillation potentials, and polyphasic potentials [1, 41]. These findings typically become present at 2–3 weeks post injury. This limits the usefulness of EMG in the immediate post-injury period. During follow-up, serial EMG testing should be obtained every 3–4 weeks to determine the type of nerve injury. The absence of recovery at 3–6 months post injury is an indication for nerve exploration.

Complete nerve injuries may not successfully conduct a signal and incomplete nerve injuries result in the slowing of the conduction velocity and prolonged latency [33, 43]. Severe axonal damage injuries may recover slowly over a period of several months. Niall et al. reported that the earliest signs of nerve regeneration occurred in the superficial branch of the peroneal nerve supplying the peroneal musculature. The peroneal muscles were noted to recover more often than the muscles of the anterior compartment [8].

Intraoperative NCV and EMG can be helpful in the evaluation of the extent of injury and the potential of the nerve to conduct an impulse. Transmitted nerve action potentials (NAPs) indicate continuity. If no conduction is identified, external and internal neurolysis should be performed. If an NAP is not detected across the injury site, excision and grafting are indicated [44, 45].

24.5.2 MRI

Magnetic resonance imaging (MRI) is an excellent imaging modality for the diagnosis of ligament injuries. It can also be combined with other studies to help define the presence and/or location of the nerve injury [27, 46]. The CPN is typically adjacent to the posterior margin of the biceps tendon and deep to the crural fascia in the posterolateral aspect of the knee. In the presence of nerve pathology, MRI can provide information about the distance between the nerve ends, the presence of constrictive perineural scar tissue, posttraumatic neuroma in chronic injuries, surrounding edema, encasing hematoma within the epineurium, mild contusion, and partial disruption of the fibers [26, 46]. Peltola et al. reported a high correlation between patients who had no clinical symptoms of peroneal nerve injury and normal peroneal nerve findings on MRI [27].

24.5.3 Ultrasound

Gruber et al. proposed utilizing ultrasonography to assess nerve injuries that warrant surgical intervention caused during knee dislocation. This method is superior to EMG

Table 24.4 EMG study interpretation

	Fibrillations	Voluntary Muscle Unit Action potential
Intact	None	Present
Neuropraxia	None	None
Complete lesions: axonotmesis/neurotmesis	Present	None
Incomplete lesion	Present	Decreased in the distributions of injury

Table 24.5 Nerve conduction study interpretation

	Sensory and motor latency	Compound motor action potential/sensory nerve action potential
Intact	Normal	Normal
Neuropraxia	None across area of neuropraxia but normal above and below the lesion	Normal above the lesion
Complete: Axonotmesis/Neurotmesis	Absent	Absent
Incomplete	Normal but may be slightly prolonged	Reduced

because EMG cannot distinguish neuropraxia and axonotmesis and also does not provide information about extraneural impairments (e.g., obstructing hematomas, encasing scar). In this small prospective study, sonographic results of four patients during surgical intervention were evaluated. They concluded that sonography allows visualization of the neural and extraneural pathologies and is additionally able to define the exact level and extension of the lesion. However, appropriate use of this technique requires experienced operators and advanced sonography equipment, which may be limiting factors at some institutions [47].

24.6 Treatment

The aim of the treatment of CPN injury and associated drop foot is to restore normal heel–toe gait. Despite the relatively high incidence of associated peroneal nerve injury, little consensus has been reached regarding treatment. The success of a mixture of nonoperative and operative treatments has been reported over the past several years. Techniques range from physical therapy and bracing to neurolysis, nerve repair, and grafting, to tendon transfers. All treatments are directed at improving function, gait, and ambulation.

24.6.1 Non-operative Treatment

Conservation treatment is initially indicated for most CPN palsies. When there is a complete injury of the CPN, the foot tends toward plantarflexion and inversion. Initial splinting and physical therapy can avoid contracture. These patients require an ankle foot orthosis (AFO) or bracing for toe clearance during gait. AFO is comprised of a molded sheet of plastic, polypropylene or polyethylene, which wraps around the posterior leg and under the foot with fabric straps across the ankle to secure the heel in place. It holds the ankle at 90° dorsiflexion. Recently, semi- hinged and more comfortable designs have become available [48, 49].

Physical therapy should include the strengthening of the remaining functional muscles and stretching of the posterior ankle capsule. Daily stretching is needed to prevent heel cord contracture [34]. If contracture develops, patients may no longer tolerate bracing.

Conservative treatment is recommended if there are signs of reinnervation during follow-up. Even with some signs of regeneration, conservative therapy may not be successful [50]. If transection of a nerve or a complete axon loss lesion is present, strengthening of the denervated muscles is not appropriate.

24.6.2 Surgical Treatment

Decisions regarding surgical technique should depend on whether the lesion is in continuity and has NAPs present in continuity. Functional outcomes after reconstruction of CPN are often disappointing when compared with other frequently injured peripheral nerves. Platt and Lond recommended exploration of peroneal nerve injuries within 3–4 weeks after the injury [51]. However, we feel 3–4 weeks is too early because neuropraxic damage may take up to 3 months to recover. While an AFO or other brace is used to prevent fixed equinus contracture, serial clinical examination and EMG testing every 3–4 weeks should be obtained to determine whether the nerve lesion is a neuropraxia or a more severe disruption. Clinical examination should note whether the lesion is complete or incomplete. In an incomplete lesion, electrical testing is unnecessary and the lesion may be followed clinically to assess recovery [1]. If no signs of clinical recovery or EMG reinnervation occur within 3–4 months after the injury, surgical exploration should be considered [44, 52, 53]. Bowman et al. supported an early exploration of the nerve during ligament reconstructions as well as waiting 9 months for re-exploration of the persistent nerve dysfunction in cases with continuity [54]. The duration between the trauma and surgery did not influence the outcome in Siedel's retrospective series [45].

24.6.3 Neurolysis

Several authors recommend early exploration and neurolysis [8, 17, 41]. Some surgeons perform neurolysis during the preliminary operative procedures for ligament reconstruction [6]. If intraoperative (NAP) recordings indicate regeneration across the lesion, acute external neurolysis is indicated. However, the lack of muscle response to electronic stimulation does not correlate to lack of regenerative potential. Neurolysis entails of myofascial decompression of the nerve. This should include decompression at the level of the fibular neck, with resection of the fibrous constrictions. When exploration is delayed, the nerve is often encased within dense scar tissue. Internal neurolysis is a more technically challenging procedure necessitating microsurgical skills. This entails freeing the individual fascicles within a nerve trunk under a microscope.

Mont et al. reviewed external neurolysis for peroneal nerve palsy of various etiologies. 30 of 31 patients (97%) had an improvement in neurological symptoms following exploration and external neurolysis [55]. In the largest reported series, 121(38%) of 318 patients with knee-level CPN injuries underwent neurolysis after documented transmittable NAPs. Kim et al. reported 88% of patients had favorable outcomes [44]. Additionally, contractility of the peroneal muscles is typically observed at 5 months following neurolysis. Tibialis anterior contraction can be seen from 12 months. Overall, the average recovery period ranged from 12 to 30 months [44]. Seidel et al. demonstrated positive functional results in 73% of patients after treatment with a similar algorithm [45].

24.6.3.1 Nerve Repair

It should be noted that nerve repair is rarely indicated in stretch or avulsion injuries that may involve several centimeters of the damaged nerve. However, refinement in microsurgical techniques and nerve conduction studies, as well as advancements in timing for microsurgical intervention, has led to significant improvements in outcomes, making nerve repair worthwhile in many cases [56]. Acute peroneal nerve repair would require knee immobilization, but current surgical techniques for ligament construction recommend an early range of motion. This dilemma influences some surgeons to observe the foot function. There is no consensus in the literature for how long the peroneal nerve functioning should be observed before a second intervention. Mont et al. demonstrated that surgical interventions performed 6 months after the index surgery had less success than early operative intervention [55]. Due to the excessive length of the nerve and abundance of connective tissue, CPN repair has a poorer prognosis compared to other peripheral nerves [57, 58].

Nerve repairs may be primary or secondary, depending on the time of repair after injury. Secondary repair is a delayed repair when the prerequisites of primary repair cannot be met [59]. If the gap is small and the two ends can be approximated with minimal tension, an end-to-end repair can be performed. End-to-end nerve repair techniques are epineural repair, group-fascicular repair, and fascicular repair. Sharp lacerations without loss of nerve substance or partial lacerations with proper alignment can benefit from epineural repair [60].

24.6.3.2 Nerve Grafting

When a neuroma in continuity that does not conduct nerve action potentials across the lesion is encountered, or when nerve stumps are identified due to a ruptured nerve and primary repair cannot be performed without undue tension, nerve grafting is required.

The ipsilateral sural nerve is the most commonly used donor nerve segment because of its size, accessibility, and relative lack of donor site morbidity.

Cable grafting simply attaches each end of the graft to the free ends of the transected nerve. Cable grafts are multiple small-caliber nerve grafts aligned in parallel to span a gap between fascicular groups. Funicular or interfascicular grafting involves anastomosis of individual funiculi within the graft to individual funiculi within the free ends of the nerve being repaired.

Nerve grafting of the CPN is rarely successful if the length of the damaged nerve is longer than six cm [44, 45, 61]. Graft length is the main predictor of outcome when grafting common peroneal nerve [45].

In a group of 138 patients receiving interfascicular nerve graft repairs for grafts less than six cm long, Kim et al. reported 75% of patients had a successful functional recovery. 38% of patients with graft lengths of 6–12 cm achieved the same functional outcome, whereas only 16% of patients with grafts of 13–24 cm attained proper functionality [44].

24.6.4 Tibialis Posterior (TP) Tendon Transfer

TP tendon transfer to the forefoot is an accepted technique for the restoration of drop foot. It can be used when nerve repair is impossible, when nerve function does not return after repair, or simultaneously with nerve repair to facilitate nerve recovery. There is still controversy about the route of transfer (circumtibial vs. interosseous), type of fixation (bone insertion vs. tendon-to-tendon fixation), and to which tendons the transfer will be made [62–64]. The posterior tibial tendon can be attached either to bony structures such as the medial cuneiform or directly to the tendon of the tibialis anterior [63]. The tendon may also be split for simultaneous attachment to the peroneus longus tendon [65]. Whenever passive dorsiflexion of the ankle beyond a neutral position is not possible, lengthening of the Achilles tendon should be performed simultaneously with the tendon transfer [63, 66, 67].

Milesi suggested that reinnervation could be impaired by the force imbalance between the active plantar flexor muscles and the passively stretched denervated foot and toe extensors. In fact, muscle atrophy in the anterior tibialis becomes obvious within 2 weeks and due to the excessive contraction of the reciprocal Achilles tendon, the foot position becomes fixed shortly thereafter. Some authors advocate combined tibialis tendon transfer with nerve repair in a one-stage protocol to rebalance the forces and allow better reinnervation [57]. Garozzo et al. reported 96% of patients had evident reinnervation at EMG and 74% reported excellent or good results with tibialis posterior tendon transfer combined with nerve repair with grafting or decompression [57]. Others also advocate that nerve grafting would give better results when applied with additional posterior tendon transfer [63, 68].

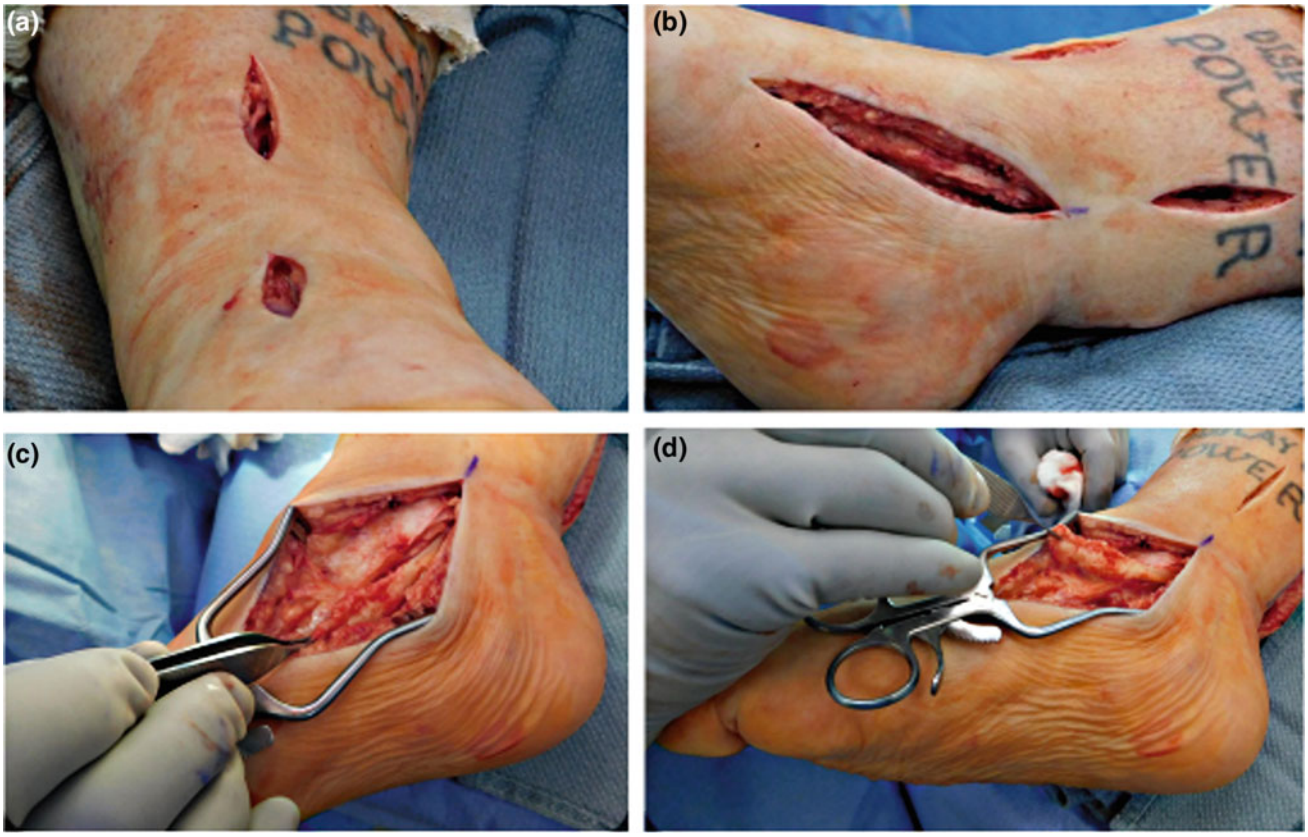

Fig. 24.2 Posterior tibial tendon harvest. **a** Incisions for passing and docking the posterior tibial tendon. **b** Incisions for posterior tibial tendon dissection. **c** Dissection of posterior tibial tendon. **d** Detachment of the posterior tibial tendon

24.7 The Authors' Preferred Operative Treatment

Many patients with peroneal nerve injury and residual drop foot present with previous knee ligament stabilization and neurolysis. Each patient will have a baseline EMG documenting the injury. Initial treatment consists of AFO bracing to prevent contracture and allow for ambulation. Repeat EMGs are performed at 1-month time intervals after knee stabilization. If there is no return of peroneal nerve function and recovery to normal strength in the intact posterior tibial muscle, the posterior tibial tendon transfer is offered.

The posterior tibial tendon is detached from its distal insertion on the navicular through a medial incision on the foot (Fig. 24.2). Great care is taken to maximize the length of the tendon. The sheath in the infra-malleolar region can be released through this incision. Attention is then directed along the medial tibia at the level of the posterior tibial musculotendinous junction. Through an incision here, the distal end of the tendon is pulled proximally. The tendon is then pulled through the interosseous membrane and out through an anterolateral incision above the ankle. At this point, the tendon can be woven through the anterior tibial tendon and combined with the proximal aspect of the peroneal brevis tendon as described in the Bridle procedure [62, 69]. Our experience suggests the tendon be transferred directly into the bone to avoid creep and loss of tensioning. This is done by passing the tendon subcutaneously across the ankle joint. Although maximum dorsiflexion potential is lost when going superficial to the extensor retinaculum, the power of the transfer is increased. This positioning also decreases the likelihood of adhesions. An additional incision is then made on the dorsal aspect of the foot in line with the third metatarsal shaft. The middle or lateral cuneiform is identified and the Arthrex Bio-Tenodesis Screw System (Naples, FL/USA) is used to obtain solid fixation into the dorsum of the foot. The ankle is placed into 20° of dorsiflexion to allow for appropriate tensioning (Fig. 24.3).

In a certain subset of patients, especially those with pes planovalgus of the hindfoot exists, transfer of the flexor

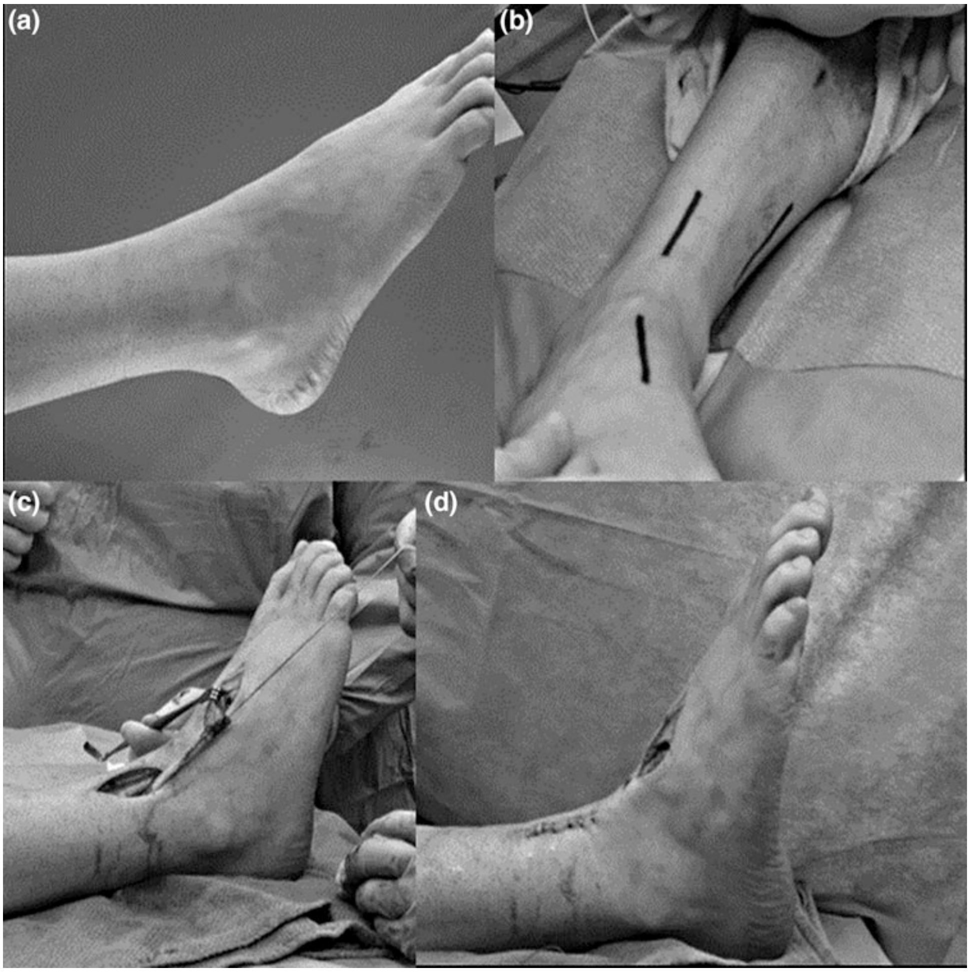

Fig. 24.3 Tibialis posterior transfer from interosseous membrane. **a** Complete drop foot preoperatively. **b** Intraoperative view of incision plans. **c** Posterior tibial tendon resected from the distal end and passed from the interosseous membrane. **d** Improved dorsiflexion after tendon transfer

digitorum longus (FDL) can be performed to give some return of plantar flexion inversion strength. During the harvest of the posterior tibial tendon, the FDL is readily available to be transferred into the naviculum at the footprint of the posterior tibial tendon. The placement of an arthrodesis screw in the sinus tarsi can help decrease the development of further deformity in these patients.

The patient is placed in a non-weight bearing splint for 2 weeks then transferred to a cam walker. Gradual ambulation is begun and increased progressively until the 6-week mark. The use of an AFO can be helpful when transitioning back to routine shoe wear. The posterior tibial tendon transfer allows the patient to be less brace dependent and perhaps even brace independent. Physical therapy is prescribed for muscle re-education. Active dorsiflexion can be initiated as early as 6–8 weeks from the time of surgery.

24.8 Conclusion

Drop foot is a common complication associated with knee dislocations and treatment can be challenging. CPN injuries are seen more commonly with high-velocity injuries, open dislocations, and when the PLC is injured. During the initial management of every suspected kneed dislocation CPN function should be documented through a thorough motor and sensory physical examination. Prospective studies documenting the treatment of common peroneal nerve palsies are lacking in the literature. Thus, a standardized treatment algorithm is yet to be established. However, the authors' preferred algorithm is demonstrated in Fig. 24.4. Early exploration and neurolysis are advocated during ligament reconstruction. If nerve functioning

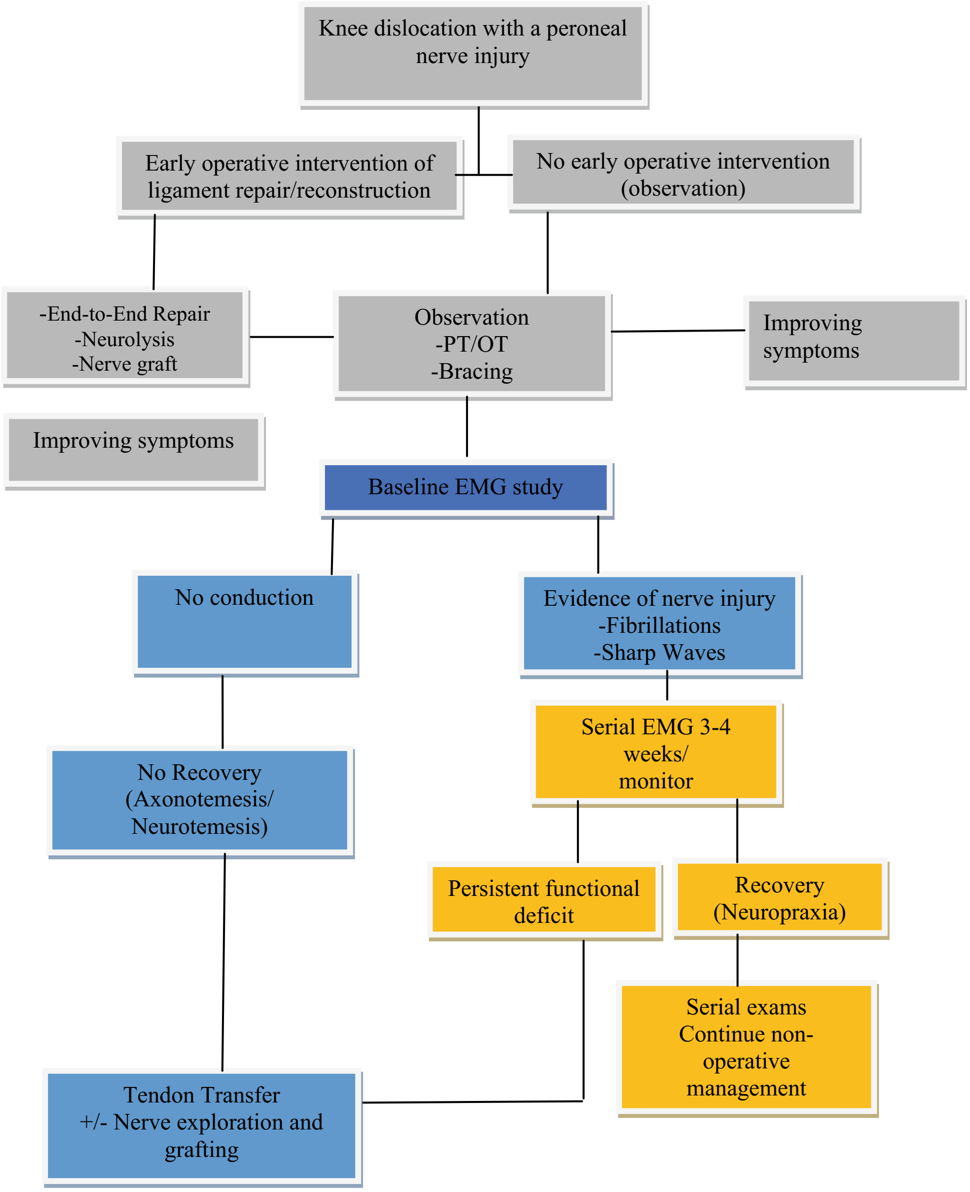

Fig. 24.4 Peroneal Nerve Injury Algorithm. Gray boxes correlate with treatment from time of injury to 3 weeks. Blue boxes indicate treatment between 3 weeks and 3 months. Gold boxes represent treatment 3 months–6 months after injury

is not returned by 1 month after the injury, serial EMG and careful clinical assessment are recommended. Nerve grafting is most successful when injuries do not exceed six cm in length. Posterior tibialis tendon transfer remains the most common surgery and offers the most reliable outcomes.

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25

Direct Nerve Transfer for Peroneal Nerve Injury in Knee Dislocations

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25.1 Introduction

Peroneal nerve injury is a frequent complication of knee dislocation with reports ranging from 14 to 40% [1]. A recent report from the Mayo Clinic has shown that patients with complete peroneal nerve (CPN) palsy have 38% chances of recuperating the capacity to dorsiflex against gravity [2, 3]. Historical treatment options [4] include observation, neurolysis, direct nerve repair, and nerve grafting in acute cases and tendon transfers as well as ankle arthrodesis in chronic cases. Due to the inconsistent outcomes of these treatment methods and significant morbidity associated with peroneal nerve palsies, new surgical treatment strategies are being developed including direct nerve transfer from the intact tibial nerve to the tibialis nerve bypassing the entire zone of injury of the peroneal nerve.

These nerve transfers may be utilized to salvage a failed nerve graft as a primary treatment strategy, to salvage cases with a late diagnosis or in combination with grafts.

Nerve transfers involve the transfer of a functional but less important nerve to a distal but more important denervated nerve [5]. The rationale for nerve transfers in lieu of nerve grafting lies in the physiology of nerve regeneration. Reconstruction of motor nerves is time dependent: irreversible changes occur at the motor endplate that makes nerve reconstruction futile after 8–10 months. Nerve grafting requires that the regenerating nerve traverse the neurorrhaphy site and grow toward the motor end plate before the time-dependent, irreversible changes occur in the end organ. Nerve transfers can be performed with the functioning nerve coapted close to the motor end plate, thus diminishing the regeneration time necessary to reach the motor end plate.

Several anatomical studies of partial tibial nerve transfers have already suggested the feasibility of neurotization of the deep peroneal nerve with partial tibial nerve donor fascicles [6, 7] or partial tibial nerve transfers directly to the motor branches of tibialis anterior [8, 9] which is the surgical technique being discussed in this chapter.

25.2 Mechanism of Injury

The anatomy of the CPN predisposes it to injury from a variety of mechanisms over a length spanning >15 cm, from its proximal origin high in the popliteal fossa to several centimeters distal to the fibular head [6]. Several intrinsic factors predispose the common peroneal nerve to injury including its superficial location around the fibular head, relatively weak vascular supply and a small quantity of epineural connective tissue.

Mechanisms of injury include laceration, compression, traction, and focal ischemia. Elongation injury more than 15% of the length of the nerve yield a complete failure of its blood supply and may cause a much longer zone of injury than a complete rupture [10]. The peroneal nerve is most susceptible to traction injury when the knee is exposed to a varus stress. Other mechanisms include external rotatory torque on the tibia, combined hyperextension and external rotation forces, and both contact and noncontact hyperextension moments. All fractures involving the fibular head or neck can cause CPN injury.

Disruption of the posterior cruciate ligament and the posterolateral corner is associated with an increased incidence of peroneal nerve injury [11]. High-velocity mechanisms such as motor vehicle accidents, pedestrians struck by vehicles, motorcycle accidents, and falls from a height, are more likely to lead to neurological injuries.

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25.3 Nerve Injury Classification

Two nerve injury classification systems are used to the diagnosis and management of CPN injuries. Seddon stratified peripheral nerve injuries into three classes: neurapraxia (mild), axonotmesis (moderate), and neurotmesis (severe) based on clinical relevance. The Sunderland classification of peripheral nerve injury defines five grades based on the pathoanatomy and physiological changes following injury and although more scientific, it is less clinically relevant as pathologic evaluation of nerves is not always feasible (Table 25.1).

25.4 Clinical

The diagnosis of neurologic injury is performed clinically. The common peroneal nerve injury results in loss of sensation to the dorsum of the foot, inability to dorsiflex the foot or extends the toes, and ankle eversion paralysis or weakness. The superficial peroneal nerve motor function is tested by asking the patient to evert the foot and the deep peroneal nerve motor function is tested by asking the patient to dorsiflex the foot and extends the toes. Sensory loss with superficial peroneal nerve injury occurs over the dorsum and lateral aspect of the foot, whereas deep peroneal nerve injury will cause loss of sensation over the first web space. Incomplete nerve injury may result in an intact sensation in the presence of a complete motor deficit or a partial motor deficit. Paresthesia in a stocking distribution should alert the clinician to the probability of compartment syndrome. It is imperative to evaluate the function of the tibial nerve. High energy injuries to the knee can often result in a combination of the peroneal and sciatic nerve injury that will often impair the function of the tibial nerve.

Tinel's sign is defined as distal tingling in the sensory distribution of a nerve on percussion of the nerve [12]. The presence of Tinel's sign is correlated with the regeneration of immature nerve fibers across a damaged section of the nerve. It is commonly used as an indicator of sensory nerve regeneration and usually appears around 3 weeks after injury. However, Tinel's sign is inconstant in patients who were found to have complete transection of the nerve and an absent Tinel's sign in those who progressed to full recovery.

The modified Medical Research Council (MRC) scale is a 0–5 graded scale, where grade 0 would be no evidence of motor function and grade 5 denotes normal strength [13] (Table 25.2).

25.5 Imaging

25.5.1 Ultrasonography

Ultrasonography is a dynamic imaging modality, and knee orientation can be modified and adjusted to evaluate the continuity of the CPN. High-resolution ultrasonography may be used instead of MRI to evaluate the location and determine the severity of nerve injury [1]. Ultrasonography has

Table 25.1 Seddon and Sunderland classifications

Sunderland	Seddon	Description	Recovery
I	Neurapraxia	Segmental demyelinization	Full < 3 months
II	Axonotmesis	Axon not continuous but endoneurium intact	1 inch per month
III		Axon discontinuity, endoneurial tube discontinuity, perineurium intact	<1 inch per month
IV		Axon discontinuity, perineurium discontinuity, epineurium intact	Surgical intervention required to re-establish nerve transduction
V	Neurotmesis	Nerve complete rupture	Surgical intervention

Table 25.2 Modified medical research council scale

MRC scale	
0	Complete paralysis
1	Minimal contraction
2	Active move with gravity eliminated
3	Weak contraction against gravity in full arc of passive motion
4	Active movement against gravity with resistance in full arc of passive motion
5	Normal strength

been used to accurately discern the specific location and length of CPN injury, the diameter of an injured but continuous CPN, and the presence of an obstructing hematoma or scar. As such, it is a helpful diagnostic tool for differentiating incomplete from complete injury [1]. That said, one of the limitations of this imaging modality is it relies strongly on the technical abilities of the user [14].

25.5.2 MRI

Magnetic resonance imaging (MRI) is the gold standard for diagnosing ligament injuries but it can also be helpful in defining the presence and location of nerve injuries [1, 15]. MRI can reveal information about the distance between the nerve ends when there is complete disruption, presence of constrictive perineural scar tissue, posttraumatic neuroma in chronic injuries surrounding edema, encasing hematoma, localized edema, presence of contusion, disruption of fibers, and encasing hematoma in the epineurium, mild contusion, and partial disruption of the fibers [15]. Patients with clinical nerve symptoms may present with an abnormal MRI, conversely, other patients may have no nerve symptoms despite the presence of apparent hemorrhage or edema surrounding the nerve [15].

25.5.3 Electrodiagnostic Testing

In the setting of peroneal nerve palsy, peripheral nerve conduction velocity (NCV) studies and electromyography (EMG) testing are routinely used in the assessment of the severity, site, and prognosis of CPN injury [1, 14]. Abnormalities indicative of nerve injury are commonly not present until approximately 10–21 days after injury as Wallerian degeneration of the injured nerve has not occurred, limiting the usefulness of EMG in the acute phase. We typically obtain the first EMG and NCV testings at 6 weeks post injury if a clinical neurologic deficit persists. Follow-up studies should be obtained for comparison at 3–4 months if neurologic recovery is incomplete and surgical intervention is contemplated. The earliest signs of nerve regeneration occur in the superficial branch of the peroneal nerve supplying the peroneal musculature [16]. Neurophysiology studies with EMG may confirm muscle denervation with fibrillation potentials in the tibialis anterior, positive sharp waves, and polyphasic potentials. Incomplete nerve injuries result in the slowing of the conduction velocity and prolonged latency, while complete nerve injuries may not successfully conduct a signal.

Intraoperative nerve conduction velocity, nerve action potentials, and EMG may also be useful to determine the extent of damage and the potential of the nerve to conduct an impulse [17].

25.6 Indications

Indications for nerve transfers in CPN injuries included peroneal nerve rupture on exploration or complete transection documented on imaging studies, any injury that failed to show clinical or electromyographic evidence of recovery of ankle dorsiflexion by 3 months postinjury, absent advancing Tinel’s sign 3 months post injury, the requirement of a nerve graft greater than 6 cm identified at the time of initial surgical exploration before nerve transfer and a normal tibial nerve [18].

25.7 Contraindications

Contraindications for nerve transfers included denervation of the muscle greater than 9–12 months from injury, preexisting peripheral neuropathy, severe injury to the tibial nerve (or sciatic nerve proximally), major posterior compartment muscle injury, and other lower extremity nerve injuries [18].

Relative contraindications include patients older than 65 years, patients with major medical comorbidities that would preclude surgery or rehabilitation, and patients with injuries or abnormalities seen on nerve testing of the tibial nerve [18].

25.8 Anatomy

In the distal one-third of the thigh, the sciatic nerve bifurcates into the CPN and the tibial nerve. The CPN, situated posterior to the conjoined biceps femoris tendon and posterior to the lateral head of the gastrocnemius muscle, innervates the short head of the biceps femoris muscle. At the level of the knee joint, the vascular supply becomes more tenuous, relying on small vasa nervorum derived from the anterior recurrent tibial artery.

The CPN then curves around the neck of the fibula, where it lies directly over fibular periosteum for approximately 6 cm, covered by only subcutaneous tissue and skin, traveling lateral to the proximal fibula.

The CPN typically divides into three branches (Fig. 25.1). The first branch, the lateral articular nerve, innervates the inferolateral portion of the knee joint capsule and the lateral collateral ligament. The second is the tibialis anterior motor branch. The proximal tibialis anterior branch often arises from the articular branch or as a separate branch at the level of the trifurcation. Between the peroneus longus muscle belly and the proximal fibula, the nerve divides into the two main branches: the superficial and deep peroneal nerves. The superficial peroneal nerve innervates the peroneus longs and brevis muscles, which function to evert and plantar flex the ankle. The deep peroneal nerve innervates tibialis anterior,

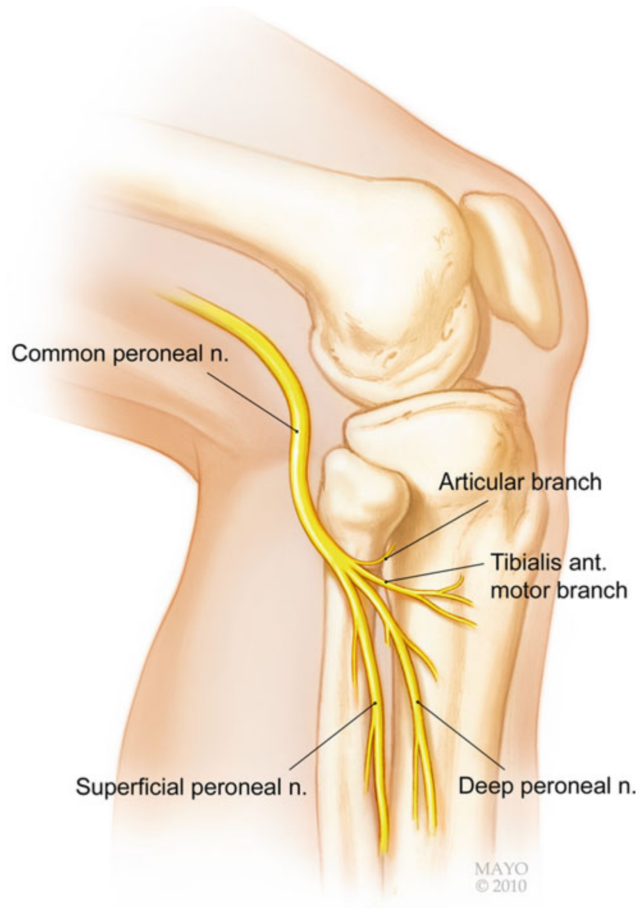

Fig. 25.1 Anatomy of the common peroneal nerve demonstrating the articular nerve branch and the nerve branches to the anterior tibialis muscle. (From Giuffre et al. [18]. Used with permission of the Mayo Foundation for Medical Education and Research. All rights reserved.)

extensor hallucis longus, extensor digitorum longus to dorsiflex the foot and extends the toes. The terminal branches of the peroneal nerve provide sensory innervation for the dorsal foot and the first web space.

25.9 Patient Positioning and Setup

The patient is positioned in supine position with a bump under the ipsilateral hip and the knee flexed. A tourniquet is applied to the upper thigh and used if needed. Use of the tourniquet will impede the nerve stimulator's ability to identify the tibial nerve motor fascicle. Therefore, if a tourniquet is used, it must be deflated for approximately 20 min to allow the tourniquet-induced transient neurapraxia to resolve, in order to choose the appropriate tibial nerve fascicle.

If indicated, the peroneal nerve is initially explored to determine the level and extent of injury (Fig. 25.2). In the setting of prior knee surgery, we recommend that the peroneal nerve stumps are tagged for future assessment by the peripheral nerve team. If the nerve gap is greater than 6 cm or the mechanism of injury suggests a lengthy stretch injury, complete peroneal nerve exploration is not necessary and a nerve transfer alone is performed.

25.10 Surgical Technique

Our technique has been previously described [18, 19]. The surgery begins with an exploration of the peroneal nerve with a midlateral incision made from the fibular head, extending distally 10–12 cm (Fig. 25.2). The common peroneal nerve is identified at the fibular neck by identifying the biceps tendon and dissecting posteriorly with the knee flexed to approximately 45–60° and dissected distally to the articular branch/tibialis anterior branch, the superficial and deep peroneal nerve branches (Fig. 25.3).

The interval between the soleus and peroneus longus is identified by its visible fat stripe (Fig. 25.4). An interval is created in a distal to proximal direction, elevating the soleus origin from the lateral and posterior aspect of the fibula. The posterior surface of the fibula is visualized with the peroneal artery and vena comitans. The tibial nerve and posterior tibial vessels are identified lying medial to the peroneal artery. The peroneal muscles are elevated subperiosteally from the anterior surface of the fibula to expose the articular, superficial, and deep branches of the peroneal nerve. The articular branch forms as part of the trifurcation of the common peroneal nerve: into the deep peroneal nerve, the superficial peroneal nerve, and the articular branch. The proximal tibialis anterior branch often arises from the articular branch or as a separate branch at the level of the trifurcation [20].

Occasionally, multiple branches to the tibialis anterior muscle exist. In these cases, the common tibialis anterior motor nerve should be identified and dissected proximally to the limit of the stretch injury and scar of the peroneal nerve at the fibular neck. The tibialis anterior motor branch(es) is divided at this level and inspected under magnification for healthy-appearing fascicles. Further sectioning is performed as needed to ensure a healthy-appearing nerve.

Nerve branches or nerve fascicles of the tibial nerve innervating flexor hallucis longus (FHL), flexor digitorum longus (FDL), gastrocnemius, or posterior tibialis muscle are identified using a handheld nerve stimulator with a current of 1–2 mA (Varistim III; Medtronic Xomed, Jacksonville, FL). An intra-fascicular dissection is carried out under loop magnification to identify 2 fascicles that result in contraction of the toe flexors, gastrocnemius or posterior tibialis muscle. The determination of whether a tibial nerve branch or a tibial nerve fascicle is used depends on the diameter of the donor nerve relative to the recipient nerve,

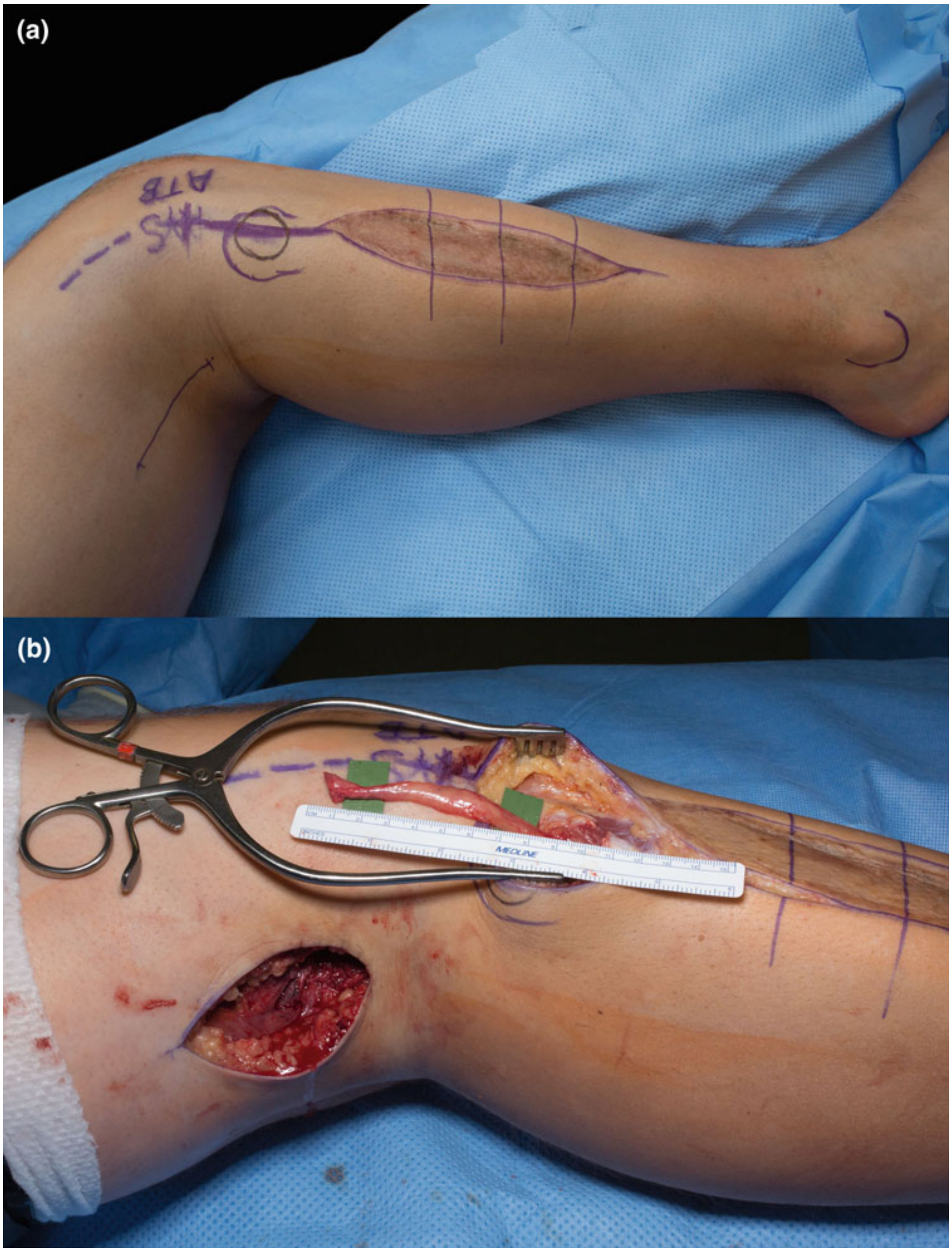

Fig. 25.2 The patient is positioned in a supine or sloppy lateral position. Demonstrated in (**a**) is the surgical incision including an incision to explore the sciatic nerve and incision to expose the peroneal nerve and tibial nerve. In (**b**), the common peroneal nerve was found to be ruptured at the level of the sciatic nerve

the branching nerve anatomy, the location and length of the donor nerves, and the potential donor deficit after nerve transfer. The donor fascicles are dissected distally and divided such that they will meet the tibialis anterior motor branch. While it is possible to transpose the chosen tibial nerve fascicles to the peroneal nerve stump superficially (over top of the fibula) for neurorrhaphy, a more direct path is possible by developing a plane deep to the fibula at the level of the proximal fibular shaft. Using blunt dissection, the interosseous membrane is opened allowing direct nerve transposition for repair (Fig. 25.5). An intraneural dissection of the tibial nerve is performed and the chosen fascicles are gently separated using a microsurgical technique. The chosen fascicles are divided distally with sufficient length to allow direct coaptation to the tibialis anterior motor branch without tension or a graft. An end-to-end repair is performed under an operating microscope using 9-0 epineural sutures (Fig. 25.6). Our preference is to use a collagen nerve tube split longitudinally and wrapped around the repair and augment the repair with fibrin glue (Baxter Healthcare Corporation, Westlake Village, CA) to both protect the repair from scar and potential disruption [21]. The wound is appropriately drained if necessary, a layered closure is performed.

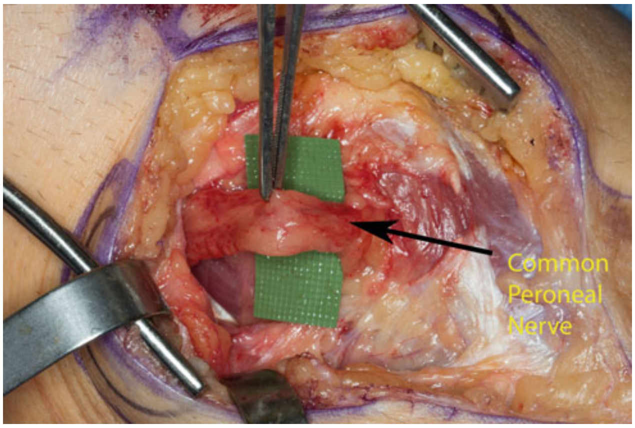

Fig. 25.3 The common peroneal nerve is identified. Here it is clearly injured with scar, flattened, elongated, and with hemorrhage

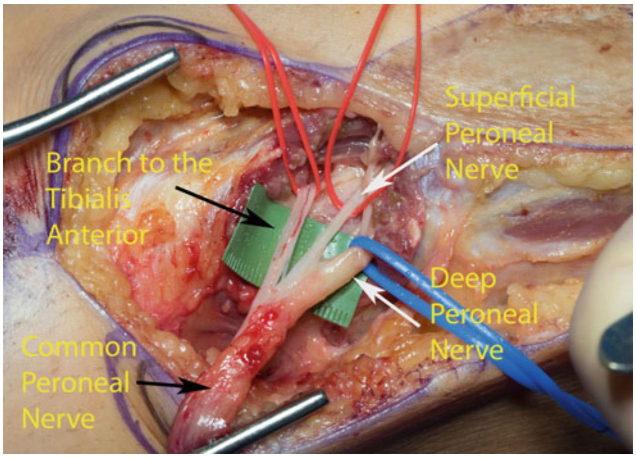

Fig. 25.4 The common peroneal nerve is carefully dissected distally. The tibialis anterior branches, the superficial peroneal and deep peroneal nerves are identified

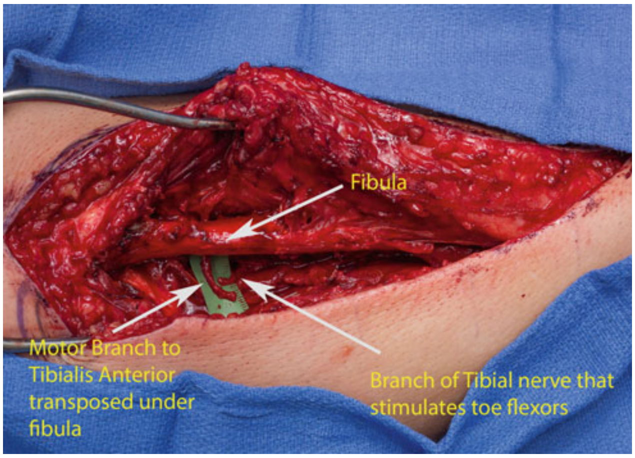

Fig. 25.5 The tibial nerve fascicle is identified and separated from the tibial nerve and divided distally. The anterior tibial nerve is passed medial and underneath the fibula to have a more direct line of coaptation to the tibial nerve fascicles

25.11 Rehabilitation

Postoperatively, the knee and ankle are immobilized and the patient remains non-weight-bearing for 3 weeks to protect the nerve transfer. After 3 weeks, the knee and ankle ROM and weight-bearing status are guided by the associated ligament surgical procedures previously performed on the knee. Patients are followed at 3-month intervals with repeat EMG’s at each of visit.

25.12 Outcomes

A multiligament knee injury is frequently the result of a high-energy mechanism, which causes severe soft tissue damage about the knee and often includes neurovascular injury. In a recent study performed at our institution, only 38% of patients recovered the ability to dorsiflex against gravity in the presence of a complete CPN palsy following knee dislocation [2, 3]. In this setting, some authors have reported that patients who present with a persistent foot drop have significantly worse functional outcomes [22]. However, in a recent matched study comparing knee dislocation patients who sustained a complete CPN palsy to those that did not, final functional outcomes showed no difference [3]. Traditionally three conservative treatment options to minimize the loss of dorsiflexion exist: ankle foot orthosis, nerve grafting with autograft nerve, and tendon transfers. Overall, these current treatment strategies for CPN injuries to regain ankle dorsiflexion in the setting of multiligament knee injury have been underwhelming [23].

A tibial nerve transfer to the motor nerve branch of the tibialis anterior muscle is advantageous in that it bypasses the zone of injury, it obviates the need for an intercalary nerve graft, and it decreases the time to regeneration by performing the neurorrhaphy close to the end organ. In addition, the nerve transfer restores ankle dorsiflexion using the intended anterior tibialis muscle for ankle dorsiflexion with minimal donor-site morbidity.

There is no clear consensus in the literature for the ideal tibial donor nerve when planning direct nerve transfer for complete peroneal nerve injury. Several authors have postulated numerous appropriate donor nerves including; combining FHL and FDL donor fascicles [6], the nerve to soleus [7], the trans-interosseous partial tibial nerve [8], and the branch to lateral gastrocnemius [9]. These authors insist on the importance of taking into account variability in anatomy, branch sizes, and required length to ensure the best result for the patient.

To our knowledge, only four studies have reported outcomes of direct nerve transfer for peroneal nerve injury.

Nath et al. [24] reported on seven of nine patients who successfully regained British Medical Research Council (BMRC) 4 or greater ankle dorsiflexion after tibial nerve

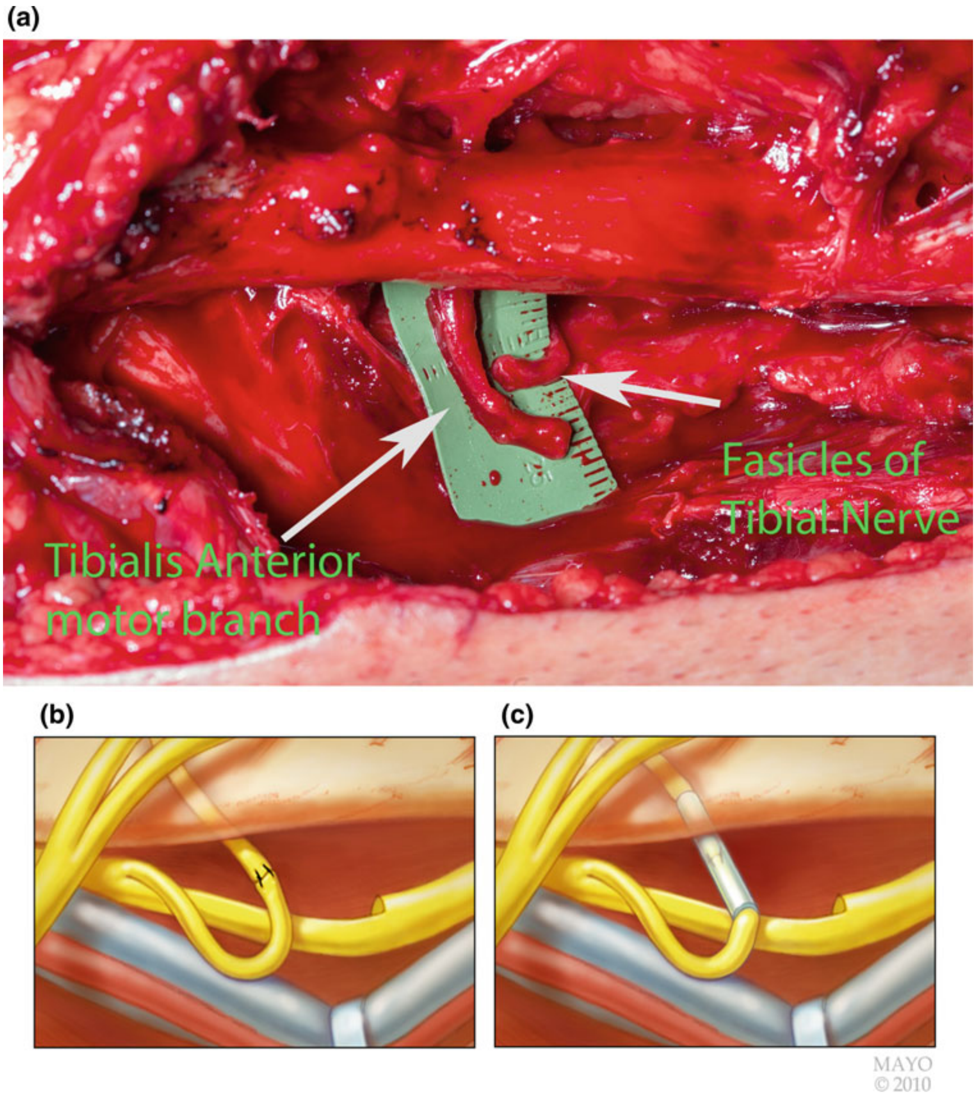

Fig. 25.6 Under the operative microscope the nerves are coapted (**a**), which is illustrated in (**b**). A split collagen tube is wrapped around the repair and fibrin glued (**c**). (From Giuffre et al. [18]. Used with permission of the Mayo Foundation for Medical Education and Research. All rights reserved.)

transfers for deep peroneal nerve injuries. The remaining two of the nine patients obtained BMRC 0 ankle dorsiflexion after the transfer [24]. The seven patients with BMRC 4 or greater ankle dorsiflexion had an age range between 16 and 65 years and the range time to surgery was 2–6 months [24]. The two patients with BMRC 0 ankle dorsiflexion were the oldest patients (66 and 70 years) with the largest time to surgery (6 and 9 months) [24].

Giuffre et al. [18] reported on 11 patients, who underwent partial tibial nerve transfer to the anterior tibial muscle to treat peroneal nerve injury after knee trauma. One patient recovered BMRC 4 ankle dorsiflexion, 3 patients recovered BMRC 3, 1 patient recovered BMRC 2, 2 patients regained BMRC1 ankle dorsiflexion, and 4 patients did not recover any muscle activity [18]. Clinically, reinnervation of the tibialis anterior occurred at an average of 7.6 months postoperatively and patients continued to recover for up to 2 years postoperatively. Nine patients were able to walk barefoot, run, navigate stairs, and participate in activities. All patients had returned to their pre-injury occupation. After the nerve transfer, seven patients did not wear an ankle foot orthotics and four patients did not limp. Of those 4 patients with BMRC 3 or greater recovery, the average age was 30 years and the average time to surgery was 4.6 months. Three of these 4 patients underwent nerve transfer between 3 and 6 months. Of the 7 patients with BMRC 2 or less recovery, the average age was 32 years and the average time to surgery was 6.5 months. Five of these 7 patients underwent nerve transfer after 6 months. The data from Giuffre et al. suggests that younger patients and those who undergo early nerve transfer before 6 months had the best results [18].

Leclère et al. also utilizing the partial tibial nerve transfer to motor branches of tibialis anterior reported on 6 patients and a neurotized lateral gastrocnemius transfer in two patients [25]. Of the 6 patients who underwent nerve transfer of the anterior tibial muscle, 3 obtained a BMRC score of 4 for ankle dorsiflexion, 1 patient BMRC 2, 1 patient BMRC1, and 1 patient BMRC 0. Of the 2 patients that underwent neurotized lateral gastrocnemius transfer, 1 patient achieved excellent results after tenolysis, whereas 1 patient achieved poor results. After the nerve transfer, five patients did not wear an ankle foot orthosis, four patients did not limp, and five patients were able to walk barefoot, navigate stairs, and participate in activities [25].

Ferris et al. reported a prospective single-surgeon series of nine consecutive patients, who underwent partial tibial nerve transfers to the motor branches of tibialis anterior for traumatic CPN injuries with BMRC 0 preoperatively in all patients [26]. Seven of the nine patients achieved a BMRC 4 or greater, 1 patient BMRC 1, and 1 patient BMRC 0 with an average follow-up period of 30.8 months [26]. Clinically apparent motor recuperation with contraction of the tibialis anterior muscle on average was first recorded at 4.5 months postoperatively (range 2–7) and clear tibialis anterior muscle excursion causing ankle movement at 10.5 months (range 8–13) [26].

One author reported complications related to the donor nerve site. This patient developed neuritis of the tibial nerve and a complete sciatic nerve lesion of unknown etiology 2 months after the nerve transfer [25]. The other authors did not report any significant complications related to donor nerve sites [18, 24, 26, 27].

It is important to recognize that all of these cohorts had sample sizes too small to draw any significant conclusions regarding the prognostic factors of age, time to surgery, and mechanism of injury.

25.13 Conclusion

The treatment of complete peroneal nerve palsy in the setting of multiligament knee injury is challenging. Currently, nerve grafting and tendon transfers are most commonly used but with inconstant outcomes. Direct partial tibial nerve transfer to the motor nerve branch of the tibialis anterior muscle is a recent surgical treatment for CPN palsy. While this technique is not very well known in the lower extremity, analogous surgeries in the upper extremity have been extensively reported and have become the standard of care in upper extremity nerve reconstruction. While preliminary reports have shown favorable outcomes, surgical timing and preoperative assessment are imperative for optimal results. Further studies are required to determine the efficacy and generalizability of this procedure and to define the variables that affect clinical outcomes.

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The Role of Osteotomy in the Multiple-Ligament-Injured Knee

26

Hervé Ouanezar, Sava Turcan, and Anil S. Ranawat

Abbreviations

ACL	Anterior Cruciate Ligament
AP	Anteroposterior
BMI	Body Mass Index
DFVO	Distal Femoral Varus Osteotomy
HKA	Hip–Knee–Ankle
HTO	High Tibial Osteotomy
LCL	Lateral Collateral Ligament
MCL	Medial Collateral Ligament
MLIK	Multiple-Ligament-Injured Knee
MRI	Magnetic Resonance Imaging
PCL	Posterior Cruciate Ligament
PLC	Posterolateral Corner
PMC	Posteromedial Corner

26.1 Introduction

Osteotomies are mainly used to correct axes or a rotational deformity of a limb segment. This procedure has proven efficacy in delaying degenerative pathology and treating native or post-traumatic bone deformity with good long-term results. However, osteotomies should not be limited to these indications. Osteotomies should be considered as a viable option to palliate knee ligaments deficiency in the frame of MLIK.

Joint alignment may be just as important as ligament reconstruction in maintaining joint stability, particularly in cases of chronic ligamentous laxity. To provide a stable and a functional knee, osteotomy can be proposed as an isolated procedure or in combination with soft tissue repair or reconstruction. The preoperative surgical plan should consider the acute or chronic nature of the lesions. A meticulous physical assessment of the frontal, sagittal and rotational components of instability are necessary for proper diagnosis in addition to the radiographic analysis.

The main goal of this chapter is to clarify the indications, the characteristics and the technical considerations of osteotomy regarding the type of instability in MLIK.

26.2 Diagnostic Work up

26.2.1 Patient History

The surgical management of MLIK remains difficult because of the complexity and the multitude of situations that physicians face. Thus, the physician must understand three aspects of the patient: the history of the pathology, the symptoms experienced by the patient, and his/her lifestyle.

The physician must research the history of previous trauma or previous surgery on the ipsilateral and contralateral knees. If any previous surgery occurred, the physician should collect previous surgical report. Important information like surgical approach and devices previously used should be noted. In addition, the exact date of the accident leading to MLIK is an important landmark because it characterizes the lesions as acute or chronic. The time from injury is benchmarked at 3 weeks; before then, lesions can be defined as acute. If the mechanism of the injury (valgus stress, varus stress, and anteroposterior dashboard injury) can be described, then it can give some clues about the affected knee's compartment. A femorotibial dislocation (even spontaneously reduced) must be looked for because of its vascular implication. Initial skin, neurovascular damages and treatment like immobilization are also recorded.

Pain, instability, locking and swelling need to be sought. These symptoms need to be related to the level of activity: from symptoms at rest to symptoms during high level activities.

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Predictive factors of postoperative complications like obesity or smoking need to be underlined. To avoid disappointment for the patient, the previous level of activity and their expectations of return to sport should be clearly enounced and discussed during the preoperative consultations.

26.2.2 Physical Exam

A comparative physical exam is mandatory. We recommend starting first with a standing exam. The examiner can appreciate the weight-bearing mechanical axis (varus knee, valgus knee, and normal) and the atrophy of the Vastus Medialis. Then, a gait analysis is recommended to detect any active flexion contracture of the knee, any hyperextension and any seesaw in monopodial weight-bearing (lateral compartment in a varus knee or medial compartment in a valgus knee). After lying down in a rest position, constitutional hypermobility is assessed. Attention needs to be paid to range of motion and pain on the ipsilateral hip and ankle. Previous skin incision is documented. Anterior and posterior muscle chains strength is evaluated. Vascular axis and pulse are checked. Swelling is sought. Full range of motion is assessed. Special attention is made to non-symmetrical hyperextension deformity (Hughston's test).

The laxity is evaluated in three different plans:

- Frontal plan: valgus stress to test the medial collateral ligament (MCL)/varus stress to test the lateral collateral ligament (LCL).
- Sagittal plan: Lachman test to test the anterior cruciate ligament (ACL)/Posterior draw test to test the posterior cruciate ligament (PCL).
- Horizontal plan: pivot-shift test/external rotational stress/internal rotational stress.

26.2.3 Imaging

26.2.3.1 Emergency MRA or CT Angiogram

It is mandatory in case of doubt of any episode of knee dislocation or any vascular involvement.

26.2.3.2 Standard Radiographs

Anteroposterior, lateral, intercondylar notch and skyline patellar views are always requested.

In the frontal plan, cartilage wear of medial or lateral compartment is noted. In the sagittal plan, a tibial translation (anterior or posterior) is evaluated. Tibial slope is also measured and compared to the contralateral side. Superior or equal to 12° is considered as pathological.

26.2.3.3 Full-Length Weight-Bearing Radiographs

The mechanical axis of both lower limbs is measured and compared on full-length weight-bearing radiographs. Preoperative planning is performed by identifying deformity at the level of the joint (cartilage wear, meniscus, or ligamentous deficiency) or at the level the tibia or at the level of the femur (bony deformity) or as a combined deformity.

26.2.3.4 Stress X-Rays

The X-ray confirms the physical examination and is recorded as preoperative evidence in the medical file. In the frontal plan, excessive varus confirms lesions of the lateral collateral ligament (associated or not with a posterolateral corner PLC injury). Excessive valgus confirms lesions of the medial collateral ligament (associated or not with posteromedial corner PMC injury). In the sagittal plan, by using the Telos system, the physician can objectively measure the differential laxity in millimeters. The ACL is tested with the knee flexed at 30° and the PCL is tested with the knee flexed at 90°. In our practice, differential in anterior tibial translation superior to 5 mm is an indication for an ACL reconstruction. Differential in posterior tibial translation superior to 9 mm is an indication for PCL reconstruction.

26.2.3.5 MRI

A magnetic resonance image (MRI) illustrates cartilage and meniscal health and can confirm cruciate and peripheral ligament tears. MRI is helpful in making the decision of surgical strategy between ligament repair, ligament augmentation, or ligament reconstruction.

26.3 Indications

The rationale for proposing an osteotomy in MLKI depends on several points like the acute or chronic nature of the injury, the global mechanical axis in the frontal plan, the anterior or posterior tibial translation on the sagittal plan, the tibial slope, and the expectations of the patient. Osteotomy could be proposed as an isolated procedure or combined with a soft tissue reconstruction or repair. Furthermore, an isolated or a staged procedure can be proposed.

26.3.1 Acute Injury

Acute injury is defined when the accident is less than 3 weeks from surgery. The acute features of the lesions can suggest ligament repair, ligament reconstruction or combined repair + reconstruction of the injured soft tissue. In this scenario, osteotomy is proposed in case of an associated mal-alignment which could compromise the efficacy of soft tissue surgery. Usually, a non-staged procedure is performed.

26.3.2 Chronic Injury

Chronic injury is defined when the accident is greater than 3 weeks from surgery. An isolated osteotomy can be proposed to stabilize the knee. We recommend a staged procedure with an osteotomy performed first and a reevaluation of the stability after a well-conducted rehabilitation protocol. In case of persistent instability, a soft tissue procedure can be added in a second surgical step. For example, when a varus mal-alignment is present in a patient with a chronic PLC injury, a corrective osteotomy should be considered prior to reconstruction. Ligaments reconstruction in a PLC injury does not tolerate varus mal-alignment, and this situation will potentially lead to a graft stretching and a failure of the reconstruction. Arthur et al. reported on 21 patients with chronic combined PLC injury and 38% had sufficient improvement after proximal tibia osteotomy and subsequent PLC reconstruction was not necessary [1].

Globally, the ideal indication for an osteotomy in MLIK would be a young active and non-smoker patient (<60 years old) with high expectations, with no flexion contracture or <15° and with a body mass index (BMI) <35. Regarding the mechanical axis and ligament deficiency, more criteria can be applied:

- In a varus knee: Mechanical Alignment <3°
- In a valgus knee: Mechanical Alignment >5°
- In a ACL-deficient knee: Tibial Slope >10°
- In a PCL-deficient knee: Tibial Slope <5°

26.4 Biomechanical Rationale

The correction of the axes in the coronal and in the sagittal planes helps the patient from both a load and stability point of view.

26.4.1 Frontal Instability

To help stabilize a knee with a frontal instability, the choice of an adequate osteotomy is made in function of the mechanical axis, the compartment side laxity, the degree of laxity, and the acute or chronic nature of the injury. We distinguish the varus knee (lateral instability) and the valgus knee (medial instability).

26.4.1.1 The Varus Knee with Lateral Instability

Associated with a lateral instability, a decreased mechanical alignment (<3°) needs to be corrected. The main goal of the osteotomy is to unload and protect the healing of the native lateral soft tissue, the PLC reconstruction or the PLC repair.

26.4.1.2 The Valgus Knee with Medial Instability

Associated with a medial instability, an increased mechanical alignment (>5°) needs to be corrected. The main goal of the osteotomy is to unload and protect the healing of the native medial soft tissue or of the MCL reconstruction or the MCL repair.

26.4.2 Sagittal Instability

There exists a linear relationship between tibial slope and tibial translation during weight-bearing. Restoring the correct anterior–posterior position of the knee in the sagittal plane is challenging. Giffin et al. described the protective effects of changing the tibial slope on knee kinematics and in situ forces in the cruciate ligaments [2, 3]. Two situations are described regarding ligament deficiency:

26.4.2.1 The ACL-Deficient Knee

An increased tibial slope (>10°) needs to be corrected. With a lower tibial slope, anterior tibial translation will decrease. The main goal of the osteotomy is to unload and protect the healing of the native ACL or of an ACL graft.

26.4.2.2 The PCL-Deficient Knee

A decreased tibial slope (<5°) needs to be corrected. With a higher tibial slope, posterior tibial translation will increase. The main goal of the osteotomy is to unload and protect the healing of the native PCL or of a PCL graft.

26.5 Surgical Treatment

Many surgical techniques are described in the literature. From high tibial osteotomy to distal femoral osteotomy, from opening wedge to closing wedge, from a medial approach to a lateral approach, from plating to external fixation, every type of osteotomy, and every type of fixation can be performed [4].

26.5.1 Frontal Instability

26.5.1.1 The Varus Knee with Lateral Instability

We recommend performing a valgus high tibial osteotomy (HTO) to protect the lateral side in the setting of a large varus thrust or an injury to the PLC. Two types of HTO are commonly proposed: the medial opening-wedge HTO and the lateral closing-wedge HTO. A medial opening-wedge HTO is an effective procedure and is commonly recommended in genu varus alignment [1].

Comparing to the lateral closing-wedge HTO, the medial opening-wedge HTO does not need an associated fibula osteotomy and reduces the risk for peroneal nerve lesion and leg shortening. We do not recommend performing a lateral closing-wedge HTO in case of PLC deficiency. Indeed, this procedure will increase the lateral instability by decreasing the tension in the lateral soft tissues. Furthermore, the lateral closing-wedge HTO does not allow for a large correction, can induce patellofemoral modification and is technically more demanding [5] (Fig. 26.1).

26.5.1.2 The Valgus Knee with Medial Instability

Mostly described for treating chondral pathology and degenerative disease, distal femoral osteotomy (DFO) is also an effective treatment for reducing forces and torques apply on the medial collateral ligament (MCL) in genu valgus alignment. By analogy with the lateral side, DFO aims to protect a MCL reconstruction or repair. Two types of DFO are commonly proposed: a medial closing-wedge DFO and a lateral opening-wedge DFO.

Depending on the expectations, DFO could be an option for the young and active patient without limitation to return to sport. Indeed, Voleti et al. demonstrated that correction of valgus knee mal-alignment through DFO, either medial closing wedge or lateral opening wedge, can reliably result in improvement in function and return to sport [6] (Fig. 26.2).

26.5.2 Sagittal Instability

26.5.2.1 The PCL-Deficient Knee

The role of the osteotomy is to increase the tibial slope to reduce the tibia anteriorly. We recommend positioning the plate in an anterior position or manipulating osteotomy gap until the anterior-to-posterior gap ratio is 1:1 which will effective increase posterior slope. We recommend adjusting gap height (Fig. 26.3).

26.5.2.2 The ACL-Deficient Knee

The role of the osteotomy is to decrease the slope to prevent an anterior tibial translation. The ideal indication is a tibial slope greater than 10°. The objective of correction must aim for a slope between 5° and 8° [7, 8]. Yamaguchi et al. concluded that a 10-degree anterior closing-wedge osteotomy of the proximal tibia lowered significantly ACL force and reduced anterior tibial translation [9]. Ranawat et al. concluded in a laboratory study that lateral closing-wedge osteotomy shows greater posterior tibial slope correction than medial opening-wedge osteotomy in an ACL-deficient knee [5]. Correction with either posterior position of plate or manipulating osteotomy gap, until the anterior-to-posterior

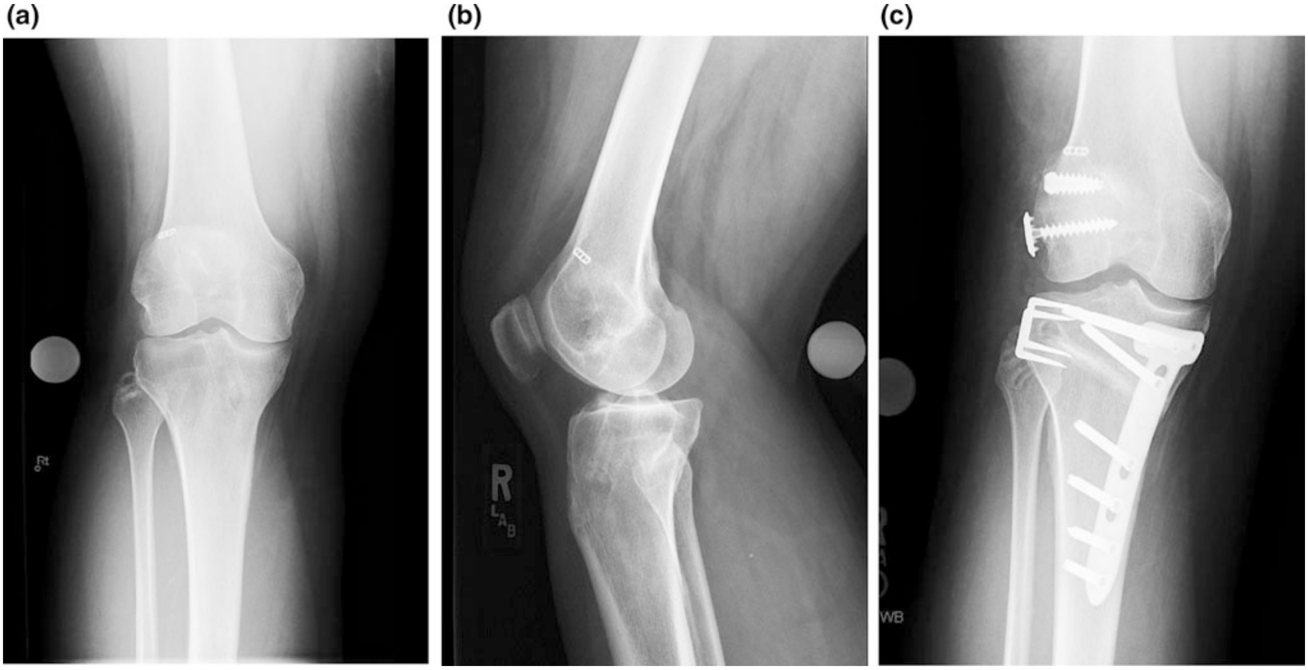

Fig. 26.1 Twenty-eight-year-old male presenting right knee persistent instability with varus alignment after failed ACL and PLC. **a** Pre-HTO anteroposterior (AP) radiograph right knee; **b** Pre-HTO lateral radiograph right knee; **c** Post-HTO and revision ACL and PLC AP radiograph right knee

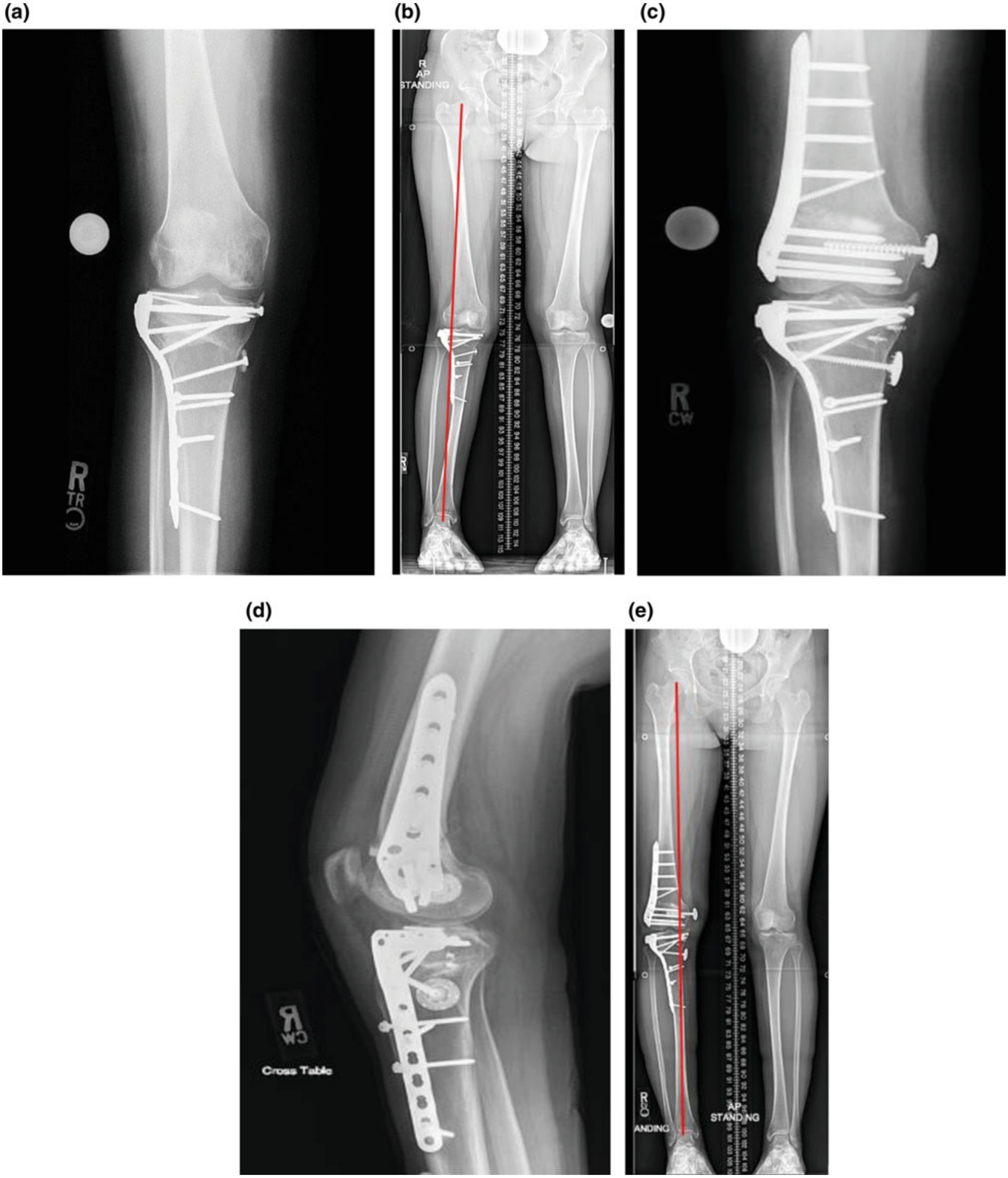

Fig. 26.2 Twenty-one-year-old female status post tibial plateau ORIF and MCL repair now with medial insufficiency. **a** Pre-DFO AP radiograph right knee; **b** Pre-DFO standing bilateral radiograph HKA; **c** Post-DFO and MCL reconstruction AP radiograph right knee; **d** Post-DFO and MCL reconstruction lateral radiograph right knee; **e** Post-DFO and MCL reconstruction standing bilateral HKA

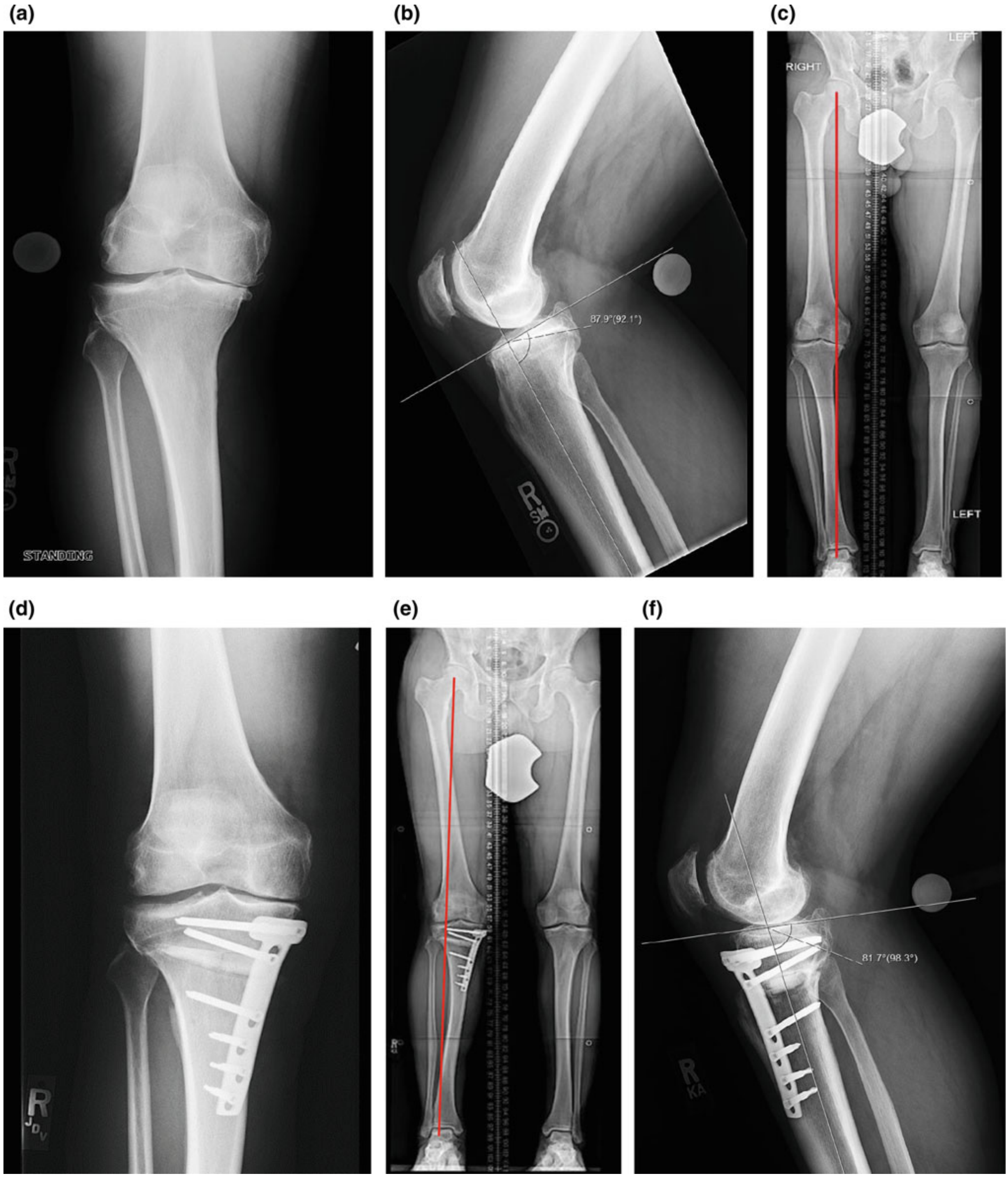

Fig. 26.3 Thirty-five-year-old male with history of PCL deficiency and medial side DJD. **a** Pre-HTO AP radiograph right knee; **b** Pre-HTO lateral radiograph right knee showing a 2.1° tibial slope; **c** Pre-HTO standing bilateral radiograph HKA; **d** Post-HTO AP radiograph right knee; **e** Post-HTO standing bilateral radiograph HKA; **f** Post-HTO lateral radiograph right knee showing a 8.3° tibial slope

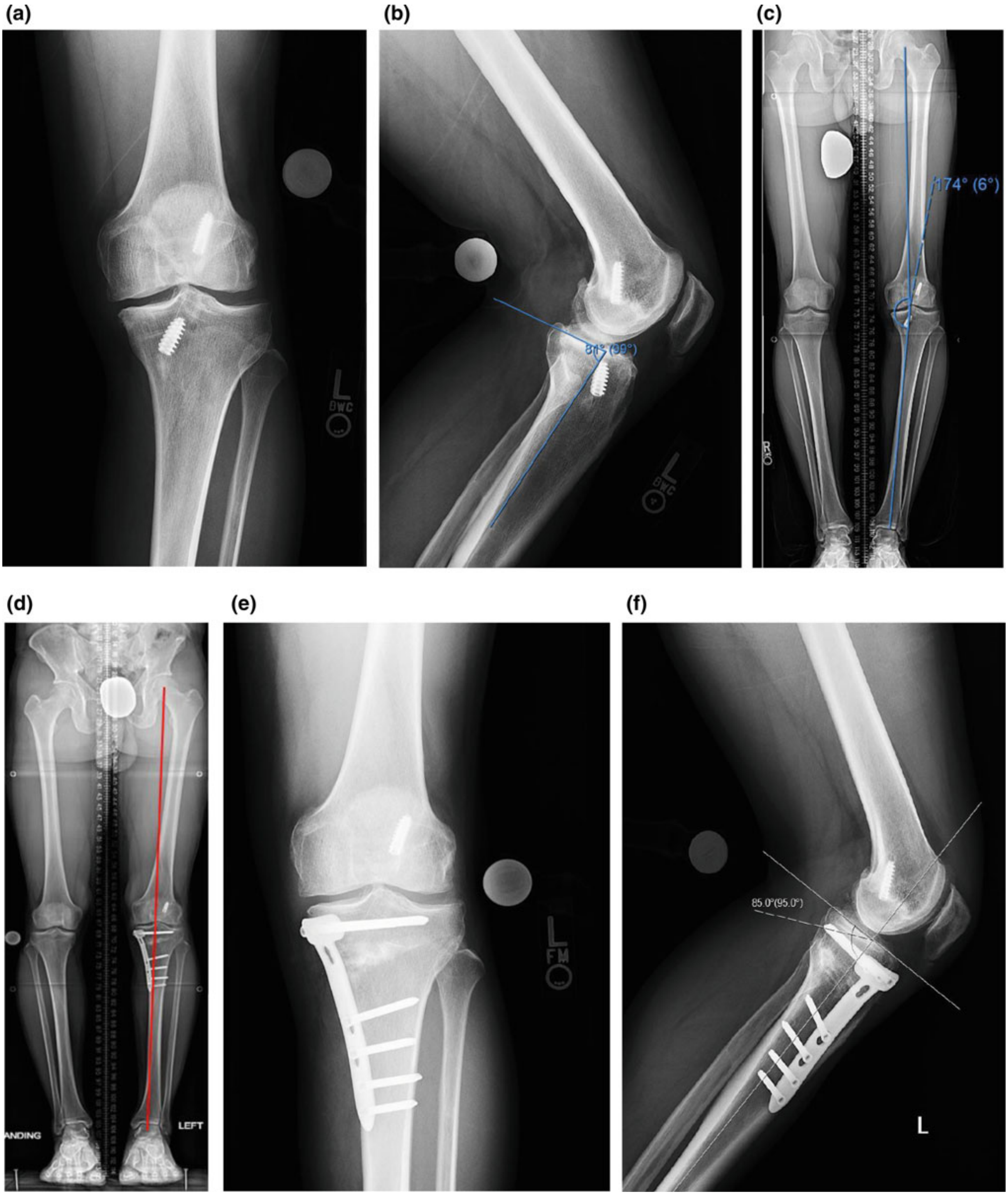

Fig. 26.4 Thirty-six-year-old male with Grade 2 medial side DJD and excessive posterior slope after a failed ACL. **a** Pre-HTO AP radiograph left knee; **b** Pre-HTO lateral radiograph left knee showing a 9° tibial slope; **c** Pre-HTO standing bilateral radiograph HKA showing 6° varus deformity; **d** Post-HTO standing bilateral radiograph HKA; **e** Post-HTO AP radiograph left knee; **f** Post-HTO lateral radiograph left knee showing a 5° tibial slope

gap ratio is 1:3 will effectively decrease the slope. We recommend adjusting gap height (Fig. 26.4).

26.5.3 Combined Instability

A biplanar HTO aims to correct the sagittal and the frontal balance of the knee. Depending on the objective of correction, both medial opening-wedge HTO and lateral closing-wedge HTO are feasible.

The medial opening-wedge HTO allows a biplanar correction while the lateral closing-wedge HTO restores the frontal alignment but not the sagittal. However, lateral closing-wedge HTO confers a more protective environment to normalized ACL kinematics. Indeed, lateral closing-wedge HTO provided more significant slope neutralization than medial opening-wedge HTO while concurrently decreasing the magnitude of anterior tibial translation in the ACL-deficient knee [5].

In a PCL-deficient knee, an increasing of the tibial slope can help to correct a posterior tibial translation. The effect of the opening-wedge osteotomy is thought to stabilize the knee by decreasing posterior tibial translation. In a biomechanical study, Naudie et al. reported that medial and anterior opening-wedge osteotomies caused anterior tibial translation, potentially restoring normal knee biomechanics in a PCL-deficient knee. In the clinical setting, Naudie et al. demonstrated that HTO in the setting of posterior instability improved subjective feelings of instability in 16 of 17 patients at minimum follow-up of 2 years [10]. Furthermore, in a systematic review of clinical evidence, Tisher et al. observed that an osseous correction of the varus alignment in the frontal plan may reduce the failure rate of PCL instability in the sagittal plan [11]. Osteotomies need to be considered as the first step in treatment for this scenario.

26.6 Conclusion

Osteotomy still plays an important role in MLIK treatment and needs to be considered in the decisional algorithm. As an active stabilizer, it gives a fundamental biomechanical answer to MLIK problems. By respecting proper indications and focusing on identification and treatment of the concomitant pathology, often in a staged manner, osteotomy is a durable and cost effective procedure with good clinical results. This efficient surgical procedure can help maintaining high knee function.

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Management of Chronic Fixed Posterior Tibial Subluxation in the Multiple Ligament Injured Knee

27

Jonathan-James T. Eno and Thomas L. Wickiewicz

27.1 Introduction

Both single and multiligamentous knee injury may lead to chronic tibial subluxation. Additionally, repair or reconstruction of the injured ligaments may not fully eliminate the potential for subsequent subluxation. While each clinical scenario in this setting is different, fundamental similarities exist that aid in effective evaluation and management. Each injured ligamentous complex in chronic tibial subluxation, including the ACL, PCL, posterolateral corner (PLC), and posteromedial corner (PMC), separately influences the position and resulting impact of the subluxation on the clinical scenario.

This chapter describes the specific role of each ligament including the ACL, PCL, PLC, and PMC as it relates to chronic tibial subluxation in multiligamentous knee injury. A detailed process of effective evaluation and management for each isolated ligament as well as a constellation in multiligamentous knee injury will also be described.

27.2 Anterior Cruciate Ligament

27.2.1 Background

Resistance to anterior translation of the tibia on the femur is largely conferred by the ACL, which has been demonstrated to provide 86% of the total resistance in this regard [1]. The ACL also functions to prevent varus, valgus, and internal and external rotational instability in knee extension in the presence of MCL or LCL injury [2]. Prior data have demonstrated reduced anteroposterior tibial laxity following ACL reconstruction [3, 4]. Nevertheless, data also exist that suggests that the native tibiofemoral relationship may not be fully reproduced following ACL reconstruction. Poor restoration of this relationship may lead to a fixed anterior subluxation of the tibia relative to the femur [5].

27.2.2 ACL Deficiency and Fixed Tibial Subluxation

Chronic, fixed anterior subluxation following ACL injury with and without reconstruction has been associated with an alteration in normal knee kinematics including physiologic tibiofemoral roll back and subsequently increased the risk of knee osteoarthritis [5, 6]. Prior studies have documented increased rate and magnitude of osteoarthritic changes in ACL-deficient knees with fixed anterior tibial subluxation, as compared to those without a fixed subluxation [6]. These data suggest that the crucial component in this setting is the abnormally fixed tibiofemoral relationship rather than the presence or absence of the ACL. It is, therefore, possible that osteoarthritic progression may be reduced with the elimination of the fixed anterior tibial subluxation and restoration of normal knee kinematics. However, no data currently exists evaluating this possibility.

27.3 Posterior Cruciate Ligament

27.3.1 Background

The PCL confers the primary resistance to posterior tibial translation relative to the femur, especially at knee flexion angles >30° [7, 8]. The PCL has also been identified as a secondary stabilizer to external rotation [7, 8]. Butler et al. [1] utilized cadaveric sectioning of the PCL to document increased posterior translation of the tibia on the femur when

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a posteriorly directed force was applied at 90° of knee flexion following sectioning. Reduction in the posterior translation was observed with knee extension [1, 9]. This observed posterior tibial subluxation replicates the abnormal tibiofemoral kinematic relationship that is observed following PCL rupture. In addition, concomitant injury of other knee ligaments may further potentiate the abnormal relationship [10]. Recognition and correction of an abnormal tibiofemoral relationship are crucial given the significantly increased knee articular surface pressures and reduced meniscal load-sharing properties that have been documented in this setting [11]. Aberrant tibiofemoral kinematics and resultant increased pressures and concentration of loads have been associated with increased osteoarthritic changes, especially in the medial and patellofemoral compartment [12–14].

Similar to the ACL, PCL reconstruction has been shown to improve knee kinematics and posterior tibial subluxation; however, opposing forces including hamstring tension and gravity increase the risk for acute posterior subluxation to progress to a chronic, fixed relationship [15, 16]. While PCL reconstruction may reduce this risk, a chronic, fixed posterior tibial subluxation may still occur and must be addressed [15, 16].

27.3.2 PCL Deficiency and Fixed Tibial Subluxation

Fixed posterior subluxation has been previously defined as a posterior tibial displacement of >3 mm relative to the femur that is irreducible to a neutral relationship with an anteriorly directed force. Examination of a fixed posterior tibial subluxation differs from that of an acute PCL-deficient knee such that minimal or no increased anteroposterior laxity is present, minimal instability exists, and a significant pain component is present. Gross visual inspection, however, will reveal posterior tibial sagging, and palpation of the anterior tibiofemoral relationship will demonstrate a posteriorly subluxated anterior tibial plateau (Fig. 27.1). Plain radiographic evaluation should be used to identify a fixed posterior tibial subluxation with focus directed to the abnormal anterior tibiofemoral relationship. Final confirmation of this relationship may be accomplished with anterior and posterior stress radiographs, which are obtained with a respective force applied to the tibia with the knee in 90° of flexion (Fig. 27.2) [17]. The gross translation that occurs as the difference between the two stress radiographs can be used to quantify the amount of fixed posterior tibial subluxation. Mean differences of 7.4 mm have been documented in PCL-deficient knees with fixed posterior tibial subluxation, as compared to 13.46 mm in PCL-deficient knees with no fixed subluxation [17].

Fig. 27.1 Lateral plain radiograph in 90° of flexion. The fixed posterior tibial subluxation is demonstrated by residual posterior sag

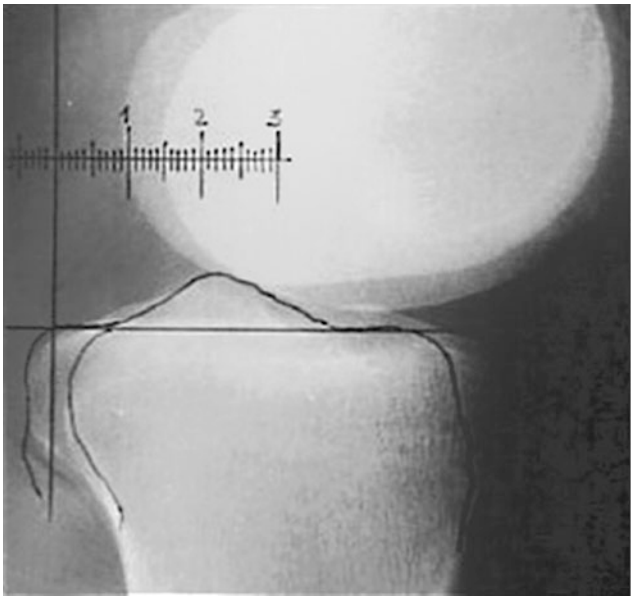

Fig. 27.2 A posterior stress radiograph with a posteriorly directed force of a patient with a fixed posterior subluxation demonstrating posterior tibial displacement

Management of acute PCL ruptures is directly dependent on the grade of PCL injury and concomitant ligamentous damage. Nonoperative treatment has been suggested for isolated PCL injuries of grades I to III, and surgical treatment within the first 2 weeks of injury if concomitant ligamentous damage is present [10]. Adequate immobilization for 2–4 weeks in a knee extension brace should be utilized for acute grade III injuries, with a particular focus on prevention of posterior tibial sag. A PCL brace may be employed to maintain an anteriorly directed force on the tibia to aid in this prevention. Physical therapy focusing on quadriceps strengthening may also aid in reducing posterior tibial subluxation in this clinical scenario [16]. Care must be taken with evaluation of chronic grade III PCL injuries as PLC injury may be present, and thus surgical reconstruction may be required for effective management in these situations [10].

Previous data has suggested that certain risk factors exist that may predispose to the development of a fixed posterior tibial subluxation. Strobel et al. [17] documented that 109 (44%) of 248 patients with PCL insufficiency had a fixed posterior tibial subluxation. Within the subgroup with a fixed subluxation, significant risk factors were identified including the use of patellar tendon graft at the index reconstruction, long-standing history of PCL insufficiency, male sex, and prior PCL surgery. In the event that a fixed posterior tibial subluxation occurs with or without PCL reconstruction, the grade of the subluxation may be determined as grades I to III. Grade I subluxation is defined as 3–5 mm, grade II as 6–10 mm, and grade III as >10 mm [17].

After the history and physical evaluation of the fixed posterior tibial subluxation is complete, an examination under anesthesia may aid to guide the surgeon in the intraoperative decision-making process. An important consideration in the patient with a prior PCL reconstruction and persistent fixed posterior tibial subluxation is the ability of the examining surgeon to intraoperatively reduce the tibia in the presence of the reconstructed PCL. If the posterior tibial subluxation is irreducible, it is possible that the index PCL graft was tensioned with the tibia in a posteriorly subluxated position at the time of fixation thus prohibiting normal knee kinematics. In this setting, the surgeon should consider PCL revision. On the other hand, if the posterior tibial subluxation is reducible during the examination under anesthesia, it is probable that the surrounding active soft tissue envelope is producing an active subluxation [17].

Nonoperative management using bracing techniques may also be utilized for fixed posterior tibial subluxation. Nightly bracing with a posterior tibial support brace locked in extension in combination with daily bracing in a functional PCL brace to maintain motion has been effective. Posterior tibial support braces should ensure full knee extension as well as provide posterior support at the calf region resulting and a passive anteriorly directed force to minimize posterior tibial sag. Prior data has documented the complete reduction of the fixed subluxation in 78.4% of grade I and 70.1% of grade II subluxations [17]. Treatment for 180 days resulted in a mean posterior subluxation improvement to 2.58 mm. However, this treatment regimen was less effective for grade III subluxations, with complete reduction in only 32% of this group. Given the limited improvement in the grade III subgroup, operative intervention is suggested.

27.4 Posterolateral Corner

27.4.1 Background

Resistance to posterior tibial translation with the knee in <30° of flexion is primarily conferred by the posterolateral corner complex (PLC) including the LCL, popliteal tendon, popliteal-fibular ligament, and arcuate complex in previous cadaveric studies [7, 8, 18]. This complex also functions as the main stabilizer in varus stress and posterolateral rotation. These studies have been further substantiated with biomechanical data, which documented significantly increased posterior laxity with PCL and PLC rupture, as compared to minimal varus or valgus laxity or rotatory instability with isolated PCL rupture [7, 8]. Restoration of translational and rotatory stability through early, operative PLC fixation is critical for improved knee stability and patient outcomes [19, 20]. Currently, no consensus exists regarding the ideal method of acute operative stabilization of collateral ligament injury, with options including repair or reconstruction. Repair is not a viable option, however, in a patient with a chronic fixed posterior tibial subluxation [21]. Restoration of lateral translational and rotatory stability in this setting should be achieved with reconstruction. A stable reconstruction is of particular importance with multiligamentous knee injury [21].

27.4.2 PLC Deficiency and Fixed Tibial Subluxation

The anteroposterior tibia position relative to the femur is closely related to posterolateral rotatory instability. Strauss et al. [22] utilized a sequential-sectioning biomechanical model in cadaveric specimens to evaluate this relationship. These data demonstrated a significantly increased tibial external rotation during progressive sectioning of the PCL, popliteus and popliteofibular ligament (PFL) and LCL. Increased tibial external rotation with an anterior tibial force was significantly greater than a neutral or posteriorly directed force, with rotational increases of 9° and 12°, respectively.

27.5 Multiligamentous Injury

27.5.1 Background

Management of multiligamentous knee injury is a complex and difficult process that has been historically addressed with a variety of techniques. Clinical and radiographic long-term outcome data is sparse in this subset of patients, given the low incidence of this injury in developed countries [23]. Clinical outcome data and radiographic criteria have been documented in a heterogeneous population with a variety of concomitant injuries [14, 24, 25]. Significant clinical and technological advances have been made to aid treatment of this injury; however, despite these advances, complications including knee instability, stiffness, and chronic, fixed tibial subluxation may continue following acute management [5, 17, 26–30].

27.5.2 Multiligamentous Knee Injury and Fixed Tibial Subluxation

The three main goals of acute treatment of multiligamentous knee injury include reestablishing the anatomic central axis of motion, recreating ligamentous stability, and maintaining the knee range of motion. Each of these three goals must be achieved to optimize patient outcomes. Studies have suggested that repair and reconstruction of multiligamentous knee injury may recreate ligamentous stability and range of motion with a normal Lachman examination and static endpoints, but a fixed posterior tibial subluxation may still exist [30]. The fixed subluxation has been attributed to a failure to recreate the anatomic central axis of motion. This abnormal central axis may be due to incorrect graft pretensioning [31] or an inability to reestablish the neutral relationship of the tibia and the femur [32]. Previous studies have also suggested that the position of immobilization following treatment of traumatic knee dislocations may also play a role in the loss of knee reduction [33]. These data documented loss of anterior and posterior reductions if immobilization was performed in the direction of the dislocation. Thus, the authors suggested that immobilization should be placed to oppose the direction of dislocation in an attempt to minimize the potential progression to a chronic fixed tibial subluxation or knee dislocation.

Few studies exist with clinical outcome data from treatment of chronic knee dislocations. Evaluation of a fixed posterior tibial dislocation in a chronic traumatically dislocated knee included a visible S-shaped knee deformity on visual inspection and an inability to ambulate [34]. The documented examination included varus laxity, anteroposterior tibial malalignment with visible posterior sag, and a normal Lachman test. This constellation of findings was consistent with a chronic posterior tibial dislocation. Particular importance was attributed to the S-shaped deformity noted on visual inspection. Radiographic evaluation is also crucial in this setting to document the degree of subluxation for grading of the injury and preoperative planning (see Fig. 27.2). Operative outcome data has also been described in a prior case report of two cases in which the patients were managed with ligament reconstruction and placement of a compass hinge external fixator [29]. Six-month follow-up evaluation of these patients demonstrated intact knee stability and range of motion arcs from −5° to 120°. Both patients were able to progress to full weight bearing.

While the compass hinge fixator and more recent advances in hinged knee bracing have enabled reconstruction of chronic knee subluxation, other previous methods of treatment have been employed including knee arthrodesis [35]. Management with knee arthrodesis sacrifices knee range of motion in order to provide pain control and knee stability [36, 37]. Unfortunately, however, chronic back and hip pain combined with poor patient satisfaction, significant disability, and decreased activities of daily living have been associated with this treatment modality in long-term outcome studies [38, 39]. These data are in sharp contrast to the high frequency of good to excellent outcomes that have been documented in the follow-up of reconstructive management [34]. Patients managed with reconstruction reported good to excellent satisfaction, school participation, pain control, and minimal laxity. Notably, despite reconstruction, knee range of motion was not fully restored with motion documented from 5° to 40°; however, this range remained larger than that which was present with arthrodesis [34]. Moreover, more recent literature employing the compass hinge fixator documented ranges of motion from −5° to 120° following reconstruction [29].

Although good to excellent results are possible with earlier stages of fixed subluxation, more advanced stages where maladaptive osseous changes of the distal femur or tibial plateau have occurred have a more guarded prognosis. In the setting of osseous changes including bony erosion, osteophytes, or advanced arthrosis, ligamentous reconstruction is unlikely to lead to satisfactory clinical results. In this case, salvage procedures or nonoperative management is recommended.

Given the significantly improved results obtained with open reconstruction of the chronic fixed posterior tibial subluxation, the authors' opinions are that this management modality should be used in the cases of grade III tibial subluxations. Grade I and II anterior or posterior subluxations may be managed nonoperatively in the aforementioned fashion with alternating functional and rigid immobilization in a reduced position. When these methods are employed, adequate reduction and stabilization may be achieved with preservation of knee range of motion and subsequently improved patient outcomes.

27.5.3 Surgical Technique: Overview

The key components to operative management of the fixed, chronically subluxated or dislocated knee include (1) knee reduction, (2) achieve stability through a balanced reduction, and (3) protect the reconstruction while maintaining a functional knee range of motion during postoperative rehabilitation.

The initial approach to a patient should be achieved through an anteromedial parapatellar arthrotomy. Development of a chronic traumatic dislocation may produce significant scarring of the injured capsular and ligamentous structures in a malreduced position. In order to achieve an adequate, anatomic reduction of the subluxated or dislocated knee joint, the significant scarring must be extensively released and removed. These releases are particularly crucial in the posterior, lateral, and intercondylar regions.

Excision of the ACL and PCL remnants should then occur. Attention can then be directed to the lateral and posterolateral regions in which careful neurolysis of the peroneal nerve should be conducted to ensure accurate identification and protection of this crucial structure throughout the remainder of the procedure. Excision of the LCL and popliteal tendon remnants can be then conducted. Significant scarring between the distal anterior femur and the extensor mechanism may be present and should be released as well. This release will also provide improved mobilization and visualization. Failure to excise scarring between the extensor mechanism and the femur can significantly limit knee flexion. The medial and lateral menisci should then be evaluated, and if repair or debridement is required, this should be performed prior to reconstruction.

Balanced reduction and stabilization must begin by recreating the central axis of the knee through ACL and PCL reconstruction. The authors prefer to perform both ACL and PCL reconstruction with allograft as this has reproducibly enabled excellent fixation while minimizing donor morbidity associated with autograft harvest. The PCL should be reconstructed prior to the ACL to ensure ease of visualization to the posterior aspect of the tibia thereby allowing accurate placement of the tibial PCL aperture. A transtibial and femoral single drill hole technique is employed during PCL reconstruction (Fig. 27.3). The PCL graft is anchored in the tibial tunnel, and the ACL graft is anchored in the femoral tunnel prior to tensioning. Final tensioning and fixation of all reconstructions should be completed sequentially as the last step of each case in the following order: PCL, ACL, PLC, and MCL. Notably, the central axis of the knee should be confirmed radiographically following tensioning and fixation of the PCL and ACL prior to proceeding with further reconstructive steps (Fig. 27.4).

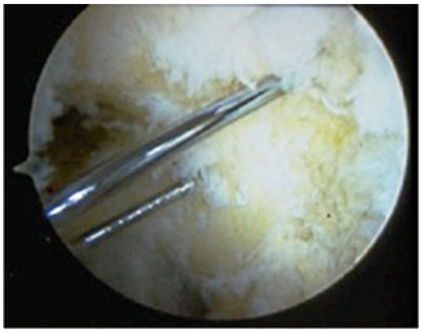

Fig. 27.3 Arthroscopic image of the femoral double tunnel technique allowing recreation of the anterolateral and posteromedial bundles during PCL reconstruction

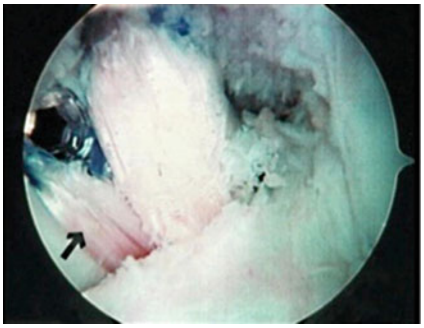

Fig. 27.4 Arthroscopic image demonstrating the completed double bundle femoral PCL reconstruction. Tensioning of the PCL and ACL should be completed prior to collateral ligament reconstruction to provide a central axis of rotation

The PLC should then be reconstructed after the central knee axis has been recreated through cruciate reconstruction. Isometric positioning of this reconstruction may be obtained by evaluating the length change of suture positioned at the desired fixation points. Minimal suture length change identifies the isometric positions for graft fixation. Note that this technique relies upon prior recreation of the central axis of the knee through ACL and PCL reconstruction. The authors recommend reconstruction of the popliteus tendon and the lateral collateral ligament with a split Y-type Achilles tendon allograft. The PLC reconstruction should be tensioned and fixed with the knee in 70° of flexion and neutral rotation.

If significant valgus laxity also exists necessitating MCL reconstruction, this reconstruction should occur at this point. The authors prefer reconstruction with Achilles tendon allograft. A guide pin should be inserted 3–5 mm proximal and 3–5 mm posterior to the medial femoral epicondyle parallel to the joint line in the coronal plane and 15° anteriorly to avoid the intercondylar notch. A suture loop should then be used to confirm isometry from the previously placed guide pin to the tibial insertion immediately posterior to the pes anserinus. This tibial insertion should be modified as necessary to ensure excellent isometry. The femoral bone tunnel should then be drilled in a cannulated fashion over the previously placed guide pin. A 9 × 18 mm bone plug is created for reconstruction and inserted into the femoral bone tunnel. The graft should then be tensioned in 20° of knee flexion, and the tendinous portion of the graft should be secured to the tibia with a spiked screw and washer.

In this fashion, the PCL, ACL, and then the posterolateral split-graft reconstruction are performed. Patellar tracking should then be assessed, and the lateral retinaculum should not be closed if maltracking is identified with attempted closure. An anterior compartment release should also be performed to reduce the risk of postoperative compartment syndrome given the extensive dissection.

Finally, protection of the surgical reconstruction, while allowing controlled functional motion, is crucial to maintaining joint stability while reducing the inherent risk of arthrofibrosis. While external hinge fixation has been used in the past to provide more rigid stability, bracing has become the current mainstay of protecting the postoperative knee. Disadvantages of external fixators include the potential risk of infection and poor patient tolerance. Additionally, the hinged external fixator employs a central axis pin for range of motion, which inherently alters the native cam knee motion arc. This alteration limits the knee range of motion as well as producing a compression and distraction force at the motion extremes. For these reasons, coupled with advances in bracing technology allowing better patient tolerance and postoperative rehabilitation, the authors suggest using a hinged brace following a stable multiligament reconstruction with an allowed range of motion to 120°.

27.5.4 Postoperative Protocol

The authors suggest that a continuous passive motion machine be used immediately postoperatively with a hinged knee brace in place. The patient should remain non-weight-bearing for 4–6 weeks, at which point the patient may transition to a prefabricated functional ACL brace and begin progressive weight bearing. Close clinical and radiographic follow-up should be conducted including contralateral lateral comparison radiographs to ensure symmetric centering of the tibia on the femur at 90° of flexion.

27.6 Conclusions

Chronic fixed tibial subluxation may occur with either single or multiligamentous knee injury, and fixed tibial dislocation may occur with multiligamentous knee injury. In both situations, however, meticulous preoperative planning including thorough patient history and physical examination and radiographic evaluation including stress radiographs and possible magnetic resonance imaging is crucial. Additionally, intraoperative examination under anesthesia may aid the surgeon in grading the subluxation and thereby guiding the intraoperative plan regarding ligamentous sacrifice and reconstruction. Nonoperative treatment may be considered for grade I and II subluxations, while operative reconstruction is preferred for grade III subluxations and dislocations. Although knee arthrodesis has been utilized previously, the sacrifice of knee range of motion with associated poor patient outcomes suggests that open reduction and ligamentous reconstruction should be the treatment of choice. Additionally, increased good to excellent patient outcomes have been achieved with reconstruction in this scenario. Despite the potential for successful outcomes with operative intervention, a caveat should accompany the scenario where chronic maladaptive bony changes have already occurred, in which case successful operative intervention is unlikely. During reconstruction, the surgeon should employ a careful methodology to reduce the potential for intraoperative and postoperative complications. Critical steps of the intraoperative reconstruction include meticulous excision of adhesions for full knee mobilization and recreation of the central axis of the knee during ACL and PCL tunnel positioning and graft tensioning. Postoperatively, stable and functional bracing in a hinged knee brace is critical to maintain knee stability and range of motion. Although chronic fixed tibial subluxation or dislocation is a rare, complex clinical scenario, recreation of knee stability and motion with excellent patient outcomes can be achieved.

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Fracture Dislocations of the Knee

28

Sanjeev Anand

28.1 Introduction

Fracture dislocations of the knee are rare injuries that involve disruption of ligamentous bonds within the knee joint, along with associated fractures of the adjoining bones. As disrupting forces travel through the knee joint, a variety of patterns of ligamentous and bony injuries occur, dependent on the direction of the forces and the position of the limb. Whilst ligamentous injuries following knee dislocation are well described [1–3], there is no standard classification system to describe the combination of bony injuries in conjunction with the knee dislocation. In the absence of an acceptable classification system, it is important to identify the personality of each of these fracture dislocations before planning their treatment. There is rarely a cookbook approach to managing these injuries. It is important to take into consideration patient factors, injury patterns, soft tissue compromise, energy expended at the injury, neurovascular status and available expertise before planning any treatment.

28.2 Classification

Broadly, fracture configurations in knee fracture-dislocations fit into three common patterns. The first group of fractures involves avulsion fractures. This relates to bony avulsion at ligamentous or capsular attachments. The second group of fractures involves weight-bearing articular surfaces of the knee joint. The third group of fractures involves bones distant to the knee joint, including fractures of the femur and tibia. For the purposes of this chapter, we will not consider fractures outside of the injured limb with knee dislocation, which may be part of the same trauma but require independent management.

Various classification systems used to classify ligamentous injuries in knee dislocation can be used in conjunction with a description of fracture patterns [1–3]. Knee dislocations can be classified based on the direction of dislocation [1], the anatomical ligaments affected [2] or the energy sustained by the injured knee. Kennedy’s position system of classification is based on the position of the tibia in relation to the femur [1]. It implies, rather than accurately identifies injured structures based on the direction of forces. Unfortunately, it does not help in situations where the dislocation has already been reduced, a situation is seen in up to 50% of dislocations [2–4]. In the Kennedy classification, medial and lateral dislocations are more likely to have plateau fractures, while anterior and posterior dislocations may have anterior or posterior cruciate ligament (ACL/PCL) avulsion fractures [5, 6].

Fracture dislocations can also be classified based on the energy imparted on the knee joint at the time of injury. These can be high velocity, low velocity or ultra-low velocity. High-velocity injuries are quite often the result of motor vehicle accidents and are more likely to have fractures of the weight-bearing skeleton. These patients often have injuries to other organ systems and bones, which may take priority in management. There is a high incidence of soft tissue injuries and neurovascular injuries [7]. A polytrauma patient requires a different approach to the management of knee dislocation compared with a patient, who has isolated knee dislocation. The timing of surgery and knee reconstruction strategy is dictated by other injuries and these patients may occasionally need temporary stabilisation and delayed secondary reconstructions.

Low-velocity injuries, sustained through sports or a fall from a height, have a lower incidence of neurovascular injuries [7, 8] and are amenable to single stage planned arthroscopic and small incision ligamentous repair/reconstructions.

Ultra-low velocity injuries are a growing concern, where patients with high body mass index sustain significant multi-ligament knee injuries (MLKIs) with trivial trauma. These injuries are more often seen in female patients, unlike other

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Table 28.1 Wascher modification of Schenck classification, incorporating fracture dislocations [2, 3]

Group	Sub-group	Definition
KD-I		One cruciate ligament injured
KD-II		Both cruciate ligaments injury
KD-III		Both cruciates and one collateral ligament injured
KD-IV		All four ligaments injured
KD-V		Knee dislocation with associated fractures[a]
	KD-V1	ACL or PCL injury with associated fracture
	KD-V2	ACL and PCL injury with associated fracture
	KD-V3M	ACL, PCL and Medial collateral ligament (MCL) injuries with associated fracture
	KD-V3L	ACL, PCL, Lateral collateral ligament/posterolateral corner (LCL/PLC) injuries with associated fractures
	KD-IV	ACL, PCL, MCL and LCL/PLC injuries with associated fracture

Add suffix ‘C’ for vascular injury and ‘N’ for nerve injury

[a] Does not include avulsion fractures which are included in the KD-I to KD-IV group

multi-ligamentous injuries. There is a high incidence of nerve (39.1–41%) and vascular (28.1–41%) injuries in this group [9, 10]. Furthermore, these patients often have associated avulsion or compression fractures due to the osteoporotic nature of their bones. These low-demand patients can often be managed by repair/reconstruction of the peripheral capsule and posterolateral corner (PLC), besides bony fixations. Very often these patients choose to forgo the option to have delayed ACL/PCL reconstructive surgeries due to their low demands.

The energy-based classification acts as a guide to the assessment of injury and future prognosis but has arbitrary boundaries and there may also be significant cross-over between different groups. Anatomic classification systems of Schenk [2] and its modification, Wascher [3], are based on identifying torn structures in the involved knee (Table 28.1). Stratification within this system requires a thorough clinical assessment. This includes assessment of neurovascular structures, an examination under anaesthesia and magnetic resonance imaging. In this system, the KD-V group comprises of knee fracture dislocations, in which ligamentous injuries are associated with significant periarticular fractures. This group is further sub-classified to mirror the ligamentous part of the classification. In this group, management of ligament injury needs to be done in conjunction with fracture management, though priority is given to restoring the weight-bearing architecture of the knee by performing early skeletal stabilisation. Where possible, consideration should be given to restore peripheral ligament stability at the same time.

28.3 Initial Assessment

As discussed earlier, these injuries are often part of a multi-system multi-organ trauma and initial management is guided by the Advanced Trauma Life Support [ATLS] system protocol. A thorough history is obtained to identify the mechanism and energy of the trauma. It is helpful to establish the direction and magnitude of the forces acting on the knee joint at the time of impact. Often, due to other co-existent injuries, these patients are unable to provide a history, therefore, a description of the scene of injury from the accompanying witnesses or paramedical team is useful. It is important to ascertain the exact time of injury, especially in cases with vascular injury or developing compartment syndrome.

Following a primary survey and secondary survey, attention is paid to the limb with the injured knee joint. It is important to carry out a thorough circumferential assessment of the whole limb. The status of soft tissues around the knee joint, including any open wounds is documented. Location of bruises gives a good clue to the site of ligamentous injury (Fig. 28.1a). We use Tscherne’s classification [11] system, which accounts for both open and closed injuries (Fig. 28.1b). Soft tissue injuries evolve over the days following injury and areas of skin necrosis may develop later. The clinician must be especially vigilant if a plaster splint, which does not allow for regular monitoring of soft tissues, is used for initial immobilisation. If there are concerns about soft tissues, a temporarizing external fixator stabilises the fracture and allows for regular monitoring of soft tissues (Fig. 28.1c). The inflammatory phase of trauma usually begins to abate 72 h after the initial trauma [12]. As soft tissues and swelling settle, it is often better to plan for any primary surgical treatment, a week following the injury.

During initial survey, it is important to assess for any deformity suggestive of persistent knee dislocation. It is not necessary to wait for imaging to reduce deformity relating to the knee dislocation, especially, if there are any concerns of the neurovascular deficit. The same principles of management of neurovascular injury apply to this group of patients

Fig. 28.1 Soft tissue injuries around the knee joint. **a** Posterior location of the bruise suggests a posterior capsular injury while the abrasion may indicate an internal degloving injury. **b** Open wound in a high energy knee dislocation. **c** External fixation to temporarily stabilise the knee joint after reduction of dislocation, vascular exploration and fasciotomy (covered with a V.A.C$^{®}$ negative pressure dressing)

as to any other knee dislocation. If there is any discrepancy in circulation between two limbs, vascular imaging is requested. Depending on the urgency, it could be either an on-table angiography for avascular limb or computerised tomographic (CT)/magnetic resonance (MR) angiography for a viable limb with feeble circulation (Fig. 28.2).

28.4 Imaging

Standard radiographs in two planes are the first line of investigation. Besides major fracture lines, a corner fracture at the periphery of the joint and avulsion fractures give an idea of soft tissue disruption. These patients often have a series of screening trauma computed tomogram [CT] scans to localise injured areas around the body. Subsequently, dedicated CT scans to accurately assess the knee fracture configuration are done. Three-dimensional CT reconstruction is a valuable tool for planning surgical strategy.

As well as using CT scans for fracture configuration, magnetic resonance (MR) scans are very useful to assess ligamentous, capsular, meniscal and chondral injury in fracture-dislocation scenarios. It is not unusual to find soft tissue injuries in periarticular fractures of the knee joint. In fracture situations, we perform MR scans if the fracture configuration suggests associated ligamentous injuries. This would apply in cases with avulsion fractures, unicondylar fractures or posterior column fractures with significant displacement.

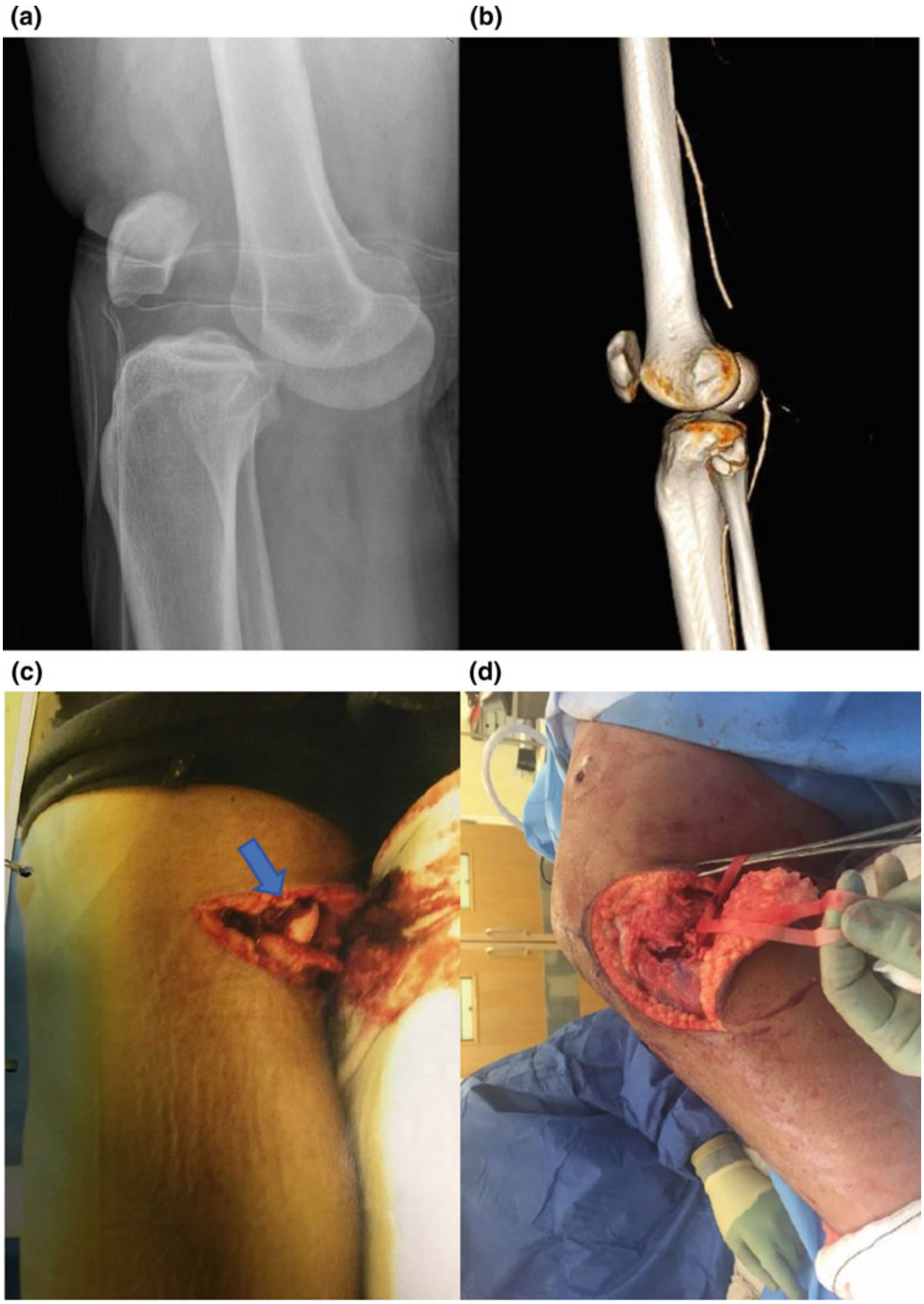

Fig. 28.2 **a**, **b** Vascular injury following open fracture dislocation of the knee joint. **c** Femoral condyles are visible through the posterior open wound (arrow). **d** Following vascular repair, open wound was extended laterally and distally for a lateral reconstruction procedure

28.4.1 Timing of Surgery

In patients with multiple associated injuries, the timing of surgery is dictated by the physiological stability of the patient and accompanying injuries. These can range from traumatic brain injury, chest, abdomen or pelvic trauma, long bone fractures and spinal injuries. Quite often these patients need urgent life-saving surgery for head, chest, abdomen and pelvic trauma, while temporary stabilisation of limb fractures and dislocations is performed acutely. These patients are monitored for their cardiovascular and pulmonary function and blood markers including serum lactate, to assess suitability and timing for definitive surgery.

Energy transferred to the soft tissue envelope is directly correlated with energy imparted to the knee joint in high-energy trauma patients [11, 13]. Increasing soft tissue injury is associated with poorer postoperative outcomes and higher complication rates [13]. The extent of soft tissue trauma is not always appreciable at the first assessment and needs regular monitoring. Early definitive stabilisation of high-energy injuries is associated with high risk of wound breakdown and infection [14, 15], while staged fracture management [temporary external fixation followed by delayed definitive fixation] results in decreased rate of soft tissue complications [16, 17].

We practice the concept of 'safe definitive surgery' as soon as patient condition allows [18, 19]. Skeletal stabilisation of the axial skeleton, including long bone fractures, is carried out at the first opportunity. Once soft tissues around the knees are settled, fracture fixation with ligament repair is carried out within 7–14 days. We aim to repair and fix all avulsions and fractures in one sitting. Collaterals are repaired, often with augmentation, at the time of fracture fixations. Post-operatively the knee is braced for 6–8 weeks while the range of motion is maintained. Cruciate ligament reconstructions are done 6–8 weeks later once capsule is healed and full range of knee movement is regained.

28.5 Tibial Plateau Fractures

Tibial plateau fractures can accompany ligamentous injuries as the axial compression forces push the femoral condyle onto the tibial plateau. On the tension side, ligamentous disruptions or avulsion fractures may result [6] (Fig. 28.3). As the traumatic force continues through the joint, the central ligaments may fail. Schatzker, in his series of 94 tibial plateau fractures, noted ligamentous injury in only seven patients (7.4%) [20]. With the advent of MR scans, ligamentous injuries in the setting of tibial plateau fractures are increasingly being recognised and have been reported in a range of 55–71% [21–23]. In one series of 103 consecutive tibial plateau fractures, 99% had some soft tissue injury. 77% sustained a complete tear or avulsion of 1 or more cruciate or collateral ligaments, while 68% had an element of posterolateral corner injury [24]. However, very few of these soft tissue injuries needed separate soft tissue stabilisation surgeries. In a prospective cohort of 82 tibial plateau fractures, whilst 73% had associated soft tissue injury, only 2% required secondary soft tissue surgery [25]. Conversely, in a series of 90 consecutive multi-ligament knee injuries, Porrino et al. [6] found 19 (21%) to have tibial plateau fracture. Of these, 47% were lateral plateau fractures, 37% medial plateau and 16% bicondylar fractures.

Moore classified his series of 132 fracture dislocations of the tibial plateau into five types [26]. Type 1 fractures involved the posteromedial plateau; type 2 fractures involved the entire condyle, medial or lateral; type 3 fractures were rim avulsion fractures; type 4 fractures were rim compression fractures; whilst type 5 fractures were four-part fractures. Type I was the commonest fracture-dislocation type in his series [26]. In the coronal plane, a compression fracture of one half of plateau would commonly be associated with ligament injuries on the other side due to tension [6].

In the Schatzker classification of tibial plateau fractures, split compression (type II) and medial condyle fractures (type IV) are most commonly associated with soft tissue

Fig. 28.3 Medial compression and lateral tension injury. Preoperative CT scans (**a**, **b**) and postoperative X-rays (**c, d**) of Moore type 2 medial condyle compression fracture with lateral side ligament injury due to tensile forces. On lateral side, allograft augmentation using bioabsorbable screws has been done

injuries to the knee joint [20]. Similarly, Delamarter et al. reported that split compression fractures are most commonly associated with ligamentous injuries [27]. Schatzker type II fractures are usually associated with MCL injuries [22]. Whereas in Schatzker type IV fractures, knee dislocations (bicruciate injuries or minimum three ligaments torn) were most common and present in 46% of cases [23]. As the grading of the fracture increases in the Schatzker classification, so does the likelihood of ligamentous injuries. However, there is no statistically significant correlation between AO fracture classification of tibial plateau fractures and ligamentous injuries [6, 23]. The Schatzker classification does not account for split fractures, as described by Moore [26] or posterior column fractures described by the Luo's three-column classification [28]. In the sagittal plane, posterior column fractures, caused by axial loading in the flexed knee often lead to anterior cruciate ligament injuries, while anterior corner fractures, caused by anterior subluxation of distal femur are associated with PCL injury [29].

For planning surgical treatment in tibial plateau fractures, we determine the columns injured [28] and the associated articular comminution or depression. This helps us identify the direction of the forces acting at the knee joint at the point of impact. We examine knee stability after fracture fixation. We aim to fix all avulsion fractures. Unless grossly unstable, the medial ligament is usually left to heal in a brace. We

Fig. 28.4 Extension of the lateral incision to expose and graft injured common peroneal nerve. **a** Lateral incision in floppy lateral position extended posteriorly to allow access for lateral reconstruction, nerve exploration and nerve grafting (FH—Fibula head). **b** Lateral exposure to show avulsed structures (ITB—Iliotibial band; LCL—Lateral collateral ligament; CPN—Common Peroneal nerve). **c** Repair of lateral structures augmented by allograft (white arrow). **d** Green markers showing the zone of injury of common peroneal nerve (blue arrow); TN-Tibial nerve). **e** Multiple cables of sural nerve graft used to bridge injured common peroneal nerve (yellow arrow). **f** Right leg showing healed surgical incision and left leg showing incision for sural nerve harvest

always repair lateral ligaments, often using allograft augmentation. Often these patients require exploration and repair of neurovascular structures. We place patients in a floppy lateral position, which allows access to the posterior and anterior aspects of the knee joint. In medial compression fractures with lateral distraction injuries, we use medial and lateral incisions. The lateral incision utilised for lateral reconstruction can be curved posteriorly to allow for nerve exploration and repair (Fig. 28.4).

In posterior column fractures with ligamentous injuries, a combination of posteromedial and anterolateral approach allows circumferential access to the knee joint. In our experience, the most common tibial plateau fracture pattern with ligamentous injury involves the posteromedial plateau with ACL avulsion. This has been seen in other series as well [30]. We expose and fix the posteromedial fragment with a posteromedial approach, protecting pes anserinus and MCL. Fracture reduction is confirmed by direct visualisation of the fracture using submeniscal arthrotomy over the medial fracture line and, indirectly, by aligning the inferior spike of posterior fragment to posterior tibial shaft. Anterolateral small incision arthrotomy is done for suture or screw fixation of the avulsed ACL fragment (Fig. 28.5). Incisions would often need to be tailored to the specific fracture patterns and ligamentous injury. A posteromedial incision curved laterally over the popliteal crease allows exposure of the entire posterior aspect of the knee joint. The anterolateral incision can be used for anterior arthrotomy if required or curved/positioned laterally to allow lateral reconstructions. In our practice, we perform arthroscopic posterior cruciate ligament reconstructions later in a staged manner, while protecting the knee in a dynamic PCL brace for the interim period. As required, screws or metalwork are removed in the second stage to allow for tibial tunnel placement.

Less often, there may be similar articular fractures of the femoral condyle, which require early stabilisation with concomitant management of ligament injuries. The case in Fig. 28.6 demonstrates that due to rotational and shearing forward force of the distal femur on a flexed knee, a combination of injuries, including Hoffa's fracture of medial femoral condyle, posterolateral corner injury, PCL avulsion fracture, medial meniscus root injury, patellar tendon avulsion and anteromedial corner fracture were sustained. This patient also sustained an open injury requiring gastrocnemius flap and skin grafting. Hoffa's fracture, PCL avulsion fracture and meniscus root were fixed with the posteromedial approach. Due to the state of the anterior soft tissues, small incisions were used to fix patella tendon avulsion and anteromedial corner fracture. Posterolateral structures were reinforced with tibialis anterior allograft through percutaneous approach, using the modified Larson technique [31]. This case effectively demonstrates the individual nature of these fractures requiring bespoke management strategies.

Ligament injury, if present and left untreated, is a major cause of poor outcome in tibial plateau fractures [32]. Conversely, if adequately treated, the presence of tibial plateau fractures in a knee dislocation scenario does not affect the final outcome significantly [33].

28.6 Avulsion and Periarticular Fractures

Knee dislocations have a much higher incidence of ligamentous and tendinous avulsions compared to standard ligament injuries [2]. These include Segond fractures, reverse Segond fractures (capsular avulsions on medial side tibial plateau, often associated with PCL injuries), tibial spine avulsions, fibula head avulsions and marginal/corner plateau fractures. It is important to identify these fractures, especially in a spontaneously reduced knee, as they give important clues as to the extent of ligamentous and soft tissue injuries. The presence of avulsion fractures occasionally simplifies the surgical plan, with focus on early fixation of avulsion fractures leading to direct healing of ligaments.

Segond fractures result from the avulsion of the anterolateral capsule from the proximal tibia. There is an ongoing debate as to whether there is a distinct anterolateral ligament with an attachment to the proximal tibia [34–37]. The Segond fracture is thought to be due to avulsion of this ligament complex [35]. MRI studies show that posterior fibres of the iliotibial band and lateral capsule are attached to this avulsed fragment [38]. The anterolateral ligament complex is injured in more than 90% of knee dislocations and injury to its distal attachment on the tibia is seen in 46% of cases [39, 40]. If an avulsion fragment is visible, we aim to repair it in the acute setting. Large fragments can be repaired with screws while small fragments are secured using suture anchors (Fig. 28.7).

Reverse Segond fractures (Fig. 28.8) are fractures of similar appearance but on the medial side caused by the pull of deep MCL fibres, following valgus external rotation forces on a flexed knee [41, 42]. This is most often associated with PCL and MCL injuries but in a series of 13 cases was shown to occasionally relate to ACL injuries as well [41].

The lateral collateral ligament, popliteo-fibular ligament and biceps femoris attach to the fibular head. Internal rotation and varus forces on the knee joint may pull these structures from their attachment on the fibular head, leading to lateral and posterolateral instability. This may be associated with significant posterior capsule injury, leading to increased hyperextension at the knee joint (Fig. 28.9). These fractures can be fixed with screws or anchors in combination with the management of associated central ligament injury.

Tibial spine avulsion fractures are usually due to ACL or PCL avulsions. In knee dislocations, PCL avulsions are

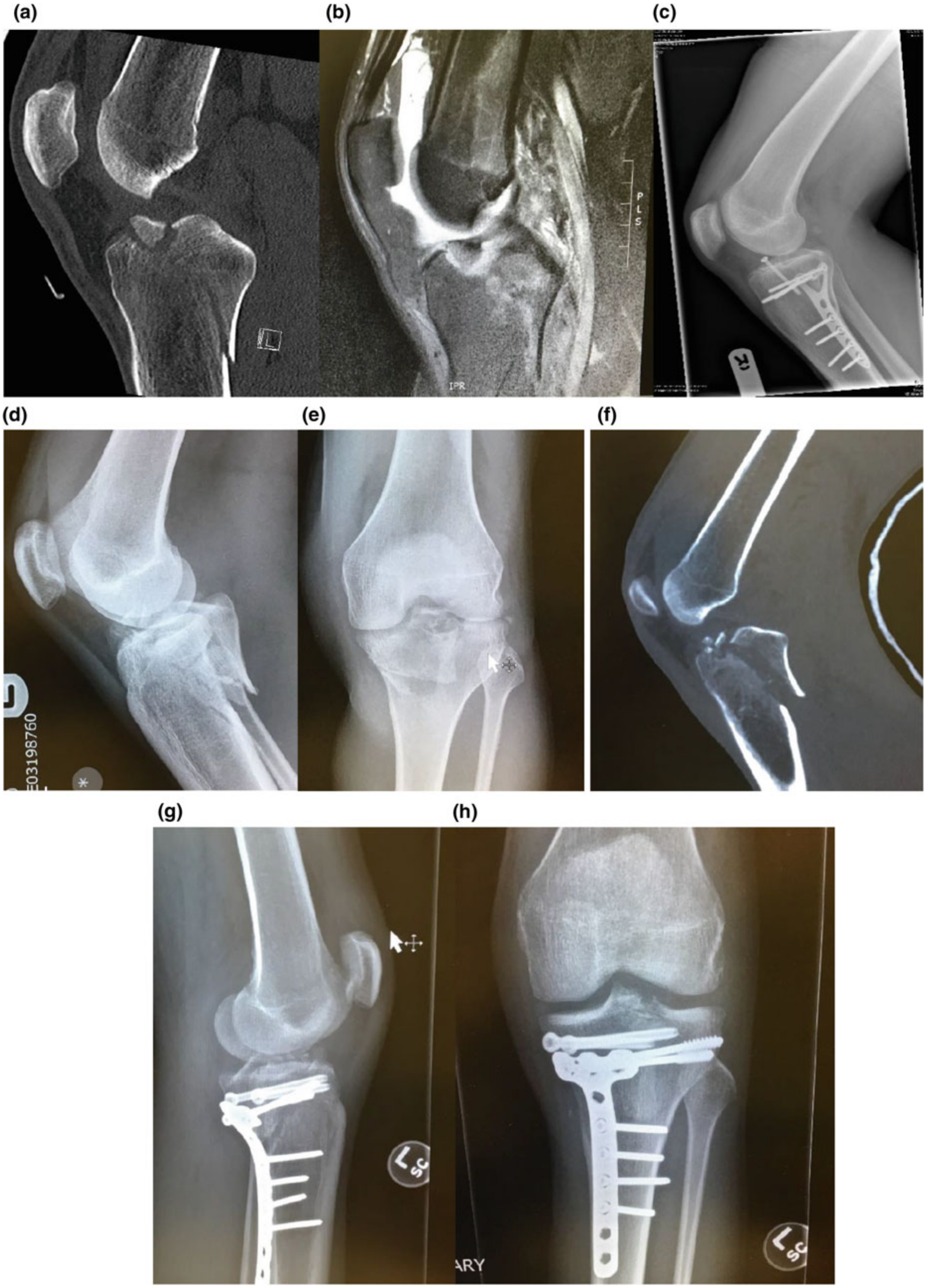

Fig. 28.5 Two cases illustrating one of the commonest fracture patterns, a combination of posteromedial tibial plateau fracture (Moore Split type 1) with ACL avulsion fracture. **a**–**c** Posteromedial tibial plateau fracture fixation with a posterior buttress plate and ACL avulsion fracture fixed using a screw. Second case with a similar fracture pattern (**d**–**h**) where a comminuted ACL fragment has been fixed using sutures

Fig. 28.6 Bespoke reconstruction. **a**–**h** Radiological images demonstrating different components of the injury. Red Arrow—PCL avulsion with adjoining medial meniscus posterior root avulsion; Blue arrow—Anterolateral corner fracture due to capsular avulsion; Yellow arrow—Patellar tendon injury. **i**, **j** Demonstration on a knee model of the direction of forces leading to this injury complex. **k** Demonstrates status of the soft tissues, prior to the ligament reconstruction. **l** Posteromedial exposure retracting medial head of gastrocnemius (MG) laterally, to fix PCL avulsion (white arrow), medial meniscus root (sutures shown holding the meniscus root) and medial femoral condyle Hoffa's fracture (FC). **m** Black arrow points to the incision used to repair anterolateral capsule and patellar tendon avulsion. Green arrow points to the lateral allograft augmentation done percutaneously to minimise soft tissue disruption. **n**, **o** Postoperative images

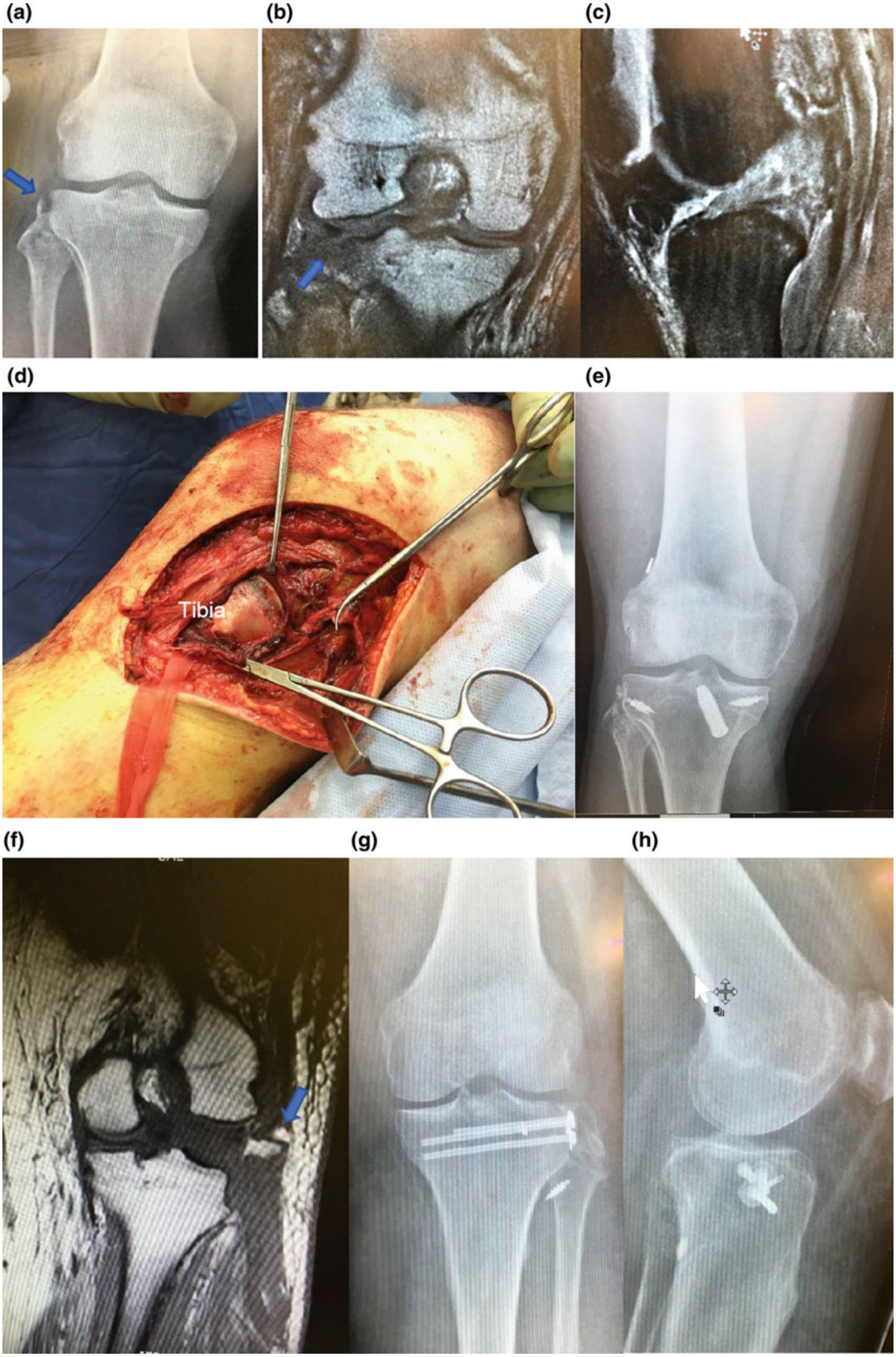

Fig. 28.7 Segond Fracture. Case 1 **a**–**e** Segond fracture (arrow) in a patient with ACL and grade III MCL injury. **d** Intraoperative picture showing bare proximal tibia. MCL fibres held in artery clips and pointer at the medial joint line. **e** Postoperative image showing ACL reconstruction alongwith MCL and Segond repair using anchors. Case 2 **f**–**h** Large Segond fracture (blue arrow) and fibula avulsion fracture, fixed with screws and anchors

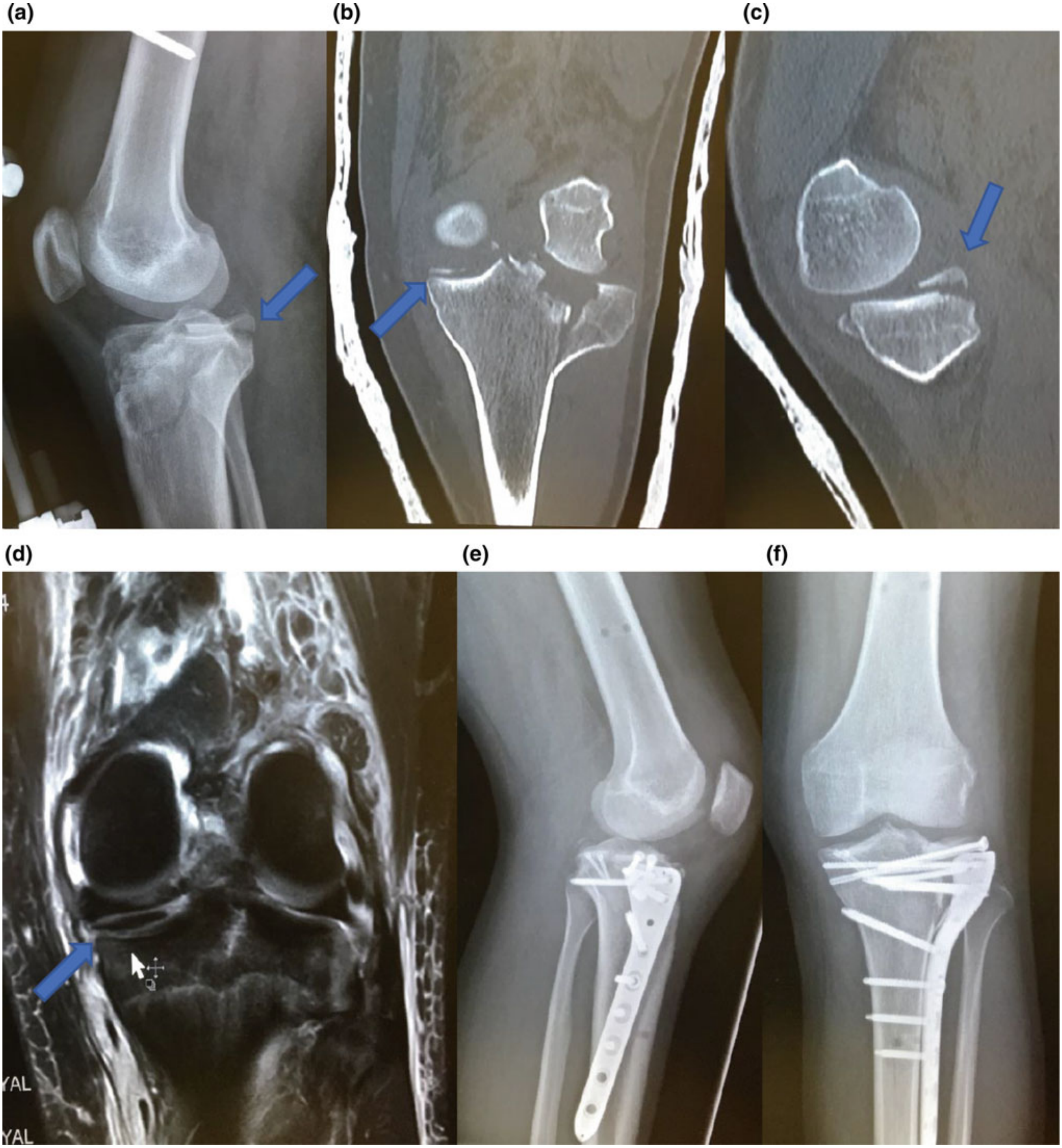

Fig. 28.8 Reverse Segond fracture (arrow). **a**–**d** X-ray, CT and MR images of reverse Segond fracture with lateral tibial plateau fracture. **e**, **f** Postoperative images

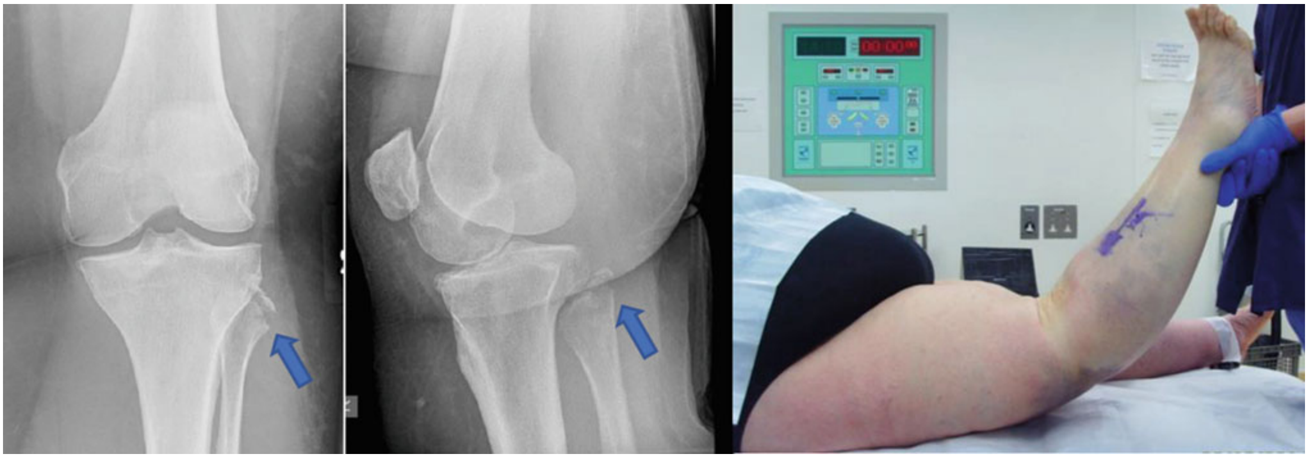

Fig. 28.9 Fibula avulsion fracture (arrows) in an ultra-low velocity MLKI associated with posterior capsular injury, leading to hyperextension at the knee joint

more common than ACL avulsions. In two separate series by Frassica et al. and Sisto and Warren, PCL avulsions were noted to be present in 77 and 88% of knee dislocations, while ACL avulsions were noted in 46 and 63% of cases, respectively [43, 44]. These avulsion fractures can be part of tibial plateau fracture complex. PCL avulsions are usually fixed using posteromedial approach, using screws. ACL avulsion fractures occasionally extend into the tibial plateau and often have the anterior root of lateral meniscus attached to it. There may be interposed medial meniscus or intermeniscal ligament underneath, which needs to be retrieved before fixation. Large ACL avulsion fragments can be fixed using screws, while comminuted fractures are best fixed using sutures which pull the avulsed fragment down to its tibial bed using bone tunnels [45]. This can be done arthroscopically or via arthrotomy, occasionally utilising the incision used for fixation of associated plateau fractures (Fig. 28.10).

28.7 Extensor Mechanism Disruption

Extensor mechanism disruption could be in the form of a patella fracture or a quadriceps or patella tendon rupture. Patella fracture usually happens as part of a ‘dashboard’ injury (Fig. 28.11) while patella tendon rupture is usually due to forward displacement of femur, pulling the tendon from its tibial attachment (Fig. 28.12). There is a limited literature on the incidence of extensor mechanism injury in knee dislocation [46]. In a series of knee dislocations, Wissman et al. found patellar tendon injuries in 36% of cases, although the majority were partial injuries [47]. A larger proportion of patients (71%) had medial patellofemoral ligament injury, usually at the femoral attachment.

In an unconscious patient or in a severely traumatised knee, it can be difficult to assess knee extension. In such patients, the continuity of extensor mechanism needs to be assessed by direct palpation as well as using imaging studies. Extensor mechanism disruption would usually be easily identified in a case of known dislocation due to extensive imaging available. In a converse situation of known patella/quadriceps tendon rupture but with a spontaneously reduced knee dislocation, it is important to keep a high index of suspicion to identify hidden knee dislocation. Knee examination in such patients with patella tendon rupture may be difficult and only an ultrasound scan may have been done to confirm the tendon rupture, thus missing underlying knee dislocation.

Restoration of the extensor mechanism is a priority. A disrupted patella tendon gives an opportunity to perform an open reconstruction of the ACL and PCL at the same time as patellar tendon repair. Treatment options include primary repair of tendon or repair with auto/allograft augmentation. Augmentation may be required if there is inadequate native tissue or in failed primary repair. We routinely augment patella tendon repair, if there is any doubt on the quality of tissues. In an acute situation, it is important to have a strong patella tendon repair to withstand the rehabilitation protocols

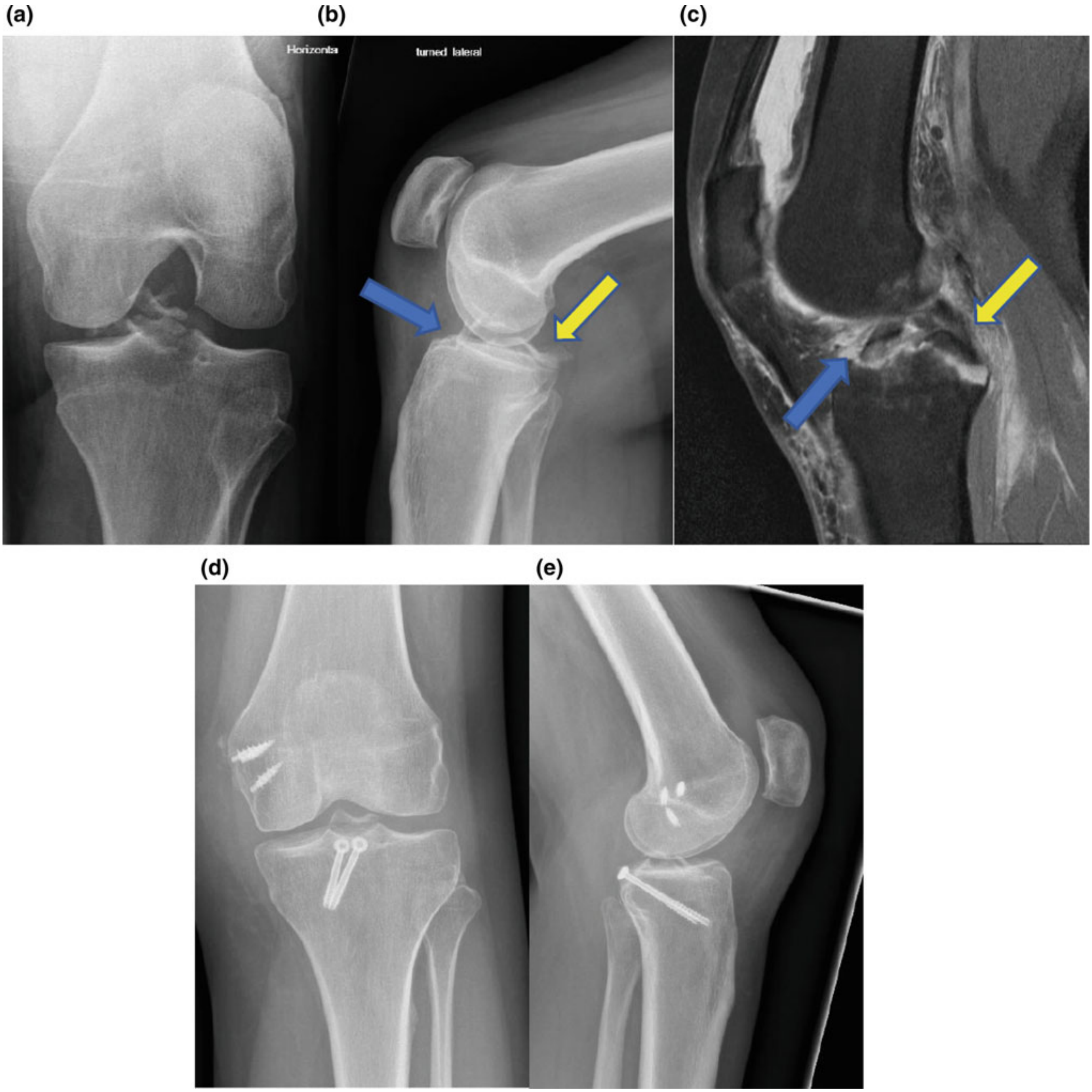

Fig. 28.10 ACL and PCL avulsion fractures. **a**–**c** ACL (blue arrow) and PCL (yellow arrow) avulsion fractures alongwith MCL injury in a horse rider. **d**, **e** Postoperative pictures showing MCL repair and screw fixation for PCL. ACL has been fixed using sutures

of associated ligament surgery. We quite often use a semitendinosus graft left attached to its tibial insertion to augment patella tendon repair. The use of hamstring graft for autogenous tendon augmentation has the advantage of improved graft incorporation and lower cost [46]. We always add another encirclage wire or tape around the patella

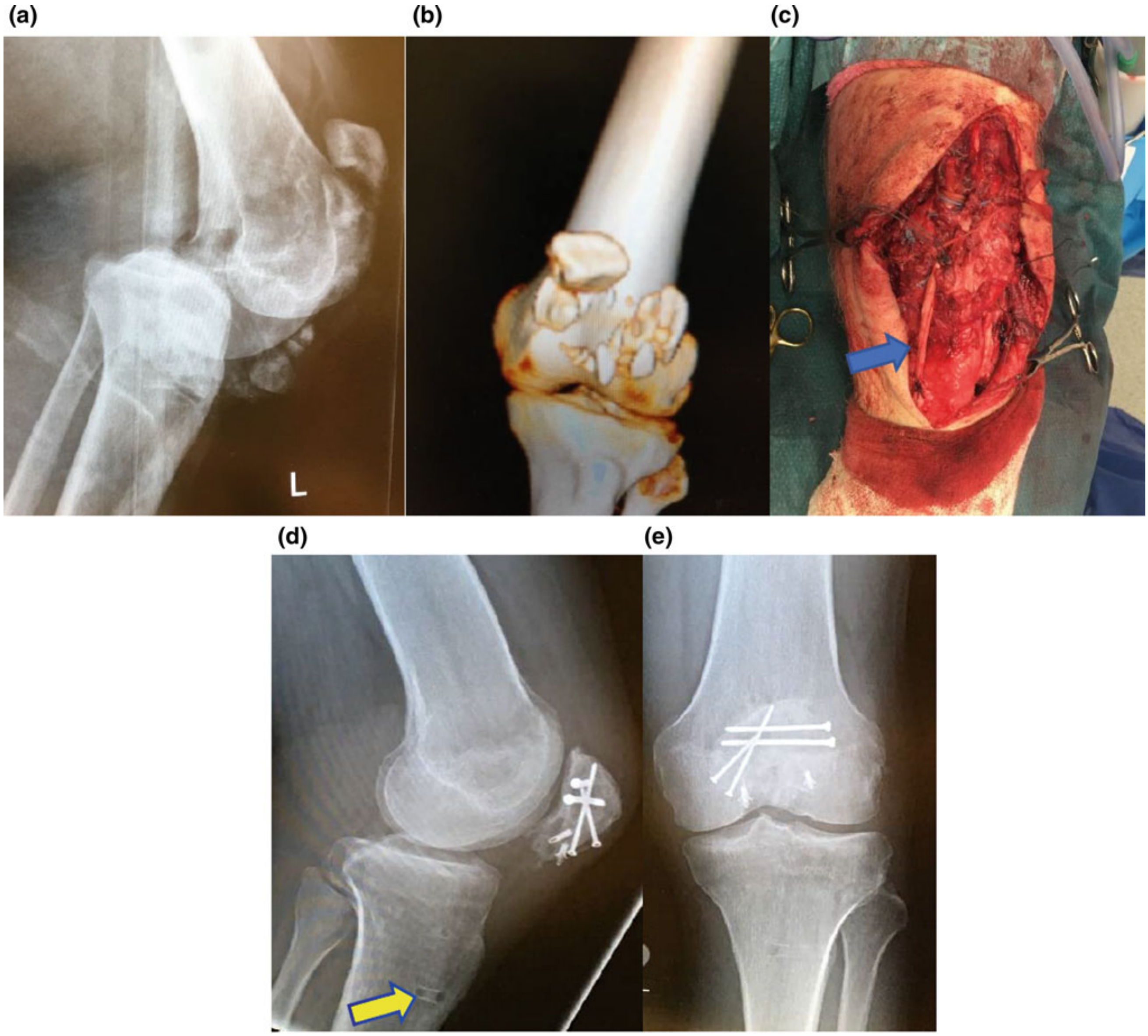

Fig. 28.11 **a–e** Patella fracture in knee dislocation. In this very comminuted fracture, augmentation of patellar tendon was done using semitendinosus autograft (blue arrow) due to significant injury to the patellar tendon. **d** Yellow arrow points towards the transverse drill hole in tibial tuberosity, used for passing nylon encirclage tape to protect patellar tendon repair

and tuberosity, to protect the repair and allow early knee flexion. We prefer nylon tape over a wire for encirclage, as wire often breaks and is visible on radiography requiring secondary removal. For quadriceps tendon augmentation, we prefer to use artificial ligament, though tendon graft augmentation techniques have been described [46].

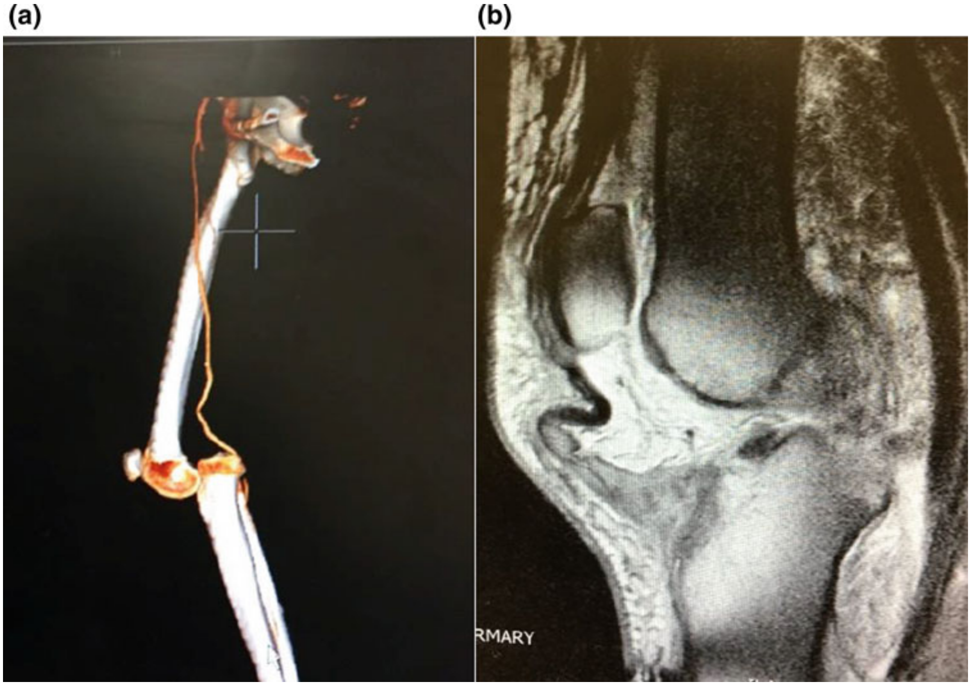

Fig. 28.12 Patella tendon injury in knee dislocation. CT scan (**a**) of an unreduced knee dislocation, demonstrating the mechanism which led to the patellar tendon rupture (**b**)

28.8 Fracture Shaft Tibia and Femur

Reports suggest that up to 30% of femoral shaft fractures have concomitant significant ligament injuries [48]. These ligamentous injuries are frequently missed and diagnosed later with instability symptoms [4]. In a series of 26 femoral shaft fractures, the ACL (50%) was found to be most commonly injured, followed by the MCL (31%), LCL (13%), and PCL (6%) [4]. In another series of 27 consecutive shafts of femur fractures who underwent MRI scans, 19% were found to have ACL injuries, 19% Gr III MCL injuries, 15% Gr III LCL injuries and 7% PCL injuries [49]. Similarly, In a series of 'floating knee' injuries, (ipsilateral femoral shaft and tibial shaft fractures), 30% of patients had evidence of ligamentous injuries [50]. Tibial diaphyseal fracture with knee dislocation is a less commonly described injury with only a few case reports in the literature [50–52]. This would be probably due to the 'dashboard' mechanism of these injuries, leading to more common association with femur fractures.

We perform early stabilisation of long bone fractures followed by examination of the knee joint under anaesthesia with stress views to identify ligamentous injuries. If feasible, in femoral shaft fractures, we use a short intramedullary nail which would not interfere with femoral tunnels in a subsequent ligament reconstruction (Fig. 28.13). In these cases, it is imperative to get the femoral fracture rotation correct to maintain patella tracking. On the tibial side, subsequent ligament reconstruction strategies may require removal of proximal screws or intramedullary nail, to allow for tibial tunnel placement.

28.9 Conclusion

Fracture dislocations of the knee are complex injuries and have a high incidence of associated injuries [3]. Appropriate early management is the key to get the best outcome. It is important to identify the potential whole complex of injuries, including injuries to the soft tissues. If local expertise is not available, these injuries are best stabilised temporarily with external fixators and referred to an appropriate level 1 or tertiary centre for definitive management. Each of these injuries is individual and requires a bespoke management strategy, taking into account the fracture pattern and associated ligament injuries. Significant rehabilitation input is required for these patients to achieve the best outcome. With a combination of appropriate surgery and rehabilitation, excellent to a good outcome, can be achieved for the majority of these patients.

Fig. 28.13 Fracture shaft femur with MLKIs. **a**–**d** Dashboard injury with fracture femur, PCL avulsion fracture, posterior horn lateral meniscus root injury (blue arrow) and posterolateral corner injury. **e**–**h** Segmental shaft femur fracture and PCL avulsion fracture, in a biker with old Dynamic hip screw (DHS). Retrograde intramedullary nail used to span both fractures, after removal of lower DHS screws. PCL avulsion fixed by posterior approach. **i**, **j** Short femoral intramedullary nail used to stabilise femur fracture avoids any conflict with the tunnels made for ACL, PCL and posterolateral corner reconstruction

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Articular Cartilage Restoration in the Multiple Ligament Injured Knee

29

Justin O. Aflatooni, Justin W. Griffin, and Kevin F. Bonner

29.1 Introduction

Multiple ligament knee injuries represent a heterogeneous patient population, often presenting with a spectrum of complex injury patterns. The strict definition of a multi-ligament injury is at least two combined ligament tears. The relatively less common, more complex, three or even four ligament injury associated with a knee dislocation is the focus of this book. Most knee dislocations involve injury to the cruciate ligaments in addition to at least one of the collateral ligaments [1–3]. In addition to the ligamentous injury which defines this group, these patients often present with concomitant injury to the meniscus, articular cartilage, neurovascular structures, and soft-tissue envelope [2, 4].

Most reports on the treatment management and results of the complex multi-ligament patients justifiably focus on the ligamentous repair and reconstruction to restore stability of the joint [1, 2, 5–10]. Most authors do not mention the incidence of articular cartilage injury or discuss treatment recommendations in this setting [1, 2, 4–8]. There is evidence that the pattern of articular cartilage damage in the multi-ligament injured knee is not significantly different than in isolated anterior cruciate ligament tears, despite the increased severity of injury [4]. Current data suggests that gross articular cartilage injury is present in 16–46% of knees undergoing ACL reconstruction within 3 months of injury [11–14]. Similar to isolated ACL injuries, in the multi-ligament injured knee, an increased incidence of chondral lesions and overall diffuse articular cartilage degeneration is often observed over time, particularly in the setting of meniscal deficiency [4, 12, 13, 15].

Despite the relatively high rate of articular cartilage degeneration following multi-ligament knee injuries, there is currently no good evidence that a focal articular cartilage injury in this setting will necessarily be symptomatic or the primary cause of progressive joint degeneration over time [16]. Many factors may influence the progression of degenerative changes following ligamentous knee injury including: meniscus integrity, altered joint kinematics, persistent instability, weight, body mass index, as well as cartilage injury at both the macroscopic and cellular level at the time of injury [15, 17–23].

Similar to chondral lesions seen in isolated acute ACL injuries, many of these lesions may remain asymptomatic for a period of time even with no treatment [16, 24]. Currently, the natural history of most chondral lesions is not clearly defined and there is limited evidence that intervention significantly alters the natural history of an asymptomatic lesion [25]. Observation or "benign neglect" of even a full thickness chondral defect may be the best treatment option in many cases, as some data suggests that the presence of these lesions may not be a significant prognostic factor effecting outcomes [26]. In fact, some recent evidence suggests that treatment of a chondral lesion with even chondroplasty can be potentially detrimental in some patients [24]. Microfracture can also potentially negatively influence outcomes when compared to debridement in some cases [25, 27]. Therefore, it may be prudent to be conservative with many of these lesions with either benign neglect or the most appropriate low morbidity, expeditious procedure in the acute setting [20]. Many of these lesions may never require further treatment until more global joint degeneration occurs with time (Fig. 29.1). Since surgical intervention within three weeks of injury is often recommended, accurate appraisal and determination of a chondral lesion's contribution to the patient's symptoms can be challenging. Additionally, cartilage restorative options are more limited in the acute setting [3].

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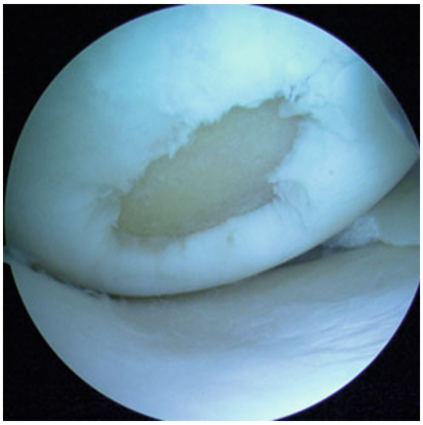

Fig. 29.1 Full thickness chondral lesion of the femoral condyle associated with a multi-ligament injury

For the subset of lesions that cause persistent symptoms with or without primary acute treatment, secondary articular cartilage resurfacing procedures can be performed according to accepted treatment algorithms. The goal of addressing these symptomatic lesions is to improve symptoms and hopefully delay the need for arthroplasty. Consideration is given to minimizing joint morbidity in a previously highly traumatized joint. Unloading osteotomies also have a role in young patients as an isolated procedure or in combination with an articular cartilage restoration procedure [1].

Multi-ligament injured knee patients can be extremely challenging with relatively high rates of chronic pain, which may often not be related to focal articular cartilage pathology. Most patients will never feel they have a normal knee [3, 9, 10]. Despite advances in the treatment of these injuries from a ligament, meniscus and articular cartilage standpoint, many develop radiographic evidence of degenerative arthritis within relatively short to midterm follow-up [18, 28–30]. Eventually many if not most of these traumatized knees will go on to require arthroplasty [28]. It is unknown at this time if the treatment of either asymptomatic or symptomatic articular cartilage lesions will alter this course [20].

29.2 Acute Treatment of Articular Cartilage Lesions Associated with the Multiple Ligament Injured Knee

Considerable debate exists within the orthopaedic community regarding the most appropriate surgical treatment for a symptomatic articular cartilage lesion [16, 31–38]. There is also lack of consensus as to the most appropriate treatment for incidental lesions found at the time of surgery performed primarily for other indications, such as ligament reconstruction [16, 24, 25, 34, 36, 37]. We also do not yet have an understanding which lesions will remain or become symptomatic with time [16, 25, 34, 37]. Many articular cartilage lesions associated with both ACL or multi-ligament injuries may not become symptomatic or necessarily be the major contributing factor to the development of degenerative changes [1, 4, 11, 16–18, 26, 34, 39, 40]. In the isolated ACL reconstruction group, there may be a trend for patients with an acute high-grade articular cartilage defects left untreated to have only slightly inferior outcomes compared to patients without chondral lesions even up to 15-year follow-up [16, 34]. However, there is also data that this may not always be the case and these focal lesions can cause significant morbidity [16, 21, 24, 37, 40–42]. Some recent studies show that the presence of a full thickness chondral lesion of the medial femoral condyle can be one of the most significant factors negatively affecting outcomes and activity levels following ACL reconstruction [42]. Some authors have shown that perhaps higher morbidity procedures may be warranted and improve longer term outcomes relative to lesser morbidity procedures [38]. Thus, even amongst experts, considerable controversy surrounds the optimal treatment of a high-grade chondral lesion in the setting of an acute ligament knee injury.

Future developments may aid in determining if “more invasive” cartilage procedures or even acute treatment at all will change the natural history in the multi-ligament injured knee. Currently, there are no trials that investigate the effect of treatment versus no treatment in the setting of ligament reconstruction. One recent study showed debridement of a chondral lesion may adversely affect outcomes when compared to benign neglect in the setting of meniscus surgery [39]. Several investigators have published case series of combining ACL reconstruction and debridement, microfracture, osteochondral autograft transfer, or autologous chondrocyte implantation (ACI) with reasonable short-term outcomes [11, 21, 25, 38]. Other studies, which have focused more on symptomatic lesions, report variable results. Some show superiority or perhaps greater durability of more invasive procedures, like ACI, while others do not [43–45]. There does seem to be a trend towards inferiority of microfracture relative to hyaline resurfacing options in terms of durability with time; however, optimal treatment is still quite controversial [46–48].

Although many think it makes sense to resurface high-grade defects in the acute setting, this may lead to the unnecessary or overtreatment of many lesions. Some patients may have inferior outcomes as a result of treatment or we may potentially convert an asymptomatic lesion into a symptomatic one [24, 25]. One must also remember that the results of any cartilage restoration procedure for an acute traumatic or incidental lesion may have optimal results

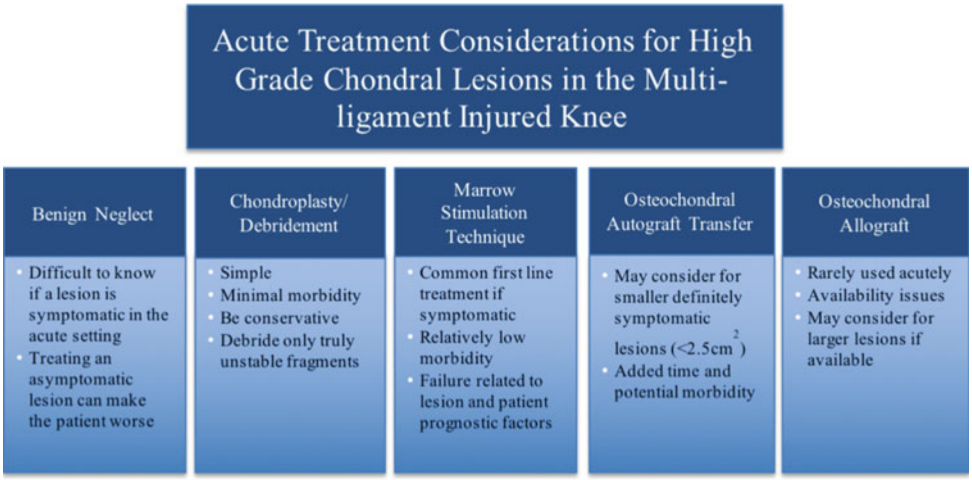

Fig. 29.2 Acute treatment algorithm for a high-grade chondral lesion in the multi-ligament injured knee

relative to other cohorts. This being said, certainly some patients with higher grade lesions are symptomatic in this acute setting, and surgical treatment is considered and reasonable if this is thought to potentially be the case [21, 41, 49]. However, the risk of persistent symptoms and reoperation may be considerably lower than what we have thought in the past [49]. The reality is that it is often difficult if not impossible to determine with certainty in an acutely traumatized multi-ligament knee the degree of symptomatology related to a chondral or osteochondral lesion. Additionally, some acutely symptomatic lesions may become asymptomatic without treatment. An acute treatment algorithm is proposed based on available options yet attempting to minimize morbidity when treating high-grade or full thickness defects in an often young individual (Fig. 29.2). The authors acknowledge that this is based on anecdotal experience and there is not good evidence to support one treatment method over another in an acute and potentially asymptomatic lesion [11, 41]. Over the past decade, we have become more conservative as data supports many of these lesions may not require treatment and we may not be altering the natural history of the knee with treatment.

29.3 Benign Neglect

As previously discussed, assessing the contribution that a cartilage defect may have on the natural history of knee morbidity is difficult to quantify, especially in the context of coexistent ligamentous, meniscus, bone, and soft-tissue pathology. Recently, there has been a growing focus on what has been colloquially referred to as "benign neglect," versus the morbidities associated with surgical intervention for cartilage defects [24, 25]. Shelbourne et al. [50] reported that the majority of their patients with a chondral lesion left in situ, at the time of ACL reconstruction, returned to recreational sports activity and knee function in the long term, regardless of the size of the lesion. They did not see a correlation between the size of the cartilage lesion and outcome scores [50]. More recently, Røtterud et al. [25] reported that chondral lesions treated with microfracture at the time of ACL reconstruction had inferior outcomes compared to those treated with "no treatment" or debridement. Debridement was not inferior to "no treatment" in this study. A confounding factor in this study however is that lesions treated with microfracture had a greater percentage of ICRS grade 4 lesions.

Although performed in the setting of meniscectomy, a recent study highlighted potentially detrimental effects of even arthroscopic debridement of a concomitant chondral lesion with unstable flaps or edges [39]. Although there was no difference in patient outcomes between both groups at 1-year follow-up, patients randomized to benign neglect had significantly better knee outcomes at multiple time points, relative to their chondroplasty counterparts [39]. Authors suggested this may be attributed to the release of inflammatory chondral degradation products within the debrided joint that contribute to persistent pain and delayed recovery in the early follow-up period [39]. It is unknown if there will be a difference between groups in the longer term. Shelbourne et al. [51] just reported on factors related to the development of arthritis 20–33 years following ACL reconstruction. Articular cartilage injury was second to only medial meniscectomy in terms of the greatest odds ratio for the long-term development of arthritis. However, it is unclear if treatment of those lesions would have changed the natural history of the reconstructed knees. At this time, benign neglect, for even high-grade lesions, may be prudent in many patients, especially for lesions with stable borders [39].

29.4 Debridement/Chondroplasty

When encountering partial thickness articular cartilage lesions with unstable edges or fragments, a conservative arthroscopic chondroplasty or debridement is our typical treatment of choice (Fig. 29.3). We will tend to utilize the same approach even for higher grade lesions in the acute setting if there are significant unstable fragments which may cause mechanical symptoms or have the potential to break off and become a loose body. There is evidence that debridement can offer benefit for symptomatic chondral lesions and there may be less of a downside relative to microfracture, especially in the setting of questionable symptomatology [25, 27].

The benefit of an arthroscopic chondroplasty is that it can be performed expeditiously at the time of the acute reconstructive procedure, which can often be quite lengthy. One should be conservative in this setting and truly only loose and unstable flaps or fragments are removed to decrease the risk of mechanical symptoms. There is currently debate on the use of radiofrequency type devices versus mechanical shavers as the optimal tool to debride and contour articular cartilage [21, 52]. There is continued concern regarding cell death related to the use of thermal devices although this is controversial [21, 52]. Recent evidence demonstrates there may be a beneficial role for contemporary radiofrequency probes alone or in conjunction with a mechanical shaver for arthroscopic debridement or chondroplasty if used appropriately [21, 52–54]. Whichever technique one chooses, debridement may carry some morbidity relative to benign neglect in some patients and thus one should be conservative when performing an arthroscopic chondroplasty in this setting [39].

29.5 Marrow Stimulation

Microfracture and other marrow stimulating techniques involve debridement of the lesion followed by penetration of the subchondral plate in order to allow the venting of marrow elements within the site of injury (Fig. 29.4). The goal is to induce a stable fibrin clot containing mesenchymal stem cells within the defect [55]. These pluripotent cells can differentiate into fibrochondrocytes, which produce a fibrocartilage repair tissue within the site [56]. This fibrocartilage repair tissue contains varying amounts of type I and II collagen and has inferior biomechanical and wear characteristics relative to hyaline cartilage [56]. Radiologic follow-up studies reveal variable rates of fibrocartilage fill which seem to correlate to patient outcomes in the short term [31, 57,

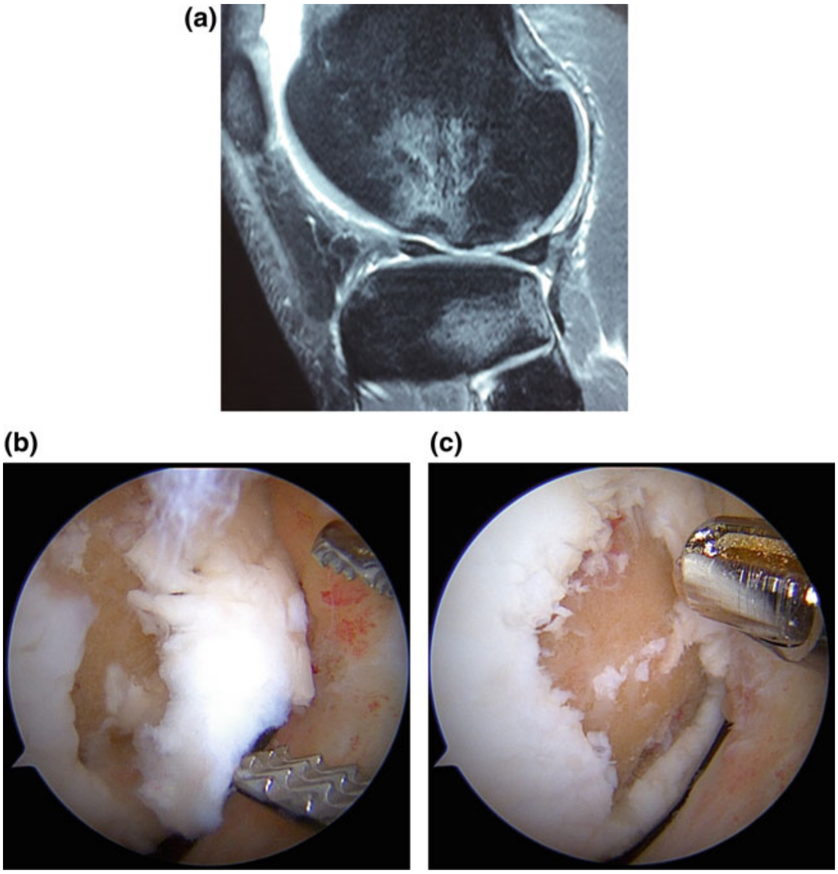

Fig. 29.3 **a** MRI of an acute traumatic chondral defect of the lateral femoral condyle associated with an ACL/MCL injury. **b** Loose chondral fragments overlying the lateral femoral condyle. **c** Following removal of loose chondral fragments and debridement

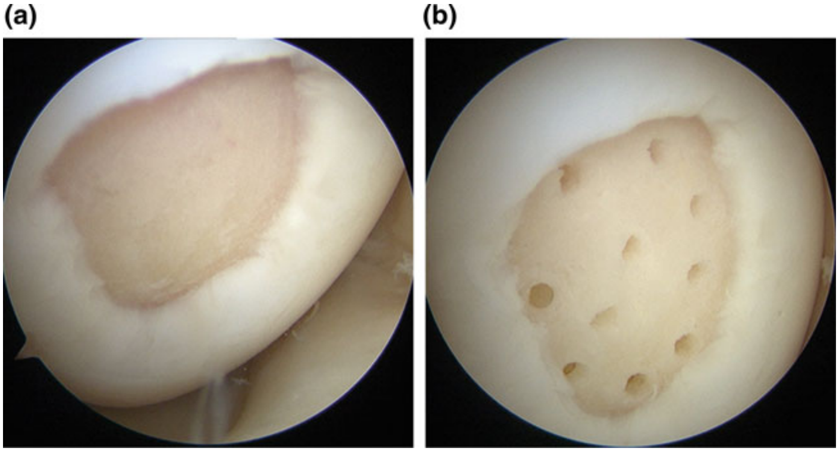

Fig. 29.4 **a** Full thickness chondral defect of the medial femoral condyle. **b** Lesion following marrow stimulation technique

58]. Short-term follow-up magnetic resonance imaging studies reveal good fibrocartilage fill between 54% to over 85% of patients with isolated defects treated with microfracture [31, 57, 58].

Various techniques are currently utilized to perform marrow stimulation. These include traditional microfracture awls, drilling with either a drill bit or newer commercially available arthroscopic drilling devices (PowerPick™: Arthrex: Naples, FL), or using smaller diameter and deeper penetrating pin devices (NanoFx®: Arthrosurface: Franklin, MA) (Fig. 29.5). Some have even gone back to arthroscopic abrasion of the subchondral plate (Fig. 29.6). Microfracture utilizing awls has clearly been the most popular and well-studied marrow stimulation technique in recent years [59]. However, there is a trend towards utilizing alternative techniques since the awl technique does indeed create a subchondral injury and may impact bone which impedes the egression of marrow elements [60–64]. Recent studies suggest that alternative methods to create access channels such as small diameter, longer impaction devices, hollow awls, or simply drilling may produce more patent marrow channels when compared to traditional awl utilization [60–65].

Marrow stimulation can be a good choice as a primary, and potentially final treatment option for full thickness chondral lesions associated with ligament knee injuries [21]. The procedure is technically straightforward, expeditious, and cost-effective with relatively minimal patient morbidity. A recent study found microfracture to be the most cost-effective surgical procedure for repairing chondral knee lesions, when compared to OAT and ACI [66, 67]. These features make this option appealing as a first-line treatment for a full thickness lesion, especially one associated with an acute multi-ligament knee injury. Treatment time and patient morbidity can be minimized, but at the same time attempting to address a defect with repair tissue which can provide significant clinical improvement [11, 56]. For symptomatic full thickness lesions which we feel likely require more than benign neglect or debridement, this has been our treatment of choice in the acute multi-ligament injured knee.

There have been no studies published specifically evaluating the results of microfracture combined with multi-ligament reconstruction. However, the intra-articular milieu in this setting may be ideal for microfracture [11]. Most clinical outcome studies of microfracture reveal improvement in 50–90% of patients [21, 31, 56, 68–72]. Results have varied based on lesion size, activity levels, length of preoperative symptoms, follow-up intervals, patient age, and authors [31, 68–75]. Negative prognostic factors include: age >35 years, lesions >2 cm^2, higher body mass index, less defect fill, symptomatology >1 year, concurrent meniscectomy, patellofemoral lesions (particularly patella lesions), or degenerative shoulders on the lesion [5–8, 11–14, 16, 18, 24, 31, 68, 69, 72–76].

In the short term, microfracture has been shown to improve patients' pain and function [77–79]. These improvements, however, often diminish over time, and treatment failures and degenerative arthritis can be expected in a significant percentage of patients, especially when negative prognostic factors are present [46–48, 74–76]. However, this may occur with any treatment in this complex patient population.

Although the rate of return to sports and higher activity levels may not be as high with microfracture compared to alternative treatment methods when treating symptomatic lesions, this is still considered controversial [71, 79–81]. A recent systematic review of higher level evidence revealed no significant difference in outcomes comparing microfracture to ACI and one study showed a higher rate of arthritis with ACI vs. microfracture [78, 82]. It is currently controversial if microfracture may affect the results of a secondary ACI procedure; however, it is not felt to affect the outcomes of subsequent osteochondral grafts [83–87].

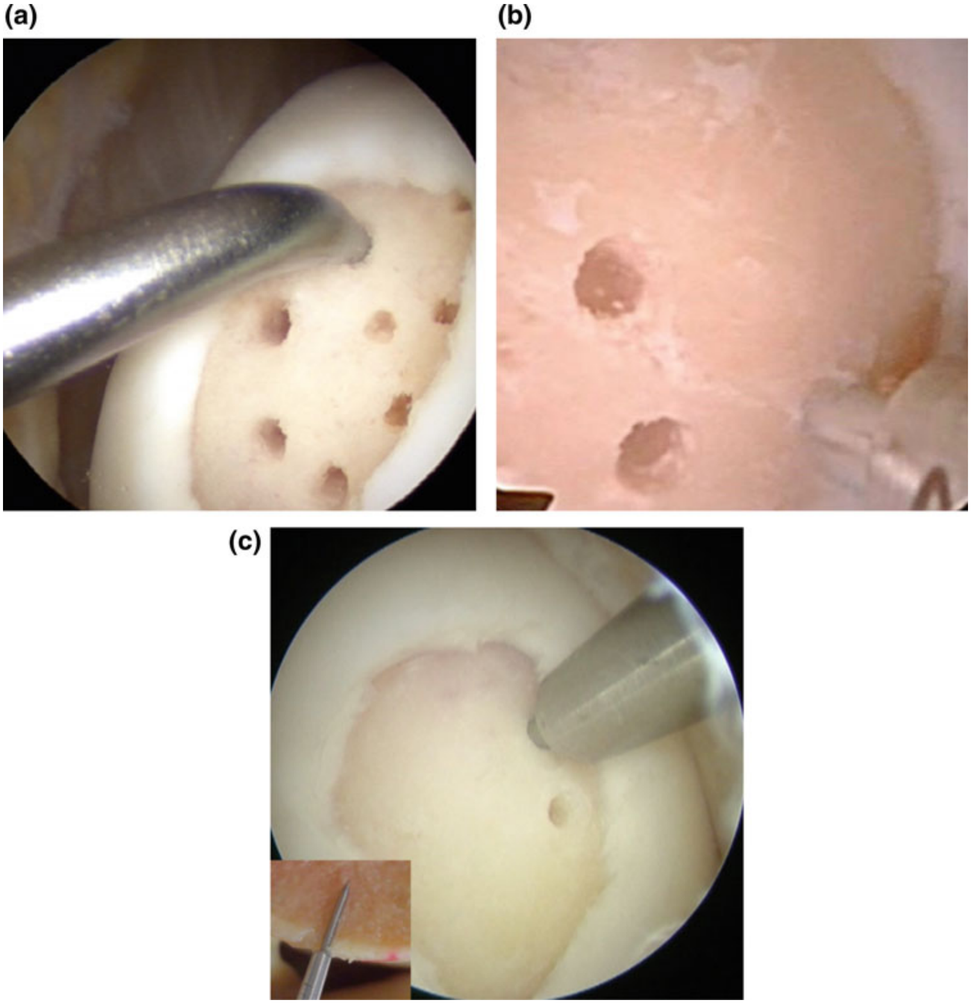

Fig. 29.5 Various marrow stimulation techniques can be performed to create channels into the subchondral bone. **a** Awl device. **b** Arthroscopic drill (Arthrex. Naples, FL). **c** Smaller diameter commercially available impaction device (NanoFx®, Arthrosurface. Franklin, MA)

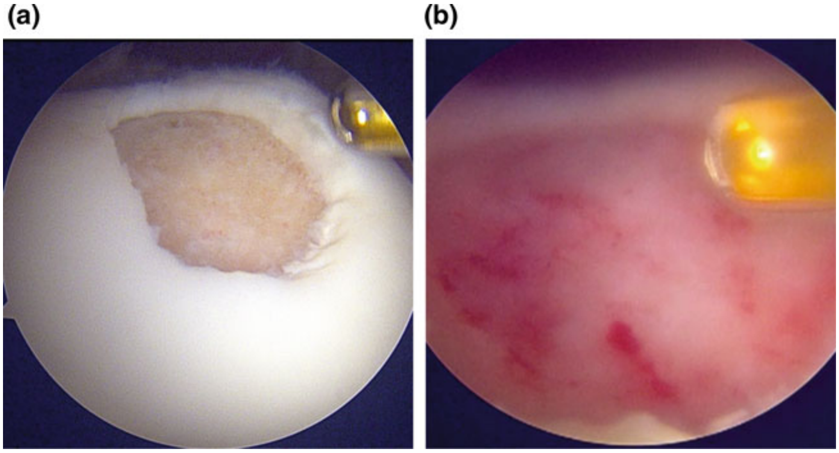

Fig. 29.6 **a** Full thickness chondral lesion of the trochlea in a 15 year old. **b** Simple abrasion to create bleeding was all that was performed to stimulate a healing response (no perforating holes were created)

29.6 Osteochondral Autograft Transfer

Osteoarticular autograft transfer or mosaicplasty in the knee joint has been performed since the mid-1990s [88–90]. This procedure involves the transfer of an osteoarticular cylindrical plug from a relatively lower weight-bearing area of the knee to a more “clinically significant” region of the joint (Fig. 29.7). Contact stress studies have defined preferred donor sites although there is some debate regarding the optimal donor harvest site [88–90]. This procedure has

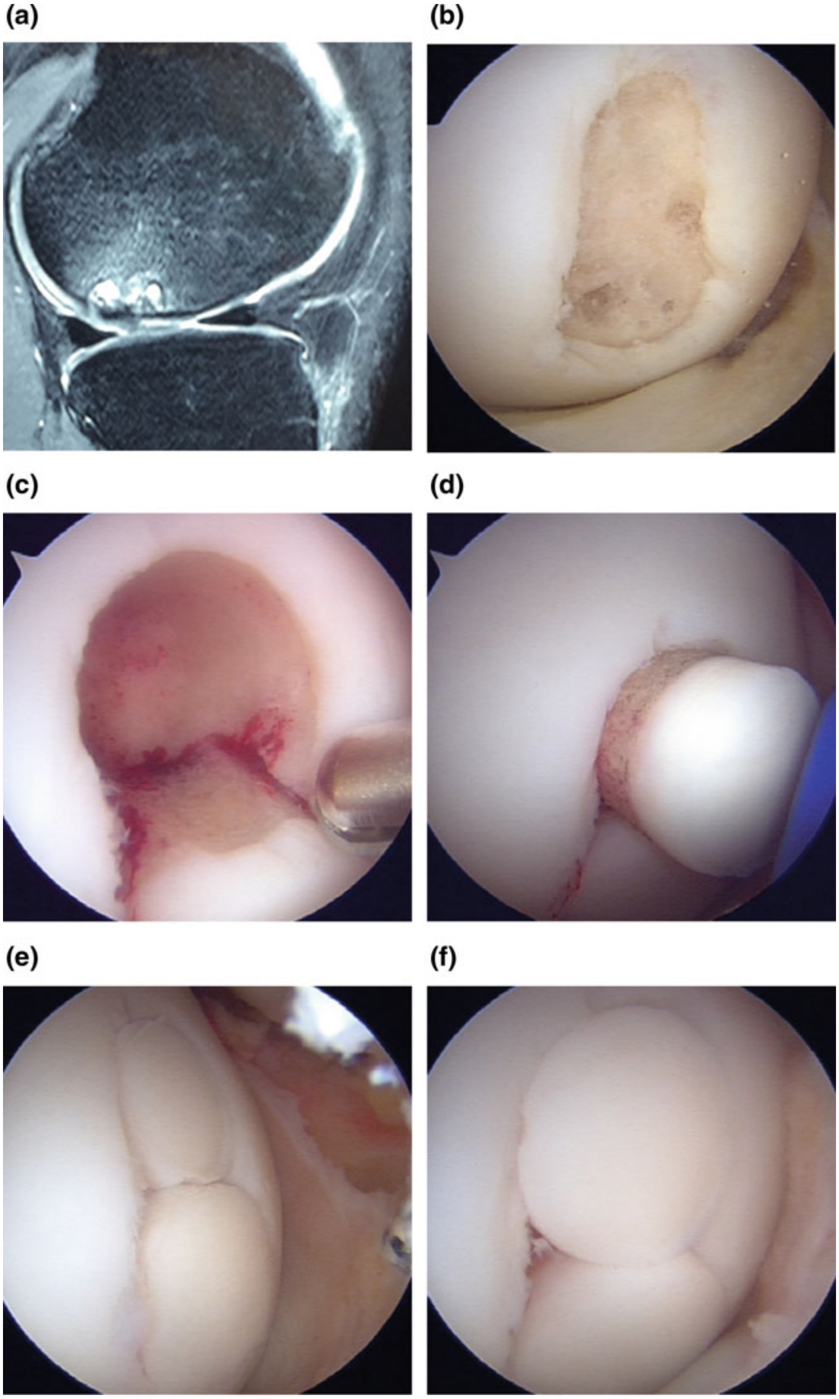

Fig. 29.7 **a** MRI of an osteochondral lesion with subchondral cystic change. **b** Arthroscopic appearance of the lateral femoral condyle lesion. **c** Second recipient site prepared (adjacent to first plug). **d** Delivering second plug into the recipient site. **e**, **f** Finished view of OAT plugs overlapped in “snowman” configuration

become a well-accepted treatment option for symptomatic chondral lesions, generally smaller than 2.5 cm^2. This technique allows for the delivery of viable articular cartilage with autologous bone, which typically achieves bone-to-bone healing within 6 weeks. Return to sports following treatment of a symptomatic smaller isolated defect with an osteochondral autograft may be highest relative to other cartilage treatment alternatives [80, 91]. Some recent studies have shown higher subjective outcomes scores with osteochondral autograft transfer when compared to microfracture in the short, medium, and long term [38, 43, 92, 93].

There is some debate regarding donor site morbidity related to the harvest site (Fig. 29.8) [88, 94, 95]. More recent studies focusing on procuring donor plugs from the knee and transferring to other joints such as the ankle have suggested that donor site morbidity may be greater than previously suspected [95]. In an effort to decrease donor site morbidity, the donor sites may be backfilled with either bioabsorbable

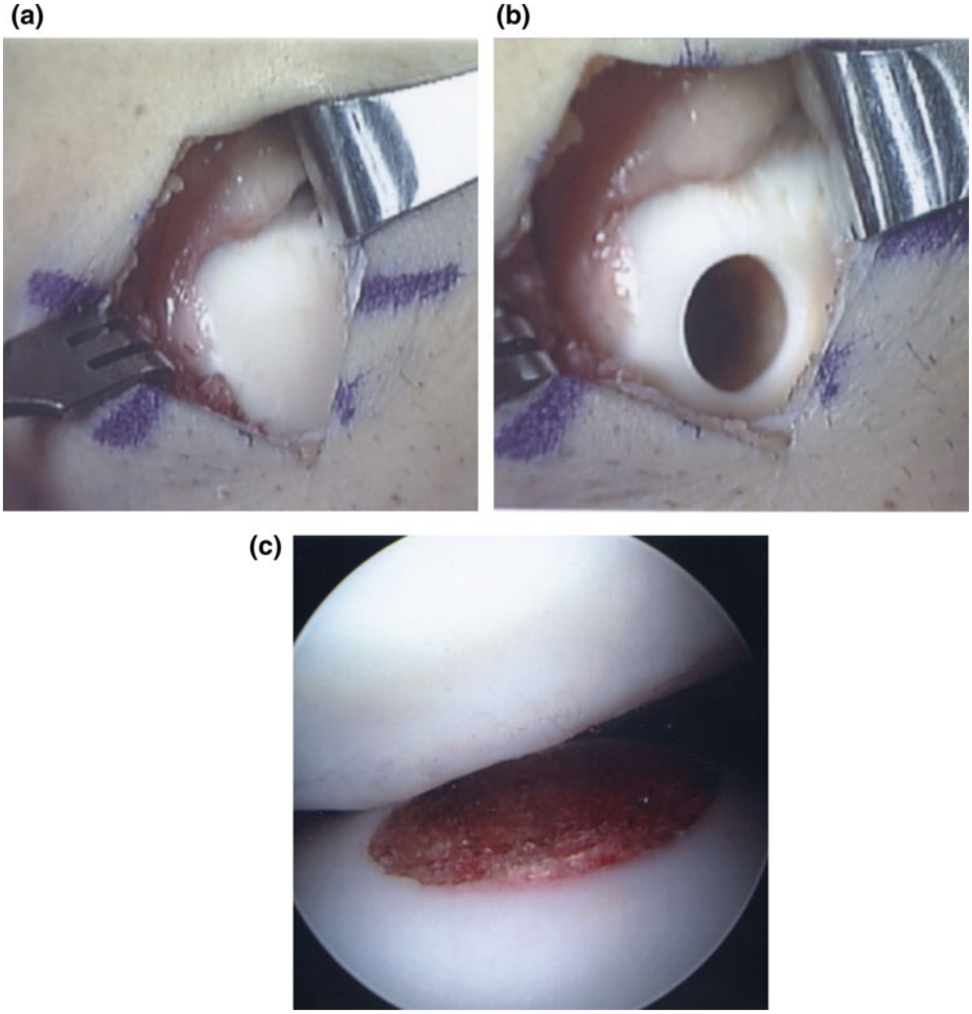

Fig. 29.8 **a**, **b** Superior lateral trochlea visualized thru mini-arthrotomy to harvest OAT donor plug. **c** Donor site (which was backfilled) does articulate under patella

scaffolds or allograft plugs (Fig. 29.8c) [88]. Backfilling donor sites may decrease the risk of postoperative hemarthrosis, but no studies to date show backfilling donor sites decreases morbidity. Synthetic grafts previously used to backfill donor sites (TRUFIT™; Smith & Nephew Endoscopy, Andover, MA) did not show consistent bone ingrowth or osteoconductivity [96]. Additionally, case reports have revealed foreign body reactions to these same synthetic scaffolds [97, 98].

Even though the osteoarticular recipient sites may often be accessed arthroscopically, many authors still prefer to harvest the donor plugs through a small lateral or medial arthrotomy to access the trochlea (Fig. 29.8a, b). Since perpendicular delivery of the plugs into the recipient site is critical to its success and this may be quite technically demanding at times, many surgeons feel more comfortable achieving this result through a limited arthrotomy.

A well-performed osteoarticular autograft transfer will often take a significantly longer surgical time compared to debridement or marrow stimulation with the potential of greater morbidity to the already traumatized joint. However, due to its availability, this is certainly an option in the acute setting. For the surgeon who is proficient with the technique, it is probably more optimal for younger, more active patients with smaller lesions (<2.5 cm^2) on a condyle. The question is whether or not the added morbidity and procedural time justify its use in the acute multi-ligament setting.

29.7 Fresh Osteochondral Allografts

Fresh osteochondral allografts have been traditionally used for the primary or secondary treatment of larger symptomatic chondral or osteochondral lesions [99–103]. Historically fresh allografts have not played much of a role in the treatment of the acute chondral lesion associated with multi-ligament knee injury in part due to availability and the uncertainty as to their need in this setting. Many acute multi-ligament knee injuries are treated surgically within 3 weeks [3]. Even if a large chondral or osteochondral lesion is identified on a preoperative MRI, getting a fresh allograft in time may be a logistic challenge. If a fresh graft can be obtained during the surgical window of opportunity in the acute setting, it may be quite desirable in some select cases. Due to the success of fresh allografts, it is becoming more popular as a first-line technique for symptomatic defects [101, 102, 104–106]. Additionally, smaller (10 mm) fresh allograft plugs are now more readily available and may be delivered arthroscopically [107]. Although fresh allograft transplantations have typically been utilized for the secondary treatment of persistently symptomatic lesions, we feel there is good evidence to support their use as a primary treatment option in select cases as well.

29.8 Autologous Chondrocyte Implantation (ACI) Biopsy and Next Generation ACI/Matrix Associated Chondrocyte Implantation (MACI®)

Autologous chondrocyte implantation (MACI®; Vericel Corp, Cambridge, Massachusetts) is a two-staged procedure requiring at least 4–6 weeks between biopsy harvest and cell implantation [84, 108]. ACI is therefore not available as a first-line treatment for most patients in the multi-ligament setting. However, if a lesion is persistently symptomatic despite primary treatment, ACI may be a viable treatment option in the future [84, 108]. If it is felt at the index operation that a chondral defect has a high chance of becoming persistently symptomatic due to its size and or the activity level of the patient, and the surgeon feels that ACI may be a viable treatment option in the future, procuring a cartilage biopsy may be prudent. This can be done quickly during the index procedure with minimal morbidity and may save the patient an additional procedure (biopsy) in the future. If the treating surgeon tends to favor other secondary options such as an allograft instead of ACI for a specific defect, and the same surgeon will likely continue the treatment over time, then a biopsy is probably unnecessary.

The cartilage biopsy is typically obtained arthroscopically from the lateral side of the intercondylar notch using curettes (Fig. 29.9). The cartilage biopsy specimen is sent to Vericel in Cambridge, Massachusetts where the chondrocytes can be isolated from the specimen, cultured, and expanded in vitro if needed for a secondary procedure.

Fig. 29.9 Cartilage biopsy may be obtained at the index procedure if the surgeon feels it may be a future option

29.9 Secondary Treatment for Persistently Symptomatic Articular Cartilage Lesions Associated with the Multiple Ligament Injured Knee

Similar to other articular cartilage treatment algorithms, patient and lesion factors need to be carefully considered when selecting the most appropriate articular cartilage treatment option in the setting of a persistently symptomatic lesion [109, 110]. Patient age, lesion size and location, activity level, and mechanical environment of the involved compartment(s) are factors which will influence treatment for these patients [20, 35, 55]. Due to the complexity of many of these patients, it can sometimes be quite difficult to assess the contribution of symptoms resulting from the chondral pathology versus the sequela of the overall joint trauma, which is often multifactorial. It is very important, not only in this group, but when treating all patients with articular cartilage pathology with a non-arthroplasty biologic procedure, for the patient and surgeon to have realistic outcome expectations. The goal in the younger patient populations is to significantly improve symptoms and postpone the need for an arthroplasty. However, many of these patients will still have a component of pain and functional disability [20, 35, 55, 84]. Middle-aged or certainly older patients may better be served with nonoperative treatment until their symptoms warrant an arthroplasty procedure.

Following recovery from initial treatment including prior ligament reconstruction, patients can be thoughtfully assessed in the office. In addition to an assessment of current complaints, a careful physical exam is essential to ascertain if the patient's complaints and exam correlate to the chondral injury in question. Prior operative reports and arthroscopic pictures are very valuable as well. MRI with cartilage sequences may or may not be helpful depending on the time interval from the initial surgery and clarity of the problem. Long-alignment films may be required if mal-alignment is suspected in the involved compartment. Diagnostic intra-articular injections are sometimes useful to differentiate between intra-articular versus extra-articular sources of pain in the complicated patient. Unloader braces are occasionally utilized to assist in differentiating pain emanating from a tibio-femoral compartment versus other potential etiologies such pain radiating from the patellofemoral compartment.

Decision-making regarding choosing the most sensible treatment option for an articular cartilage injury in these patients is not always straightforward. It is important to involve them in the process since outcomes are often not optimal in this challenging group. Essentially a risk/benefit analysis is deliberated based on current evidence to determine realistic potential improvement versus an individual's tolerance to treatment failure and complications. The following section of the chapter discusses potential treatment options for the treatment of persistently symptomatic defects associated with a previous multi-ligament injury. Special considerations for treatment of symptomatic chondral lesions in this patient population are highlighted in Fig. 29.10. This assumes that mal-alignment is not significant or will be concomitantly corrected. The more diffuse the chondrosis in the involved compartment, the more likely the authors favor correcting the mal-alignment through an unloading osteotomy only. The more focal the defect, the more we tend to favor unloading the compartment and resurfacing the lesion at the same setting. If meniscal deficiency is thought to be a contributing factor, this should also be addressed at the same setting of the chondral resurfacing [111].

The younger the patient, the more aggressive we tend to be with biologic alternatives. The opposite is true with individuals who are older and more sedentary or if their pathology is beyond the scope of what can be reasonably be treated with a biologic approach. Unfortunately, many of these patients may be quite young for an arthroplasty, but it still may be their most reliable option when their symptoms justify further intervention.

29.10 Marrow Stimulation

Marrow stimulation may be considered as a viable treatment alternative if the lesion was initially untreated or simply debrided. It is currently the most common procedure utilized to address chondral lesions in the knee following arthroscopic debridement [59, 112]. Many high-level athletes have returned to even the professional level following microfracture although typically not in the setting of multi-ligament knee injury [43, 45, 113]. It is important to recognize negative prognostic factors with marrow stimulation including larger defects and patients over the age of 35 years old [31]. Also, the rate of return to sports when a symptomatic defect is treated may not be as high as with alternative treatment options [71, 79, 81, 114]. In the setting of an individual who has persistent symptoms, thought to be localized to a chondral lesion, in a previous multi-ligament injured knee, we

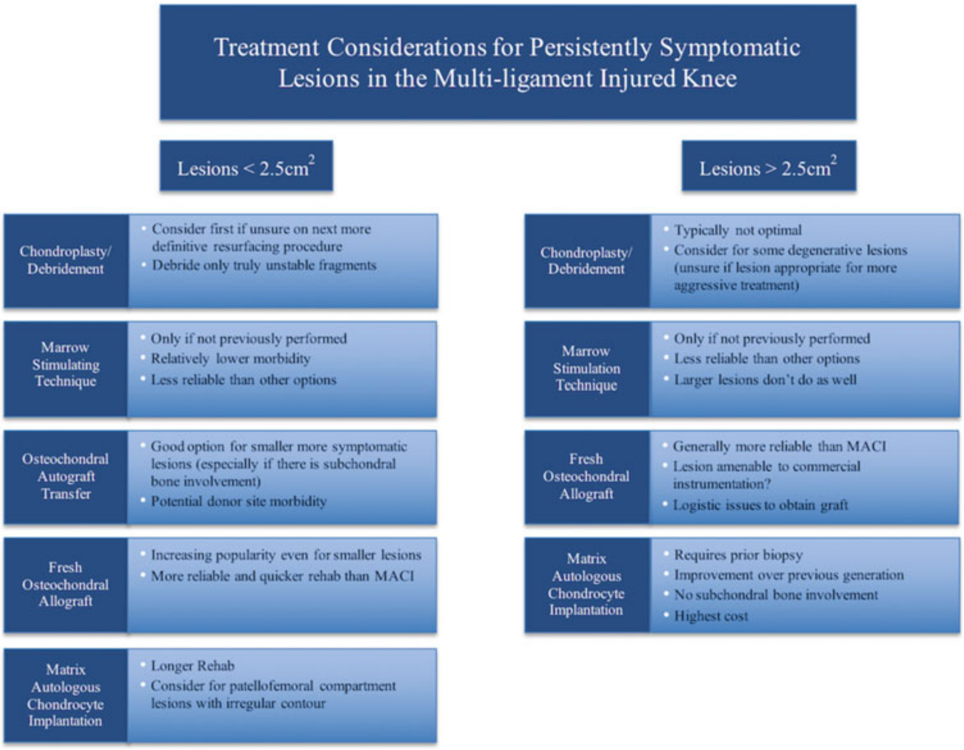

Fig. 29.10 Treatment options and considerations for persistently symptomatic lesions associated with the multi-ligament injured knee

tend to opt for other resurfacing alternatives which may be more reliable or durable.

29.11 Osteochondral Autograft

Osteochondral autograft transfer procedures have been used with success in the treatment of select chondral defects as outlined previously in this chapter. Advantages include the ability to resurface a defect with autologous viable hyaline cartilage utilizing locally available osteochondral grafts. The grafts are press-fit and heal relatively quickly due to autologous bone-to-bone healing. This can be performed as a single operation without waiting for grafts, which makes it convenient. The downsides of this option include the potential for donor site morbidity and limitations on the size and number of grafts available. Typically, this is an option for lesions less than 2.5 cm^2.

29.12 Fresh Osteochondral Allografts

Fresh osteochondral allografts have a fairly extensive clinical history, extending over three decades [99, 115–120]. Allograft transplantation is gaining in popularity due to increased appreciation of reliable restoration of viable hyaline cartilage with normal architecture when compared to alternative treatment options for larger defects [99, 101, 107, 121, 122]. Although there are logistic issues associated with obtaining allografts, including waiting for an appropriate graft, the procedure itself is not very technically demanding in most cases. The technique can be accomplished with commercially available instrumentation systems versus preparation of a customized “shell” graft. The technical aspects of the procedure have been well described elsewhere and will not be described here [121]. Fresh allografts are most useful in treating larger chondral or osteochondral lesions (>2.5 cm^2) but can also be utilized for smaller defects in an effort to minimize morbidity (Fig. 29.11) [123]. This is especially appealing in a multi-ligament injured knee.

The long-term success of osteochondral allografts is dependent upon preservation of the hyaline cartilage surface, healing of the osseous base to the host bone, and maintenance of structural integrity during the remodeling process [99, 124]. Investigators have shown chondrocyte viability is paramount in order to maintain the normal extracellular architecture of hyaline cartilage and to prevent the development of degenerative joint disease, but the acceptable degree of chondrocyte viability required is unknown at this time [125–127]. Although nonviable cartilage will appear grossly normal for a period of time, it will not maintain its histologic, biochemical, or biomechanical properties. As a result, the cartilage will fibrillate, develop clefts, and erode over time [125, 126]. Recent results of decellularized nonviable allografts have reflected this natural history with high reported failure rates [127]. It is important to note that current “fresh” allografts are actually refrigerated for a period of time prior to implantation, in contrast to historical fresh allografts, which were transplanted much closer to time of procurement [128].

Immune compatibility testing and postoperative immunosuppression are not required with osteochondral allograft transplantation despite the fact that chondrocytes and subchondral bone have both been shown to have immunogenic potential [53, 54, 129, 130]. Chondrocytes are surrounded by a matrix that isolates them from the host immune cells and makes them relatively “immunologically privileged” [117, 118]. Although donor cells within the osseous component are immunogenic, their immunogenicity is muted and probably not clinically significant in most patients [131, 132]. However, a local inflammatory response is stimulated by both the surgical trauma and the graft itself [133]. This response is primarily directed against the bone constituent of the graft that contains the marrow elements and other immunogenic elements [134]. In general, the osseous component of osteochondral allografts retains its structural integrity and is replaced with host bone via creeping substitution over a period of years [135–138]. If the nonviable bone trabeculae cannot withstand mechanical stresses during the remodeling process, subchondral microfracture, collapse, and fragmentation may occur (Fig. 29.12) [99].

Long-term chondrocyte viability and clinical success following osteochondral allograft transplantation has been shown in multiple reports [139–144]. Although no reports have focused on the multi-ligament patient, multiple authors have published on the outcomes of osteochondral allografts in younger patient populations with relatively good success [101, 104–106]. Failures do occur with this technique and survivorship will decrease with follow-up intervals as with any resurfacing procedure [141–147]. Furthermore, unlike secondary cellular treatments, results of fresh allografts are not adversely affected by prior marrow stimulation procedures [107, 146]. However, failures tend to be more related to the osseous component of the graft and may include fragmentation and collapse (Fig. 29.12) [99, 145].

There are significant advantages and disadvantages to the use of allograft tissue. Advantages include the lack of donor site morbidity, the ability to treat large defects including associated subchondral bone deficiency or pathology, and the ability to reliably restore viable hyaline cartilage when compared to alternative treatment options. Disadvantages include supply issues and the logistics of delivering an aseptic, size-matched graft with a high percentage of viable chondrocytes. Additionally, failures of the osseous component of a graft can create more of a problem in a young

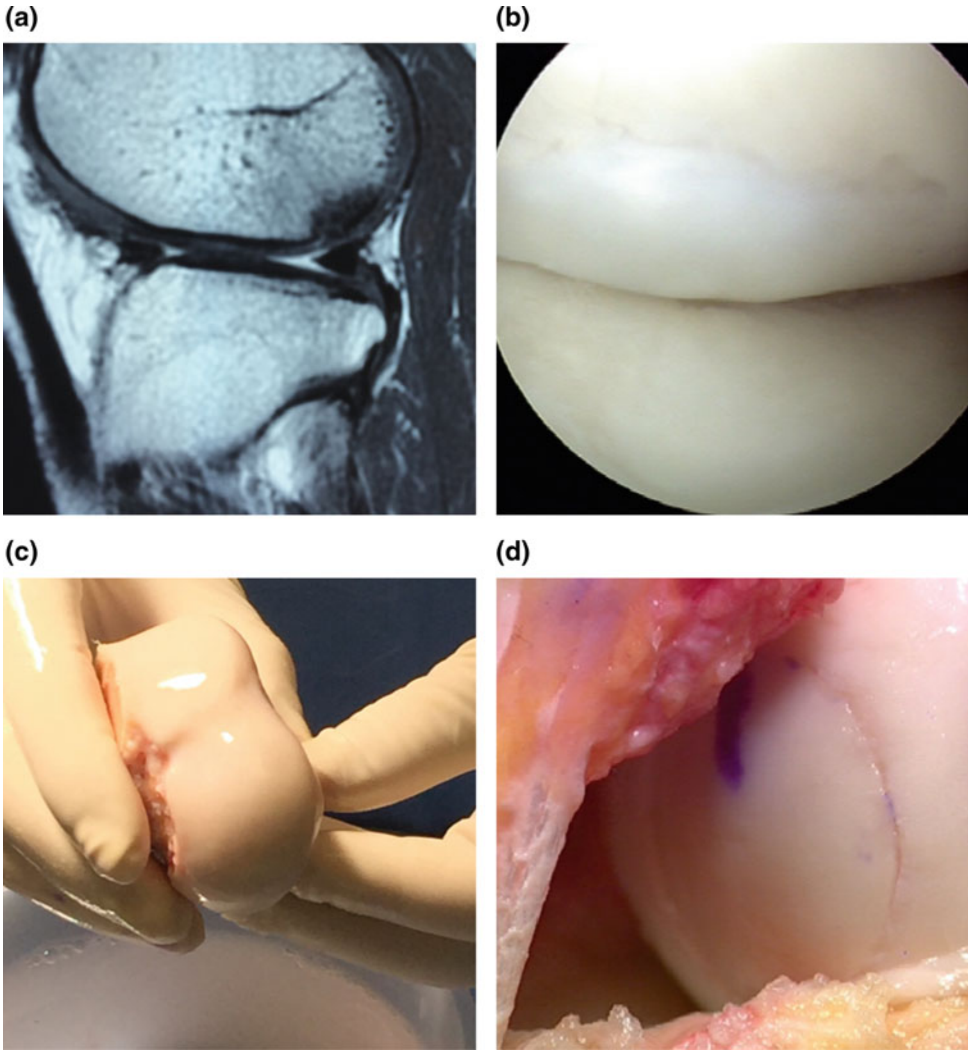

Fig. 29.11 Large chondral lesion of the lateral femoral condyle treated with a microfracture at the index ligament reconstruction. The patient had persistent symptoms despite a stable knee. The lesion was revised with a fresh osteochondral allograft. **a** MRI following microfracture. **b** Fibrocartilage within the previously microfractured defect (patient with continued symptoms despite good fill). **c** Fresh refrigerated size-matched lateral condyle. **d** Fresh allograft implanted through a lateral arthrotomy

patient than if the subchondral bone was not violated. Many clinical and basic scientific studies support the theoretical foundation and efficacy of osteochondral allografting and as a result, the procedure has become more popular with time [99, 139, 150, 151].

29.13 Next Generation ACI/Matrix Autologous Chondrocyte Implantation (MACI®)

Matrix ACI (MACI®; Vericel Corp, Cambridge, Massachusetts) is a two-staged procedure requiring at least 4–6 weeks between biopsy harvest and cell implantation [84, 108]. Thus, MACI® is impractical as a first-line treatment for most patients in the multi-ligament setting. However, if a lesion is persistently symptomatic despite primary treatment, MACI® may be a viable treatment option [84, 108]. When considering MACI® for revision procedures, it may be helpful to consider the nature of the original procedure [146]. Furthermore, if available from the index procedure, prior cartilage biopsy procurement would save an additional step and make this option more attractive. Currently in the United States, MACI® is indicated for the treatment of femoral lesions. However, many feel that MACI® may offer its best application in the patellofemoral compartment [147].

There has been more limited utility of this resurfacing technology than what was perhaps initially projected in the late 1990s. This is perhaps due to several reasons including technical difficulty, associated morbidity of the procedure (arthrotomy and periosteal patch harvest in 1st generation ACI, depicted in Fig. 29.13), and controversy related to efficacy and histology of ultimate repair tissue for a costly procedure [66, 148–150]. There is certainly increasing evidence in the literature related to the use of ACI/MACI® and its efficacy [33, 57, 84, 151–153]. Studies have shown fairly good results for generally difficult patient populations [32, 147, 154–156]. ACI seems to show more consistent defect fill when

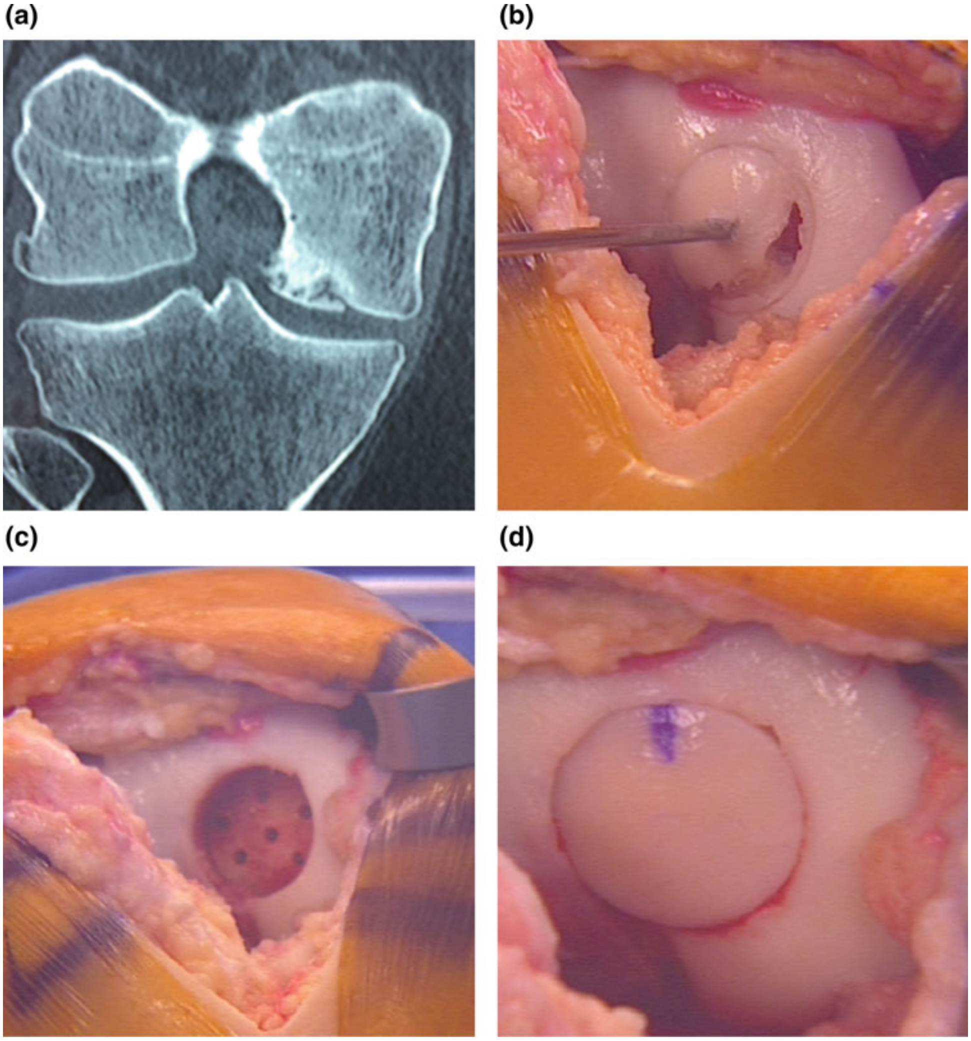

Fig. 29.12 **a** CT image reveals subchondral fracture following implantation of a fresh osteochondral allograft in a 21-year-old patient. **b–d** Revising the failed allograft with a new fresh allograft

compared to microfracture, especially with larger lesions [57, 151, 152]. Durability of repair tissue and the ability to return to sports may be improved with ACI relative to marrow stimulating techniques although this is certainly controversial [80, 84, 150–153]. Current generation MACI®, which uses autologous chondrocytes cultured onto a porcine collagen membrane, offers clear advantages compared to the prior generation. The membrane graft is fashioned intra-operatively to the appropriate size and secured with fibrin glue (Fig. 29.14), There is no longer a need to harvest and suture periosteum which not only was technically challenging but increased morbidity. Additionally, the use of periosteum with ACI has been associated with hypertrophy and the need for additional arthroscopic debridement [151, 152, 157].

For symptomatic larger defects of the femoral condyles, MACI® and osteochondral allografts are often considered more optimal choices compared to microfracture or autologous osteochondral transfer. One level 1 randomized controlled trial found MACI® to yield significant improvement over microfracture for treatment of defects larger than 3 cm^2 at 5-year follow-up [158]. MACI® is a reasonable choice for this indication for a surgeon comfortable with the procedure and a patient willing to comply with the lengthy rehabilitation. A benefit of MACI® over a fresh allograft in a symptomatic patient is scheduling convenience and not waiting a potentially considerable period of time for an available fresh graft. Depending on size and availability, wait times may be more of an issue for some surgeons and centers. Additional potential advantages of ACI over allograft transplantation include eliminating concerns about the risk of disease transmission albeit extremely low, and the chondral lesion is not converted into an osteochondral lesion with bone loss should the allograft fail. MACI® may be more optimal for patellofemoral lesions due to the technical difficulty associated with placing a cylindrical osteochondral allograft at these sites. However, approval for isolated patellar lesions can be an issue since ACI/MACI® was FDA approved for the femoral condyle only [147].

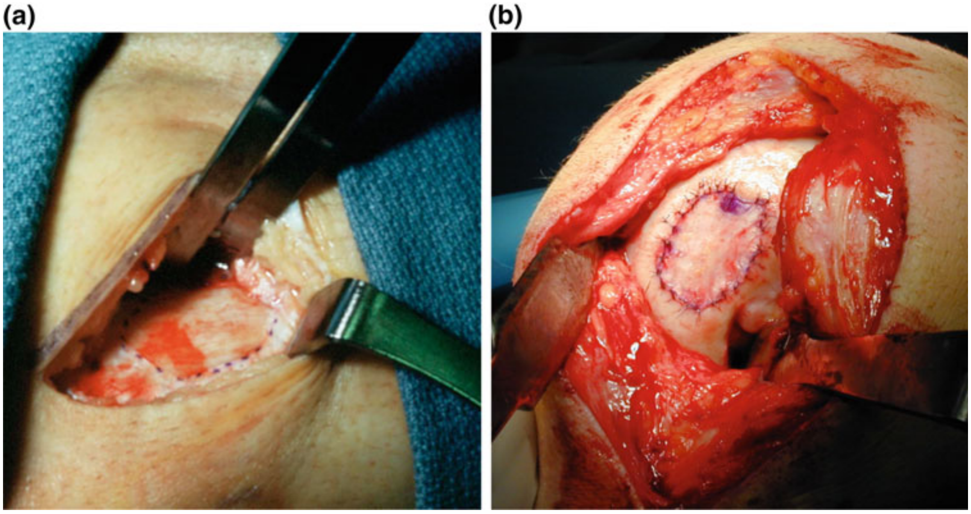

Fig. 29.13 **a** Periosteal harvest. **b** View of sutured periosteal patch over defect involving the medial femoral condyle. This image was from the prior generation ACI (no longer performed with the current generation technique)

ACI is not without limitation, challenges, and controversy. The added cost of procuring and culturing the cells should be considered. Patients must also be aware and comply with the lengthy rehabilitation period required for this procedure to be effective. Cost concerns and some studies questioning whether the ultimate outcome and repair tissue justifies these issues are what seem to limit its current use by many surgeons [45, 159]. A recent study conducted a cost-effectiveness analysis on microfracture, OAT, and ACI and found that 1st generation ACI was the least cost-effective surgical method compared to the others [66]. Interestingly, however, same study found 2nd generation ACI to provide a statistically significant greater improvement in function over the other methods; although cost-effectiveness for MACI® was not available for comparison [66]. A recent assessment by the National Institute for Health Research reported that the incremental cost/effectiveness ratio of newer generations of ACI are within normally accepted limits compared to microfracture [25]. Advocates feel the cost is justified if it can more reliably generate higher quality tissue fill with greater longer term durability [160, 161].

Recent reviews evaluating the benefits of MACI® have shown positive results [162]. In the short term, MACI® has been shown to improve Tegner and Lysholm scores when measured up to 60 months follow-up with patients experiencing significant improvement within 6 months of surgery [38]. In a recent systematic review, at 5–10-year follow-up, MACI® was shown to provide improvement of KOOS and SF-36 scores in patients receiving MACI® for patellofemoral or femoral lesions. Similar to other treatment options, higher failure rates are seen with patellofemoral lesions versus femoral lesions. Total failure rate was 9.7% with the most common causes of failure included progressive osteoarthritis, graft dislocation or delamination, and lack of clinical effect [113].

29.14 Unloading Osteotomy

Discussion of articular cartilage resurfacing in younger individuals requires a discussion of the role of an unloading osteotomy. Historically, most osteotomies were performed to unload weight-bearing forces from an advanced arthritic compartment to a healthy compartment without performing an “articular cartilage resurfacing” procedure. Currently, altering the biomechanical forces of the joint in the setting of a symptomatic focal defect and mal-alignment is felt to be important for the long-term success of the resurfacing procedure [33]. Debate remains as to the degree of clinical improvement that can be attributed to the unloading osteotomy versus the cartilage resurfacing with these combination cases [163].

High tibial and distal femoral osteotomies are most commonly used to unload the medial and lateral compartments, respectively (Fig. 29.15). Tibial tubercle osteotomy via anteriorization (anteriormedial or straight anterior) can be performed to address the patellofemoral compartment. Various osteotomy techniques can be performed which are beyond the scope of this chapter. Depending on the age of the patient, degree of articular cartilage involvement, and complexity of the overall knee pathology, it may be prudent to avoid an osteotomy altogether and to pursue nonoperative or less aggressive measures until they are ready for an arthroplasty procedure (Fig. 29.16).

Patients who have a cartilage defect of the femoral condyle as well as a mechanical axis that is outside the neutral zone, bordered by the tibial spines, should be strongly considered to have an osteotomy as part of the cartilage repair treatment [33]. Physicians who treat cartilage lesions should be comfortable with performing osteotomies but at the same time respect their added morbidity and potential

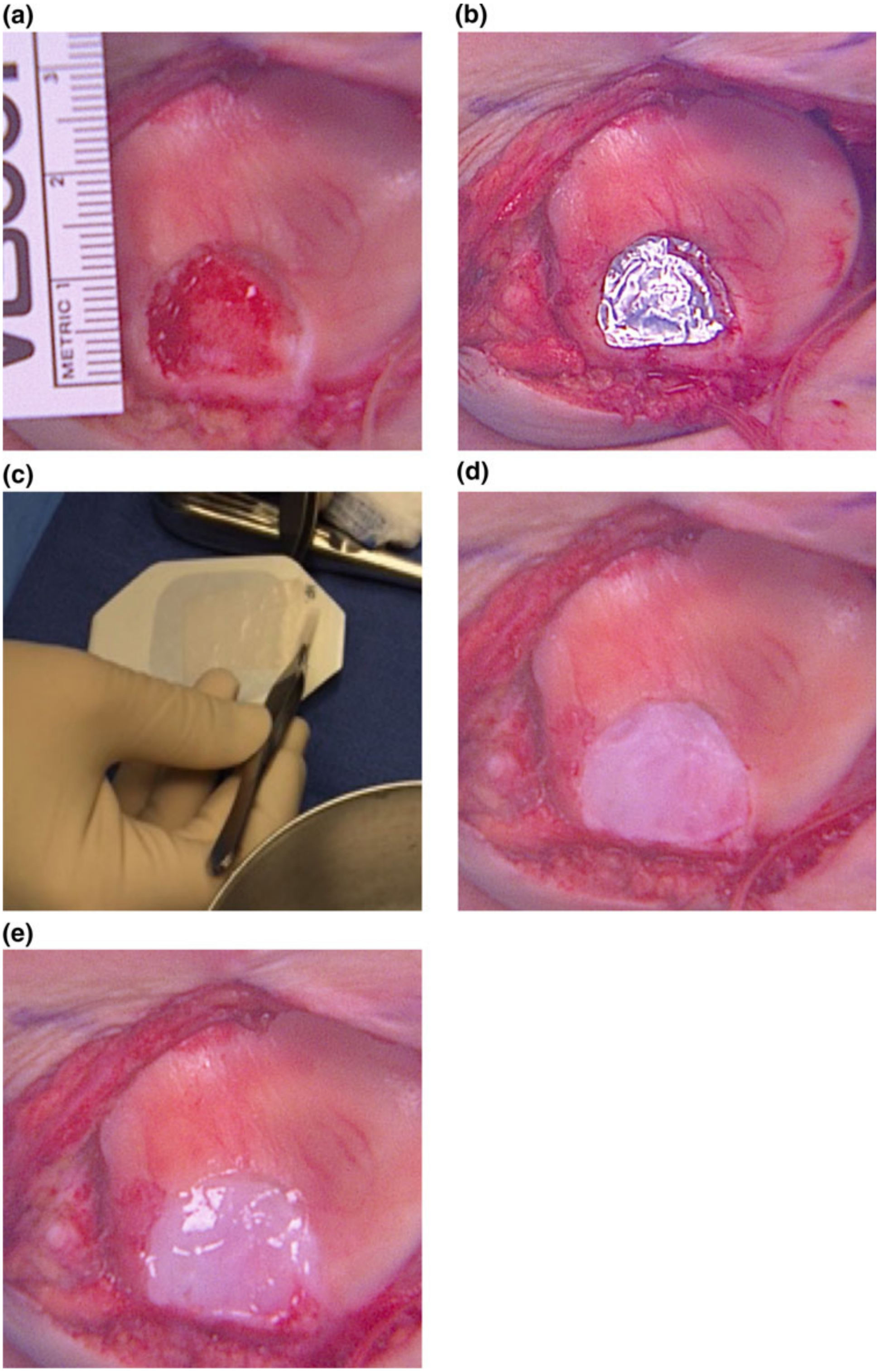

Fig. 29.14 **a** Full thickness chondral defect of the patella treated with prior debridement and unloading osteotomy. **b** Creating template of the defect. **c** MACI collagen membrane placed over paper (assists with handling and preparation). **d**, **e** Implanting the MACI implant and securing with fibrin glue

complications [164]. Clearly, the greater the mal-alignment the greater the chance of failure of any isolated resurfacing procedure. Unlike the classical unloading osteotomies performed for diffuse degenerative arthrosis, which place the mechanical axis well into the unaffected compartment, osteotomy in a younger patient with more of a focal defect has a post-correction goal of neutral in most cases. As a result, the correction is typically smaller in many cases.

In a recent report of multi-ligament injuries in athletes, 8% of the 26 patients underwent an osteotomy by 8 years for

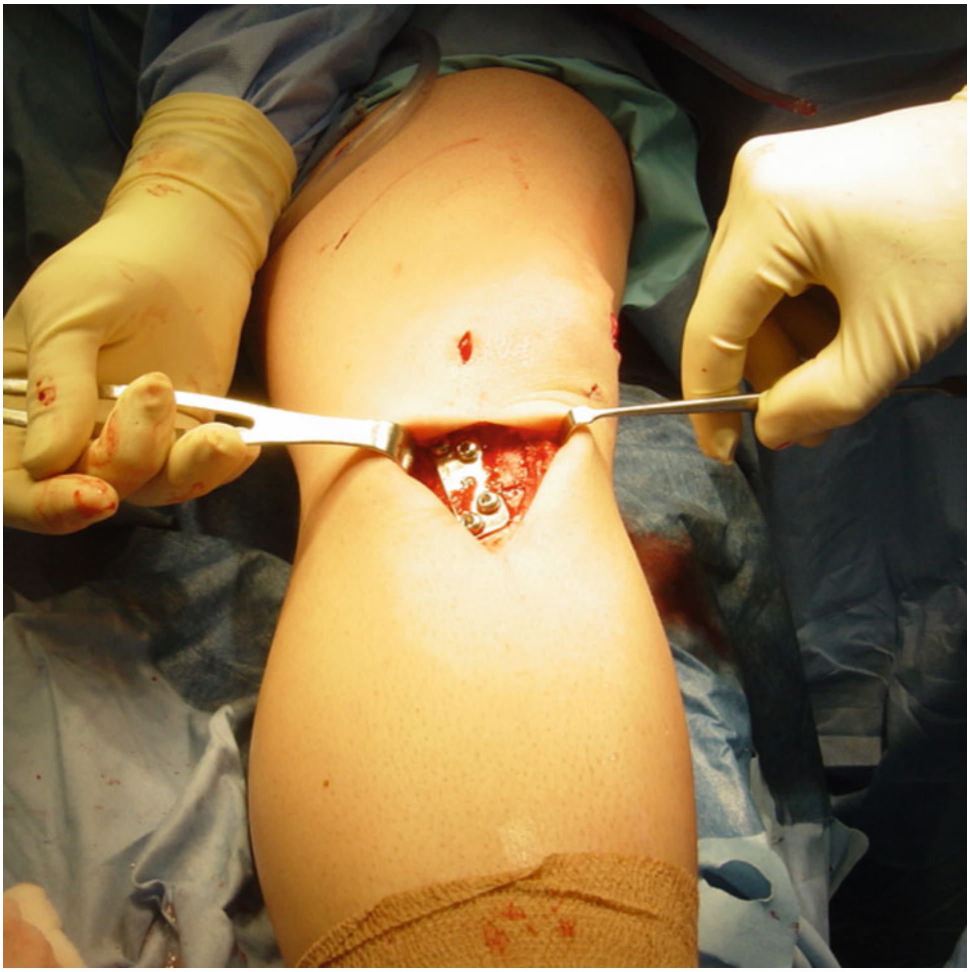

Fig. 29.15 High tibial osteotomy performed in conjunction to OAT of the medial femoral condyle

symptomatic diffuse degenerative changes. Arthritis and not focal cartilage defects were the clinical issue in this group at follow-up. Unfortunately, this is often the outcome in the multi-ligament injured knee. In younger active patients with more diffuse degenerative changes which are not amenable to cartilage resurfacing, it may be prudent to perform an isolated unloading osteotomy. Post-op alignment goals would be similar to the classic technique [33, 164, 165].

29.15 Future Technologies

Articular cartilage repair is evolving, and new technologies are being explored to increase treatment options available to surgeons and patients. Some of these new techniques include: future generation ACI, implantation of particulated autograft or allograft articular cartilage, stem cell therapies, and methods to further optimize marrow stimulation techniques. These and other technologies are in various investigational stages, and further research will determine which will prove to be more efficacious than conventional options.

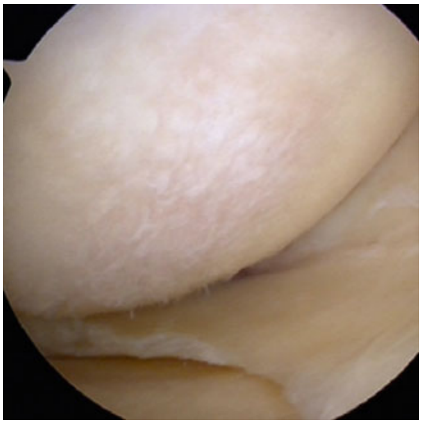

Fig. 29.16 Middle-aged patient with slowly progressive diffuse chondrosis of the medial femoral condyle treated nonoperatively for 10 years following PCL injury

Many future technologies focus on improvement or evolution of current marrow stimulation procedures. The use of hyaluronic acid-based cell-free scaffold is being explored to augment the results of current marrow stimulation techniques [166]. Some literature suggests this technique may improve recovery time and certain patient outcome scores at up to 2-year follow-up [166]. Autologous Matrix-Induced Chondrogenesis (AMIC™) fixes a defect matched, acellular, type I/III collagen membrane over a standard microfracture procedure in order to stabilize the mesenchymal clot within the defect [167]. Autologous articular cartilage chip transplantation is being explored to potentially improve repair tissue within a treated defect [168]. Particulated allograft articular cartilage has also shown to be of clinical benefit [169, 170]. A recent systematic review comparing microfracture with biologically augmented microfracture acknowledged growing evidence that augmentation may provide greater therapeutic benefit over standard microfracture [171]. Further investigation and time are needed before reliable clinical outcome data is powerful enough to warrant common implementation.

Optimism surrounding novel technologies must be tempered by the reality that the treatment of articular cartilage defects has been a much more formidable task than perhaps appreciated twenty years ago. As a result of understandable FDA challenges and difficulty in proving superiority of biologic resurfacing options in heterogeneous patient populations, the development of novel treatment options may be more arduous than perhaps appreciated by some. As new techniques are evaluated and potentially become available, treatment algorithms will continue to evolve over time for this challenging patient population.

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Meniscal Injuries and Treatment in the Multiple Ligament Injured Knee

30

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30.1 History of Meniscal Injury, Repair, and Replacement

The critical function of the meniscus to help preserve cartilage in the knee was first presented by Fairbanks in 1948 when he described the classic radiographic changes associated with osteoarthritis after complete meniscectomy [1, 2]. Thus, the significance of the meniscus in cartilage protection has influenced the current treatment of meniscal injuries with the primary goal of maintaining meniscal integrity and attempting to preserve maximal meniscal tissue to allow restoration of tibiofemoral contact force and load distribution.

The concept of meniscus replacement can be dated back to 1916 and 1933 when fat interposition was utilized to substitute for the meniscus [3]. In 1908, the first meniscus transplant surgery was reported in the literature in the setting of limb salvage via complete knee transplantation [4]. More recently, Locht et al. reported the use of massive proximal tibial osteochondral allografts with meniscus allograft to treat chronic tibial plateau fractures [5]. The short-term success of meniscus allograft transplantation (MAT) was shown in animal studies in the 1980s [6, 7]. The first modern meniscal allograft transplantation was performed in 1984 [3]. Since then, there have been no randomized controlled trials or long-term outcome studies for the procedure.

The earliest known report of meniscal repair was in 1889 when Dr. Thomas Annadale sutured the torn meniscus of a miner [8]. Since that time arthroscopic all-inside, inside-out, and outside-in meniscal repairs have all been described with varying levels of success. In recent decades, the essential role of the meniscal root in overall meniscus function has been recognized [9–13]. Additionally, meniscal integrity secondarily prevents excess tibial translation and strain on a reconstructed anterior cruciate ligament (ACL) [14]. Despite sparse literature for combined ligamentous reconstruction and meniscal root treatment, many techniques have been proposed for root repair.

30.2 Patient Demographics

It has been estimated that over 850,000 meniscal procedures are performed each year in the United States [15–18]. Males sustain meniscal tears 2–4 times as commonly as females, and these injuries usually occur in the third decade of life or later [19]. The medial meniscus is more commonly torn in all age groups [1, 20]. Following a multi-ligamentous knee injury, it is not uncommon to have a concomitant meniscal and/or chondral injury due to the high energy trauma often sustained by the knee. Krych et al. [21] retrospectively reviewed all patients treated over a 21 year period at a single institution for PCL-based multi-ligamentous knee injury or a minimum of three disrupted ligaments. The authors found 55 and 48% of patients had an associated meniscal or chondral injury, respectively, at the time of surgery. There was no difference in occurrence of medial or lateral meniscal tears. However, patients >12 months from time of injury had significantly higher rates of chondral injury to the lateral and patellofemoral compartments [21]. Both meniscus root repair and MAT are relatively new procedures with little prospective data, and minimal data published in conjunction with multi-ligamentous knee reconstruction.

A recent meta-analysis of meniscal root repair of the posterior horn medial meniscus analyzed 8 studies with various repair techniques to determine clinical and radiographic outcomes following root repair [22]. Among the

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eight studies, there were only 230 total patients. The mean age was 55.02 years. Despite some patients undergoing combined ligamentous reconstruction, there was no subgroup analysis performed [22]. A meta-analysis to determine the cost-effectiveness of meniscal root repair published this year sought to compare root repair, meniscectomy, and nonoperative treatment for medial meniscal root tears [23]. In their analysis, there were 344 patients in 13 publications, in whom the mean age was 55.15 years. Eleven of the thirteen reported male: female ratio; the procedure was more commonly performed in females (82.5%) versus males (17.4%) [23].

An early systematic review of the literature on MAT attempted to establish four clinical guidelines for surgeons considering MAT as a treatment option in their patients: (1) ideal patient for MAT, (2) ideal method of graft sizing, preservation, and implantation, (3) postoperative rehabilitation guidelines and timing to return to sporting activity, and (4) overall success rate of MAT [24]. The review included 15 studies (3 level III evidence and 12 level IV evidence) and included 516 patients with 547 MATs (263 lateral and 284 medial). The mean patient age in this series was 33.4 (range: 14–55). The procedure was more commonly performed in males (68%) compared with females (32%). Mean follow-up time for this series was 55 months (range: 6 months to 14.5 years) [24]. A more recent systematic review of 14 articles (1 level III evidence and 13 level IV evidence) published between 2000 and 2007 included seven articles from the aforementioned systematic review and analyzed 352 MAT procedures in 323 patients [25]. The 7 new studies included in this review were published between 2005 and 2007 included 160 patients with 161 MATs (69 lateral and 92 medial). The mean patient age was 33.9 (range 14–58). Based upon this data, the majority of MAT procedures are performed for active patients in their third and fourth decades with a previous history of meniscectomy. There is a trend of MAT more commonly being performed in men and for the medial meniscus [25].

The above studies indicate a stark difference in meniscal root repair and meniscal allograft transplantation population groups. The root repair cohort is overall older and more predominantly female; whereas, meniscal allograft transplantation is younger and more predominantly male.

30.3 Meniscus Structure and Function

The menisci are fibrocartilaginous structures with the primary function for load transmission, shock absorption, increasing joint congruity, reducing joint contact stresses, joint lubrication, and nutrition [1, 15, 17, 26–32]. The menisci are primarily composed of water (75%) and type I collagen (20%) with smaller proportions of proteoglycans, cells, and types II, III, V, and VI collagen [33, 34]. The function of the meniscus is to convert compressive axial loads across the joint into tensile strain dispersed by the collagen fibers in the meniscus, thereby increasing load-sharing and decreasing point-loading across the articular cartilage. Collagen fibers within the meniscus are arranged in a circumferential pattern and are held together by radially oriented collagen fibers arranged to resist hoop stresses, helping to prevent displacement of the menisci during loading [35].

There are several critical differences between the medial and lateral menisci. First, the lateral meniscus is c-shaped and covers nearly 50% of the lateral plateau compared with the medial meniscus, which is more oval shaped and covers only 30% of the medial plateau. Second, the lateral meniscus is much more mobile than the medial meniscus and is more prone to injury in acute traumatic events. Third, the lateral meniscus is an integral structure in the lateral joint space because it helps improve articular conformity of the lateral femoral condyle to the relatively convex lateral tibial plateau. Nearly 70% of load transmitted across the lateral joint space is through the lateral meniscus compared to 50% for the medial meniscus [36]. Finally, the medial meniscus has the additional role as a secondary stabilizer to anterior tibial translation in an ACL deficient knee, and the lateral meniscus has no known clear role in knee stability [19, 37].

30.4 Effects of Root Tear and Meniscectomy

Biomechanical studies investigating the effects of partial and complete meniscectomy have reaffirmed the importance of maintaining meniscal integrity. Partial meniscectomy is preferable to complete meniscectomy but there still is increased contact stress compared to an uninjured knee and earlier degenerative osteoarthritis results from this condition [38, 39]. Several important points should be made when considering meniscectomy. First, resection of the lateral meniscus has been shown to increase peak joint contact pressures when compared to medial meniscectomy and increase the incidence of osteoarthritis [40]. Therefore, the importance of the lateral meniscus should be stressed, and every attempt should be made to preserve lateral meniscus integrity. Secondly, radial tears in the central portion of the meniscus may not be amenable to fixation and may be best treated with debridement. Excessive debridement or debridement that extends to the peripheral meniscus completely disrupts the circumferential fibers and this has been shown to be biomechanically equivalent to a complete meniscectomy [41]. Finally, resection of 75% or more of the posterior horns of the menisci biomechanically functions as a complete meniscectomy [41, 42].

The posterior meniscal roots anchoring to the tibia are generally defined as the central most origin of the posterior horn of the medial and lateral menisci and are within 1 cm peripheral of that point [9]. These tears occur both acutely and in a chronic nature. Lateral meniscal root tears occur more commonly in an acute traumatic injury and have been described as often as in 8% of ACL tears in one series [43–45]. Although in the setting of a multi-ligamentous knee injury, medial meniscal root tears occur have been reported to occur in 2.74–50% of patients [46, 47]. Notably, the higher of the numbers occurred in a small cohort of patients treated for multi-ligamentous instability associated with severe medial knee instability [47].

In vitro, the biomechanical effects of a posterior medial meniscal root tear lead to an increase of 25 and 13% in peak contact pressures in the medial and lateral compartments, respectively [9]. Additionally, the effects on contact pressures between an isolated medial posterior horn root tear and complete medial meniscectomy were the same. Once the meniscus was repaired with a pull through transtibial technique, joint kinematics returned to normal. In the setting of an ACL reconstruction, biomechanical analysis demonstrates increased anterior tibial translation and rotatory instability with sectioning of the medial meniscal root as well as with meniscectomy [14, 48].

Regarding the lateral meniscal root, LaPrade et al. [49] performed biomechanical testing on a variety of posterior meniscal root tears—avulsion and complete radial tears at 3 and 6 mm from the root [49]. All conditions led to decreased contact area and increased contact forces in the lateral compartment throughout a range of motion from 0 to 90°. There were no changes in area or load in the medial compartment. Similar to the findings of Allaire et al., after in situ pullout suture repair, contact area and peak loads in the compartment returned to normal. Similar findings have been reproduced in a cadaveric setting on both the medial and lateral menisci [50, 51].

The stabilizing effect of the posterior horn of the lateral meniscus to both rotatory and translation has recently been studied. Shybut et al. [52] demonstrated increased rotatory translation in ACL deficient knees with a combined lateral meniscal root tear compared to the intact meniscal root state; however, despite a trend toward increasing translation during Lachman testing, there was no significant difference between the intact lateral meniscal root and deficient knees [52]. Frank et al. [53] conducted a similar follow on study but additionally included specimens with and without an intact native ACL. This study reinforced the findings of Shybut et al. by showing increased rotational translation in knee flexion with a lateral meniscal root tear in both the intact and sectioned ACL states. Isolated anterior tibial translation only occurred significantly at 60° of knee flexion with an intact ACL, at 30° of knee flexion with an ACL deficient knee [53]. These studies show the important rotatory stabilization of the lateral meniscus that has only recently been recognized.

Clinically, posteromedial root tears have been associated with >3 mm of meniscal extrusion as well as strongly associated with medial joint line osteophytosis and medial compartment articular cartilage loss [12], although the chronicity of the tears leading to this pathology is not known because this was based on a retrospective imaging review. Patient subjective outcomes following complete meniscectomy are disappointing in long-term outcome studies [54–58]. Studies have demonstrated the correlation of clinical and radiographic osteoarthritis in patients with a history of previous meniscectomy [1, 59]. A systematic review looking at the clinical and radiographic outcomes in patients undergoing meniscectomy described the preoperative and intraoperative predictors of poor outcomes to be total meniscectomy, removal of the peripheral rim of the meniscus, lateral meniscectomy, degenerative meniscal tears, presence of chondral damage, and increased body mass index (BMI) [58]. As a result of the poor outcomes following total meniscectomy, MAT has been an acceptable alternative in a symptomatic and meniscal deficient knee.

30.5 Indications

Factors associated with indications for either a meniscal root repair or MAT are similar in consideration for restoration of alignment and ligamentous stability of the knee. However, for the success of MAT, far more stringent considerations of patient characteristics must be considered. Preservation of the patient's meniscal tissue when possible is essential. As mentioned above, reported outcomes of meniscal root repair tend to have a mean patient population in the 5th and 6th decades of life. LaPrade et al. [11], however advocate that the ideal patient is typically younger and active (<50 years). Additionally, Moon et al. [60] retrospectively identified risks for poor functional and subjective outcome following medial meniscal root repairs. Specifically, patients with Outerbridge Grade 3 or 4 chondral lesions had worse American Knee Society (AKS) and Lysholm score than those with only Grade 1/2 lesions. Additionally, varus alignment >5° was independently associated with poorer VAS, AKS, and Lysholm scores. Preoperative evaluation of imaging and intraoperative arthroscopic evaluation help guide the surgeon for root repair planning and patient counseling.

The relative indications for meniscal transplantation are variable, however, MAT should be considered as a viable option in patients who are: skeletally mature, young and active, prior history of complete or near complete meniscectomy, pain localized to affected compartment, normal mechanical alignment and stability, absence of moderate to advanced osteoarthritis, and normal range of motion. Concomitant chondral injury, ligamentous instability, or malalignment must be addressed prior to or in conjunction with meniscal transplantation. Although there is no evidence to support prophylactic MAT in asymptomatic patients, young athletes with a complete lateral meniscectomy present a clinical challenge with rapid progression of osteoarthritis commonly experienced. In this highly selected population, early MAT procedure may be a reasonable consideration.

There has been some clinical evidence that the success and rate of healing of the allograft is improved in patients with minimal degenerative changes in the involved joint [61]. Noyes et al. demonstrated that knees with less than Outerbridge grade 3 changes had a complete healing rate of 70% and a partial healing rate of 30%. On the contrary, knees with grade 4 changes had a 50% failure rate. Advanced arthrosis has also correlated with higher incidence of graft extrusion on MRI and higher risk of failure [57].

The success of MAT depends on ligamentous integrity of the knee. Ligamentous instability should be restored with reconstruction prior to or in conjunction with MAT. Medial MAT can provide additional AP stability when performing an ACL reconstruction when compared to ACL reconstruction alone in the setting of medial meniscus deficiency [62]. There is insufficient evidence to suggest that ACL reconstruction with MAT prevents the progression of osteoarthritis or decreases pain when compared to ACL reconstruction alone. In contrast to the medial meniscus, lateral MAT has failed to provide additional stability in the ACL deficient knee [63].

Normal mechanical alignment is critical to the success of MAT and cannot be overstated. Garrett and Stevenson were among the first to report the high failure rate of MAT in extremity malalignment [64]. Malalignment (most commonly the varus type) can create increased contact stress on the allograft tissue and prevent proper revascularization of the allograft from the capsular peripheral blood supply and can lead to graft failure. Good to excellent results in 85% of patients after MAT have been demonstrated when performed with concomitant realignment osteotomy [65].

Relative contraindications to allograft transplantation are obesity, infection, and inflammatory arthritis. The ultimate goal of the surgery should be to provide pain relief for the patient during activities of daily living and not return to high-level athletic competition. Therefore, communication with the patient and appropriate preoperative counseling are paramount to the success of the surgery and patient satisfaction. Further research is needed to determine the expected return to high-level sports and long-term outcomes of these procedures to help guide surgeons and patients alike.

30.6 Graft-Specific Factors

Method of preservation, secondary sterilization, and method of graft sizing are critical factors for the success of MAT. There are four methods to preserve grafts once they are harvested: fresh, cryopreserved, fresh-frozen, and freeze-dried or lyophilized. Fresh grafts can be stored at 4 °C for about 1 week. The benefit of fresh grafts is the high percentage of donor cell viability, with the theoretical advantage of better maintenance of the mechanical integrity of allograft tissue [66]. The short period of viability creates difficulty when time is necessary for graft sizing, sterilization, serological testing, and implantation; therefore, fresh allografts are rarely used. Freeze-dried or lyophilized grafts are rarely used due to the biomechanical alteration and shrinkage of the allograft during the freezing and implantation process [3]. Most meniscal allografts are fresh-frozen or cryopreserved. Fresh-frozen grafts are rapidly cooled to −80 °C and maintained at this temperature. The process of freezing is detrimental to cell viability but has no effect on the biomechanical properties of the allograft. Cryopreserved grafts are frozen in a controlled fashion using a cryoprotectant glycerol-based medium to retain cell viability. The expense associated with cryopreservation may not be warranted given evidence to suggest that fresh-frozen grafts clinically have similar results and that cell viability may not be necessary given histological analysis that demonstrates early graft repopulation with host cells [67, 68].

The implantation of allograft tissue has the potential to transmit bacterial, viral, or fungal infection and secondary sterilization is used to limit this risk. Gamma irradiation was a common means of sterilization of allograft tissue but studies have shown that the dose of irradiation needed to prevent HIV and hepatitis C also caused significant disruption of the mechanical properties of the graft [69, 70]. Ethylene oxide has also been used for sterilization, but its use was discontinued due to the formation of synovitic reactions and effusions. At present, there is no consensus on the best means of sterilization, and tissue banks have developed newer sterilization techniques with limited clinical evidence.

Graft sizing is important to match the size of the native meniscus and best restore the normal biomechanics of the knee joint. There are multiple protocols for sizing the meniscus that utilizes plain radiographs, MRI, or CT and may utilize the injured or uninjured extremity for measurements [71, 72]. Whichever technique is utilized, the accepted margin of error should be within 5% or smaller of the native meniscus. Recently, it has been demonstrated that greater than 10% size mismatch can alter the biomechanics of the joint and place increased stress on the meniscus allograft [73]. The most commonly utilized protocol has been described by Pollard et al. which utilizes bony landmarks on AP and lateral plain radiographs [74]. This technique has been associated with some variability of meniscus width and length dimensions. MRI and CT scan measurements were once thought to more accurately predict allograft size, but they have consistently underestimated the size and have not proven to be superior to radiographic measurements [71].

30.7 Graft Implantation

MAT can be performed through either an open or arthroscopic approach using several different methods. Two systematic reviews of MAT suggest that there is no one ideal method of surgical approach or fixation [24, 25]. Cadaveric and clinical studies support several basic principles when performing MAT: anatomic meniscal horn placement, rigid fixation of the meniscal horns, and stable peripheral capsular suturing to allow for revascularization [24, 25, 75].

Attachment of the meniscal horns can be performed with bone plug fixation, slot technique (bone bridge), or soft tissue suture ligation. Cadaveric biomechanical studies have supported the use of anatomic bone plug fixation in order to best recreate the normal contact mechanics of the menisci [76–78]. Secure fixation of bone plugs is commonly used for medial MAT to avoid disrupting the native footprint of the ACL, which inserts medially on the tibia between the two horns. Lateral MAT can also be performed with bone plugs but the use of a bone bridge technique has also been described. The proximity of the anterior and posterior horns of the lateral meniscus to each other is a factor cited. The bone bridge technique avoids the risk of tunnel convergence during transplant surgery; however, given the development of low-profile reamers it is possible to place separate sockets close to each other and still maintain the proximal tibial plateau integrity. Animal models have demonstrated decreased tensile strength and increased failure rate with only soft tissue fixation of the meniscal horns [79, 80].

Stable peripheral capsular fixation when performing MAT is critical in order allow for graft revascularization and healing. Inability to stabilize the periphery of the MAT can lead to a failed allograft transplant. Vertical mattress sutures should be utilized when fixing the allograft to the capsule because of increased tensile and pullout strength [75].

30.8 Perioperative Considerations

Proper patient selection is the most important factor in considering meniscal allograft transplantation. Meniscal deficient knees experience abnormal contact forces and may already have advanced degenerative changes. MAT is a technically challenging procedure, and patients with relative contraindications should not be offered this treatment. Risk factors such as high body mass index and tobacco use may be modifiable, but their presence in meniscal deficient patients may make MAT inappropriate.

Mechanical alignment in the coronal plane is one of the most important factors for successful MAT. If an osteotomy is required to correct mechanical malalignment, this may have significant impact on concomitant and future staged procedures. The authors prefer to perform osteotomies as the initial procedure in malaligned limbs. The osteotomy is usually performed with a concomitant knee arthroscopy to evaluate the meniscal status and condition of the articular cartilage. In acute cases with multi-ligamentous knee injuries, collateral and/or cruciate repairs/reconstructions may be performed early to allow for rehabilitation. In chronic cases, the authors prefer to first ensure proper alignment, and perform any needed collateral reconstructions. After 3–6 months of healing and rehabilitation, we perform a staged MAT along with any necessary cruciate reconstructions. Size-matched meniscus allografts in addition to any chondral grafts can generally be procured during this time period. It also provides for an adequate healing time of the osteotomy site to allow for hardware removal in cases of tunnel obstruction. Cruciate reconstruction is usually performed in conjunction with the meniscus transplantation as an empty notch significantly facilitates this technically challenging procedure.

In almost all cases, the treatment of an acute multi-ligamentous knee injury does not involve planning for meniscus transplantation. As previously discussed in other chapters, it is imperative to have a high index of suspicion for a vascular injury. After emergent reduction and confirmation of the patient's vascular status, it is important to define all of the injuries. The presence and management of fractures may dictate the surgical approach, as well as the extent of ligamentous involvement. Meniscal injury has been noted in 50% of knee dislocations [81]. All peripheral tears, as well as, meniscocapsular injuries should be repaired. These repairs are usually performed during initial open repair or arthroscopic evaluation. Sub-total or total meniscectomy is rarely necessary, but thorough documentation of each compartment is important as MAT may be indicated in the future. Since meniscal grafts need to be size-matched, staged transplantation is the approach usually taken and is most appropriate in multi-ligamentous knee injuries as ligamentous stability is the primary goal. Since the meniscus provides additional stability, concomitant meniscal transplantation may be considered in cases of total meniscectomy and cruciate deficiency. However, in the authors' experience, MAT is typically performed in a delayed fashion following initial ligamentous reconstruction. Our institution's experience revealed that very few meniscal transplantations have been performed in patients that sustained true knee dislocations. In 84 meniscal allograft transplants performed at our institution from 2005 to 2010, only three were multiple ligament injured knees, with two undergoing concomitant ACL/PLC reconstructions, and one had a PCL/PLC reconstruction. Furthermore, we are aware of only one report of a multiple ligament injured knee undergoing combined cruciate reconstruction and MAT [82].

30.9 Root Repair Techniques

With modern arthroscopy, two primary techniques with multiple variations have been described for meniscal root repair—transtibial pullout suture and suture anchor repair. The transtibial pullout suture requires the use of either standard braided suture or a suture tape. To grasp the torn root, a variety of techniques have been described. Mitchell et al. analyzed 4 different repair constructs involving number of standard sutures (single versus double simple pass through the meniscus) and suture pattern (loop or locking loop single suture) [83]. The authors found the most common failure in all groups was secondary to suture pullout. The strongest resistance to avulsion was with a locking looped suture. Additionally, using the locking looped suture, there was no significant difference compared to force required to avulse the native medial meniscal root. Using 2 standard braided sutures or a tape suture passed in simple fashion through the sectioned meniscal root, Robinson et al. evaluate a porcine model for load failure [84]. Maximum load to failure was 2–3× higher in the tape group.

Unlike the transtibial pullout technique which generally only requires the use of standard anteromedial and anterolateral arthroscopy portals, use of an all-inside anchor technique requires either a high posterior medial or high posterior lateral portal to introduce the anchor perpendicular to the cortical surface at the native insertion. Use of these portals can be technically challenging, and few biomechanical studies have been published comparing suture anchor to transtibial pullout. Feucht et al. [85] compared meniscal displacement with cyclic loading and maximum load to failure between transtibial pullout technique and suture anchor repair. Suture anchor repair demonstrated decreased displacement but no difference in maximum load to failure [85]. Further studies are needed to evaluate the two techniques.

30.10 Authors' Surgical Technique—Root Repair

The authors prefer the arthroscopic transtibial pullout technique for root repair. In the setting of concomitant cruciate ligament reconstruction, appropriate preoperative planning for tunnel placement is paramount. Standard operating room setup for knee arthroscopy with the patient supine, a tourniquet on the thigh, and a lateral C-clamp are used with the foot of the bed remaining up. A 30° 4.0 mm arthroscope is used with superomedial outflow. Standard anteromedial and anterolateral portals are established; additionally, for ACL reconstruction a low anterior medial portal is established. After graft harvest and diagnostic arthroscopy, the notch is prepared to allow adequate visualization of the posterior roots (Fig. 30.1). In the setting of a root repair without cruciate ligament reconstruction, viewing through the Gilquist interval or an accessory medial or lateral portal may be required.

The torn meniscal root is approached using a meniscal knee Scorpion (Arthrex, Naples, Fl) and two #0 Fiberlink sutures (Arthrex, Naples, Fl) each passed to created two locked loops adjacent to the edge of the tear (Figs. 30.2 and 30.3). An ACL guide is then used to drill a 6 mm Flipcutter drill (Arthrex, Naples, Fl) to the meniscal root anatomic insertion from the anterior medial cortex. In the setting of an ACL or PCL reconstruction, the angle on the guide is increased to create a tunnel which will avoid the other tibial tunnel. Once the Flipcutter is retro-drilled for a depth of

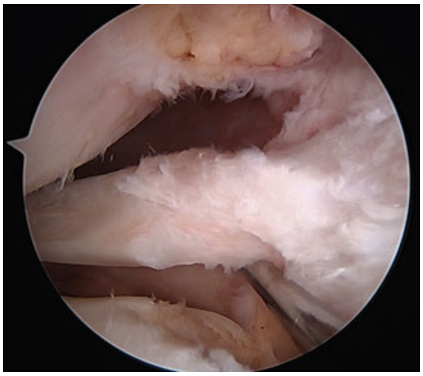

Fig. 30.1 Lateral meniscal root tear seen on diagnostic arthroscopy

Fig. 30.2 Root elevated to allow passage and drilling of tunnel

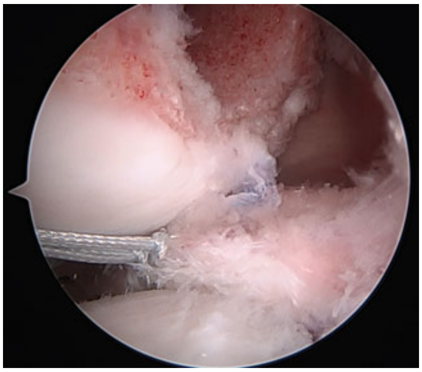

Fig. 30.3 Meniscal scorpion used to pass 2× locked loops through meniscal root

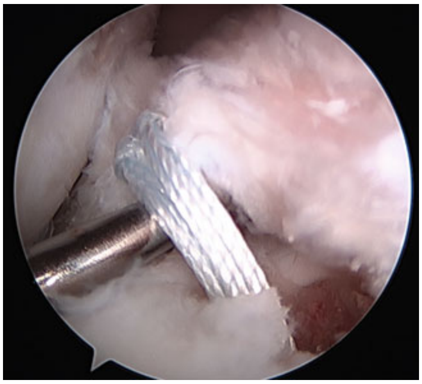

Fig. 30.4 Suture shuttled through tunnel

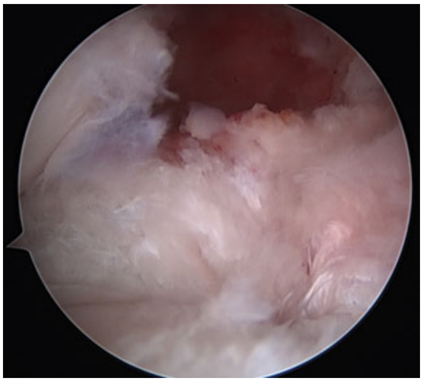

Fig. 30.5 Final repair image

5 mm, a #2 Fiberstick suture (Arthrex, Naples, Fl) is introduced from the distal end of the tunnel into the joint, and these are used as shuttling sutures. Once the sutures have been passed, reduction of the meniscal root is verified under arthroscopic visualization (Fig. 30.4). The author's preferred technique for ACL reconstruction requires hyperflexion of the knee and a low anterior medial portal. Due to this, the root repair sutures are not secured until after the ACL reconstruction is complete to prevent stress on the repair. Then the root repair sutures are tied over a cortical button (Fig. 30.5).

30.11 Authors' Surgical Technique—MAT

As previously mentioned, proper mechanical alignment and ligamentous stability must be considered prior to meniscal allograft transplantation. While ligament reconstruction may be performed concomitantly with meniscus transplantation, high tibial osteotomy or distal femoral osteotomy should be performed in a staged fashion. Ideally, MAT should be delayed 6 months from the osteotomy to allow for healing and subsequent hardware removal as needed. An arthroscopic evaluation at the time of osteotomy allows for a thorough assessment of the meniscus and cartilage. In cases with neutral alignment confirmed by weight-bearing hip to ankle alignment radiographs, ligamentous deficiencies are confirmed by physical examination and stress radiographs as necessary.

As previously discussed in this chapter, there are several techniques to perform MAT. The authors prefer to use an arthroscopic approach with bone plugs for both medial and lateral transplantation [86]. The bone plugs are fixed into recipient sockets on the tibial plateau.

Surgery begins with graft preparation which is initiated while the patient is being setup in order to minimize anesthetic time. The free meniscal graft is prepared from the hemi-plateau allograft with attached donor meniscus (Fig. 30.6). 8 × 10 mm tapered bone plugs are harvested from the hemi-plateau while maintaining their attachment to both the anterior and posterior meniscal roots (Fig. 30.7). A permanent #2 suture is delivered up through a central vertical drill hole in each bone plug and exits on the superior surface of the meniscus. A horizontal type stitch is delivered through the meniscal root then the suture is brought back down through the central hole of the bone plug. A second #2 suture, the posterior horn stitch, is placed in a vertical fashion through the meniscal allograft 1 cm from the posterior horn bone plug. A third #2 suture, the mid-body stitch, is placed 1 cm from the posterior horn stitch in a similar fashion (Fig. 30.8). After all, sutures are placed, the graft is wrapped in a moist sponge and secured on the back table until the knee is ready for graft passage.

After diagnostic arthroscopy, the notch is prepared for cruciate reconstruction. In cases of cruciate intact knees, space is cleared to facilitate posterior bone plug passage through the notch. For medial meniscal transplants, a small amount of the PCL PM bundle is debrided along with the extreme lateral aspect of the MFC and the medial eminence (Fig. 30.9). Lateral meniscal transplants require minimal

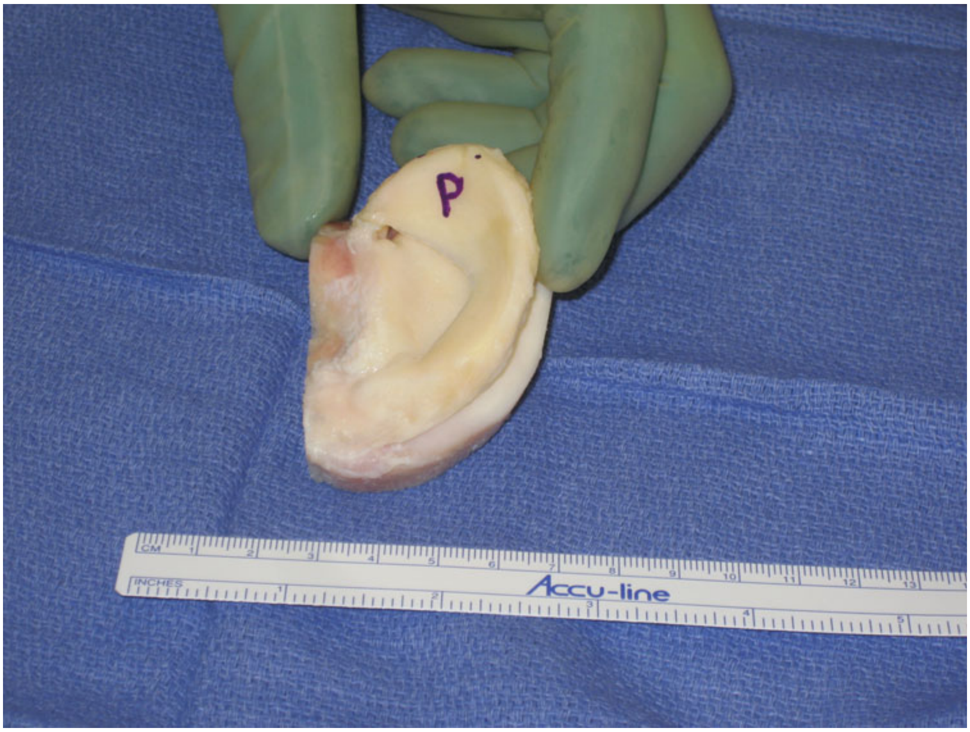

Fig. 30.6 A size-matched fresh-frozen donor hemi-plateau with meniscus is obtained from a tissue bank in order to fashion a free meniscus graft

Fig. 30.7 Bone plugs measuring 8 mm diameter by 10 mm long are fashioned to recreate the anterior and posterior meniscal root attachment sites to the tibia

debridement of the ACL PL bundle along with the medial aspect of the LFC and lateral eminence. Once a 9 mm smooth dilator can be easily passed (Fig. 30.10), the preparation is adequate.

Next, the meniscal remnant is removed. This is performed using a combination of a radiofrequency probe, meniscal scissors, and an arthroscopic biter to cut along the periphery of the meniscus. The goal is to leave a 1–2 mm rim of

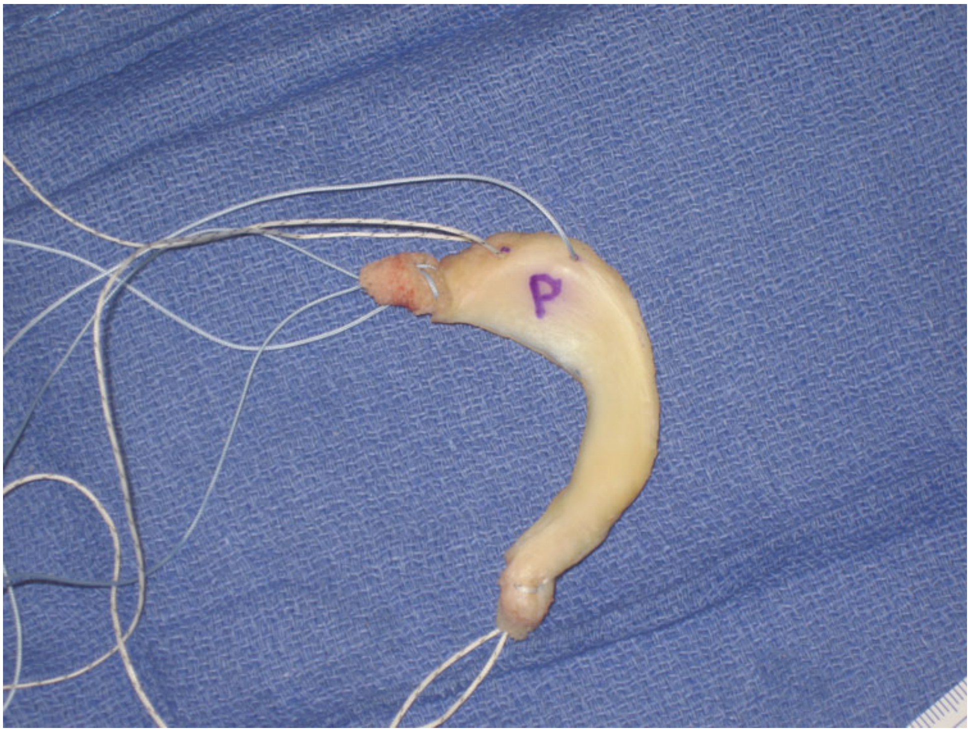

Fig. 30.8 Completed bone plug meniscal allograft with number two permanent sutures passed up central vertical holes in the bone plugs, passed transversely across the root, and back down through the bone plug. Two additional number two sutures are placed in the meniscus in the posterior horn and mid-body of the meniscus

Fig. 30.9 For medial meniscus transplants, a small amount of the PCL posteromedial bundle is debrided along with the extreme lateral aspect of the medial femoral condyle and the medial tibial eminence to facilitate bone plug passage

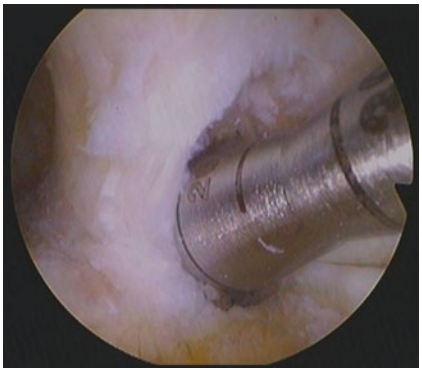

Fig. 30.10 For lateral meniscus transplants, a minimal recession of the ACL posterolateral bundle and debridement of the medial aspect of the lateral femoral condyle and lateral tibial eminence is performed to facilitate bone plug passage. Successful passage of a 9 mm tunnel dilator confirms that adequate space exists to pass the posterior bone plug

meniscal tissue while preserving the chondral surfaces (Fig. 30.11). The insertion of the posterior horn footprint is cleared of soft tissue and marked with the radiofrequency device (Fig. 30.12). An 8.5 mm posterior horn bone tunnel or socket is created. While a traditional tunnel can be used, a reverse-drilled socket is preferable to minimize tunnel convergence which may be a concern in a multiple ligament injured knee requiring several tunnels. The authors prefer to use an 8.5 mm FlipCutter (Arthrex, Naples, FL) through a tibial ACL aiming guide to create an 8 × 10 mm socket at the posterior horn attachment site (Fig. 30.13). A passing suture is placed through this hole out the anterior portal.

A standard medial or lateral approach for the inside-out meniscal repair technique is then performed. The medial or lateral gastrocnemius fascia is elevated and a retractor is placed to protect the vessel. A second suture is placed 1 cm from the posterior root socket using a suture shuttling device. This suture is passed through the capsule and out the medial or lateral incision and serves as the shuttling suture for the posterior horn suture in the meniscus (Fig. 30.14). A third passing suture, the mid-body suture, is placed 1 cm from the last one in a similar fashion. Suture management at

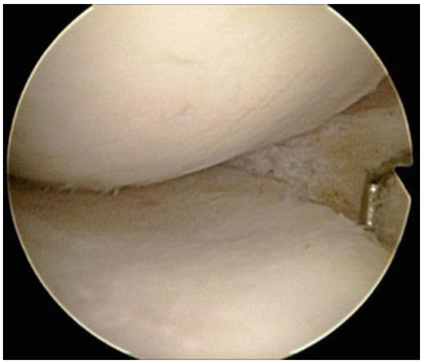

Fig. 30.11 A 1 to 2 mm residual rim of native meniscus is preserved in order to allow secure fixation of the donor meniscus with meniscocapsular suture passage. Extreme care is taken to protect the chondral surfaces during this preparation

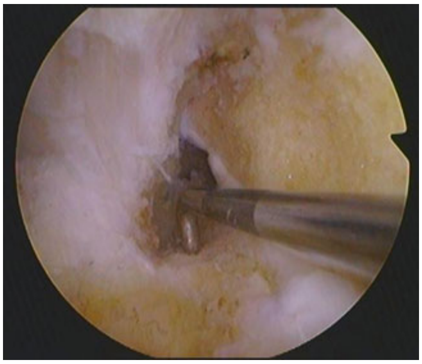

Fig. 30.12 The posterior horn insertion site is cleared of all soft tissue and marked with a radiofrequency device

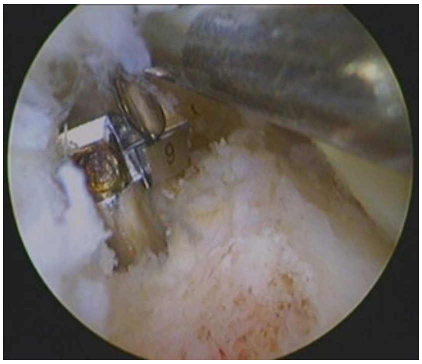

Fig. 30.13 An 8 mm diameter FlipCutter (Arthrex, Naples, FL) is used to create an 8 mm diameter by 10 mm deep socket in the anatomic posterior horn footprint using a tibial ACL aiming guide. A passing suture will be placed through this hole and socket for passage of the posterior horn bone plug

this point forward is critical to minimize suture entanglement which interferes with graft passage. The authors prefer to keep the sutures in an ordered fashion with the mid-body suture clamped high on the drape, the posterior horn suture clamped in the middle, and the posterior root suture clamped low. Again, suture organization is paramount for successful graft passage. At this point, the knee is prepared for meniscus transplantation.

With the camera in the anterior portal opposite the compartment being transplanted, an enlarged ipsilateral portal is created to allow the small finger to freely enter into the joint. Prior to graft passage, a ring grasper is used to “run” the passing sutures from outside to inside the joint to confirm that all three sutures exit the enlarged portal without any soft tissue bridges. The graft is then passed into the knee (Fig. 30.15) by first securing the posterior bone plug into its posterior socket. Next, the posterior horn is passed under the femoral condyle by pulling on the posterior horn and mid-body sutures (Fig. 30.16). Passage of the posterior horn can be assisted by varus or valgus stress to open the transplanted compartment and by a blunt outflow trocar to gently direct the meniscus underneath the condyle. The posterior root bone plug is secured by tying its sutures through a button on the anterior cortex. The posterior horn and mid-body sutures are tied together over the capsule. At this point, an inside-out meniscal repair is performed working from posterior to anterior (Fig. 30.17). The anterior root bone plug is assessed for where it lays in relation to the anterior tibia. An 8 × 10 mm socket is made through the enlarged portal at this position. A guide pin is drilled from the anterior tibial cortex into this socket, and a bent suture passer is used to pass the anterior bone plug sutures out the tibial cortex. The bone plug is pulled into its socket and the sutures are tied together through a button on the anterior cortex.

When performing concomitant PCL reconstruction, the authors prefer to pass the meniscus graft and secure the posterior bone plug, followed by the mid-body repair. Before we secure the anterior bone plug, we typically pass and fix the PCL on the femoral side. After completing our meniscal transplantation, we then secure the PCL on the tibia using the tensioning boot as covered in other chapters.

30.12 Rehabilitation

Rehabilitation after meniscal root repair or allograft transplantation should allow for healing of the meniscus without exceeding the load to failure of the meniscocapsular sutures or meniscal root fixation. Basic science studies have investigated meniscal motion and loading patterns associated with muscle activation through various knee flexion angles. Meniscal motion is significant during knee flexion and extension [87]. Specifically, flexion greater than 90° results in significant meniscal motion and displacement of the posterior horn from the capsule [35, 88]. In contrast, extension reduces the meniscus to the capsule, and there is minimal motion with less than 60° of flexion [87]. Case

Fig. 30.14 A 90° suture lasso (Arthrex, Naples, FL) is used to place a posterior horn passing stitch and a mid-body passing stitch through the capsule and out the medial or lateral posterior skin incision. After graft passage, the two sutures in the posterior horn and mid-body will be tied to each other over the posterior capsule

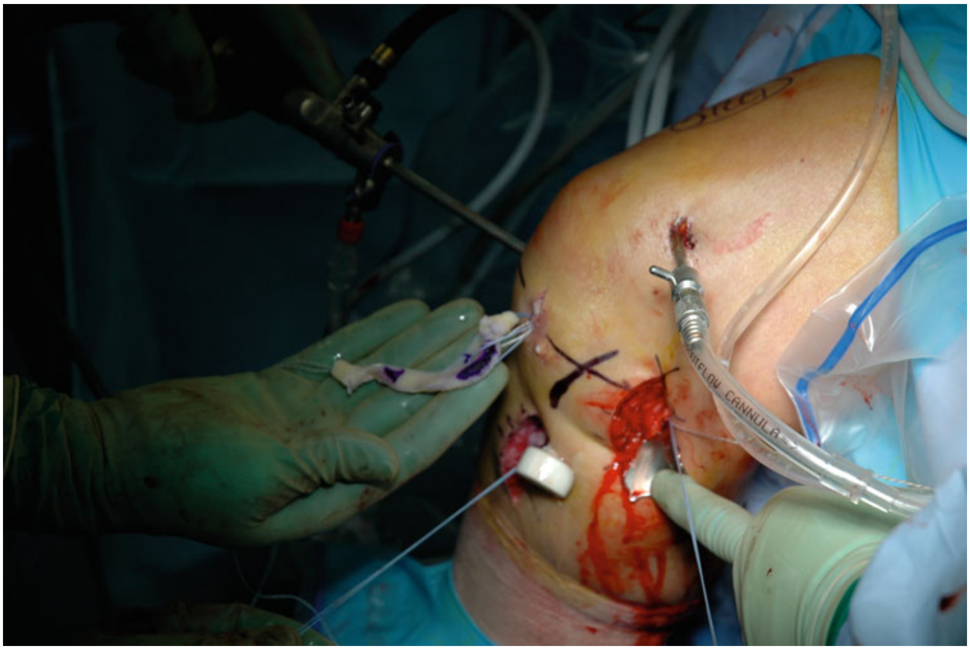

Fig. 30.15 The graft is passed into the knee through the enlarged portal and facilitated by first securing the posterior bone plug into its socket

series have shown favorable outcomes with regimented early range of motion protocols [89, 90]. Clinical trials comparing different rehabilitation protocols to determine the clinical effect of these biomechanical studies and case series are unavailable. In the absence of high-level evidence for specific rehabilitation protocols, postoperative restrictions are often determined by concomitant cartilage, ligament, or limb realignment procedures [89].

The authors follow a three-phase rehabilitation protocol (Table 30.1). The first phase is a protective phase and extends 6 weeks from surgery. The patient is kept partial weight-bearing and wears a brace at all times locked in full extension. The patient passively ranges the knee from full extension to 90° of flexion. The second phase generally extends from weeks 7 through 12 after surgery. This phase focuses on returning full range of motion and achieving a

Fig. 30.16 Sequential traction of the posterior horn and mid-body sutures is used to pass the meniscus beneath the femoral condyle. This may be assisted with appropriate varus or valgus load on the knee and a blunt outflow trocar

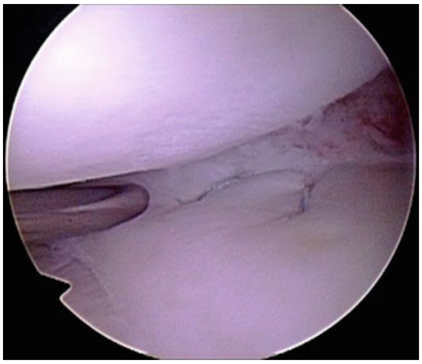

Fig. 30.17 Zone specific cannulas are used to perform a standard inside-out meniscal repair from posterior to anterior

normal gait pattern. The brace is continued but unlocked to allow full range of motion. The patient progresses to full weight-bearing during weeks 7 and 8 and crutches are discontinued when a normal gait pattern is achieved. The third phase goes between 4 and 6 months postoperatively and it is aimed at a return to activity. The brace is discontinued and the focus is on regaining leg strength and a walk to run program. The patient is advised to avoid contact and collision sports for 9 months after surgery at which point they can return to full activities.

Minimal data exists regarding return to sporting activity following meniscal root repair; though the single study specifically addressing radial meniscal root tears suggests 100% return to sport in 11 patients [91]. Meniscal allografts have a limited life span with deteriorating outcomes over time despite revascularization of the tissue [92, 93]. As a result, the authors do not recommend a return to high-demand activities that involve cutting, pivoting, jumping, or carrying heavy loads. While greater than 60% of meniscal allograft patients return to some level of sporting activities, the goal of meniscal allograft transplantation should be a painless knee during activities of daily living [25, 94].

30.13 Outcomes

Meniscal root repair and meniscal allograft transplantation are successful in reducing pain, decreasing effusions, and improving knee function. These clinical improvements are likely due to the improved load transmission characteristics of the intact meniscus or meniscal allograft compared to the meniscectomized knee [95]. Long-term outcomes following posterior root repair are sparse but suggest improved clinical and economic outcomes for patients and the healthcare system. There is little evidence that meniscal allograft transplantation slows long-term progression of cartilage degeneration. Therefore, the goals of MAT should be to reduce pain, decrease swelling, and improve knee function in the short term while performing activities of daily living.

Despite a high incidence of meniscal injuries after multi-ligamentous knee injuries, very few studies have reported outcomes on MATs with multi-ligamentous knee reconstructions [96], and only two studies evaluate outcomes following posterior root repair in the setting of multiligamentously unstable knee [46, 47]. The literature on multi-ligamentous knee injuries treated with reconstruction and meniscal allograft are limited to individual case reports [72, 82].

The natural history of the meniscectomized knee is consistent cartilage degradation and development of osteoarthritis [1]. Compared to a stable meniscectomized knee, a knee that sustains trauma resulting in multi-ligamentous injury presumably has cartilage damage and altered mechanics that may hasten the development of arthritis regardless of treatment.

30.14 Prevention of Osteoarthritis

Contact pressure area and peak loads have been evaluated in both root repair and MAT. Multiple animal and cadaveric models have suggested chondroprotective effects of both by increasing contact areas across the affected compartment and decreasing peak contact loads.

Following lateral posterior root tears, peak contact pressures increase up to 13%, but return to normal following root repair [97]. However, following lateral posterior root repair, contact areas do not return to the uninjured state and remain decreased [49]. In lateral meniscal allograft transplants, peak local contact pressures decrease 55 to 65% compared to meniscectomy, but contact pressures remain higher than the intact state [95]. Peak pressures are restored to near normal after lateral allograft transplantation and bone plug fixation was found to be superior compared to suture fixation alone [98].

In the medial compartment, meniscal root tear and complete meniscectomy increased contact pressures by 25%. Following root repair, peak loads, and contact areas return to

Table 30.1 Sample postoperative protocol for isolated meniscal allograft transplantation

PHASE I	Generally 0–6 weeks post-op
Phase I goals	ROM: full knee extension, 90° knee flexion
Precautions	Wear brace at all times No bending knee with load applied (i.e., squat, leg press, etc.)
Crutches	Begin with touch weight-bearing: progress gradually only when wearing brace locked at 0° ○ Wks 1–2: Partial weight-bearing @ 0–25% body weight ○ Wks 3–4: Partial weight-bearing @ 25–50% body weight ○ Wks 5–6: Partial weight-bearing @ 50–75% body weight
Brace	Locked at 0° extension for 6 weeks
Rehabilitation ~Weeks 1–2	Begin patellar mobilizations and scar massage after suture removal Calf pumping with tubing Heel slides— assisted as needed: within the limits of 0-90° Static quad sets, SLRs (in brace)
~Weeks 3–4 ~Weeks 5–6	Supine passive extension with towel under heel, Gentle HS stretching Short arc quads—may add light weights as tolerated Seated bilateral calf raises—progress to standing bilateral calf raises Hamstring Curls—lightweight in a painless ROM Beginning level pool exercises: only gait training and deep water jogging
PHASE II	Generally 7–12 weeks post-op
Phase II goals	Normal gait and stair ambulation, Full Knee ROM
Precautions	Continue to wear brace at all times (except while sleeping), No jogging
Crutches	Progress gradually to full weight-bearing during weeks 7–8 post-op
Brace	Open to full ROM
Rehabilitation 7–8 weeks 9–10 weeks 11–12 weeks	Stationary bike, Gait training, progressive strengthening Standing balance exercises, progressive strengthening Along with stationary bike, gradually add elliptical for conditioning
PHASE III	Generally 4–6 months post-op
Phase III goals	Jog at own pace and distance, ≥90% quadriceps and hamstring strength, ≥90% hop for distance compared to the uninvolved side
Precautions	*NO* participation in contact/collision sports or military schools
Brace	None required
Rehabilitation 13–16 weeks 17–26 weeks	Progressive functional training, strengthening, and balance training Progressive jogging program
Miscellaneous	No return to contact/collision sports or military schools until 9 months After 6 months post-op: Exercises in phase III are continued, gradually increasing intensity and duration as tolerated with the goal of full return to activity @ ~9 months post-op

similar to the uninjured state [9, 97]. After medial meniscal transplantation, maximum and mean contact pressures are reduced 75% and this contact pressure reduction is closely related to the accuracy of size-matched graft tissue [77].

No animal models to evaluate arthritis progression following meniscal root repair exist. Two recent meta-analyses sought to evaluate human clinical outcomes following medial meniscus posterior root tears [22, 23]. Chung et al. [22] evaluated eight studies with follow-up ranging from 13.4 to 48.5 months. The Kellegren–Lawrence grade progressed in 10.6% of patients; worsening of the Outerbridge changes occurred in 17.3%. Faucett et al. [23] using a Markov predictive model found in a cohort of patients aged 55 years that over 10 years medial meniscus root repair led to 53% progression of OA and 33% progression to total knee replacement. However, meniscectomy and nonoperative treatment would lead to 99.3 and 95.1% progression of OA, respectively, and 51.5 and 45.5% progression to total knee arthroplasty [23].

A sheep model was utilized by Szomor et al. [99] to evaluate in vivo chondroprotective effects of meniscal transplantation. The area of damaged articular cartilage was reduced by 50% with meniscal allograft or autograft compared to meniscectomized animals 4 months after surgery. Similarly, Kelly et al.

[100] used a sheep model to compare meniscectomized animals with lateral meniscal allograft transplantation. The cartilage was evaluated at 2, 4, and 12 months with gross inspection, magnetic resonance imaging, T2 mapping, biomechanical testing, and histologic analysis. Significant chondroprotective effects of meniscal allograft transplant were found compared to meniscectomy, but there was still more cartilage damage in the meniscus transplant group compared to the meniscal intact control group. The authors concluded that meniscal allografts provide significant, but incomplete, protection from cartilage degradation in short-term follow-up after meniscectomy [100].

Rijk et al. [101] utilized a rabbit model to compare radiographic and cartilage cellular activity changes one year after meniscectomy or meniscal allograft transplant. No differences in these parameters were found between the meniscectomized animals and the meniscal allograft transplanted animals with the conclusion that transplantation does not prevent degenerative changes with longer follow-up in this rabbit knee model [101, 102].

The chondroprotective effects of meniscal allografts in human subjects have been described only in case series. Ha et al. [103] noted no progression in arthrosis grade in 77.8% of knees evaluated with magnetic resonance imaging or 64% of second-look arthroscopies evaluated at relatively short-term follow-up of 31 months. Verdonk et al. [104] reported that 41% of knees with fresh meniscal allograft transplants had no further decrease in tibiofemoral joint space width at a minimum of 10 years postoperatively. The authors concluded that the operation had a potentially chondroprotective effect based on the absence of additional joint space narrowing [104]. While this study is compelling by its longer term follow-up, a randomized trial or prospective comparison to a meniscectomy control group is necessary to define the clinically relevant chondroprotective effects of meniscal allografts compared to meniscectomy.

30.15 Healing

In the setting of multi-ligamentous knee injury, only two studies evaluated outcomes of posterior meniscal root tears [46, 47]. Both studies were isolated to medial posterior root tears. All patients underwent transtibial suture pullout repair. At a mean of 41.1 and 26.7 months follow-up, 100% had either MRI or second-look arthroscopy evidence of complete healing [46, 47]. However, in an older population with isolated meniscal root repair, Moon et al. [60] and Jung et al. [105] reported 9.7 and 50% failed repair after 30 months and either increased rates of meniscal extrusion or no improvement, respectively. There is insufficient data to determine rates of healing in a young population. The data regarding rates of healing in an older population is concerning; however, clinically, patients significantly improve from their preoperative state.

Animal studies have reported healing of meniscal allografts with host cellular repopulation in peripheral meniscal tissue. Fibrovascular scar tissue has been shown in a dog model to be the mechanism of healing to the capsular tissues for cryopreserved menisci [106]. A normal cellular distribution was found, but the allograft cells had a decrease in the number of metabolically active cells. Fresh and cryopreserved menisci showed peripheral healing and revascularization in a goat model, but biochemical changes were noted in the extracellular matrix at six months after transplantation [107].

During healing, a transplanted meniscus is revascularized and repopulated with host cells. DNA probe analysis in a goat model revealed that cells from the meniscus did not survive transplantation, and host cellular DNA was identified completely by 4 weeks [108]. DNA analysis of meniscal allograft tissue retrieved one year after transplantation confirmed host repopulation in a patient [67]. Cells derived from the synovial membrane with characteristics similar to synovial cells and fibroblasts repopulate the meniscus in meniscal allograft biopsies 16 months after implantation [109]. The authors in this study also noted cells indicative of an immune response directed at the meniscal allograft, but it did not affect the clinical outcome.

30.16 Clinical Outcomes

Of the two studies above regarding meniscal root repair and multi-ligamentous knee reconstruction, only 16 patients have recorded Lysholm and IKDC scores. Kim et al. [46] reported at a mean of 41.1 months, Lysholm scores improved from 73.7 preoperatively to 92.5, and IKDC improved from 49.3 preoperatively to 91.8. Ra et al. [47] reported very similar outcome scores. Lysholm improved from 74.6 to 93, and IKDC improved from 47.6 to 91.6. The authors also reported that 6 of 7 patients in their cohort were considered “elite athletes” [47]. However, there is no mention of return to sporting activity.

The clinical evidence for the success of meniscal allograft transplantation is derived from case series. Comparisons between studies are difficult due to a lack of uniformity on surgical technique, sterilization and preservation methods, outcome measures reported, and patient selection. Furthermore, important characteristics that may affect outcome are not uniformly described including method of size matching, concomitant chondral and ligamentous injury, and limb alignment. With these limitations of clinical outcome comparisons after meniscal transplantation noted, a recent systematic review reported patient satisfaction ranges from 62.5 to 100% and early failure rates range from 7 to 35% [25, 110–112]. The early failure rate averaged 10% when excluding older patients with preexisting osteoarthritis [25].

Milachowski [3] first reported meniscal allograft transplantation in 1989 and reported an 86% success rate with 22 meniscal allografts at 14 months after surgery. Noyes et al. [61] reported on 96 fresh-frozen, gamma-irradiated meniscal allografts and noted a 58% failure rate which has been largely attributed to the gamma irradiation. Recent series with improved sterilization and preservation methods have shown improved outcomes. A prospective case series of 40 meniscal allografts with anterior and posterior bone plug fixation had an 86% success rate and IKDC scores in the normal or near normal range at 2 years [111]. Cryopreservation was the most common type of graft preparation. Another case series of 40 patients treated with frozen, non-irradiated meniscal allografts implanted with a bone plug technique, IKDC and Modified Cincinnati scores improved significantly after surgery with reductions in pain, decreased effusions, and improved function [113].

30.17 Long-Term Follow-Up—MAT

While early results of allograft transplantation have been successful with objective and patient-reported outcome measures, long-term results remain the most important. Van der Wal evaluated 63 cryopreserved meniscal allografts with soft tissue fixation alone at 13.8 years after surgery [92]. A 29% failure rate and deterioration in patient outcomes over time was noted. Lysholm scores of 79 at 3 years after surgery significantly declined to 61 at final follow-up. There was no difference in Lysholm scores between allograft survivors and those that failed requiring a knee arthroplasty [92]. Wirth et al. [93] reported a decline in Lysholm scores from 84 at 3 years to 75 at 14 years follow-up. A 55% failure rate at 11.8 years in a recent case series of 22 cryopreserved meniscal allografts was noted. The authors noted improvements in pain and function with only fair results at longer term follow-up [114]. In contrast to this, a series of 50 cryopreserved meniscal allografts implanted with soft tissue only fixation had a 10% failure rate [115].

30.18 Medial Versus Lateral—MAT

Outcomes of medial versus lateral meniscal allograft transplantation have been different in several series [104, 114, 116, 117]. In one study, lateral meniscal allografts had a 76.5% survival rate at 10 years while medial allografts had a 50.6% survival rate at 9 years [117]. In contrast, another series had a 25% medial allograft failure rate compared to a 50% lateral failure rate at 11.8 years after surgery [114]. Several authors found no significant differences in outcomes between medial and lateral meniscal allografts [90, 118, 119]. The disparity in outcomes may potentially be attributed to differences in ligamentous stability or mechanical alignment. A recent systematic review of meniscal allograft transplantation found no difference in outcomes between medial and lateral allograft transplants [25].

30.19 Preexisting Osteoarthritis—MAT

Preexisting knee osteoarthritis portends a worse prognosis after meniscal allograft transplantation. An 80% failure rate was noted in knees with advanced arthrosis compared to 6% in patients with normal articular cartilage or mild arthrosis in an early study of meniscal allograft transplantation [25, 120]. Improved postoperative Lysholm and Tegner scores in patients with Outerbridge scores of less than 2 have been noted, while patients with Outerbridge scores greater than 3 in any area did not improve with surgery [90]. Evaluation of 29 meniscal allografts using magnetic resonance imaging revealed allograft degeneration was associated with moderate and severe chondral wear and the authors recommended preoperative assessment to identify patients at risk for failure [121].

Defining the optimal time to offer meniscal allograft transplantation remains difficult. Total meniscectomy results in long-term degradation of articular cartilage [1]. While only limited data is available to support meniscal allograft transplantation to prevent or slow progression of osteoarthritis, it is currently the only surgical option for young patients with a symptomatic meniscus deficient knee. Prophylactic meniscal allografts before the onset of symptoms in an attempt to prevent degenerative changes have been reported [122]. Without clinical studies proving chondroprotective benefits, meniscal allografts are not currently recommended for asymptomatic meniscus deficient patients. Waiting for a patient to develop cartilage degeneration and symptoms may reduce graft survival and symptomatic relief. Given this difficult clinical situation, we recommend yearly follow-up for young patients with meniscus deficient knees with weight-bearing radiographs to monitor progression of symptoms and joint space narrowing. Future surrogate markers of cartilage degradation (i.e., imaging or biomarkers) may enable earlier detection to help define the appropriate indications for meniscal allograft transplantation. Little evidence exists supporting the routine use of MRI or bone scanning in such patients and the cost over time obtaining such studies may be prohibitive.

30.20 Extrusion—MAT

Meniscal allograft extrusion is reported in 40–100% of patients after transplantation [103, 104, 123]. While some studies have shown inferior clinical outcomes associated with meniscal extrusion, other studies have failed to show meniscal extrusion to be associated with clinical outcomes [121]. Lee [41] evaluated 43 patients treated with a variety of fixation techniques and found that 40% of grafts extruded an average of 3 mm at one year after surgery, but the extrusion did not progress at the five-year evaluation. The presence of graft extrusion did not correlate with joint space narrowing or clinical outcomes at 5 years [41].

Ha et al. [103] evaluated 36 patients 31 months after meniscal allograft transplantation and noted average meniscal extrusion to be 3.9 mm. No correlation with clinical, radiologic, or arthroscopic outcomes and meniscal extrusion were found. Gonzalez et al. noted all 33 patients in a case series of meniscal allografts had meniscal extrusion that averaged 36.3% of the width of the meniscus [123].

30.21 Allograft Tear Rate—MAT

The symptomatic tear rate after meniscal allograft transplant ranges from 10 to 36% and is the most common reason for revision surgery after transplantation [25, 65, 113, 114, 123, 124]. Magnetic resonance imaging of meniscal allografts correlates with arthroscopic findings regarding capsular incorporation and allograft tears [121]. Meniscal allograft tears are treated with partial meniscectomy, revision repair of capsular attachments, or resection in large tears not amenable to repair. There is no literature to guide treatment for allograft tears and the decision to repair or resect is individualized and based on tear pattern, size, and quality of the remaining allograft tissue.

30.22 Outcomes Related to Graft Morphology—MAT

Sizing characteristics that are most important to clinical outcome and the tolerance of the anatomy to accept deviations from those measurements have not been defined. Cadaveric studies have demonstrated that tibiofemoral contact pressures after meniscal allograft transplant are returned most closely to the native state with appropriately size-matched graft tissue [77]. Meniscal grafts larger than the native meniscus lead to increased forces across the articular cartilage, while smaller grafts result in increased forces across the menisci [73].

Pollard performed a cadaveric study that showed meniscal sizing could be accomplished with standard anteroposterior and lateral radiographs [74]. On anteroposterior films, medial and lateral width could be estimated from the peak of the tibial eminence to the periphery of the tibial metaphysis. Medial and lateral meniscal length was reported to be 80% and 70% of the tibial plateau on the lateral radiograph, respectively. Shaffer compared radiographic and magnetic resonance imaging to actual meniscus dimensions finding that both modalities were more than 2 mm different than actual dimensions [71]. A recent report found that meniscal sizing based on height, weight, and gender may be more accurate than radiographic measurements [125]. Further research is needed to accurately define the sizing parameters that correlate with outcome and the best methods to match those to the recipient anatomy.

30.23 Fixation Method—MAT

Numerous techniques have been described for medial and lateral meniscal allograft transplantation, but studies have drawn a distinction between techniques that employ bony versus soft tissue fixation of the meniscal horns. Successful function of the meniscus demands stable fixation of the meniscal horns. Biomechanically, loss of horn fixation has been shown to be equivalent to a total meniscectomy [95]. Cadaveric studies have shown that stable fixation of the anterior and posterior horns are necessary for the restoration of the load-sharing properties of the meniscus [77, 78]. While no clinical study has directly compared different methods of fixation, biomechanical studies have shown tibiofemoral contact mechanics to be superior with use of bone plug fixation of the meniscal horns [76, 98]. Despite these models, clinical series have shown successful results with soft tissue only fixation of the meniscal horns [123, 126]. The authors of the series note the potential for an unexplained in vivo remodeling unaccounted for in cadaveric studies, the immunogenicity of transplanted bone, and technical ease as rationale for soft tissue fixation of the meniscal horns.

30.24 Meniscal Allograft with Ligament Reconstruction

While case series and case-controlled trials are available to evaluate outcomes associated with single ligament reconstruction with meniscal allograft, only individual case reports are available describing multi-ligamentous knee reconstruction with a meniscal allograft transplant [72, 82].

Wirth et al. reported the first series of anterior cruciate ligament reconstructions with concomitant meniscal allograft transplantation and noted Lysholm knee scores of 75 at 14 year follow-up [93]. Sekiya et al. reported 86% normal or near normal IKDC scores 3 years after anterior cruciate ligament reconstruction with meniscal allograft transplantation [127]. Small case series with mean long-term follow-up of 10 and 20 years have corroborated the short-term good results with meniscal allograft and concomitant ACL reconstruction [116, 128]. A case-controlled trial of 16 ACL reconstructions with meniscal pathology matched medial meniscus transplantations with meniscal repair or partial meniscectomy [129]. At 5 years follow-up, the groups had similar IKDC and Lysholm scores with only the meniscal allograft group having more swelling. A recent systematic review revealed no difference in outcomes between isolated meniscal allograft transplantation and those with concomitant procedures [25].

30.25 Meniscal Allograft with Osteotomy

The long-term survival of meniscal transplantation requires appropriate mechanical alignment. Prior reports have documented the importance of normal joint alignment in patient outcomes and survivability of meniscal allografts [57, 126]. A high tibial or distal femoral osteotomy is useful to unload a damaged compartment and to protect the transplanted allograft. In contrast to osteotomy for osteoarthritis, mechanical alignment is adjusted to align with the opposite tibial spine of the transplanted meniscus [130]. A case series of meniscal allograft transplants with concomitant procedures revealed a survival rate to be longer when performed with a high tibial osteotomy [126]. Mean survival time in combination with osteotomy was 13 years, and the 10-year survival rate was 83%. Cameron and Saha [65] reported on 34 knees that received a tibial or femoral realignment osteotomy and a meniscal allograft with 85% attaining good to excellent results at a mean follow-up of 31 months. A realignment osteotomy can be performed concomitantly or as a staged procedure to restore neutral mechanical alignment, offload damaged articular cartilage, and protect a transplanted allograft.

30.26 Conclusion

Both meniscal root repair and meniscal allograft transplantation are challenging procedures that improve patient satisfaction after severe combined ligamentous and meniscal injury to the knee. Combined meniscal root or MAT and multi-ligamentous knee reconstruction is uncommon in the literature, and limited clinical evidence exists in the regarding outcomes for these combined procedures.

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31 Management of Extensor Mechanism Disruption and Patellofemoral Instability in the Multiple Ligament Injured Knee

Jonathan M. Cooper and Christopher A. DeFalco

31.1 Background

Extensor mechanism disruptions of the knee are defined as an injury to the quadriceps tendon, patellar tendon, patellar retinaculum, or patellar fracture resulting in loss of continuity of the mechanism. These injuries in isolation are fairly uncommon with patellar fractures being the most common with an incidence of 0.5% followed by quadriceps tendon ruptures and patellar tendon ruptures, respectively [1, 2]. The location of the disruption is often age dependent with 80% of patellar tendon disruptions in patients under age 40 and 80% of quadriceps tendon disruptions in patients over age 40 [3].

The majority of extensor mechanism disruptions are due to low energy injuries in a patient with underlying tendinopathy [4]. Zernicke et al. [5] reported that in a healthy tendon, the force required to cause a rupture is 17.5 times the body weight. Histological changes within ruptured tendons also support this theory with 97% of 981 ruptured tendons studied, including 53 patellar tendons, showing degenerative changes on histology [6, 7]. It is also important to recognize that the underlying tendinopathy contributing to a tendon rupture may be due to systemic factors (e.g., renal failure, systemic lupus erythematous, rheumatoid arthritis, diabetes mellitus, and anabolic steroids) [8–10].

Extensor mechanism ruptures are the result of eccentric contraction of the quadriceps muscles with the knee fixed in a semi-flexed posture and the foot planted [11, 12]. With regards to the patellar tendon, ruptures tend to occur at the proximal insertion rather than mid-substance. The proximal and distal portions of the patellar tendon experience a higher strain during normal tensile loading along with decreased collagen fiber stiffness when compared to the mid-substance. These findings lead to the proposed mechanism and location of failure for the patellar tendon [1].

Diagnosis of isolated extensor mechanism ruptures can be difficult and is frequently missed. A retrospective analysis by Siwek and Rao showed that 38% of 72 extensor mechanism ruptures (36 patellar tendons and 36 quadriceps tendons) were initially misdiagnosed [3, 12]. While the literature of a concomitant injury to the extensor mechanism in the setting of a multiligament knee injury is quite sparse, it is essential to maintain a high index of suspicion. In a retrospective review, Wissman et al. found a 36% (5/14 patients) incidence of patellar tendon rupture in his small patient cohort of 14 knee dislocations [13]. Distracting injuries can make diagnosis of an associated extensor mechanism rupture difficult. It has been reported that the diagnosis may be missed between 10 and 50% of the time with a delay in diagnosis stretching from days to months [3, 14].

31.2 Anatomy

The extensor mechanism is composed of the quadriceps tendon, the patella, patellar tendon, and patellar retinaculum. The quadriceps tendon is the coalescence of the rectus femoris, vastus medialis, vastus intermedius, and vastus lateralis muscles. The quadriceps acts as a dynamic stabilizer to the patella. The femoral nerve provides innervation to each of the quadriceps muscles.

The musculotendinous junction of the quadriceps tendon forms approximately 3–5 cm proximal to its insertion on the superior pole of the patella, enveloping the patella on superior, medial, and lateral sides as it traverses distally. On average, the quadriceps tendon is 8 mm thick and 35 mm wide [8]. The tendon itself has abundant vascularity and receives its blood supply from several sources: descending geniculate artery, medial and lateral superior geniculate arteries, and branches of the lateral circumflex femoral artery

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[15–17]. Although the tendon itself is quite vascular, there is an ovoid area approximately 1.5 × 3 cm in the deep portion of the tendon that is avascular [18].

The continuation of the quadriceps tendon beyond the distal pole of the patella is called the patellar tendon. This tendon has a width of approximately 30 mm, although it often broadens distally as it inserts on the tibial tubercle, with an average thickness throughout its length of 4–7 mm [19]. The blood supply to the patellar tendon is not as robust as the quadriceps tendon. The major vascular contributions to the patellar tendon consist of the following: antero-proximally it is supplied by the inferior lateral geniculate artery, antero-distally by anastomoses between the inferior medial geniculate and anterior tibial recurrent artery, and posteriorly by vessels from the infrapatellar fat pad [20]. It can also be noted that the proximal and distal aspects of the tendon are relatively avascular when compared to mid-substance.

Histologically speaking, the majority of the wet weight of the patellar tendon comes from water (60–70%), while collagen contributes 70–80% of the dry weight. Type I collagen is predominant at 90%, with Type III collagen providing 10% [21].

The patella is a sesamoid bone within the extensor mechanism. The quadriceps and patellar tendons stabilize the patella proximally and distally. The medial and lateral aspects of the trochlea of the femur provide bony restraint medially and laterally. More recently, further soft tissue restraints of the patella have been studied. The medial patellofemoral ligament (MPFL) is the primary soft tissue restraint medially, providing 50–60% of the total force against lateral patellar movement [22, 23]. The patellotibial and patellomeniscal ligaments play a secondary role in stabilizing the patella. The MPFL is an extra-articular ligament, lying between the medial retinaculum superficially and the joint capsule deep. It is 4.5–6.4 cm long and 1.2–1.9 cm wide with a total tensile force of 208 N [24]. Of note, the vastus medialis obliquus inserts onto the anterior third of the MPFL and exerts a force that adds to the medial stability of the patella [25]. The origin of the MPFL is situated in an area on the medial femur between the medial femoral epicondyle and the adductor tubercle [26]. It then traverses anteriorly and laterally, inserting on the proximal two-thirds of the medial patellar border.

31.3 Diagnosis

The diagnosis of an extensor mechanism rupture can be difficult. Siwek et al. showed a 38% misdiagnosis rate in isolated extensor mechanism ruptures and Li reported the diagnosis is not always obvious [3, 14]. Quadriceps and patellar tendon ruptures may have an associated palpable defect in the affected tendon. However, in the setting of a multiligament knee injury, diagnosis can be more difficult on clinical exam alone. Often there is an associated large hemarthrosis and significant soft tissue swelling which can preclude palpation of a defect in the quadriceps or patellar tendons [27].

As with all musculoskeletal injuries, a full history and physical exam is imperative. Patients will often report a “pop” and an inability to extend the knee. However, with trauma, the patient may not be coherent at the time of injury or there may be an associated injury that could cause a similar sensation. Inspection may demonstrate a knee deformity with the possibility of a patella dislocation or an actual knee dislocation. The position of the patella in relation to the normal knee should be assessed along with any variation in tilt or tracking compared to the normal knee. An extensor lag can be indicative of an extensor mechanism rupture though a straight leg raise in general can be challenging for many patients in the acute setting. One must recognize that a patient may still be able to maintain extension against gravity with an intact retinaculum, however, they will be unable to actively extend the knee [27, 28].

When an acute knee injury with a large effusion is encountered, imaging modalities are vital to make a correct

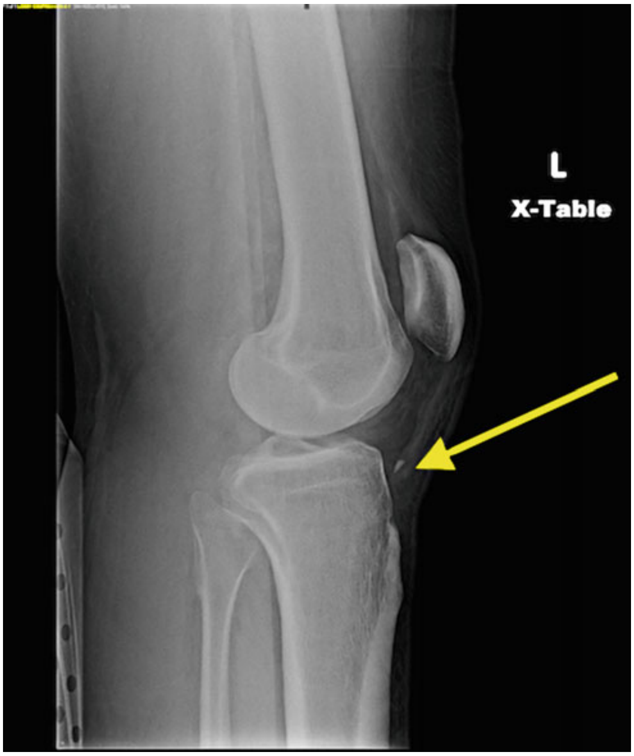

Fig. 31.1 Lateral radiograph demonstrating patella alta secondary to a patellar tendon avulsion off the tibial tubercle in a multiple ligament injured knee. Note the *yellow arrow* marking the small avulsion fragment off the tibial tubercle

diagnosis. Extensor mechanism disruptions can be identified on MRI scans that are often obtained as part of the diagnostic workup. The MRI remains the gold standard for diagnosis of partial or complete quadriceps and patellar tendon ruptures. These injuries can also be inferred based on a lateral X-ray of the knee showing patella alta or baja, although partial ruptures may not demonstrate changes in patellar height (Fig. 31.1). Thus, it is through a combination of a thorough history and physical exam, as well as imaging modalities, that an accurate diagnosis of an extensor mechanism disruption in the setting of a multiligament knee injury can be made.

31.4 Imaging

In the setting of a patient with knee pain, inability to bear weight, and especially with an acute injury and/or inability to extend the knee, anteroposterior and lateral knee radiographs should be obtained. Findings on these images concerning for an extensor mechanism disruption include patella baja (quadriceps rupture) or alta (patellar rupture) (Fig. 31.1). Patella baja or alta can be identified based on either the Insall-Salvati (I-S) or Blackburne-Peel (B-P) ratios measured on a lateral X-ray. The I-S method is the ratio of the patellar tendon length divided by the patella length. The B-P method is the ratio of the length from the inferior aspect of the patellar articular surface to a horizontal line at the level of the tibial plateau divided by the length of the patellar articular surface. The B-P ratio does have lower interobserver variability and is less variable based on knee flexion angle [29]. The I-S ratio is considered normal from 0.8 to 1.2 with more recent literature reporting a broader normal range from 0.74 to 1.5 [30]. The B-P ratio is considered normal with a ratio of 0.8 [31]. Therefore, patella alta is seen with an I-S > 1.2 (possibly 1.5) and Blackburne-Peel > 0.8, indicating a patellar tendon rupture, while patella baja is diagnosed with an I-S < 0.8 (possibly < 0.74) and Blackburne-Peel < 0.8, representative of a quadriceps tendon rupture.

High-resolution ultrasound is an effective imaging modality to identify both patellar and quadriceps tendon ruptures in both the acute and chronic settings. A hypoechoic or anechoic area within the normal linear echoic tendon is diagnostic of a tear [32]. In a recent retrospective review by Foley, the results of ultrasound were compared to surgically confirmed high-grade partial or complete quadriceps ruptures. In the 23 surgical cases, the ultrasound positively diagnosed a rupture in all of them (100% sensitivity). Sixteen normal quadriceps tendons were also reviewed and all were found to be normal by ultrasound (100% specificity) [33]. It is important to note that this study was performed by two musculoskeletal fellowship-trained radiologists with 8 and 15 years of musculoskeletal sonographic experience. Thus, while ultrasonography is a viable diagnostic tool, it is operator dependent and thus significant variability in the sensitivity and specificity of the test exist [1, 27].

Although an MRI is the most sensitive imaging modality for patellar or quadriceps tendon ruptures as well as MPFL tearing, it is often not imperative in an isolated injury. A study by McKinney in 2008 reported only a 9.6% rate of associated intraarticular injuries in patients with a quadriceps tendon rupture [34]. Due to the low incidence of associated pathology found on MRI and the additional cost when compared to radiographs and ultrasound, when there is suspicion of an isolated extensor mechanism rupture, MRI should only be used if other diagnostic imaging modalities are inconclusive or there is concern of concomitant injuries. However, in the multiligament knee injury, an MRI is routinely obtained to evaluate all potentially injured structures as well as help define the nature of the injury. An MRI can also be helpful in identifying the location and degree of medial soft tissue injury in the setting of patellofemoral instability. In detecting injuries to the MPFL, the MRI has a sensitivity of 85% and specificity of 70% [35].

31.5 Treatment

Managing the multiple ligament injured knee in conjunction with an ipsilateral injury to the extensor mechanism requires full recognition of the extent of the injury in order to establish an appropriate and timely treatment plan. Given the natural history of an unrepaired rupture of the extensor mechanism resulting in significant disability ambulating with activities of daily living, operative fixation is indicated for a complete rupture of the extensor mechanism [3]. Many studies have demonstrated favorable outcomes with surgical repair of the extensor mechanism within the first few days as opposed to delayed treatment. Delay in diagnosis results in contraction of the quadriceps tendon and adhesion formation surrounding the injured tissue. This can result in challenges mobilizing the proximal and distal extent of the extensor mechanism injury. Though there are few contraindications to repair of the extensor mechanism, medical comorbidities and the soft tissue envelope surrounding the knee must be optimized before proceeding with operative repair. Medical conditions such as recent myocardial infarction or stroke, heart failure, renal failure, or other conditions that predispose the patient to an unusually high perioperative risk of complication are a few examples of comorbidities which must be coordinated with the appropriate medical services. Local factors such as contaminated wounds, poor soft tissue quality, or inadequate soft tissue coverage should be addressed while planning operative repair to minimize the risk of infection or wound complications. Once medical comorbidities and the soft tissue envelope surrounding the knee have been optimized, timely surgical repair of the extensor mechanism is recommended. While acceptable results after delayed treatment have been reported in some studies, such a delay often involves a more challenging surgical repair, or a more complex reconstructive technique using allograft may be necessary.

Instability of the patellofemoral joint in the multiple ligament injured knee is most often related to the significant traumatic injury to the retinaculum and does not routinely require extensive assessment of predisposing risk factors for patellofemoral instability related to bone morphology, alignment, or biomechanics. As in isolated patella instability, it is primarily lateral instability of the patella, which is most commonly seen in the setting of the multiple ligament knee injury. One must keep a discerning eye for assessment of a patella dislocation and the possibility of a more severe knee injury. Not only do patients confuse a patella dislocation with a knee dislocation, but also trained healthcare providers can be deceived when assessing patellofemoral instability and/or tibiofemoral instability. Mechanism of traumatic injury with visible deformity as well as spontaneous reduction can be present with both injuries. However, the significant risk of neurovascular injury with a knee dislocation demands the ability of the provider to accurately assess and diagnose the injury. When simultaneous patellofemoral and knee instability occur, it is most often with severe femoral-based injuries to the medial collateral ligament. As with isolated patellofemoral instability, a history of any patellofemoral instability should be obtained from the patient to take into account for treatment planning. A first-time traumatic patella dislocation with normal anatomy often warrants beginning with conservative treatment. In the presence of a multiligament knee injury, patella instability may not significantly alter the treatment plan unless a significant structural injury is identified that could inhibit maintaining a stable patellofemoral joint in the future. The surgeon must also consider how associated chondral and osteochondral injuries of the patellofemoral articulation may affect surgical planning and timing [36].

Attention to preoperative planning and possible staging of these injuries is vital along with balancing operative room time and resources, surgeon schedule, and a patient's social/support structure. Detailed preoperative planning is paramount given the possible number of skin incisions and bone tunnels/sockets required to safely access all injured structures in the multiple ligament injured knee with an extensor mechanism disruption or patellofemoral instability.

31.6 Surgical Decision Making

In general, an isolated patellar or quadriceps tendon rupture involves straightforward surgical decision making with primary surgical repair in a timely manner. In contrast, the involvement of a concomitant ipsilateral multiple ligament knee injury complicates the surgical decision-making. The decision to stage the extensor mechanism and the ligament reconstruction or perform the entire knee operation under a single anesthetic involves evaluating the many variables defining the unique character of each injury (Fig. 31.2). The injury character and associated articular cartilage or meniscus pathology can often dictate emergent, early, or delayed timing for surgical intervention. The surgeon also needs to assess the relative stability of the joint as an inability to maintain knee joint congruency could require temporary spanning external fixator placement to maintain joint congruency prior to definitive management.

The patella needs to be assessed in the setting of a multiple ligament injured knee to determine its involvement if any for appropriate decisions to be made. Accurate assessment for disruption of the extensor mechanism proximal or distal to the patella needs to be recognized along with medial or lateral instability of the patella. It is common for the

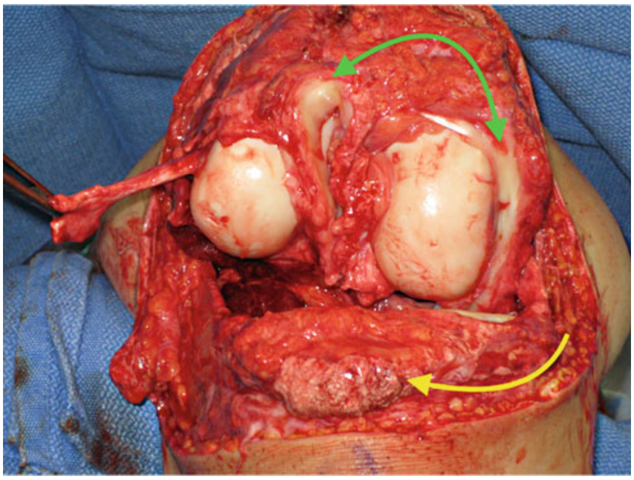

Fig. 31.2 Intraoperative photograph of an open dislocation of a right knee. Many findings define the unique character of this injury including the forceps holding the fibular collateral ligament avulsion off of the fibular head, complete rupture of both cruciate ligaments and the displacement of both intact menisci (*green arrow*). It is however the extensive anterior soft tissue injury with disruption of the entire anterior capsule and the mid-substance patellar tendon rupture (*yellow arrow*) which characterizes this injury

peri-patellar structures to suffer some degree of injury in conjunction with a multiple ligament knee injury. Identification of an injury on MRI is not sufficient to necessitate surgical intervention. The surgeon must carefully assess the overall involvement of the extensor mechanism in order to render the appropriate surgical and nonsurgical treatments.

Each multiple ligament injured knee is going to present a group of challenges and concerns which require attention during treatment decision-making, preoperative planning, and intraoperative decision-making. For example, a patient may present with a compromised extensor mechanism in conjunction with a three-ligament knee injury (Fig. 31.3). The comminuted fracture fragments raise concern for the integrity of the patellar tendon attachment to the inferior pole of the patella. This extensor mechanism injury should heal without surgical treatment as long as further injury is not caused such as with aggressive manipulation in a stiff knee or extreme hyperflexion during examination or surgery. In summary, approach each multiple ligament injured knee with a treatment plan catered to the unique character of the injury.

31.7 Extensor Mechanism Surgical Techniques

The patient is placed supine on a standard operating room table with fluoroscopy access from the opposite side of the table to assess appropriate patellar height compared to the contralateral knee as well as assist in ligament reconstruction in a concomitant procedure. A well-padded tourniquet is placed on the upper thigh and inflated based on surgeon preference. Our preference is to keep the foot of the table up for all knee reconstruction procedures using a lateral stress post and foot/knee positioner instead of using a leg holder. A bump is placed under the operative hip to assist in balance of the extremity. This is surgeon preference allowing circumferential access to the knee. All bony prominences are well padded and all extremities well supported as these procedures can last a significant period of time, placing the patient at risk for iatrogenic injuries. This is the position we use for the majority of our multiligament knee reconstruction procedures.

31.7.1 Patella Based Repair Techniques

Repair of the patellar tendon to the inferior pole of the patella or quadriceps tendon to the superior pole is performed through a centered longitudinal skin incision taking into account the soft tissues and additional procedures which may be required. Full-thickness skin flaps are developed medially and laterally to expose the tendon injury along with the medial and lateral retinaculum as this is likely torn and will require repair. The tendon rupture should be mobilized from adhesions and debrided of fibrous tissue to isolate healthy tissue for repair. The superior or inferior pole of the patella should be debrided to a boney bed to maximize bone to tendon contact for the repair.

Our preferred technique involves the use of two #2 or #5 nonabsorbable braided sutures sewn in a locking Krackow

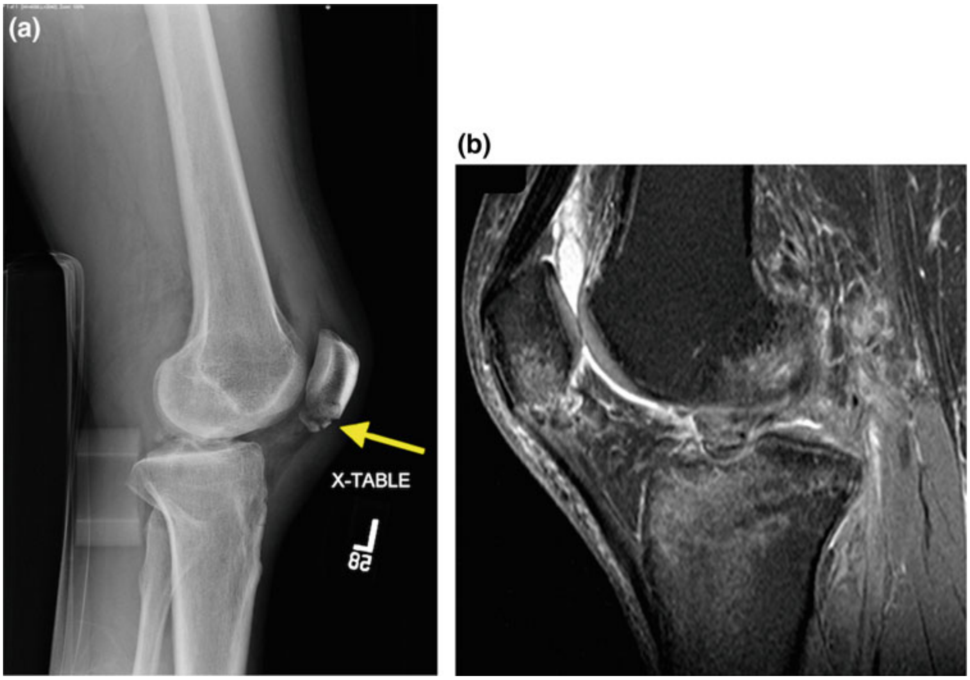

Fig. 31.3 **a** Lateral knee radiograph demonstrating a comminuted fracture at the inferior pole of the patella (*yellow arrow*). **b** Sagittal MRI image showing the patellar tendon to be intact though the extensor mechanism compromised secondary to the fracture

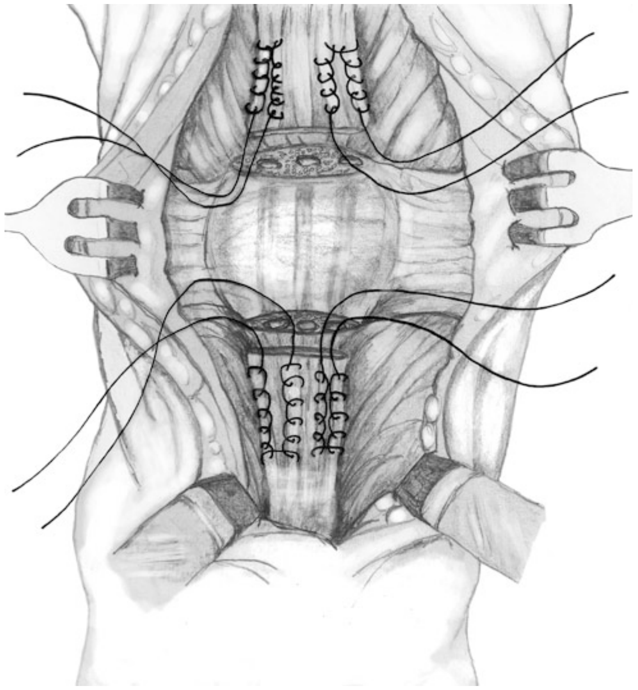

Fig. 31.4 Rupture of the quadriceps tendon off the superior pole of the patella or the patellar tendon off the inferior pole of the patella are repaired with nonabsorbable suture sewn in a Krackow fashion and passed through 2.0–2.5 mm bone tunnels. The sutures are then tied over a bone bridge at the opposite end of the patella from the injury

fashion to obtain strong suture purchase with the collagen fibers of the injured tendon (Fig. 31.4). A 2.0–2.5 mm drill bit is then used to drill three parallel longitudinal tunnels across the patella. A Hewson suture passer is used to shuttle the sutures through the patella and then tied directly over the bone bridges on the opposite end of the patella from the tendon injury. The repair can often be oversewn with #2 nonabsorbable suture to the strong tissue overlying the patella. The medial and lateral retinaculum is then repaired with #1 absorbable suture. At the conclusion of the extensor mechanism repair, it is helpful to determine the safe arc of motion to minimize tension on the repair during early rehabilitation range of motion exercises.

31.7.2 Tibial Tubercle Based Repair Technique

A patellar tendon avulsion off the tibial tubercle can be more challenging to manage, as the tissue can be tenuous (Fig. 31.5). This is again performed through a centered longitudinal skin incision taking into account the soft tissues and additional procedures which may be required. The medial and lateral dissection is often less extensive than patella based injuries. The capsular injury often involves an avulsion from the anterior tibia rather than the medial and lateral retinacular tears seen with patella based injuries. The tendon is again mobilized from adhesions and debrided of fibrous tissue to isolate healthy tissue for repair. The tibial tubercle is prepared with a rongeur, rasp, curette, etc., to create a healing bed of bleeding bone. Given the superficial nature of the tibial tubercle, our preference is to perform a low-profile repair with limited knots or even knotless fixation. A nonabsorbable #2 suture is sewn in a locking Krackow fashion from the free end of the tendon along the medial and lateral borders of the patella tendon. Two suture anchors are placed at the proximal attachment of the tendon on the tibial tubercle (Fig. 31.6a). Our preference is to have the anchors preloaded with nonabsorbable tape suture. The sutures from the proximal anchors are then passed through the proximal aspect of the avulsed tendon attachment and tied depending on surgeon preference. These sutures are then placed in a crisscrossed fashion and secured with two knotless anchors at the distal tibial tubercle insertion along with the #2 Krackow suture creating a low-profile repair with a broad footprint (Fig. 31.6b).

Fig. 31.5 Sagittal MRI image showing the patellar tendon avulsed from the tibial tubercle (*yellow arrow*)

31.7.3 Patellofemoral Instability Surgical Technique

Patellofemoral instability in the setting of a multiligament knee injury primarily focuses on repair of the retinaculum and joint capsule. When the injury is a focal avulsion off of the femur (Fig. 31.7), repair is performed using suture anchors in the medial femoral condyle between the medial femoral epicondyle and the adductor tubercle at the

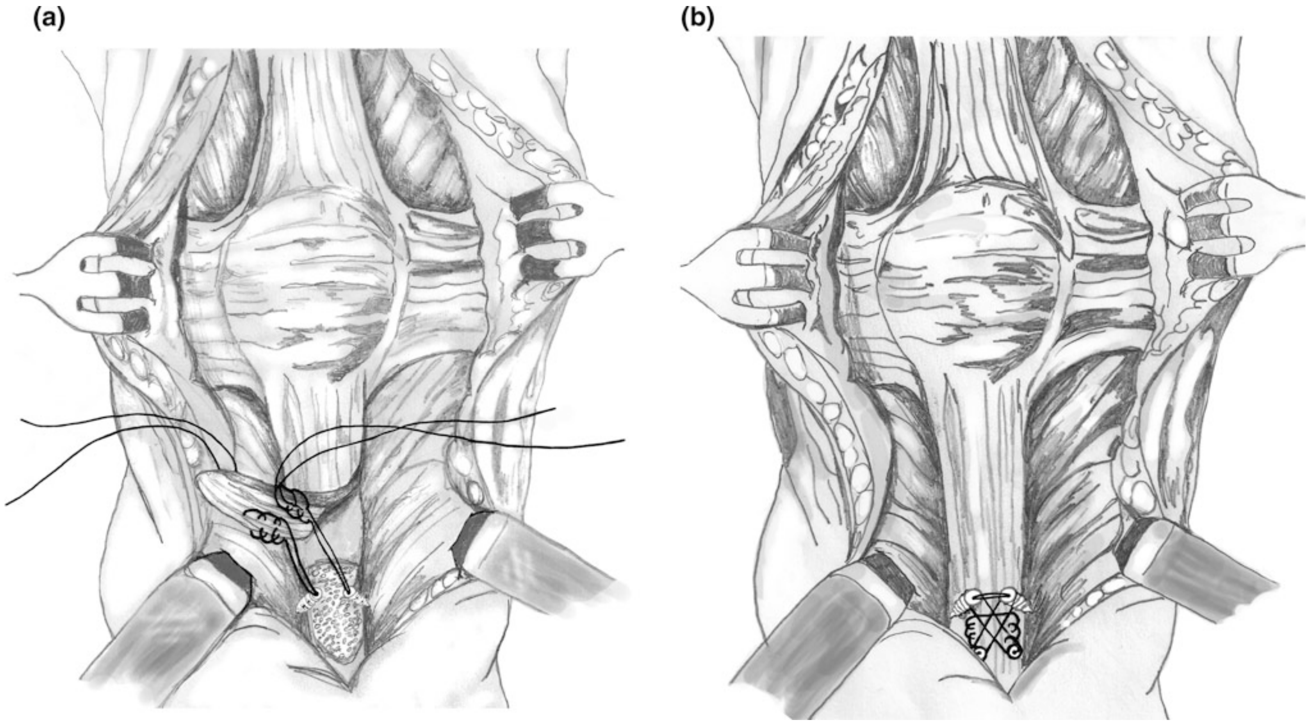

Fig. 31.6 **a** Patellar tendon avulsed from the tibial tubercle. Nonabsorbable #2 suture is sewn in a locking Krackow fashion along the medial and lateral borders of the patellar tendon. Suture anchors are placed at the proximal aspect of the prepared healing bed of bleeding bone. The sutures from the anchors are passed through the patellar tendon at the desired proximal site of attachment. **b** The proximal sutures along with the Krackow sutures are brought to two knotless anchors at the distal aspect of the repair to the tibial tubercle

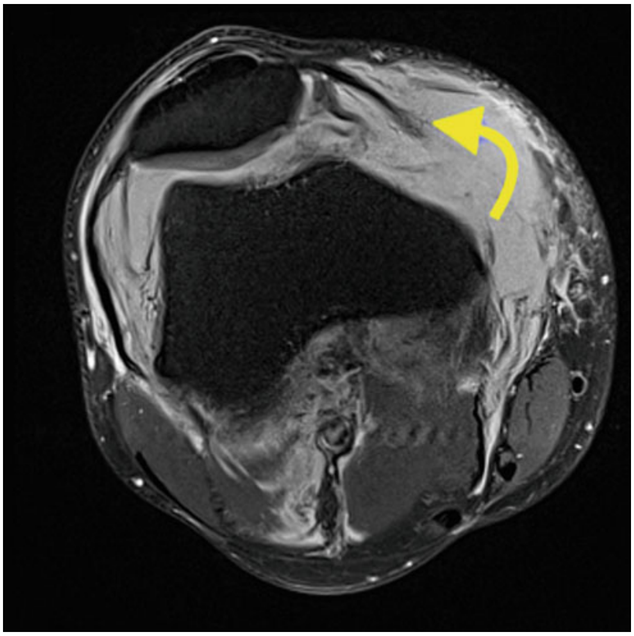

Fig. 31.7 Axial MRI image demonstrating avulsion of the MPFL off the medial femoral condyle (*yellow arrow*)

attachment of the MPFL. If the capsule is torn mid-substance or stretched, a side-to-side repair or retinacular/capsular imbrication is performed using nonabsorbable suture. In the setting of a multiple ligament knee injury, patellofemoral stability can typically be obtained in this manner to achieve future patella stability. If however the medial tissue is insufficient, a reconstruction of the MPFL may be indicated. In that case, our preference is to use a gracilis tendon allograft to reconstruct the MPFL with a double attachment to the patella and a single attachment between the medial femoral epicondyle and the adductor tubercle.

31.8 Postoperative Rehabilitation

In relation to the extensor mechanism and patellofemoral repairs, the patient is placed in a knee immobilizer or hinged knee brace locked in extension and allowed weight bearing as tolerated with crutches for 6 weeks. The brace can be unlocked for range of motion with physical therapy from 0° to 45° for the first 3 weeks and then working toward 0°–90° between 3 and 6 weeks. Early range of motion through a minimal tension arc of motion is important to minimize the risk of postoperative stiffness. During the postoperative rehabilitation, the multiple ligament injured knee often has many factors, which will dictate postoperative restrictions such as the ligaments involved as well as any articular cartilage and meniscus procedures performed.

31.9 Complications

The most common postoperative complication following extensor mechanism repair in a multiligament knee injury is stiffness along with quadriceps weakness. The stiffness can be quite severe with concern for arthrofibrosis. Closed manipulation under anesthesia may be considered if the patient is struggling to achieve adequate flexion by 12 weeks. This has been described as a finite number of 120° by 6–8 weeks for isolated extensor mechanism injuries [1]. Given the many variables with these complex injuries, it can be valuable to use a flexible definition for adequate flexion. A range between 90 and 120 degrees of flexion by 12 weeks can be a guide or one can consider a variation from the normal knee of greater than 20°–40°. It can also be helpful to differentiate slow continual progression with therapy and range of motion compared to a plateau when considering a manipulation under anesthesia. Quadriceps atrophy, up to 2–3 cm circumferentially, has been noted in past studies but does not seem to compromise final return to strength and function with adequate rehabilitation [3].

Optimizing the soft tissue envelope preoperatively and respecting it intraoperatively with careful incision planning for all required procedures can minimize the risk of wound complications and infection. Meticulous attention to suture and hardware placement in the subcutaneous area around the patella and tibial tubercle can help limit wound problems.

Patella baja and alta have been reported with extensor mechanism repair and may lead to subsequent patellofemoral degenerative arthrosis. Technical consideration of this potential complication during tensioning of the tendon repair is a must, and appropriate patellar height should be confirmed on lateral radiograph intraoperatively prior to final tensioning to avoid this complication [1, 4]. Sterile preparation and draping of both lower extremities is another way to use the normal limb as a template to reestablish appropriate patellar height intraoperatively.

31.10 Pearls

- Many variables define the unique character of each injury and affect the treatment. A single treatment algorithm cannot encompass the full spectrum of injuries to the extensor mechanism in the multiple ligament injured knee.
- Preoperative planning is paramount in the surgical management of these injuries. The plan must take into account a thorough history and physical exam, imaging studies, and examination under anesthesia and fluoroscopy in order to be complete.
- Patient positioning and access to the entire knee is critical if planning to surgically address the injury in its entirety under a single anesthetic.
- Surgical timing of the multiple ligament injured knee must prioritize associated injures including: vascular, soft tissue, extensor mechanism, meniscus, articular cartilage, fractures, and repairable structures.
- Patellofemoral joint instability can be present in conjunction with tibiofemoral instability. This injury needs to be recognized and taken into consideration during surgical decision-making though can often be treated conservatively.
- Do not get overly concerned with slow progression of these patients. These are severe injuries with many variables affecting their progress.

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32 Multiple Ligament Knee Injuries in the Professional Athlete

Joel L. Boyd and Scott Linger

32.1 Introduction

Knee injuries involving multiple ligaments, which may or may not include knee dislocation, are most often seen in high velocity trauma; however, there are subsets of patient that sustain these complex injuries with low-velocity (sports injuries) and ultra-low-velocity mechanisms (i.e., stepping off a curb) [1]. Up to 33% of all knee dislocations are sports-related injuries [2]. The ultra-low-velocity injuries are typically associated with older age and obesity. For the purpose of this chapter, we will focus on low-velocity multiple ligament knee injuries seen in athletes and the unique treatment and return to play decisions the surgeon must consider.

The complete workup and examination of a dislocated knee is described elsewhere in this text. The initial evaluation of an on-field knee injury includes a vascular exam. The low-velocity subset of patients who sustain a multiple ligament knee injury during sports most often spontaneously reduce immediately following the injury, but can still sustain a vascular injury [3]. A high level of suspicion should be maintained by the clinician to determine the need for further vascular studies of the lower extremity. If there is evidence that a frank dislocation occurred or if there is any asymmetry of lower extremity pulses, then further vascular workup should be obtained.

Previous studies have shown better outcomes with operative over non-operative treatment in multiple ligament knee injuries [4–7]. Specifically, surgical treatment has shown a higher percentage of excellent/good International Knee Documentation Committee (IKDC) scores as well as higher rates for return to work (72% vs. 52%) and return to full sport (29% vs. 10%) [8, 9].

Cruciate reconstruction as opposed to repair has been well accepted as cruciate repair results in unacceptable residual instability and decreased return to activity [8]. Reconstruction of the cruciate ligaments is well accepted, but when discussing the management of the collaterals there is more controversy. Shelbourne has shown excellent results with en masse acute repair of the lateral structures done in a single stage with anterior cruciate ligament (ACL) reconstruction and non-operative treatment of the posterior cruciate ligament (PCL). He has a high level of return to play with this algorithm—13/16 athletes [10]. However, there have been studies recommending lateral and posterolateral reconstruction even in the acute setting citing better functional outcomes and fewer failures (need for reoperation) [8].

Therefore, non-operative treatment is typically not considered for the general population let alone the professional athlete [9]. If an athlete is going to return to his or her career after a multiple ligament knee injury, then surgical reconstruction of the cruciate ligaments and reconstruction versus repair of the collateral structures can give the athlete his or her best chance to return to their sport.

The timing of surgical management has also been examined, with multiple studies showing improved patient outcomes with acute surgical management (within 3 weeks after injury). In a study by Karataglis et al., 46% of patients with chronic multiligament deficiency were able to participate in sports (the study does not mention level of sports competition) after surgery, and 91% returned to work [11]. Delayed surgery is typically reserved for high energy trauma requiring care for the soft tissue envelope and often involving the use of external fixation, not for athletes where these injuries are typically low velocity. Patients treated acutely have been shown to have higher subjective scores and better objective restoration of knee stability [8]. Early treatment resulted in higher mean Lysholm scores (90 vs. 82) and a higher percentage of excellent/good IKDC scores

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(47% vs. 31%), as well as higher sports activity scores (89 vs. 69) on the Knee Outcome Survey [8]. Some considerations when treating multiligament injuries acutely include the use of gravity for arthroscopy rather than a pump to avoid excessive fluid extravasation and possibly performing the surgery as an open procedure as there is likely still capsular disruption which can risk compartment syndrome and adversely affect visualization [4, 12]. In contrast, Mook et al. [13] argued that delayed reconstructions of severe multiligament knee injuries could potentially yield equivalent outcomes in terms of stability when compared to acute surgery; however, in the acutely managed patient, early mobility is associated with better outcomes. Jiang et al. [14] in their review of surgical timing for knee dislocations determined better outcomes with staged treatment for KD-III knee dislocations. In most cases for the professional athlete, the surgery will be done acutely as accelerated range of motion protocols has significantly diminished the risk of arthrofibrosis in the postoperative period.

32.2 Injury Patterns

While many patterns of multiligamentous knee injuries have been described including global laxity (KD-IV) and knee dislocations with intact PCL, combined ACL/medial collateral ligament (MCL) injury is the most common pattern seen in the athlete [15, 16]. The second most common pattern is likely ACL + PCL with posterolateral corner (PLC) involvement. The remaining injuries seen in athletes will be heterogeneous, but for the purpose of this chapter, we will focus on the two most common patterns of multiple ligament knee injury seen in the elite athlete:

1. ACL + MCL (up to 70%) [16]
2. Bicruciate + PLC (likely most common multiligament knee injury with major trauma as opposed to the athlete) [17, 18].

32.3 Isolated Ligament Injuries

The sports medicine orthopaedic surgeon is well versed in the diagnosis and treatment of isolated ACL injuries in various populations, but there are several considerations when treating athletes with other isolated ligament injuries of the knee.

Isolated MCL injuries are treated non-operatively in a majority of professional athletes; however, the return to play might be considerably different depending on not just the grade of injury but also on the sport played. For example, an American football player has a high chance of returning to play in 1–3 weeks following an MCL sprain regardless of the grade of injury, but a hockey player with the same injury may have a prolonged recovery (4–6 weeks) due to the valgus stress placed on the sprained ligament with each stride of the skate. It is imperative to understand the physiologic load placed on the athlete's knee during competition during his or her sport. Grading an MCL injury is based upon physical examination and/or MRI findings. Grade 1 injury is defined as valgus laxity of 3–5 mm or high intensity signal seen superficial to an intact ligament. Grade 2 MCL injury is valgus laxity 5–10 mm or high intensity signal seen medial to the ligament with high signal within the ligament or partial tearing. Grade 3 MCL injury is valgus laxity > 10 mm or complete disruption of the ligament on MRI. Isolated MCL injuries will rarely require surgical management except in cases of valgus laxity without firm endpoint in full extension (indicating a posteromedial capsular or posterior oblique ligament injury) or in cases where distal tibial avulsions fail to heal after a period of 4–6 weeks with the use of a hinged knee brace.

Fibular collateral ligament (FCL) injuries in isolation are rare but have an excellent prognosis after both operative and non-operative management in the elite athlete [19]. This injury can often be seen in wrestlers and there are multiple reports in the literature of successful return to sport with either non-operative treatment or FCL reconstruction, with non-operative management possibly allowing faster return to play. LaPrade et al. reconstructed the FCL in a cohort of 16 patients with grade 3 FCL injuries with good results and no resultant laxity; however, most of the patients in this cohort had more complex injury patterns and not simply isolated FCL tears [20]. Bushnell et al. compared operative and non-operative treatment for grade 3 isolated FCL injuries in elite football players and found no difference in functional outcomes or subjective instability between the groups. The most significant difference was return to play, which was 9 weeks faster in the non-operative group [21]. The senior author previously published his experience with isolated FCL injuries in the National Football League (NFL). Eight grade 3 injuries were treated with hinged knee brace for an average of 4 weeks. All players had residual laxity of 1–3 mm and none complained of subjective laxity. The average length of missed competition time was 4.6 weeks [19]. Grade 1–2 and isolated grade 3 injuries will likely do well with non-operative treatment; however, grade 3 injuries that involve other PLC structures should be considered for operative reconstruction.

Athletes with isolated PCL injuries, especially grade 1 and 2, are typically treated non-operatively with a high success for return to sport. A dynamic PCL brace might be considered during the rehabilitation period for 4–6 months to possibly decrease final laxity at healing [22]. When analyzing the incidence of PCL injuries, Fanelli et al. found only 7% were isolated PCL injuries and only 18.5% of his series were sports-related injuries [23]. While dashboard injuries are likely the most common mechanism for PCL injuries for the general trauma population, a fall on a flexed knee with the foot in plantar flexion is likely the most common mechanism for the athlete [24]. Surgical reconstruction is indicated for grade 3 isolated PCL, multiligament knee injury with PCL tear, or chronic PCL injury with residual posterior laxity and dysfunction with deceleration, stairs, or declines. Another consideration in isolated PCL injuries is repair of a femoral sided avulsion or "peel off". In these injuries, residual PCL length is maintained and can be reapproximated to the femoral insertion. Van der List and DiFelice have described an arthroscopic PCL repair technique with suture augmentation which has the advantage of preserving the native tissue, maintaining proprioception, and is minimally invasive compared to reconstruction [25]. Whether or not this technique will produce similar results when compared to reconstruction is yet to be determined.

32.4 ACL + MCL

There is little evidence to suggest the best strategy for managing the MCL in a combined ACL + MCL knee injury. Some suggest early conservative management of the MCL with functional bracing and delayed reconstruction of other injured ligaments. With this approach, eventual surgical management of the MCL injury may be considered if excess valgus laxity is present intraoperatively after reconstruction of other ligaments. Petersen et al. studied combined ACL + MCL injuries and compared early ACL reconstruction versus delayed ACL reconstruction with all MCL injuries treated non-operatively. In 27 patients, they performed early ACL reconstruction (<3 weeks) and in 37 patients the ACL was reconstructed >6 weeks. The delayed group had a lower rate of motion complications, lower rate of repeat arthroscopy, and better results in Lysholm score, leading them to recommend delayed ACL reconstruction [26]. Schierl et al. reported on results from 28 patients with grade 1 or 2 MCL injuries treated functionally with delayed ACL reconstruction. The majority demonstrated stable healing of the MCL and ACL and good or excellent knee functions and muscle strength if grade 1 or 2 valgus laxity and treated functionally [27]. Dale et al. [28] performed a review of ACL + MCL injuries and made several recommendations: ACL reconstruction could be performed in a delayed fashion to give the MCL time for healing, and to pay special attention to a "Stener" type lesion where the distal MCL fibers have been displaced superficial to the pes anserinus making MCL healing much less likely. Grant et al. also studied this combined ACL + MCL injury pattern and concluded that the ACL should be reconstructed once full knee ROM is obtained with MCL stability checked during examination under anesthesia. Residual laxity of the MCL was treated operatively with repair versus reconstruction [29].

In contrast, Millett et al. reported on 19 ACL + MCL combined injuries and performed early ACL reconstruction with non-operative management of the MCL. None of their patients experienced ACL graft failure or valgus instability, but 1 patient required surgery for arthrofibrosis. They felt early surgical reconstruction of the ACL with non-operative treatment of the MCL in combined injuries is acceptable and results in excellent clinical and functional outcomes [30]. Bollier et al. in their review of combined ACL and MCL injuries recommend early ACL reconstruction and MCL repair when there is increased medial joint space opening with valgus stress in full extension, a significant meniscotibial deep MCL injury, or a displaced tibial sided superficial MCL avulsion (Stener lesion). Otherwise delayed ACL reconstruction with testing during EUA for residual laxity on valgus stress is acceptable [31].

For those patients undergoing MCL repair versus reconstruction, Hanley et al. [32] studied differences in outcomes and found higher patient-reported outcomes at a mean of 6 years follow-up with MCL reconstruction.

Another surgical option which is relatively new is ligament augmentation with non-collagen materials. Most often this is done to augment an existing ligament that may not be providing the expected stability. One report by Ateschrang et al. showed promising results for combined ACL + MCL injuries treated within 14 days of injury and had grade II or III MCL laxity. They had no arthrofibrosis during follow-up, excellent valgus stability, and mean Lysholm score of 89.1. This may be a viable technique in the acute setting [33].

It is imperative that all injured structures have been identified based on physical exam and MRI findings. An often overlooked injury is the posteromedial corner, which includes the posteromedial joint capsule, condensations of the capsule considered by some to be discrete ligaments (posterior oblique ligament and oblique popliteal ligament), and the semimembranosus and its expansions [34]. Physical examination to test for anteromedial rotary instability (AMRI) is performed at 30° of flexion with valgus stress as well as with anterior drawer with combined tibia external rotation. Medial joint space widening and anterior medial plateau subluxation, respectively, are positive findings [35]. AMRI in the multi-ligament knee injury and widening of the joint space with valgus stress at full extension deserve to be addressed at the time of ligament reconstruction. In situations with large tissue sleeve avulsions, this might be considered for repair; however, in more chronic settings with attenuated tissue, then reconstruction should be performed. Multiple techniques have shown success and include a combined POL/MCL reconstruction described by multiple authors [36–39], as well as an anatomic 2 graft approach as described by LaPrade et al. [40]. Whatever technique is used, the treating surgeon must ensure that rotational stability of the knee is attained.

The senior author's preferred technique for MCL repair or reconstruction is as follows:

- For distal avulsion injuries, repair to bone using bioabsorbable or biocomposite knotless anchors above the level of the pes tendons. And if the exam shows evidence of posteromedial rotary instability, then reefing of the posteromedial capsule with mattress sutures is performed.
- When MCL reconstruction is performed, it is completed with a single arm allograft or autograft with interference screw fixation in both the femur and tibia. If there is posteromedial rotary instability, then an additional posterior oblique ligament limb is placed just posterior to the MCL graft on the femur and is inserted just below the joint line on the posterior medial tibia and again fixed in place with interference screws.

32.5 ACL + PCL + PLC

Combined ACL + PCL + posterolateral corner (PLC) injury is a common multiligament pattern and will be the most common injury pattern following knee dislocations. This pattern is often referenced as the most common multiligament knee injury pattern; however, this is based on trauma center data as opposed to sports medicine data [18].

The combination of knee MRI findings with a thorough physical exam under anesthesia will determine instability patterns. In addition to varus testing at 0° and 30° of flexion, special attention must be paid to dial testing at 30° and 90° of knee flexion as well as posterior drawer in tibial external rotation to assess for posterolateral rotary instability indicating a posterolateral corner injury. The reverse pivot shift is also an important component to examining the PLC. It is performed with the knee at near 90° and with a valgus load and external rotation on the tibia, the knee is slowly extended. If the previously subluxated lateral tibial plateau reduces at approximately 35°–40°, this is a positive test [41]. Posterior stress radiography is also useful for chronic posterior instability workup with more than 12 mm of posterior tibial subluxation (side-to-side difference) indicating a combined PCL and PLC injury [42]. Peroneal nerve function should be evaluated as up to 13% of all PLC injuries may include peroneal nerve injury [41].

The authors prefer a classification system, which considers location of injury, as well as the specific ligaments injured on the posterolateral corner:

- Type I: Isolated ligamentous injury of the posterolateral corner (PLC), including the FCL, popliteus, or popliteofibular ligament injury.
- Type IIa: Combined ligamentous injury of the PLC including injury to the distal FCL and hamstring, with either avulsion or fracture of the fibular head. (May repair with immediate stability attained.)
- Type IIb: Combined ligamentous injury of the PLC including injury to the FCL and popliteus, occurring at the proximal femoral origin.
- Type IIIa: Posterolateral corner knee blowout injury.
- Type IIIb: Posterolateral corner knee injury with single or bicruciate injury.

Review of recent literature suggests the degree of ligament, other soft tissue, and neurovascular injury occurs across a spectrum in patients. In particular, Type IIa injuries, and Type III injuries may be associated with peroneal nerve injury. Type III injuries will also typically be associated with increased posterolateral rotary instability.

For the professional athlete complete tears of both the ACL and PCL warrant reconstruction with the technique of choice of the treating surgeon. Transtibial arthroscopic techniques as well as tibial inlay techniques have been used to reconstruct the PCL. The tibial inlay technique was developed to avoid the "killer turn" on the posterior aspect of the tibial plateau, which may cause abrasion and attenuation of the PCL graft [43]. The all-inside arthroscopic technique to retro-drill sockets in both the tibia and femur has allowed a technically easier surgery by avoiding having to take the entire graft around the "killer turn." MacGillivray et al. compared transtibial to tibial inlay techniques in a cadaver study and showed greater than 30% of the tibial tunnel group failed at the "killer turn" before 2000 cycles of testing could be completed, whereas all the tibial inlay grafts survived testing. Despite these consistent in vitro findings describing graft attenuation with the transtibial technique, outcome studies have failed to find a clinical difference between the two techniques, including a recent systematic review [44–47]. Many patients continue to have posterior laxity postoperatively; however, this has not correlated with worse outcomes [47]. Some authors feel that double-bundle reconstruction of the PCL will provide enhanced posterior stability when compared to single-bundle techniques, but a recent systematic review comparing the 2 techniques found that in 7 of 8 studies, there was no functional or objective difference [48]. Based on these findings, it seems reasonable to use either a single-bundle or double-bundle reconstruction with a transtibial tunnel, all-inside, or tibial inlay technique.

In regards to addressing the PLC surgically (PLC includes FCL), Levy et al. demonstrated a significantly higher rate of failure for repair of lateral sided structures when compared to reconstruction; therefore, they felt reconstruction was a more reliable option in the setting of a multiligament knee injury [49]. Geeslin et al. also showed in a systematic review that repair of acute grade III PLC injuries had a substantially higher postoperative failure rate [50]. Acute repair of the lateral structures continues to be a workhorse for some surgeons. If the injury can be addressed in a timely fashion (<3 weeks) and there is good tissue quality, then a repair might be considered. McCarthy et al. [51] reviewed results on 44 reconstructions and 18 repairs and found low failure rates in both groups (4.7% reconstruction and 11.1% repair). Some surgeons would recommend augmenting the repair with an allograft based on the higher failure rate with repair alone [49]. Bony avulsions of the lateral complex either proximal or distally are likely amenable to repair and internal fixation.

There are numerous reconstructive techniques for the lateral and posterolateral knee structures. Choosing the most appropriate technique should be based on surgeon experience, damaged anatomical structures, and attaining coronal, translational, and rotational stability postoperatively.

The senior author's preferred PCL reconstruction technique is an arthroscopic all-inside with allograft. For the posterolateral corner, if the main issue is varus instability, then the preferred reconstruction is a modified Larson technique (Fig. 32.1) using a single graft and interference screw fixation for both the FCL arm and the popliteus arm. If posterolateral instability needs to be restored in addition to varus instability, then the senior author prefers an anatomic posterolateral corner reconstruction as described by LaPrade.

32.6 Concomitant Injuries

Concomitant injury to the articular cartilage and meniscus may play an important role in returning athletes to play following multiligament knee injuries. Kaeding et al. looked at over 2000 multiligament knee injuries surgically treated and found ACL + MCL injuries showed a high incidence of lateral meniscus tears and multiligament injury patterns showed chondral damage similar to the ACL-only group. Most interestingly they determined ligament injuries repaired acutely had significantly less articular and medial meniscal damage than chronic repairs [16]. Krych et al. also found increased time to treatment led to higher rates of articular lesions, especially in multiple compartments. Of their cohort of 122 knees, 76% had associated chondral or meniscal injury (55% with meniscal tear and 48% had chondral damage) [52]. This same group tried to determine if meniscal tears and articular damage is predictive of inferior patient outcome after surgical reconstruction. Of the 95 patients available for average 6-year follow-up, IKDC scores were significantly lower for patients with any cartilage damage, combined medial and lateral meniscus tears, and medial-sided articular cartilage damage [53].

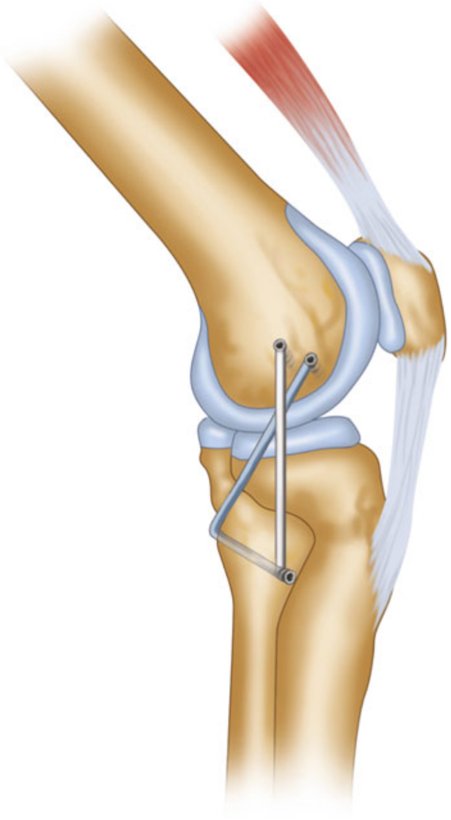

Fig. 32.1 Modified Larson technique for reconstruction of FCL and popliteus with a single graft

Although there are many variables determining a patient's final outcome, these findings would suggest that concomitant meniscal or cartilage damage is a poor prognostic factor for a professional athlete trying to return to play at the same level after a multiligament knee injury.

32.7 Other Considerations

32.7.1 Block Versus No Block in the Elite Athlete

Returning to sport for a subsequent season after surgery relies on beginning a postoperative rehabilitation program as soon as possible to regain motion and strength. One consideration in expediting rehabilitation is the use of a regional block during surgery. Magnussen et al. performed a randomized controlled trial of femoral nerve block (FNB) versus no nerve block which resulted in decreased strength (isokinetic quadriceps strength testing at 60°/second) and poorer Knee Injury and Osteoarthritis Outcome Score (KOOS) symptom subscale score at 6 weeks following ACL reconstruction compared with controls. These differences resolved by 6 months postoperatively. With the mainstream use of adductor canal blocks (ACB), one can avoid a femoral nerve block which may slow rehabilitation [54]. Abdallah et al. analyzed 100 patients with ACB versus FNB. In regards to opioid consumption and pain scores, there was no significant difference indicating an ACB is not inferior to a FNB for pain control after ACL reconstruction. The maximal voluntary isometric contractions for ACB and FNB at 45 min were 26.6 pound-force (24.7–28.6) and 10.6 pound-force (8.3–13.0) ($P < 0.00001$), respectively, indicating superiority of ACB. Compared with FNB, the study findings suggest that ACB preserves quadriceps strength in the acute postoperative period and provides non-inferior postoperative analgesia for outpatients undergoing ACL reconstruction [55]. In a retrospective comparative study by Krych et al., the hypothesis that patients treated with continuous FNB for postoperative analgesia following ACL reconstruction with patellar tendon autograft will have inferior knee extension (quadriceps) strength and function at 6 months follow-up was affirmed. However, no differences were observed in return to sport, bringing into question whether these statistical differences translate into meaningful clinical consequences after ACL reconstruction [56].

Some surgeons would advocate to avoid a peripheral nerve block altogether for the professional athlete to avoid possible quadriceps weakness, delayed return to sport, and to avoid the extremely rare prolonged or permanent nerve injury. A recent retrospective review by Christensen et al. compared 230 patients with FNB versus 30 patients with ACB who underwent ACLR. Isokinetic strength testing was performed at 6 months postoperatively, which showed persistent fast-activation isokinetic strength deficits following ACB. These findings are concerning, especially for the professional athlete [57].

The risks of nerve blocks (nerve injury, prolonged weakness) must be weighed against the benefits (pain control, decreased opioid consumption) and a shared decision made by both the surgeon and athlete.

32.7.2 Rehabilitation

A 2017 review article by Lynch et al. discussed various concepts and controversies in rehabilitation following multiligament knee reconstructions. Goals of their criterion-based rehabilitation progression are primarily getting back to normal activities of daily living and secondarily return to work/military duty/sports at the same level. They outline three phases of rehabilitation which include tissue protection, restoration of motor control, and optimization of function. Other specific considerations include avoidance of stretching the hamstrings, gastrocnemius, and posterior capsule to avoid disrupting posterior based repairs and/or reconstructions. Controlled weight bearing is beneficial for cartilage and meniscal nutrition, provides beneficial proprioceptive input to the knee, and promotes muscle activity [58].

Jenkins et al. studied 20 knees with a wide variety of injuries for quadriceps and hamstring strength at 2 years after multiple ligament reconstruction. They found quadriceps and hamstrings had peak torque 85 and 90%, respectively, of the uninjured extremity. Hamstring strength recovered faster than quadriceps strength; however, at 2 years, there was no significant difference in percent strength of either muscle group when compared to the uninjured side [59].

Some of the same principles of evidence-based rehabilitation for ACL reconstruction should be extrapolated to multiple ligament knee reconstructions and applied when considering reinjury after return to sport. Grindem et al. published on the Delaware-Oslo ACL cohort and developed simple decision rules, which if followed decreased the risk of reinjury. For their patients returning to cutting and pivoting sports, the reinjury rate was reduced by 51% for each month return to sport was delayed until 9 months after surgery, after which no further risk reduction was observed. The authors highlighted the importance of symmetric quadriceps strength, use of functional testing, and return to sport timing as factors which may modify reinjury [60].

Blood flow restriction (Fig. 32.2) has gained popularity recently and has been applied to a variety of injuries and postoperative rehabilitation protocols. Following multiple ligament knee reconstruction, early strength training with heavy weight to induce muscle hypertrophy is not feasible; however, introduction of low-load resistance training with blood flow restriction may produce significant hypertrophy and strength gains [61]. Whether or not blood flow restriction will become standard of care for rehabilitation protocols is yet to be seen, but the surgeon and therapist should be familiar with its application and contraindications.

Specific rehabilitation protocols should be determined by the surgeon at the time of reconstruction based on the combination of ligament repairs/reconstructions as well as concomitant procedures such as meniscus repair and cartilage restoration procedures. The progress and specifics of rehabilitation should be a team approach with the physical therapist and surgeon.

32.7.3 Return to Play

While return to play (RTP) rate for isolated ACL reconstruction is often considered high among the athletic population, this may be a biased assumption. According to MOON (multicenter orthopaedic outcomes network) group data an isolated ACL reconstruction in 147 high school or

Fig. 32.2 Example of blood flow restriction training where the cuff is inflated to allow a predetermined percentage of blood flow and low weight training is then performed

college football players, RTP was 63 and 69%, respectively with 27% of players stating that they subjectively returned at a level of play below preinjury level. The authors stated psychological factors may be significantly underestimated in return to play [62]. The RTP rate for multiligament injuries is expectantly lower and appropriate expectations must be discussed with the patient. While returning to sport for a professional athlete is of high importance, obtaining a functional and stable knee remains the primary goal for the surgeon. In a study by Harner et al. [4] nearly all 31 patients were able to perform daily activities with few problems; however, the ability of patients to return to high-demand sports and strenuous manual labor was less predictable. Hirschmann et al. reported on elite athletes returning to preinjury sports activity level following complex bicruciate ligament reconstruction. Only 8 of 24 athletes in their cohort were able to reach preinjury sports activity level [63]. Other studies have mentioned return to sport but with less specificity as to type of activity and level of participation. Jenkins et al. [59] reported >95% of patients returning to work; however, only about 1/3 of patients returned to the same level of sport. Karataglis et al. [11] had 91% of patients returning to work and 46% being able to participate in sport of any level.

While not professional athletes, active duty military personnel might provide a similar group of patients participating in high-demand activity with motivation to return to duty. Ross et al. reported 13/24 (54%) of their patients were able to remain in active military duty following multiple ligament knee reconstruction [64]. A recent 2017 study by Barrow et al. reported only 41% return to duty; however, their study population was 85% high energy mechanism [65].

Fanelli et al. reported on 44 patients with multiligament knee injuries at a minimum follow-up of 5 years and found 93% of patients returned to their preinjury level of activity with a stable and functional knee; however, this patient population was most applicable to the general working class, not high-level athletes [66].

A 2017 systematic review by Everhart et al. reviewed 21 studies including 524 patients with multiligament knee injuries. Overall, the return to high-level sport was only 22–33%, while return to any type or level of sport was 53.6%. This rate is lower than expected as there were some non-operatively treated patients included in this analysis. A systematic review will include a diverse patient population and may not be completely applicable to the elite athlete [67].

Recently, Bakshi et al. reviewed multiligament injuries in NFL athletes. 51 athletes between 2000 and 2016 were studied—47% had ACL + MCL tears, 53% had a multiligament injury involving the PCL or PLC, which included 8 knee dislocations. Overall return to play was 63%; however, the ACL + MCL group had a higher return to play (71%) compared to both the PCL/PLC involved group (56%) and knee dislocation group (50%). Mean time to return to play was 10.4, 13.7, and 20 months for ACL + MCL, PCL/PLC involvement, and knee dislocation groups, respectively. Returning to the same performance level was 48% in the ACL + MCL group and a dismal 18% when the injury involved the PCL or PLC [68].

Understanding the continuum of multiligament knee injuries from a combined ACL tear with MCL sprain on one end, to the 4 ligament tear knee dislocation with associated neurovascular injury on the other end, is imperative to manage both the injury as well as the professional athletes' expectations.

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Internal Bracing in Multiple-Ligament Knee Reconstruction

33

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33.1 Introduction

Multiple-ligament knee injuries create a complex environment of multidirectional instability. Repair and reconstruction of the injured cruciate and collateral ligaments carries the goal of correcting this multidirectional instability and restoring function. In a large proportion of patients, traditional techniques for reconstruction can successfully restore stability. However, some patients are plagued with residual laxity due to ligament elongation during healing or graft elongation during ligamentization. Recently, the technique of “internal bracing[1]” has showed promise in protecting against residual laxity.

Suture augmentation or suture reinforcement, also referred to commonly as “internal bracing”, involves passage of a high tensile strength synthetic material along the trajectory of a repaired or reconstructed ligament to act as a biomechanical checkrein against elongation (Fig. 33.1). An internal brace is intended to be a load-sharing construct that allows a ligament to see physiologic forces without elongating. In other words, it allows a ligament to be stressed while protecting against excessive strain. When the goal is stability, strain and elongation are the enemy. Since elongation manifests itself clinically as laxity, the prevention of elongation during rehabilitation and healing is of paramount importance.

Importantly, an internal brace is not meant to create a synthetic ligament. Thus, the technique is not intended to replace ligament repair or reconstruction. Synthetic ligaments, as we will discuss in this chapter, showed early promise but poor clinical outcomes. This technique has a different biomechanical profile that is designed to augment existing techniques. Early biomechanical data has begun to show a beneficial effect of internal bracing. Surgical techniques have been published that allow for arthroscopic implantation during ligament repair or reconstruction. And, while there is a paucity of clinical outcomes data thus far, early anecdotal evidence and case presentations have shown impressive results.

In this chapter, we will discuss the history of synthetic ligaments and the advent of modern suture tape augmentation with internal bracing. We will then discuss the available biomechanical and clinical data to support its use. Finally, we will present the indications and contraindications of internal bracing in the context of a case discussion.

33.2 Historical Context

The history of cruciate ligament reconstruction is fraught with attempts at synthetic reconstruction or augmentation. The use of synthetic material for ligament reconstruction originated as early as 1918 with the use of either wire or silk suture to reconstruct a deficient anterior cruciate ligament [1]. These initial techniques had poor results and were initially abandoned in favor of biologic reconstructions, which remained the standard throughout the mid-twentieth century.

While biologic reconstructions showed excellent results, clinicians remained concerned about donor site morbidity with autograft, and disease transmission with allograft. This lead to renewed interest in synthetic alternatives. In 1973, Proplast, a polytetrafluoroethylene (PTFE) with embedded carbon or aluminum oxide fibers, was released. This material was used in an extra-anatomic reconstruction to add length to a patellar tendon autograft [2]. Results of this system for ACL replacement were poor, with frequent failures within 1 year and a satisfaction rate of only 52% [3]. In an attempt

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[1] “Internal brace” and “internal bracing” in this chapter are used as descriptive terms regarding the technique and principle and do not refer to the proprietary Internal Brace™ device (Arthrex, Naples, FL).

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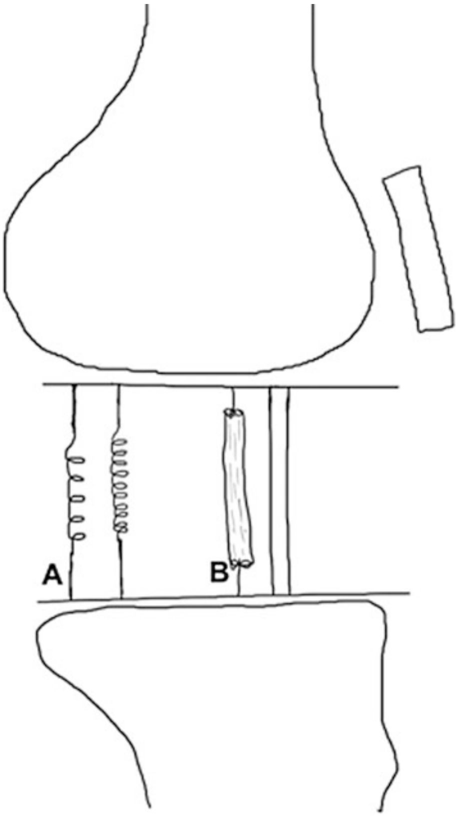

Fig. 33.1 Internal brace schematic demonstrating the parallel spring theory. The internal brace in part B shares load with the graft in the same way that two parallel springs of different spring constant (part A) can see different amounts of load while maintaining equivalent elongation

to build on these results, an expanded PTFE ligament consisting of strong interconnected fibrils was developed. This expanded PTFE showed improved results, with 83% satisfaction in one series [4]. However, this device was still prone to elongation and breakage after cyclic loading [5].

While PTFE ligaments were being studied, a competing synthetic carbon fiber ligament was also developed. Initial formulations were prone to degradation into carbon wear particles that seeded the joint and lymphatic system [6]. To combat this, collagen-based and synthetic coatings were attempted. Unfortunately, clinical results with these implants for ACL replacement were poor, with a good result in only 41% of patients [7].

Synthetic cruciate ligament replacements continually showed poor clinical results through the 1970s and 1980s so a new idea was proposed—augmentation. The Ligament Augmentation Device (3M Company, St. Paul, Minnesota), popularized by Kennedy, was a flat polypropylene braid that sought to improve the tensile strength and creep resistance of an ACL reconstruction [8]. This device was studied extensively with an overall failure rate for ACL reconstruction of 13.2% and a 4.9% risk of reactive synovitis according to a recent meta-analysis [9]. In addition, a prospective, randomized comparative trial failed to show a benefit over reconstruction without augmentation [10].

In recent years, new suture materials have reached the market. As we discuss in the next section, these materials have high tensile strength and are more biologically inert. This has led to a renewed interest in synthetic augmentation in the form of internal bracing. The goal of these devices is to provide a stable, load-sharing implant during the critical initial period of healing. Ideally, augmentations of graft material or ligamentous repairs with internal bracing should have a sufficient biomechanical profile to allow patients to return to weight bearing sooner with rapid return to range of motion postoperatively.

33.3 Biomechanics

33.3.1 Basic Principles

Internal bracing is performed by implanting a material of high tensile strength parallel to the course of a repaired or reconstructed ligament. From a simplified theoretical mechanical perspective, the suture tape (internal brace) and ligament act as parallel springs. In a parallel spring construct, the elongation (χ) of the system is equivalent to the elongation in each spring ($\chi_{\text{Total}} = \chi_{\text{Ligament}} = \chi_{\text{Brace}}$). In other words, one spring cannot see more strain than the other assuming they are fixed at the same length. The force (F) in the system is equal to the sum of the forces in the two springs ($F_{\text{Total}} = F_{\text{Ligament}} + F_{\text{Brace}}$). The internal brace is designed to be significantly stiffer than a repaired or reconstructed ligament. Therefore, under load the internal brace protects the ligament by resisting a greater proportion of the force under the same amount of elongation. This is proportional to the ratio of their spring constant (k) $\left(\frac{F_{\text{Brace}}}{F_{\text{Ligament}}} = \frac{k_{\text{Brace}}}{k_{\text{Ligament}}}\right)$. These equations can be modified from force, elongation, and spring constant to stress, strain, and modulus by factoring in the cross-sectional area and length of the internal brace and ligament.

33.3.2 Materials

FiberWire (Arthrex Naples, FL) is constructed with a core of several small individual strands of biocompatible polyethylene covered with braided polyester suture material. FiberTape (Arthrex, Naples, FL) is a flat, broad version of this same material, designed and marketed as having the ability to disperse loads over a larger surface area [11–13]. This makes for a biologically inert suture with the ability to resist greater mechanical force by reducing the effective mechanical stress $\left(\text{stress} = \frac{\text{Force}}{\text{Area}}\right)$. Multiple companies make products of similar structural properties: Ultratape® (Smith and Nephew Memphis, TN) and Force Fiber® (Stryker Kalamazoo, MI), for example, have similar internal biomechanical study results demonstrating improved stiffness over braided wire suture alone.

Little data exists regarding the use of braided wire suture (e.g., FiberWire, Arthrex) versus braided wire tape (e.g., FiberTape, Arthrex) in bracing in the human knee specifically. Rather, arthroscopic rotator cuff repairs provide us with much of the data comparing the two. Bisson evaluated 10 paired bovine infraspinatus tendon repairs using either polyethylene tape versus suture. While they found no difference in ultimate tensile load, stiffness, or elongation between the two, testing of the suture versus tape in isolation showed that the 2-mm tape was approximately 3 times as stiff as the No. 2 suture and failed at 3 times the loads of the No. 2 suture [14].

33.3.3 Clinical Biomechanics

Understanding of these mechanical and material principles has caused internal bracing to gain popularity in the recent decade in the knee, as well as other joints in the body, to address soft tissue deficiencies in high-stress environments. When evaluating the internal brace in the context of a Broström construct, Schuh et al. [15] found superior performance in terms of angle at failure as well as failure torque for the internal brace group compared to the suture anchor and traditional Broström techniques in fresh human cadavers. This corresponds to a similar study performed by Viens, which demonstrated that internally braced anterior talo-fibular ligament (ATFL) reconstructions were at least as strong and as stiff as the native ATFL at time zero [16]. They additionally found the bracing technique to have increased ultimate load to failure.

Studies of the internal brace in the upper extremity have yielded promising results as well, particularly with regard to ulnar collateral ligament reconstruction [17]. Dugas et al. found that in reconstruction of the UCL, augmentation of the primary repair with a FiberTape internal brace yielded decreased gap formation at low cyclic speeds. They posit that this decreased gapping may permit accelerated rehabilitation protocols in patients undergoing this operation. The same group then evaluated similar reconstruction constructs under cyclic valgus loads—ranging from 2 to 10 N-m—and found the repair with internal brace to be superior to the gold standard reconstruction with respect to gap formation at 10, 100 and 500 cycles [18]. Armed with the promising data from the ankle and elbow, a transition to ACL reconstruction and repair bracing seemed inevitable given the strength of the materials under load.

Currently, augmentation of ACL repairs with internal bracing is gaining considerable popularity. While initial attempts at direct repair with absorbable suture—such as those described by Feagin and Curl—showed a high rate of failure, use of nonabsorbable suture anchored at the femoral condyle as described by Marshall et al. showed promising results as a preliminary "internal brace" [19, 20]. Attention has subsequently shifted back to repairs as a viable method of treating some ACL injury patterns [21–23].

Animal studies have provided insight into the biomechanical advantages of having an internal brace during ACL repair. While human cadaveric biomechanical testing is limited, animal models have demonstrated improved biomechanical properties compared to repairs alone. Seitz et al. [24] evaluated a sheep model in which they transected the ACL at the femoral insertion. After randomizing 20 sheep knees to repair with versus without internal bracing using polyethylene terephthalate band (similar to coated polyethylene, as above), biomechanical properties were better with internal bracing but in both groups were inferior to the properties of the contralateral limb. Fischer et al. evaluated restoration of native joint biomechanics with the use of suture augmentation in the goat stifle joint, which mimics the human knee joint [25]. Using two sutures (#2Fiberwire, Arthrex, Inc. Naples, FL), they placed tunnels in the femur and tibia and attached to the respective bones using suspensory fixation. They found anterior tibial translation was closer to the intact state when internal bracing was added to the ACL repair. The investigators also found a reduced load on the medial meniscus when using this construct. Additionally, a German language study using a porcine knee model found that an internal bracing technique with transosseous suture repair of the cruciate ligaments was biomechanically superior to cruciate ligament reconstruction with hamstring grafts [26]. Finally, in an ex vivo biomechanical model of ACL reconstruction using porcine tibia, Bachmeier et al. found that suture tape reinforcement significantly reduced elongation and ultimate failure load without overly stress-shielding the graft material [27].

Promising biomechanical results also exist for repair and reconstruction of the medial collateral ligament (MCL). Gilmer et al. [28] evaluated repair with internal bracing compared with the intact MCL, repair alone, and allograft reconstruction of both the MCL and posterior oblique ligament. The experiment consisted of 3 Assays: Assay 1 compared repair with internal bracing with the intact MCL and posterior oblique ligament, assay 2 compared repair alone with repair with internal bracing, and assay 3 compared anatomic repair with internal bracing with allograft reconstruction. Using 27 matched cadaveric knees loaded in valgus, they found the moment to failure was significantly greater for internal bracing and the valgus angle at failure was significantly less. Further, Internal bracing was similar to allograft reconstruction in their testing. They concluded that internal bracing was both advantageous for resisting deformity at higher loads, and had biomechanical properties similar to allograft reconstruction.

Finally, a Dürselen et al. [29] performed a biomechanical evaluation of six techniques for suture augmentation of the posterior cruciate ligament (PCL) in a cadaveric model. Their group found that the optimal internal bracing technique restored posterior drawer stability with AP translations similar to the native knee under applied load. They postulated, like other authors, that this would protect a reconstruction against elongation during the healing phase.

33.3.4 Future Directions

Further biomechanical research regarding internal bracing of the ACL, LCL, MCL, and PCL with modern techniques, as well as multiple-ligament internal bracing, is warranted. There have been anecdotal concerns regarding over-constraint of the knee, as well as its application in the pediatric population. These must be addressed in both biomechanical and clinical settings. Overall, however, current biomechanical testing in human and animal models provides extremely promising results for stronger constructs more resistant to elongation, thus allowing potentially earlier weight bearing, range of motion, and mobility protocols in patients treated with these techniques.

33.4 Clinical Outcomes

While biomechanical evidence supporting the role of an internal brace in orthopaedic procedures is well documented, the clinical outcome data is limited due to its relatively recent emergence. The evidence is building, as multiple technique and biomechanical studies reporting promising early outcomes are actively enrolling prospective studies [18, 30–33]. Much of these data are related to applications in the foot and ankle, with some early results becoming available for these techniques within the knee. Unfortunately, no studies to date have directly addressed internal bracing in the context of multiple-ligament reconstructions. Therefore, we discuss here the provisional results of isolated ligament internal bracing with the caveat that these results will need to be validated further in the setting of multidirectional instability.

Currently, the most well documented clinical support for internal bracing is with the modified Broström procedure. Yoo et al. [34] performed a retrospective evaluation comparing 22 patients undergoing arthroscopic modified Broström procedure with an internal brace compared to 63 patients without a brace. Both groups showed significant improvement in American Orthopaedic Foot and Ankle Society (AOFAS) scores at final 24 month follow-up, however the braced group had significantly ($p < 0.001$) higher AOFAS scores at 6 and 12 weeks postoperatively [35]. Additionally, the braced group was significantly more likely to return to sport at 12 weeks compared to the non-braced group ($p < 0.001$). While there were no wound complications in either group, the braced group did show a 9% of patients reporting an inversion deficit postoperatively due to overtightening of the brace. Similar results were reported by Coetzee et al. [36] in 81 patients using an open technique and reporting an average of 12 weeks to return to sports, and 79% of patients reporting near full return to pre-injury level of activity at 11.5 months postoperatively. In a series of 24 patients undergoing a mini-open modified Broström with internal brace, Cho et al. [37] reported return to walking on uneven ground at 9.6 weeks, jogging at 10.2 weeks and an average subjective satisfaction score of 93.8 out of a possible 100. They also reported a significant improvement in both talar tilt, and anterior talar translation at final 2-year follow-up. Collectively, current clinical data indicates that the use of an internal brace for the modified Broström procedure leads to good patient satisfaction with earlier return to activity than the same procedure without a brace.

Outcomes for additional procedures have also been described in limited series. In 24 mid substance Achilles tendon tears repaired with an internal brace with average follow-up of 26 months, there were zero re-ruptures, no wound complications with patients on average returning to activity at 18.2 weeks [30]. In the same series, authors report an Olympic athlete that was able to return to running at 12 weeks and return to explosive sprinting by 18 weeks postoperatively. Regauer et al. [31] describe a technique for the use of an internal brace for syndesmotic injuries of an ankle reporting successful anatomic reduction of the syndesmosis on postoperative CT as well as documented stability with stress testing intraoperatively.

van Eck et al. [38] recently performed a systematic review evaluating the role of an internal brace for repair of midsubstance ruptures of the ACL. They evaluate the biomechanical role of bracing in ACL repair as well as substantial evidence in animal studies suggesting its potential benefit. Human studies are limited to case reports; however, the data is promising. In pediatric patients undergoing ACL repair, internal bracing led to restoration knee stability on clinical exam with complete ACL healing on second look arthroscopy [39]. In adult patients with acute tears who underwent repair with internal bracing, median Lysolm scores were 100, with International Knee Documentation Committee Subjective Knee Form (IKDC) score of 98.9 and only a 2 mm difference in Lachman exam compared to the nonoperative knee [40–42].

The clinical evidence in support of the use of an internal brace is continuing to build with the limited data currently in the literature revealing promising results. Clinical data are particularly sparse thus far for the knee and there are no clinical studies of the results of this technique in multiple-ligament injuries. Larger series and prospective trials with long term outcomes are in process and will continue to reveal the value of this procedure in the future.

33.5 Case Presentations

33.5.1 Case I

A 50-year-old male competitive triathlon athlete presented after a dirt bike motorcycle accident with the injury shown in Fig. 33.2. He was found to have an open KDIV knee dislocation (ACL, PCL, MCL, LCL) with peroneal nerve injury. He was initially managed at an outside hospital with a debridement, external fixator, MCL repair, and attempt at lateral collateral ligament repair. MRI is shown in Fig. 33.3. At the start of these cases, the senior author recommends performing a stress fluoroscopy exam with comparison to the contralateral side. In this case, stress fluoroscopy showed significant instability to posterior drawer and varus (Fig. 33.4). Due to the midsubstance tear of the ACL, an allograft ACL reconstruction with internal bracing was performed. In contrast, as the PCL injury was a proximal avulsion type pattern, a PCL primary repair with internal bracing was chosen. As the LCL repair had pulled off the fibular head but was not severely retracted proximally, a revision LCL repair was performed with internal brace bracing as well as an internal brace of the anterolateral ligament and lateral capsule. In addition to the use of a Fiber Tape construct placed over a large broad button off the distal medial femoral metaphysis, the authors also add an additional construct created by combining 2 separate TightRope (Arthrex, Naples, FL) together to add better control of construct tensioning. Tensioning of the varus laxity on the injured knee is then set under fluoroscopic guidance at the same laxity of the contralateral knee (which was measured fluoroscopically and documented at the start of the case). By 8 weeks postoperatively, the patient was able to run in place without pain, although we stressed to the patient that we did not want him to attempt jogging until at least 4 months postoperatively in order to allow more time for adequate ligament healing and quadriceps and core strengthening. By 12 weeks, the patient had near full motion and he reported that he was bicycling over 50 miles per week without pain (Fig. 33.5). He was able to single leg hop and lateral shuffle without pain by 7 months postoperatively. His Lachman, posterior drawer, varus, and valgus exams remained stable and he had no reported instability events.


Fig. 33.2 Case I clinical photograph demonstrating an open posterior knee dislocation

33.5.2 Case II

A 35-year-old male extreme skier, with a prior history of left traumatic below knee amputation, presented to our institution with a contralateral right knee dislocation from a ski accident. He was found to have a posterior cruciate ligament injury with a grade 3 posterior drawer, a complete distal lateral collateral ligament tear, an anterolateral capsular tear, and a MCL strain. He had an intact anterior cruciate ligament and negative Lachman test. A prone dial test indicated that his posterolateral corner remained intact. Stress fluoroscopy demonstrated at 30° of flexion, valgus load produced approximately 14 mm of laxity versus 12 on the right lower extremity. Varus stress testing in the left lower extremity at full extension was 21 mm of opening versus 11 mm in the right lower extremity. Varus stress testing at 30° of flexion was 21 mm of opening versus 13 mm on the right lower extremity (Fig. 33.6). He underwent allograft PCL reconstruction with internal brace augmentation, and repair and internal bracing of the anterolateral ligament/lateral capsule and lateral collateral ligament complex (Fig. 33.7a).

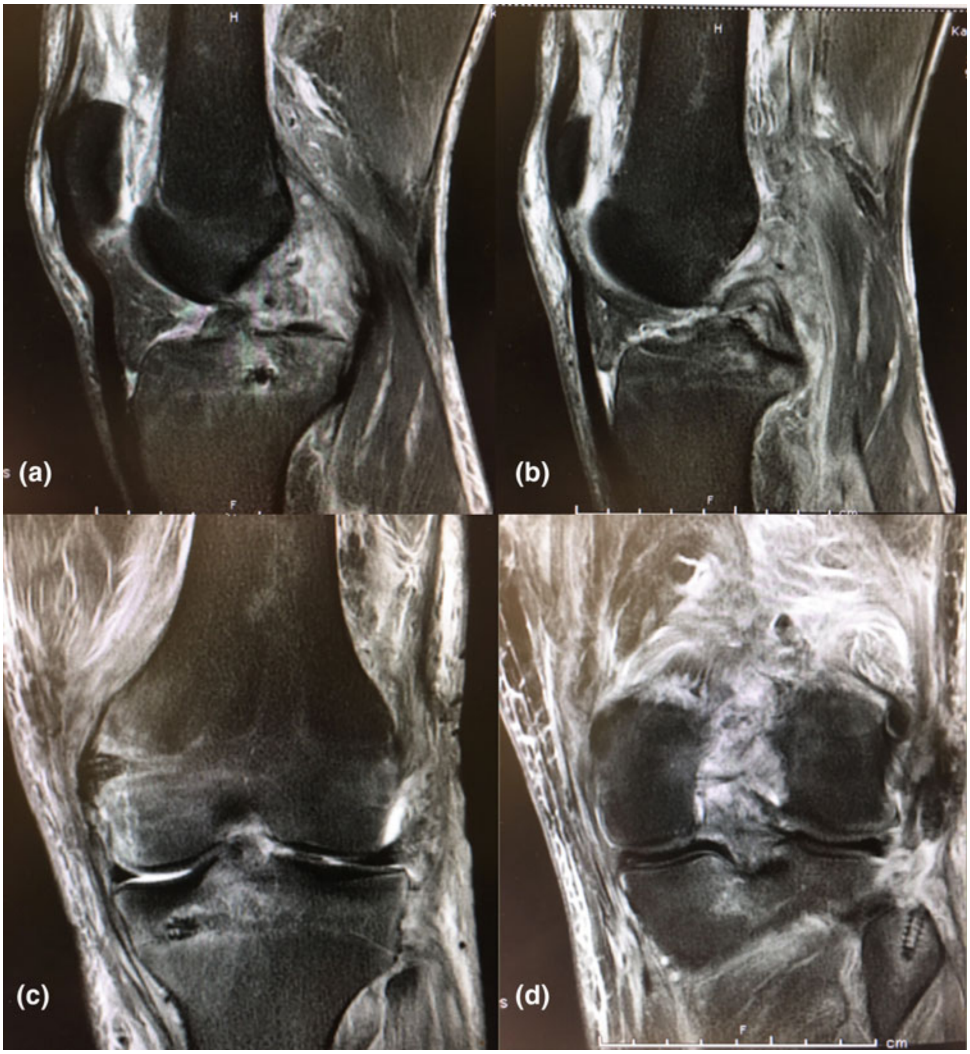

Fig. 33.3 **A**–**D** Case I MRI images upon presentation to our institution. Of note, the patient had acute MCL and LCL repairs at the outside facility. The MRI demonstrates ACL and PCL tears as well as a repaired MCL and a failed LCL repair. Panel **A** shows the ACL tear, Panel **B** shows the PCL proximal avulsion, Panel **C** demonstrates the MCL repair, and Panel **D** shows the failed LCL repair

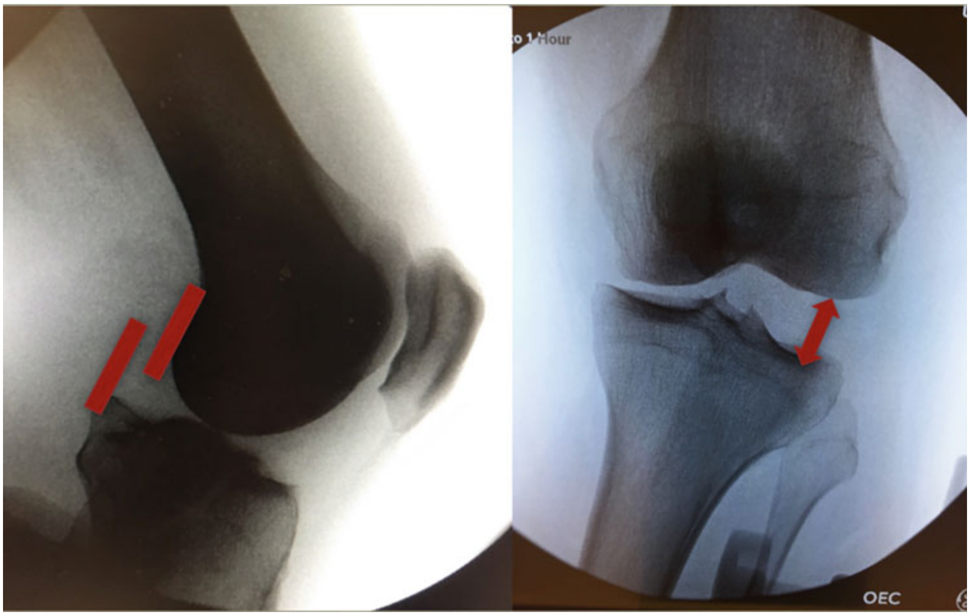

Fig. 33.4 Stress radiographs in a posterior drawer and varus load demonstrate significant instability

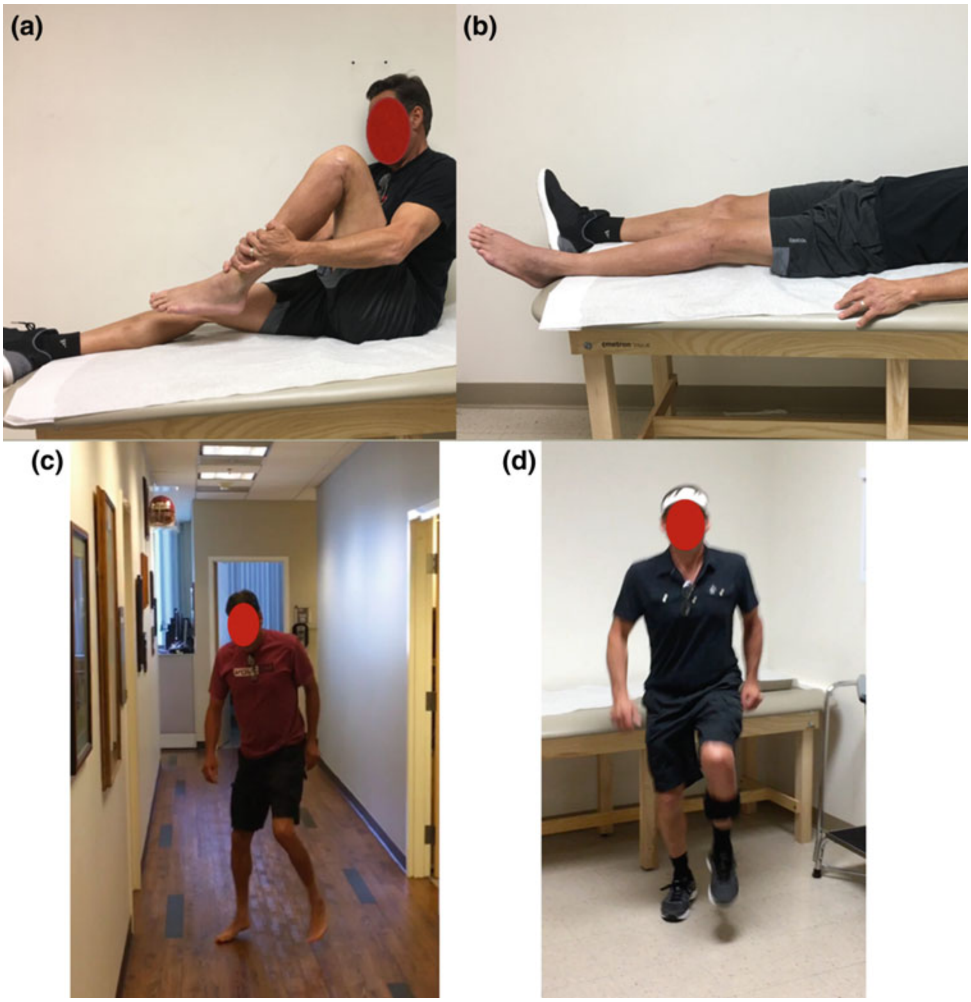

Fig. 33.5 Clinical photographs demonstrate restoration of range of motion. The patient was pain free and able to deep squat and bicycle 50 miles per week by 3 months postoperatively. By 7 months, he was able to single leg hop and lateral shuffle without pain

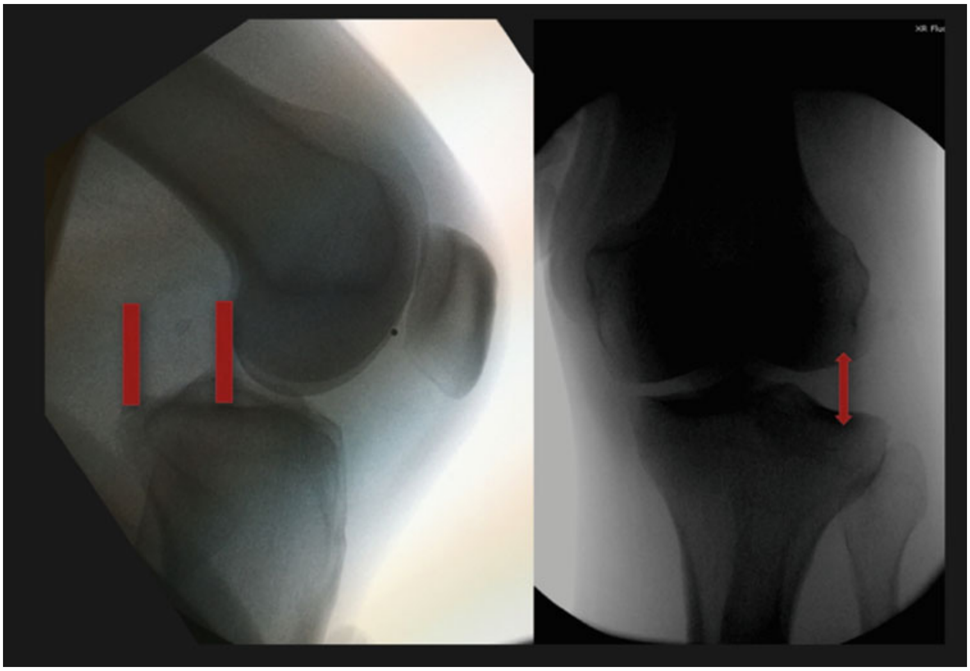

Fig. 33.6 Case II stress fluoroscopy demonstrating posterior subluxation during posterior drawer, and significant varus laxity due to PCL and LCL injuries

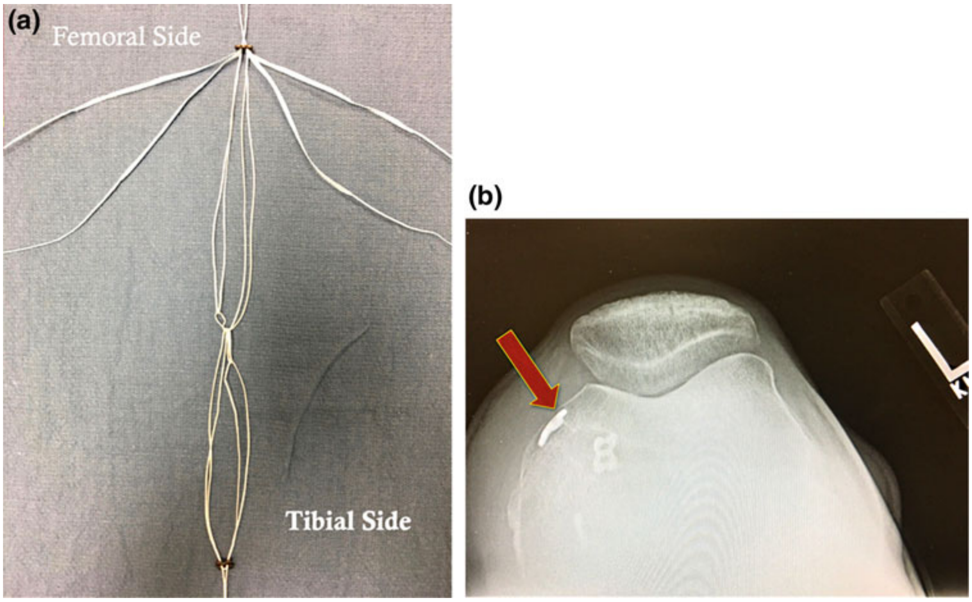

Fig. 33.7 **a**, **b** Internal brace construct with two integrated TightRope sutures for support of the anterolateral capsuloligamentous repair. The suture is tunneled to the medial side for fixation (*red arrow*). This patient's extreme activity caused a recession of the button into the femur

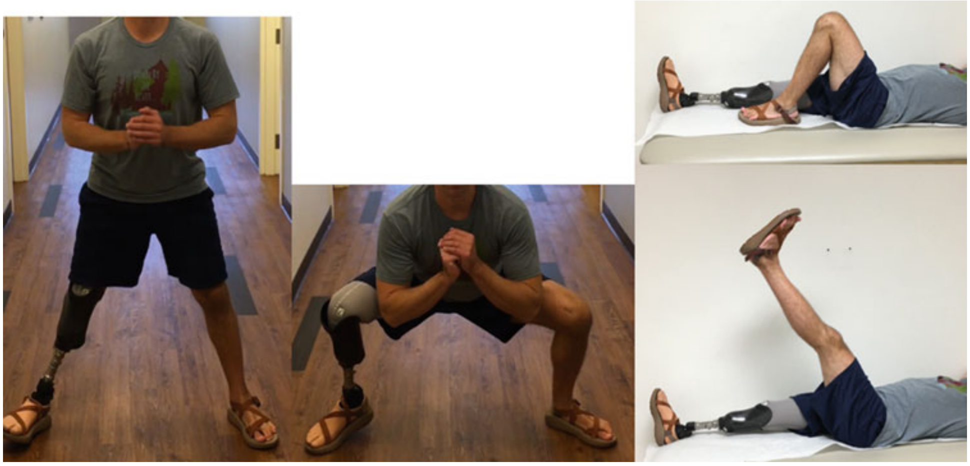

Fig. 33.8 Case II demonstrates good return of function by 8 months, even in a patient with a contralateral below knee amputation and high energy knee dislocation

By 8 months postoperatively, he had full motion and was performing CrossFit and Olympic Weightlifting exercises (Fig. 33.8). At 9 months, he went back to extreme skiing against medical advice including aerial backflips and was able to tolerate this with minimal knee pain. At his 10-month visit, he had increased laxity to a 1+ posterior drawer due to this extreme activity and profound noncompliance early in the postoperative period. However, even with placing an extreme amount of forces on his PCL reconstruction, we firmly believe the addition of the internal brace to the allograft reconstruction prevented catastrophic graft failure. This can be seen by the fact the femoral button fixing the allograft construct and the internal brace separately has recessed deep into the cortical bone of the distal femur secondary to the extreme forces which have been placed on the PCL graft and internal brace construct (Fig. 33.7b). We believe the addition of the internal brace has allowed his to reconstruction remained intact and not fail.

33.6 Author's Technique

The senior author uses an arthroscopic internal brace technique. This technique has been previously published for ACL and PCL repair, but the principles extend to reconstructions as well [43, 44]. Patients are closely evaluated preoperatively with assessments of clinical laxity and range of motion. Careful attention is paid to neurovascular status. If a vascular repair was performed, advanced imaging is considered to determine the location of the vascular graft within the posterior knee. If peroneal nerve palsy is present, intraoperative exploration is discussed. Radiographs are

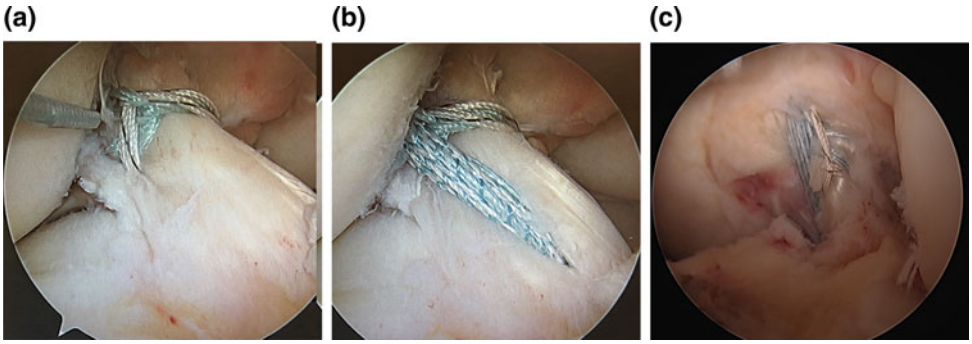

Fig. 33.9 **a**, **b** Example of an ACL femoral avulsion repair with internal brace. The remnant tissue is captured with braided wire sutures. A 3.5-mm tunnel is drilled adjacent to the femoral and tibial footprints, with care not to violate the remnant attachments. The remnant tissue and suture are passed through the femoral tunnel. A braided suture tape is then passed through both the tibial and femoral tunnels parallel to the graft. **c** Example of a PCL repair with internal brace using a similar technique, but with anatomic PCL tunnels

reviewed for concomitant fractures or malalignment. If there is pathologic malalignment, osteotomies are considered. MRI is reviewed for the involvement of each ligament and capsular structure. Attention is paid to the location of ligament injuries—if proximal or distal avulsions are present, repair is favored over reconstruction. Prior to surgery, the surgeon must be prepared to repair or reconstruct all involved ligamentous structures. Appropriate instrumentation and graft materials must be available. We favor the use of allograft tissues in these injuries to avoid the additional insult of autograft donor site morbidity.

Once planning is complete, the patient is assessed a final time for soft tissue healing. If significant swelling, blistering, abrasions, or open wounds are incompletely healed, surgery is delayed. It has been our experience that the majority of the soft tissue trauma will resolve by 2–6 weeks after injury, which represents our goal for the time of initial surgery.

Patients are placed supine on a standard operating table with the use of a tourniquet. Stress fluoroscopy and diagnostic arthroscopy are performed at the start of the case. In particular, prior to the sterile prep and drape, the surgeon performs a fluoroscopic Lachman and posterior drawer as well as varus and valgus loads at full extension and 30° flexion. The amount of laxity is measured with a ruler on the c-arm monitor. These numbers are recorded and compared to the contralateral side. This exam serves to finalize the clinical indication, and the uninjured side serves as a guide for each patient's native laxity.

We then proceed to diagnostic arthroscopy. Any meniscal procedures are completed first. We then move on to ligamentous repairs or reconstructions as indicated in this order: posterior cruciate → anterior cruciate → anterolateral ligament → posterolateral corner → collateral ligaments.

If preoperative planning and diagnostic arthroscopy indicate that a cruciate or collateral ligament is torn via a proximal (or distal) avulsion, repair is attempted prior to a reconstruction. In these cases, the remnant tissue is captured with braided wire sutures (Fig. 33.9). A 3.5-mm tunnel is carefully drilled through the femoral and tibial footprints, with care not to significantly injure the remnant attachments. The remnant tissue and suture are passed through the femoral tunnel. A braided suture tape is then passed through both the tibial and femoral tunnels parallel to the graft. The principle is the same for both ACL and PCL augmented repairs.

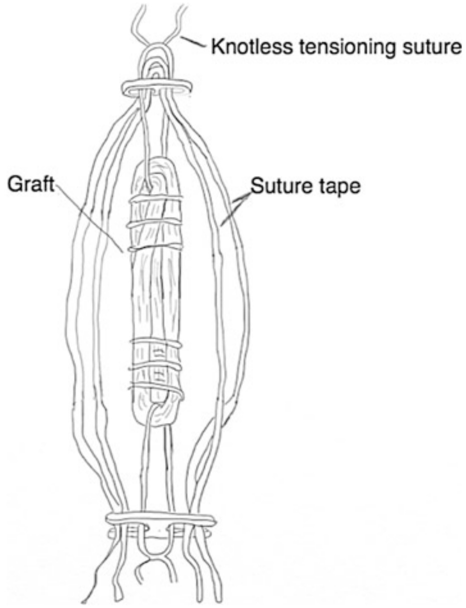

Fig. 33.10 Senior author's depiction of the internal brace-graft construct. There is a standard quadrupled graft incorporated into a knotless tensioning suture on either end (e.g., Tightrope, Arthrex, Naples, FL). This is incorporated into a suture button on both sides. In addition, there are two limbs of suture tape material that pass through the button with independent tension. The senior author has now added a larger button to femur side of the construct for better more secure femoral fixation. This now requires an additional small incision medially (PCL) or laterally (ACL) in order to apply the larger button, as the buttons used are now too large to travel through the femoral tunnel

If a repair is not possible, we will proceed with reconstruction. We use standard techniques to create tibial and femoral tunnels with anatomic alignment. The primary modification to existing reconstruction techniques is the addition of the internal brace to our graft construct. For cruciate ligaments, as shown in Fig. 33.10, we create a graft-brace construct that is passed as a single unit into each tunnel. The central portion consists of a quadrupled allograft incorporated into a knotless suspensory suture tensioning device (e.g., Tightrope or GraftLink, Arthrex, Naples, FL). In addition, braided suture tape is passed alongside the graft. The graft and braided suture are incorporated into a suture button on the femoral side, but fixed independently on the tibial side with suture anchors. This allows them to act as parallel springs with load sharing. Care is taken not to overtighten the internal brace portion as this can stress-shield the graft and capture the knee. The senior author has modified his original technique and now uses a larger button on femur side of all of the constructs in order to provide more secure femoral fixation. This now requires an additional small incision either medially (for a PCL repair or reconstruction) or laterally (for an ACL repair or reconstruction) in order to apply the larger button to the internal brace and tightrope as they exit the femoral tunnel. The larger buttons

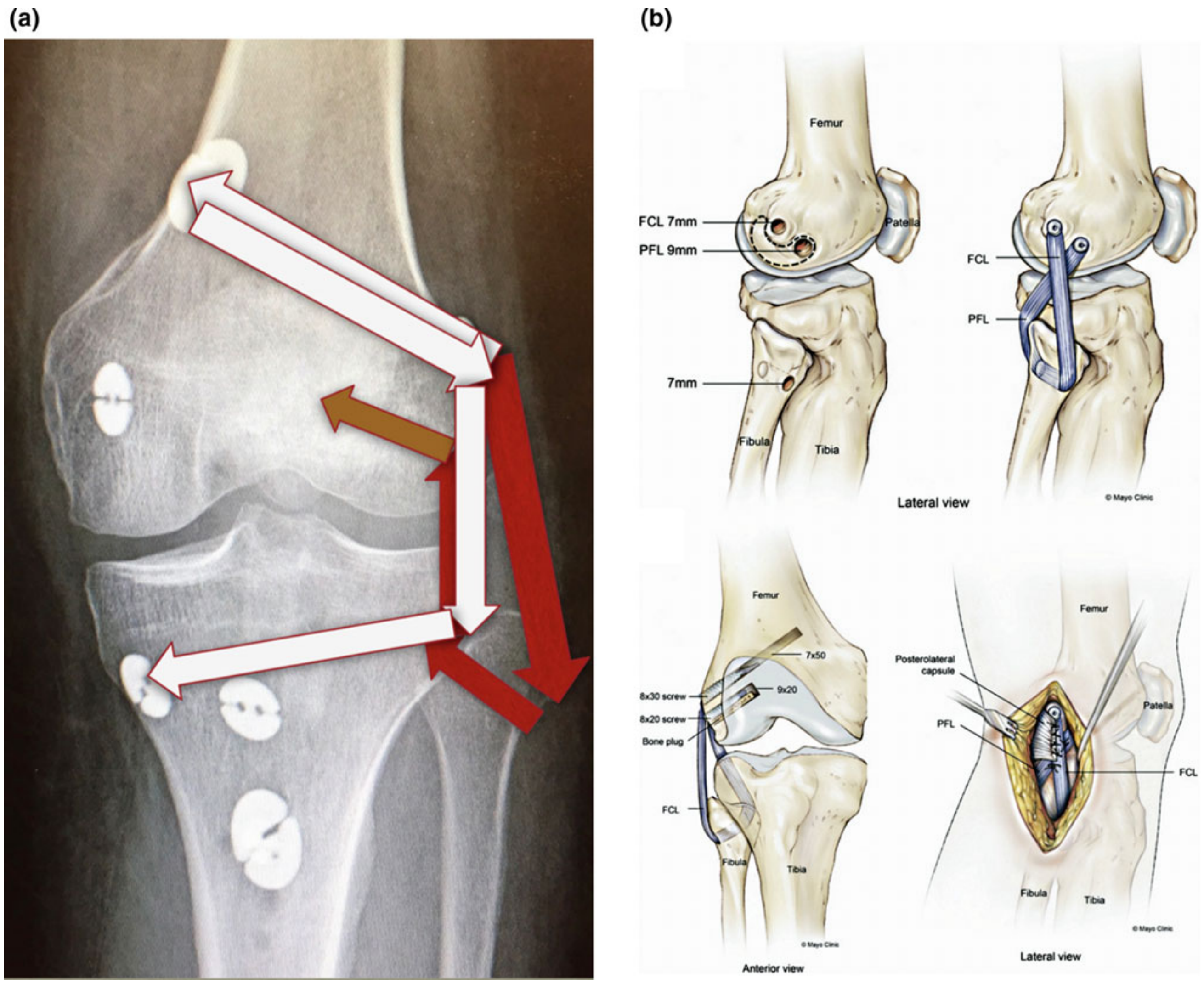

Fig. 33.11 **a** Anatomic LCL and popliteofibular ligament (PFL) reconstruction with two combined TightRopes acting as an internal brace augmentation for the anterolateral ligament and lateral capsule. Red arrows show graft trajectory. White arrows show the tightrope internal brace construct trajectory. The brown arrow is a biocomposite interference screw fixing the PFL limb on the femur. The LCL limb is fixed in the femoral tunnel with separate suspensory TightRope fixation. This patient additionally had bicruciate reconstructions that account for the other suture buttons visible on this radiograph. **b** Illustration of the graft orientation in this construct, reproduced from Schechinger et al. [46] with permission from Elsevier

now used are now too wide to travel through the femoral tunnels, and as a result are more resistant to be pulled back into the femoral tunnels under repetitive stress cyclic loads.

For collateral ligaments, the same principles are applied. Repair is attempted first and, if not feasible, reconstruction is carried out. In both cases, we will augment the procedure with a braided suture tape secured via bone tunnels. Importantly, fixation is independent to allow for the load-sharing effect of the internal brace. In these cases, tunnel convergence and positioning must be considered carefully. An exemplary case is shown in Fig. 33.11a. In this case, an anatomic lateral collateral ligament and popliteofibular ligament reconstruction is performed (as described by Arciero) using a single limb of tibialis anterior allograft tissue with a single transfibular tunnel and two separate femoral tunnels (red arrows) [45]. Figure 33.11b illustrates the original construct as described by Schechinger et al. [46]. In addition, an internal brace construct made of two combined Tightropes is used to repair and brace the anterolateral ligament and lateral capsule. The internal brace construct originates from the same femoral tunnel as the LCL graft and is secured to the same femoral button used to secure the LCL limb of the graft. The tibial side of the construct inserts on the native insertion site of the ALL (as radiographically described by Heckmann et al.) is secured over a button on the medial tibial metaphysis shown (white arrows) [47]. Another example is shown in Fig. 33.12. In this case, a repair was performed and augmented with a two-limbed internal brace construct. A Tightrope is incorporated for tensioning and two suture tape limbs add stability.

33.7 The Role of Internal Bracing in Multiple-Ligament Knee Reconstruction

There are currently no studies that establish clinical practice guidelines for modern internal bracing during multiple-ligament knee reconstruction. The following recommendations are based on the experience of the senior author and should be taken as Level V evidence (Tables 33.1 and 33.2).

The goal of internal bracing in this population is to achieve sufficient stability to allow for early rehabilitation. The goal of early rehabilitation is to prevent excessive joint stiffness and to restore function in a way that allows for early return to work and activities of daily living. As discussed in this chapter, the internal brace is a checkrein against graft elongation. It is designed to protect against increasing laxity during rehabilitation. In our early experience with this technique, patients have had sufficient stability to participate in early physical therapy without instability events or increasing laxity. Ongoing research will determine if these differences are maintained over an extended postoperative course, and if these results are rigorous enough to show a statistically different clinical outcome.

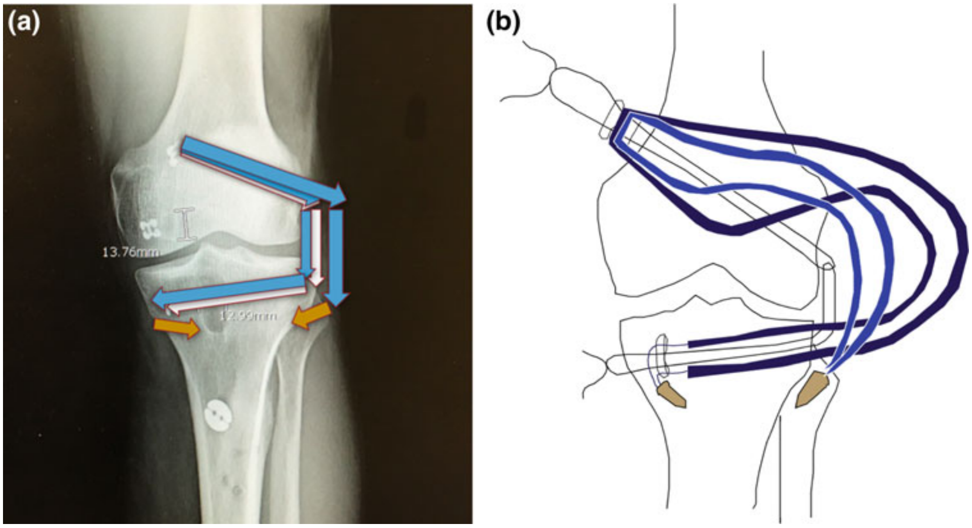

Fig. 33.12 **a** Lateral collateral ligament repair with internal bracing. A Tightrope is used to calibrate tension (*white arrow*), while two suture tape limbs are used to provide added stability. The sutures are incorporated into the same femoral button. One limb is secured with a suture anchor on the fibula (*brown arrow*) and another is tunneled to the medial tibia. The medial side is secured with a suture button and supported with an additional suture anchor (*brown arrow*). This is diagrammed in panel **b** where the black suture consists of two interlaced Tightropes, and the blue suture represents two Fibertapes, anchored on both the fibula laterally and the tibia via a tunnel medially. This is the same construct shown in Fig. 33.7a, but with a different application

Table 33.1 Indications and contraindications for internal bracing in multi-ligament knee reconstruction

Indications	Contraindications
• KD I or greater with high energy mechanism	• Articular cartilage lesions Outerbridge Grade III or IV [48]
• Grade III laxity of PCL, LCL, or MCL	• Untreated mechanical axis malalignment
• Grade III pivot shift	• Isolated ligament injury with routine reconstruction
• Ligament repair in MLIK	• Radiographic osteoarthritis with Kellegren-Lawrence grade 2 or above [49]
• Patient at risk for poor compliance with postoperative precautions	

Table 33.2 Benefits and risks of internal bracing in multi-ligament knee reconstruction

Benefits	Risks
• Increased stability	• Over-constraint of the knee
• Early rehabilitation potential	• Excessive stress-shielding of the graft
• Protection against poor compliance	• Lack of clinical outcomes data thus far

33.8 Summary

Internal bracing, or suture augmentation, is an emerging technique in knee ligament surgery. With a foundation in historical attempts at synthetic ligament replacement or reinforcement, internal bracing uses a different technique with a different biomechanical profile. The internal brace acts as a stiff spring in parallel to a repaired or reconstructed ligament, guarding it against strain. Early biomechanical data have shown promise for improved strength and less elongation under load for repairs and reconstructions that use this principle. Clinical data thus far are sparse, with no studies of internal bracing outcomes in multiple-ligament knee injuries to date. Future research and development is required to improve our understanding of internal bracing and to solidify its role in the management of the multiple-ligament injured knee.

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34

Multiple-Ligament Knee Injuries in the United States Military Active-Duty Population

Mark P. Pallis, Joseph T. Lanzi Jr., Estephan J. Garcia, William M. Weiss, and Andrew G. Chan

Abbreviations

ABI	Ankle–brachial index
ACL	Anterior cruciate ligament
ATLS	Advanced trauma life support
CT	Computerized tomography
DNBI	Disease and non-battle injuries
IED	Improvised explosive devices
LCL	Lateral collateral ligament
MCL	Medical collateral ligament
MOS	Military occupational specialty
MRI	Magnetic resonance imaging
OEF	Operation enduring freedom
OIF	Operation Iraqi freedom
PCL	Posterior cruciate ligament
PEB	Physical Evaluation Board
PLC	Posterior lateral corner
TCCC	Tactical combat casualty care
US	United States
USAF	United States Air Force

34.1 Patient Demographics

The United States (US) Military is a high-risk population for multiple-ligament knee injuries due to the physically demanding nature of the profession and exposure to austere environments and combat situations. The active-duty service member in the US Military is typically young, healthy, and predominantly male. The specific job requirements are unique when compared to the general population. Service members must function at a high physical level to perform specific duties and pass fitness requirements. This high activity level is similar to other athletic populations; however, the addition of combat exercises and exposure define the military experience. Combat activities are the ultimate contact sport, and musculoskeletal injuries and combat wounds are endemic in these endeavors [1].

Musculoskeletal injuries are the most prevalent health problem in the military. In a review of the armed forces' database over a 6-year period, there were greater than 13,800 hospital admissions for injuries resulting from athletics or physical training. The knee was most often injured, with ACL tears identified as the most common injury [2]. Similarly, the epidemiology of knee injuries in the US Military from 2000 to 2005 demonstrated an overall incidence of 31 per 1000 [3], which is nearly 14 times greater than that of the general US population [4]. The demographics of the US Military and more specifically the exposure of service members to increased risk of high-energy knee injuries make this population particularly susceptible to multiple-ligament knee injuries.

34.2 Mechanism of Injury

Multiple-ligament knee injuries in military service members can be caused by high-energy trauma like motor vehicle collisions, combat-related injuries including penetrating and blast trauma, and athletic or low-energy fall mechanisms typically seen in civilian populations. Penetrating trauma and blast injuries are unique mechanisms of injury for military personnel, and those exposed to combat. The level of trauma inflicted by combat injuries is in excess of that seen in civilian trauma and can both cause and impact the treatment of multiple-ligament injured knees.

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Combat-related musculoskeletal injuries occur during times of military conflict. For most of the past decade, the US Military has been involved in two military conflicts: Operation Iraqi Freedom (OIF) in Iraq and Operation Enduring Freedom (OEF) in Afghanistan. It is estimated that more than 34,000 US Military personnel have sustained combat-related musculoskeletal injuries since the start of OIF and OEF [5], and 54% of all combat-related wounds involved the extremities [6]. Explosive blast is regularly found to be the principal mechanism of injury in Iraq and Afghanistan and can cause significant associated trauma impacting treatment.

Primary blast injuries can cause injury to bone, cartilage, ligaments, neurovascular structures, and complete disruption of the soft tissue envelope or limb resulting in amputation. Secondary blast injuries are due to associated projectiles and can vary in severity from penetrating trauma to amputation. Penetrating trauma to the knee can disrupt ligamentous structures, and damage associated structures such as cartilage, bone, neurovascular structures, and the soft tissue envelope. Tertiary blast injuries are essentially contact injuries associated with the blast and can result in multiple-ligament injuries similar to those encountered with athletic or blunt trauma mechanisms.

Explosive mechanisms can include improvised explosive devices (IED), explosively formed projectiles, rocket-propelled grenades, and land mines. These agents have been found to account for 75–81% of all musculoskeletal casualties incurred in OIF and OEF [1]. Musculoskeletal injuries can be sustained either on foot or while inside a vehicle. In dismounted personnel, the destructive force of IEDs can create severely contaminated soft tissue and osseous wounds. Patients with soft tissue damage and wound contamination related to blast injuries are predisposed to wound complications, heterotopic ossification, osteomyelitis, and soft tissue contractures [1]. Ligamentous knee injuries are often unnoticed in combat trauma patients due to factors including the extent of other injuries, the need for in-theater resuscitation, and the spontaneous reduction of knee dislocation. While the survivability of the mechanism is always in question, blast and penetrating injuries have significant implications for treatment of the multiple-ligament injured knee that must be considered and addressed before ligamentous reconstruction.

In previous conflicts, "Disease and Non-battle Injuries" (DNBI) have placed a major burden on the military healthcare system [1], and their impact on combat readiness is significant. These injuries have been traditionally thought of as "non-combat" or "garrison" injuries, and are often overlooked in the active-duty service member. These injuries can account for approximately 1 million lost duty days per year and have a greater impact on combat readiness than typical combat injuries [1]. The knee is the most common joint affected by DNBI, and knee injuries are the most frequent reason for surgical intervention in the US Military population [1]. Sports and exercise-related injuries encompass a large spectrum of the DNBI in the US Military, and this is a shared mechanism of multiple-ligament knee injury with civilians.

Military training often involves high demand physical activity, combined with unpredictable terrain, unexpected contact, and significant additional equipment loads. These parameters create similar conditions responsible for multiple-ligament knee injuries in civilian athletes. Many military bases have recreational gymnasiums, courts, and fields for sports participation, where many soldiers can participate in intramural sports. An investigation of United States Air Force (USAF) service members over a 10-year period found that basketball is the most popular sport in the USAF and has the most participation injuries [1]. The most common mechanism of injury was from landing awkwardly from a jump (26%) followed by landing on another player's foot (17%) [1]. Sports participation is a positive way for military service members to enhance physical fitness while increasing morale and camaraderie; however, there is a negative impact in terms of injury and does expose them to possible multiple-ligament knee injuries.

34.3 Spectrum of Injury

In the military population, the spectrum of multiple-ligament knee injury can vary widely in terms of ligaments involved, and extent of associated injuries to cartilage, bone, neurovascular structures, and disruption of the soft tissue envelope. Popliteal artery injury and neurovascular compromise resulting in compartment syndrome are common in combat-related injuries. Owens et al. demonstrated that all military patients with knee dislocation had disruption of the ACL and PCL, with 93% sustaining a lateral collateral ligament (LCL) injury and 86% having a posterior lateral corner injury (PLC) [7]. They also identified a vascular injury in 3.5%, and a peroneal nerve injury in 75% of patients which is significantly higher than that in civilians. Barrow et al. found in their cohort of combat-related injuries that the most common pattern of knee injury (20%) was combined disruption of the ACL, PCL, PLC, and MCL [8]. 72% of these patients sustained an ipsilateral extremity fracture in addition to knee dislocation. There was a high incidence of patients that sustained vascular (64%) or neurologic injuries (64%), both in excess of that observed in civilian cohorts. Open knee injuries were observed in over half of patients (55%), with 24% sustaining a traumatic arthrotomy, 24% sustaining open tibia fractures, and 7%

sustaining open femur fractures [8]. This increase in severity and associated injury compared to civilians is a consequence of the increased energy of the causative mechanism of injury in combat.

A majority of combat-related blast injuries will result in amputation, either as an immediate effect of the trauma or for management of an unsalvageable limb. During OIF and OEF, the incidence of major amputations was 2.1 per 1000 soldier combat-years, with half (50%) of these being transtibial amputations [9]. The diagnosis and treatment of multiple-ligament injured knees following transtibial amputation present unique challenges. Physical examination, including quantitating anterior tibial translation with the Lachman test and identifying varus and valgus laxity, is often unreliable due to the shortened lever arm of the tibia [10]. Examination can be performed with a prosthesis in place; however, the liner and prosthesis can decrease the sensitivity and affect tactile feedback. A case series of combat-related multiple-ligament knee injuries in transtibial amputees found that insertion of half-pins into the residual limb improved the reliability of examination and manipulation during surgery [10]. Magnetic resonance imaging (MRI) can aid with diagnosis but many combat amputees have hardware or retained shrapnel which may preclude this. Other advanced imaging options, including computerized tomography (CT) with arthrogram, have undetermined diagnostic capabilities for extra-synovial ligamentous knee injuries [10, 11].

34.4 Emergent Treatment

Although the military population presents significant differences in demographics, mechanism, and spectrum of injury, the principles of management remain largely the same as those of civilian patients, with the exception of care in combat. As these injuries are frequently associated with high-energy trauma, immediate concerns in non-combat settings always include the management of life-threatening injuries according to the Advanced Trauma Life Support (ATLS) guidelines, as for civilian trauma. As a part of the "disability" portion of the primary survey, management of knee dislocations and multiple-ligament injuries will include reduction and stabilization of the limb (if this has not occurred spontaneously) and neurovascular assessment. As discussed, multiple-ligament knee injuries in the military population can occur in many of the same scenarios that they do in civilian trauma—sports or athletic activities, motor vehicle collisions, and falls from height—but there are special considerations in the injured military patient related to the circumstances and mechanism of injury.

In a combat setting, initial management is strictly dictated by the principles Tactical Combat Casualty Care (TCCC) which proceeds in three phases: care under fire, tactical field care, and tactical evacuation care [12]. During care under fire, the priority is to neutralize the ongoing threat and if possible tactically move the casualty to cover or concealment to rapidly assess for massive extremity hemorrhage and tourniquet placement, if appropriate. Initial concern is achieving tactical superiority, and until this is established, further treatment of the injured cannot occur.

Once tactical superiority is established, tactical field care can occur. This phase proceeds similar to trauma care for civilians but is both modified and complicated by the mechanisms of combat trauma in austere settings. The trauma inflicted on the extremity by combat is more likely to represent a threat to life and limb than injuries in civilian settings, and these are frequently mangled and complicated by amputation [13]. According to TCCC guidelines, treatment should follow the (modified from ATLS) mnemonic "AABCDE" where the first two letters represent arterial bleeding and airway, respectively [12, 13]. Due to the high proportion of penetrating trauma in combat scenarios, and significant impact on survival, the application of direct pressure or a tourniquet has increased priority in combat scenarios. The remainder of the pneumonic proceeds as it does in ATLS and involves management of other immediate threats to life. As part of the latter stages of this, reduction of the knee dislocation should be performed (if it has not occurred spontaneously). Once reduced (or if reduction is not possible), the knee should be stabilized with an immobilizer or temporary splint. Open injuries should be provisionally irrigated and debrided before dressing, and antibiotics initiated as soon as possible. Pain management and stabilization of other injuries should occur in preparation for transport to a casualty collection point for evacuation.

Tactical evacuation care involves the transfer of the combat patient to higher echelons of care based on the severity of injury and ease of transport due to distance and terrain. At each higher echelon facility, principles of tactical trauma management should be continued with reassessment of "AABCDE". A forward surgical team (Echelon II) is usually the first point of evacuation, but these are typically limited to basic resuscitation with damage control surgical capabilities. Once the patient is stabilized, immediate reduction of the knee should be performed (if not already accomplished) with detailed physical examination to determine ligamentous stability and neurovascular status according to the capabilities of the facility. Vascular examination should include ankle–brachial index (ABI) at a minimum if vascular injury is not obvious. Advanced vascular imaging and surgery are seldom available at forward surgical teams, so immediate transfer to a higher echelon of care should become the priority if vascular injury is present. Tourniquets should only be removed when prepared to obtain proximal arterial control. The knee should be stabilized definitively to maintain reduction. A knee immobilizer may be sufficient, but if the reduction cannot be maintained or a vascular injury is present, the knee should be stabilized in a reduced position of approximately 20° of flexion with a spanning external fixator. Pins should be placed in the distal tibia and proximal femur, ensuring adequate separation from future incisions. Depending on the situation and constellation of injuries, irrigation and debridement of open wounds and fasciotomies may also be indicated at this time to manage compartment syndrome or reperfusion injury. Additionally, vascular shunts may be placed to maintain limb perfusion during transport. If there is no vascular injury, then after stabilization, transport to a higher level of care for definitive treatment can be done when convenient.

Further evacuation to a combat support hospital (Echelon III) for evaluation and treatment by orthopedic and vascular surgeons is usually required for patients with vascular compromise or abnormal examination and should be done urgently. These echelon III facilities may also have advanced imaging modalities available for further vascular investigations such as CT with angiogram. Transitions through echelons II and III of care, and treatments received, are variable and dependent on location and staffing.

34.5 Definitive Treatment

Definitive management of multiple-ligament knee injuries should be performed after transfer of the military patient to the care of an experienced subspecialty-trained orthopedic sports medicine surgeon. This generally occurs in one of several military medical centers (Echelon V) located in the United States. Treatment of associated injuries and reconstruction of the multiple-ligament knee injury should proceed as described in the civilian orthopedic literature. As in the civilian patients, it is vital to recognize that every multiple-ligament knee injury is unique. While treatment principles are being developed and investigated, these may not apply to every knee, and treatment is dictated by the specific constellation of associated injuries including those to the ligaments. Specific to the military population, the mechanism of injury, concomitant soft tissue damage, and requirements for return to duty may influence the surgical plan.

Controversy exists in many aspects surrounding multiple-ligament knee reconstruction, as discussed in other chapters. While the definitive answers to many of the questions are still being investigated, surgeons who treat these injuries rely on what has been learned from limited cohorts and personal experience. Surgeons treating military patients have a smaller body of literature to draw from regarding treatment and outcomes in this population, but many of the lessons from the civilian literature are applicable to the military setting.

While the timing of definitive surgical reconstruction of multiple-ligament knee injuries is often determined by both associated injuries and patient factors, the civilian literature has provided some insight into optimal timing of surgery. Definitive management of military patients is more likely to be influenced by associated injuries incurred at the time of knee injury, due to the increased likelihood of significant trauma and soft tissue disruption. Also, for those injured in combat or overseas, transport time to an upper echelon treatment center or to the United States will influence when this can occur. The civilian literature has demonstrated that definitive management within 3 weeks of injury is optimal for patient outcomes, and when possible, military patients are treated similarly [14, 15]. As discussed, the increased likelihood of associated injuries and tissue trauma, and logistic issues related to patient transport, may prevent treatment of the military patient during this time frame. However, timely definitive reconstruction remains the goal for military patients. Similarly, treatment of the civilian multiple-ligament injured knee that occurs in a single operative session has demonstrated better outcomes than those that are staged [16]. In the military setting, the preference is also for a single-stage reconstruction when possible.

The specific techniques for multiple-ligament knee reconstruction remain controversial and are largely determined by surgeon preference. The authors endorse anatomic techniques for multiple-ligament knee reconstructions in both civilian and military patients. As discussed in previous chapters, principles include anatomic repair when possible, followed by reinforcement with reconstruction based on anatomic principles. The literature demonstrates that outcomes of reconstruction are superior to repair alone for the collateral ligaments, and this should be performed as early as safely possible following injury [15]. Complete tears of the cruciate ligaments are best treated with reconstruction, and if necessary these can be staged. Due to the tissue requirements for multiple-ligament knee reconstruction, and insufficient autograft options without risk of compromising remaining knee stabilizers, allograft tissue is preferred. There is increased availability of allograft tissue in the US, and sterilization methods have improved, demonstrating improved outcomes compared to autograft, but controversy remains as to which graft is superior [17, 18]. Associated injuries, which may be more common in military patients due to the mechanism of injury, should be addressed as they would in civilian patients. As in civilian patients, the goal is to return the military patient to function, although the level of function required for military service may exceed that of the average civilian.

34.6 Rehabilitation

Rehabilitation of multiple-ligament knee injuries has lagged behind treatment in terms of research and continues to be highly conservative and surgeon specific. The rehabilitation protocols used by military surgeons for multiple-ligament knee injuries in service members are similarly based on conservative principles of bracing, no or limited weight-bearing, and restricted range of motion in the initial phases. Range of motion and weight-bearing are progressed as time allows for healing of the reconstructed ligaments and associated injuries, and braces are worn for a number of months.

Military service members are unique as patients, as they are typically highly motivated to return to duty, and often place concern for themselves and their own well-being second to service to their unit and country. This motivation can be beneficial in driving their recovery but is also a concern when it comes to ensuring these patients take adequate time for healing and avoid disrupting their reconstruction or cause further injury. It is important for service members to remember that if they are unable to properly perform their duties, they place not only themselves, but their unit and mission in jeopardy.

Improvements in surgical technology and better understanding of anatomic reconstruction techniques have led some to consider accelerated rehabilitation protocols for multiple-ligament injured knees, though these have not been fully investigated [19]. There is a move toward earlier weight-bearing and knee range of motion to improve the functional outcomes for both civilian and military patients, in which the authors support. However, caution remains, particularly in military patients, as it is imperative to remember that each patient, duty requirements, associated injuries, and multiple-ligament knee injury are unique and may require individualized progression of rehabilitation. Even in an accelerated model, it remains important to consider the balance between allowing time for healing and return to function.

34.7 Complications

The complications of multiple-ligament knee injuries are well documented in the civilian literature, and most commonly include knee stiffness or residual ligamentous laxity. While there is limited literature detailing outcomes of multiple-ligament knee injuries in military populations, these complications may be expected in a higher proportion of patients due to the increased trauma and tissue destruction inflicted in combat [8]. Predisposing factors in combat that increase the likelihood of complications in military patients include the high incidence of open injuries, amputations, and infection. Neurovascular injury, specifically to the peroneal nerve and popliteal artery, are significant complications of injury seen in civilian knee dislocations. Again, due to the increased energy of combat trauma, these complications are seen in a higher proportion of military patients [6, 8] and represent a significant threat to both life and limb [13]. While the complications of multiple-ligament knee injury and reconstruction observed in civilians are also seen in the military, they are more common due to the mechanism and extent of injury, and are likely more significant.

34.8 Return to Duty

Return to duty following a multiple-ligament knee injury can be challenging in a military population. To be considered “fit for duty,” a service member must be able to perform at a physical level specific for their occupational specialty and he or she must pass military physical fitness requirements [8]. The literature pertaining to return to duty following multiple-ligament knee injury in military patients is limited. A return to duty rate of 54% following arthroscopically assisted surgical reconstruction of 24 active-duty soldiers with multiple-ligament knee injuries has been reported; however, 46% underwent medical discharge due to their injury [20]. No correlation was identified between military occupational specialty (MOS) or severity of injury and medical discharge, although higher rank was correlated with return to duty after surgery. Senior ranking service members are better able to control their work environment, allowing job modification and alternative physical fitness testing, whereas junior enlisted service members have more strenuous daily physical demands and less flexibility. Following surgical reconstruction, soldiers reported knee stability but were only able to perform sports at “half-speed” with some limitations in daily living functional scores [20].

An investigation of combat-related multiple-ligament injured knees reported a return to duty rate of 41% in 46 military service members, with 28 eventually appearing before the Physical Evaluation Board (PEB) [8]. The PEB determines fitness for duty and may recommend retention with duty limitation, medical retirement, or temporary disability. Patients with a high-energy mechanism, neurovascular injury, compartment syndrome, traumatic knee arthrotomy, or intra-articular femur fracture were found to be less likely to return to duty [8]. The most important variables identified for military separation were placement of a knee-spanning external fixator and poor range of motion at the time of evaluation by the PEB. Patients with a knee-spanning external fixator also had high rates of postoperative infections, in addition to poor knee range of motion [8]. This may represent the influence of the severity of the initial trauma on outcomes, and subsequent return to duty, but more information regarding predictors of return to duty is required.

In the civilian setting, the goals of treatment for multiple-ligament injured knees include stability with functional motion and return to full activities. The military goals are similar, but strive for return to full duty which carries increased physical expectations. Military patients should be counseled that despite this goal, there is evidence from the literature to suggest rates of return may be lower than that in civilian populations. Further investigation of predictive factors, treatment methods, and rehabilitation is required in both populations.

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Knee Dislocations in the Morbidly Obese Patient

35

Ian Power and Frederick M. Azar

35.1 Introduction

Knee dislocations are uncommon injuries, accounting for less than 1% of all orthopaedic injuries [1–8]. Historically, these have been classified as high-velocity or low-velocity injuries [4, 5, 9–11], with low-velocity injuries reported most commonly during sports and occasionally low falls from less than 5 ft [10, 12–14]. More recently, a trend has been noted for knee dislocations in obese patients resulting from low-velocity mechanisms [15–19]. Marin et al. first described knee dislocations in two morbidly obese patients who sustained their injuries during simple ambulation [18]. Hagino et al. described knee dislocations in 7 patients, 4 of whom were moving from a sitting to standing position and 3 of whom had spontaneous dislocations while walking; the average body mass index (BMI) was 53 [17]. A later study documented an increasing prevalence of low-energy knee dislocations in obese patients from 17% in the first 5 years of the study (1995–2000) to 53% in the second 5 years (2007–2012) ($p = 0.024$) [16]. A case series of 17 patients by Azar et al. was the first to use the designation “ultra-low-velocity” (ULV) knee dislocations, separating them from sporting injuries and high-velocity trauma mechanisms [18]. All of these dislocations occurred during activities of daily living (e.g., same-level fall, stepped off curb, tripped on carpet), and all were in patients with a body mass index (BMI) ranging from 30 to 68. As the obesity epidemic has reached younger and younger individuals, so has ULV knee dislocation become more common in these patient populations. The youngest reported patient with a ULV KD was an obese 8-year-old boy who had resultant popliteal artery thrombosis that was treated with anticoagulation [16]. Hamblin et al. described an ULV KD in a 15-year-old girl with a BMI of 40 [20].

BMI is an indirect calculation of body fatness. It is the ratio of a person’s weight in kilograms divided by height in meters, squared. A BMI of less than 25 is considered normal, 25–29 is considered overweight, over 30 is considered obesity, and 40 or more is considered extreme obesity. This has also been called class 3 obesity, “severe” or “extreme” obesity, and “morbid” obesity [21]. Obesity definitions continue to expand, and a now a BMI of more than 50 is known as “super obese” [22]. From 2000 to 2012, the rate of obesity among patients with knee dislocations tripled (from 3.37 to 10.18%, $p < 0.0001$), and morbid obesity doubled (from 4.51 to 9.09%, $p < 0.0001$) [23]. Overall obesity and morbid obesity rates increased, but not to the levels seen in those sustaining knee dislocations, indicating that this may have to do with improved awareness and reporting.

35.2 Mechanism

Despite the increased recognition of these dislocations, no consistent definition for different mechanisms has emerged, and overlapping terminology has added to the confusion: low-velocity, spontaneous, spontaneous nontraumatic, pathological, and ultra-low-velocity have all been used to describe these injuries.

A significant amount of energy is required to dislocate the knee [5]. This can be accomplished by increasing velocity or mass. As knee dislocations have become classified into categories based on mechanism, “low velocity” and “low energy” have been used interchangeably; however, even low-velocity and ULV injuries involve high energy because of the significant mass involved. In the laboratory, 650–800 psi of force is required to overcome soft-tissue restraints and dislocate a knee anteriorly [24]. During the gait cycle, as much as 2000 lb of force can be transferred across the tibiofemoral joint in a patient weighing 400–500 lb [25]. Hagino et al. hypothesized that all injuries in their 7 patients resulted from the extreme load of massive body weight

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(220–702 lb) placed on the knee joint from shifting body mass [17]. Obese patients also have displaced centers of mass and altered gait kinematics and are at increased risk of falls [26, 27]. Analysis of gait mechanics in obese patients has demonstrated at least 30% displacement of center of mass ($p < 0.05$), 23% decrease in speed ($p < 0.01$), and desynchronization of more than 40% ($p < 0.05$), increasing their risk of falls [26]. Gait patterns in obese patients provide a wider, more stable base, with a longer double-support phase, in an attempt to compensate for these gait abnormalities and prevent more frequent falls [27]. Laxity of the uninjured knee has been reported in these patients, suggesting that hyperlaxity also may play a role in knee dislocations in obese patients [18, 28].

The direction of dislocation is an indication of the force of the dislocating mechanism and has implications for concomitant injuries. Most reported ULV dislocations are anterior (Fig. 35.1) [9, 15, 28], likely caused by supraphysiologic loads and failure of the ligamentous and capsular restraints about the knee [25].

35.3 Diagnosis

Knee dislocation should be considered in obese and morbidly obese patients presenting with knee pain after low- and ultra-low energy injuries, including falls, even though the dislocation may appear reduced on initial radiographs in the emergency department [28–31]. In a morbidly obese patient with a large soft-tissue envelope and difficulty identifying an effusion, deformity of the femur and tibia at the knee can be difficult to assess clinically [32]. Occasionally, radiographs may be omitted, the diagnosis may be missed, and treatment may be delayed, which can have catastrophic consequences. One patient in the study by Azar et al. required amputation because of ischemia (delay of vascular surgery of more than 8 h) [15].

Fig. 35.1 Anteroposterior (**a**) and lateral (**b**) view of anterior knee dislocation in morbidly obese patient

Patients with morbid obesity also present a difficult ligamentous examination, especially for inexperienced examiners, and a high index of suspicion is crucial.

35.4 Associated Injuries: Vascular

The reported rate of vascular injury with knee dislocation has varied widely, generally ranging from 25 to 30% of all knee dislocations [15], from 3.3 to 6% in athletes and other mixed low-energy mechanisms and 7% in high-velocity injuries [10, 13, 33, 34]. The tethering of the popliteal artery at Hunter's canal and the soleus arch places it at risk for injury during knee dislocation [29, 34, 35]. Anterior knee dislocations result from a hyperextension mechanism, which places the popliteal vessels at the most risk. This occurs near 30° of hyperextension, causing the posterior capsule and anterior and posterior cruciate ligaments to fail [15]. Schenck classification KD-III and KD-IV dislocations are most common with ULV mechanisms [15, 28, 36].

Vascular injuries requiring surgical treatment occur in 26–41% of ULV dislocations [15, 16, 28, 36]. Several studies have shown increased vascular injuries with increasing obesity, with an increasing linear correlation with vascular injury in nonobese (5%), obese (7%), and morbidly obese patients (10%) [23]. Georgiadis et al. reported that more obese patients sustained vascular injuries (33%) than nonobese patients (9%) and were more likely to have a popliteal artery injury requiring repair; vascular repair was required in 28% of patients with a BMI >30 kg/m^2 and in 39% of those with a BMI >40 kg/m^2 [16]. Azar et al. noted that patients with vascular injuries had a higher BMI than those without, but this did not quite reach statistical significance [15]. Morbidly obese patients have a higher odds ratio of vascular injury than nonobese patients and obese patients [23, 37] and higher rates of open vascular repair (39%) than patients with high-energy mechanisms (6%) [16].

Given the high rate of associated vascular injuries, it is essential to evaluate pulses and obtain ankle–brachial indices (ABIs) and, if needed, selective arteriography [16, 25, 30, 34, 37, 38]. Use of ABIs has been shown to have excellent sensitivity and specificity in detecting arterial injury requiring surgical treatment [37, 39]. Further imaging or arteriography may be needed for patients with ABIs <0.90 [39, 40]. Observation for 48 h with routine examinations without arteriography has been shown to be safe in patients with a normal neurovascular examination and an ABI >0.90 [34]. The selective use of arteriography has been recommended because of a potential delay in treatment of popliteal artery lesions and iatrogenic complications from arteriography [41–43] (Fig. 35.2). Howells et al. proposed an algorithm for determining the necessity of arteriography after knee dislocation: abnormal ABI (<0.9) but palpable pulses, arteriogram at the discretion of the attending physician; pulse discrepancy compared to the contralateral side, arteriography [44] (Fig. 35.3). Using this algorithm, popliteal artery injury was identified in 9 (17%) of 53 patients; there were no missed vascular injuries. These authors cautioned, however, that rigid adherence to the algorithm is not appropriate and that a measure of clinical judgment is needed. Nicandri et al. also proposed a selective arteriography protocol that begins with reduction of the dislocation and a physical examination after reduction. If hard signs of vascular injury are present (e.g., active hemorrhage, distal ischemia, or expanding pulsatile hematoma), immediate surgical exploration is done, with or without preceding arteriogram at the discretion of the surgeon [45]. If a distal pulse is present and the limb is well-perfused with ABI of >0.90, the patient is admitted to the hospital for close observation and serial physical examinations by the physician for at least 24 h. If asymmetric pulses or distal pulses and a well-perfused limb with an ABI of less than 0.90 are present, an arteriogram is obtained.

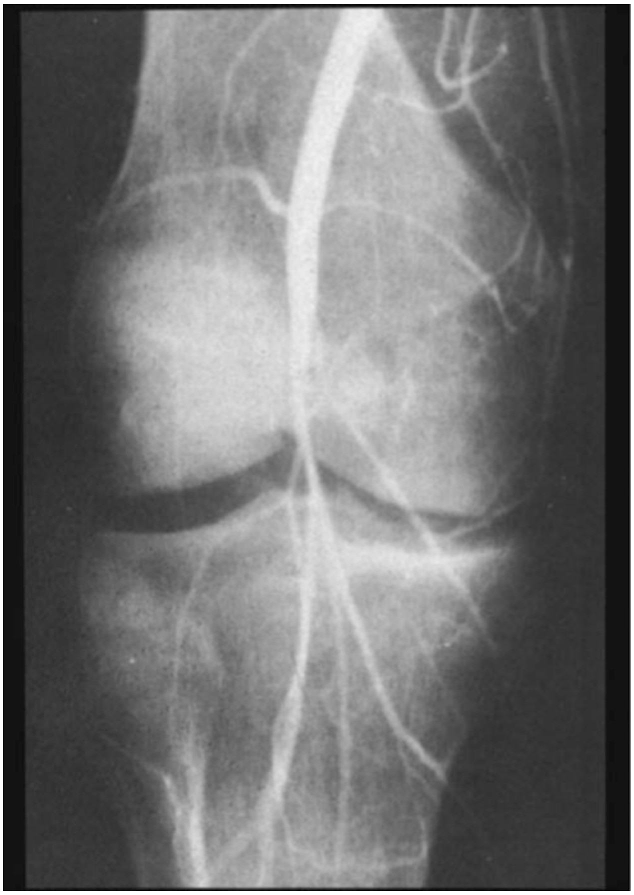
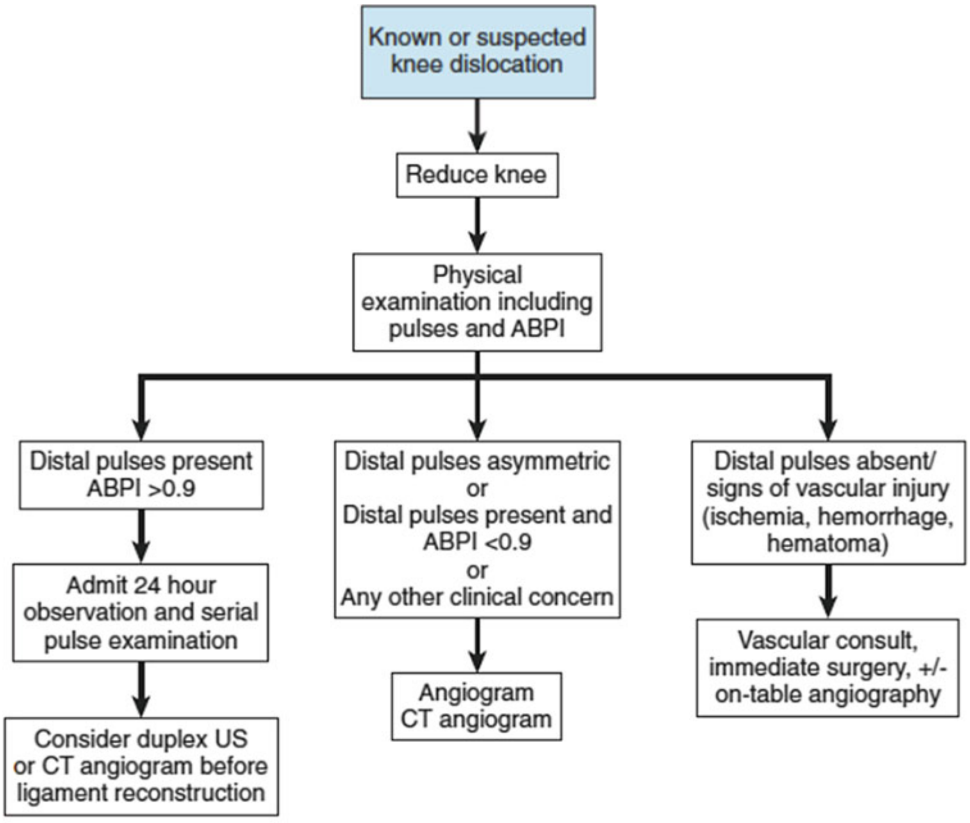


Fig. 35.2 Arteriogram

Early reports of vascular injury following knee dislocation showed that vascular repair should occur preferably within 6 h, with a maximum of 8 h warm ischemia to avoid

Fig. 35.3 Treatment algorithm for knee dislocation. Modified from Howells NR, Brunton LR, Robinson J, Porteus AJ, Eldridge JD, Murray JR. Acute knee dislocation: an evidence based approach to the management of the multiligament-injured knee. Injury 2011;42:1198–1204. With permission from Elsevier



APBI = ankle brachial pressure index; CT = computerized tomography; US = ultrasound

a high amputation rate [9]. Green and Allen reported an 87% salvage rate when revascularization occurred within 8 h of injury, compared to an amputation rate of 85% when revascularization was attempted more than 8 h after injury [9]. Arterial intimal tears that are non-occluding can be observed following vascular consultation [35]; however, these non-occluding intimal tears may go on to thrombose and become occlusive and, therefore, can be treated with surgical repair [46].

35.5 Associated Injury: Neurologic

Reported rates of neurologic injury with knee dislocation also have varied widely, from 9 to 49% [4, 5, 7–10, 14]. Traditionally, this has been thought to be approximately 20%, with Shelbourne et al. [10] and Engebretsen et al. [13] reporting rates of 19 and 21%, respectively. Peroneal or tibial nerve injuries are reported in 39 to 41% of knee dislocations, with about half having return of function [15, 23, 36].

Obese patients and morbidly obese patients have higher rates of nerve injury (42 and 41%, respectively) than non-obese patients (4%, $p = 0.002$ and $p < 0.001$). The highest reported rate of nerve injury occurred among morbidly obese patients with a low-energy mechanism, with 7 of 13 (54%) having a nerve injury [16].

35.6 Treatment

35.6.1 Initial Treatment

Upon presentation in the Emergency Department, closed reduction is attempted. If possible, a ligamentous examination is performed once the knee is reduced. If reduction is successful, a brace is fitted with the knee in 30°–45° of flexion. A well-padded splint can be used in place of a brace, but a brace allows easier access for compartment monitoring and evaluation of the knee and other injuries. If reduction cannot be maintained in a brace or splint, an external fixator should be applied and used for 4–6 weeks (Fig. 35.4). Post-reduction radiographs should be closely inspected for anatomic reduction and to ensure there is no interposed tissue that may block complete reduction. If post-reduction radiographs show a well-maintained reduction, the patient is admitted for monitoring. After documenting a detailed neurovascular examination, the patient is followed with

Fig. 35.4 External fixation of ULV dislocation in obese patient

serial examinations for 48 h. Regardless of the clinical examination findings, we frequently obtain an arteriogram because of the high risk of popliteal artery injury associated with ULV knee dislocations. If indicated, vascular surgery consult is obtained.

If the patient has an open knee dislocation, an arterial injury requiring repair, or compartment syndrome, or if closed reduction is unsuccessful or cannot be maintained, he/she is taken to the operating room urgently. The knee is immobilized with external fixation using two bicortical half-pins placed in the femur and in the tibia. Use of transarticular pins or olecranization of the patella should be avoided because of the risk of infection, chondral damage, and damage to the extensor mechanism.

35.6.2 Operative Treatment

Several studies have compared operative and nonoperative treatment of ULV knee dislocations. Azar et al. reported that patients who had ligament reconstruction had better Hospital for Special Surgery (HSS) scores (fair) than those treated without reconstruction (poor) [15]. The trend among studies is to treat most, if not all, patients with ligamentous reconstruction and selective repair [15, 28, 36]. Operative treatment of all injured structures in knee dislocations has been shown to result in better range of motion, decreased flexion contracture, and better Lysholm scores; however, patients may still have significant disability [15, 28, 47]. To minimize the risk of postoperative stiffness and graft failure in multiligament-injured knees, concurrent and anatomical reconstruction of all injured structures has been recommended so that knee ROM can be instituted early [48–51].

Multiligamentous reconstruction in the obese or morbidly obese population is associated with several challenges, including longer operating room times, need for special equipment (e.g., bariatric table), and difficulty with positioning [11, 17, 28] (Fig. 35.5). Often multiple or special operative tables are required, as well as the use of extensive incisions and significant blood loss (Fig. 35.5). Operative times have been reported to be significantly longer (5 h compared to 2.5 h) when obese and morbidly obese patients were matched to patients with similar surgery and BMIs between 20 and 30 kg/m^2 [28]. Georgiadis et al. reported difficulty with dissection, retraction, and visualization in morbidly obese patients [16]. Patients often are positioned supine because of their body habitus and concern for airway protection, and any vascular repair must be done from a medial approach [16]. Specialized or larger equipment and implants may be needed. Streubel et al. described a patient with a BMI of 69 in whom difficulties in stabilizing a knee following vascular repair was caused by a lack of Schanz pins large enough for external fixation [11]. Prior to surgery, there may be difficulty in obtaining braces or stabilizing the knee without external fixation, while postoperatively there may be difficulty in fitting custom braces to patients [28, 32]. Use of a tourniquet should be approached cautiously, and used for as little time as possible in patients with a revascularization procedure [38].

Specific attention to reconstruction of the posterolateral corner may be most important in improving outcomes in this population [10].

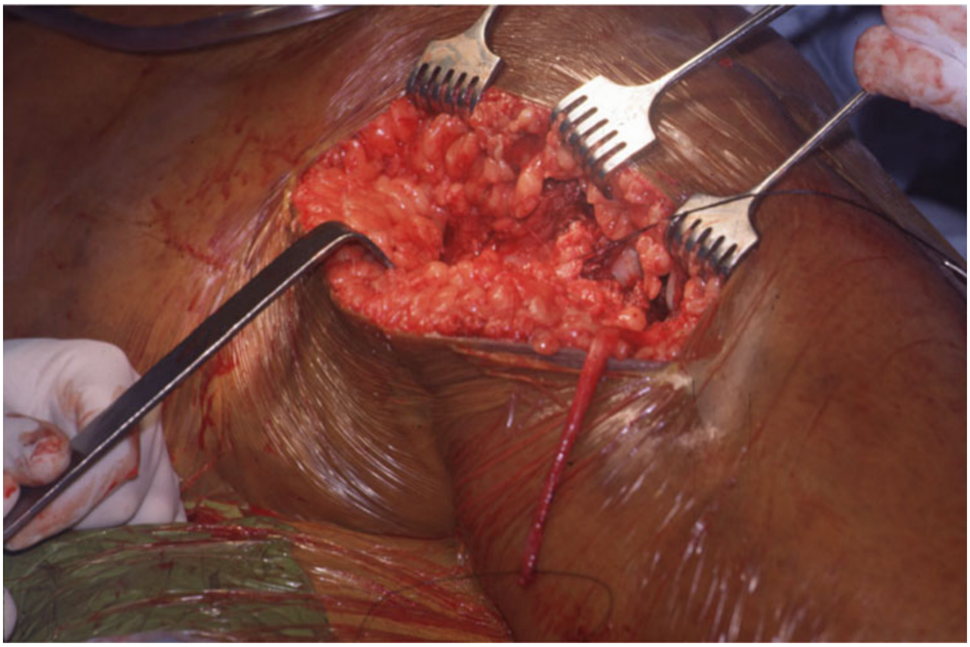


Fig. 35.5 Operative photograph

35.7 Technique

35.7.1 Preoperative Preparation

- At least two assistants are necessary to hold the limb during preparation and draping to prevent neurovascular injury.
- Special accommodations are made as needed to allow safe positioning of the patient on the operating table.
- Availability of a vascular surgeon may be indicated.
- Either no tourniquet is used or tourniquet use is kept to a minimum.
- A thorough examination under anesthesia is carefully performed to confirm the injured structures.
- With acute injuries, limited arthroscopy is done to evaluate meniscal and chondral injuries, which are treated before ligament repair/reconstruction. Some ligament repairs and reconstructions can be done arthroscopically or with arthroscopic assistance; however, arthroscopy should be limited because of the risk of fluid extravasation, which could precipitate compartment syndrome.

35.7.2 Approach for Open Repair/Reconstruction of Ligamentous Injuries

- The approach used depends on the structures injured (Fig. 35.6).

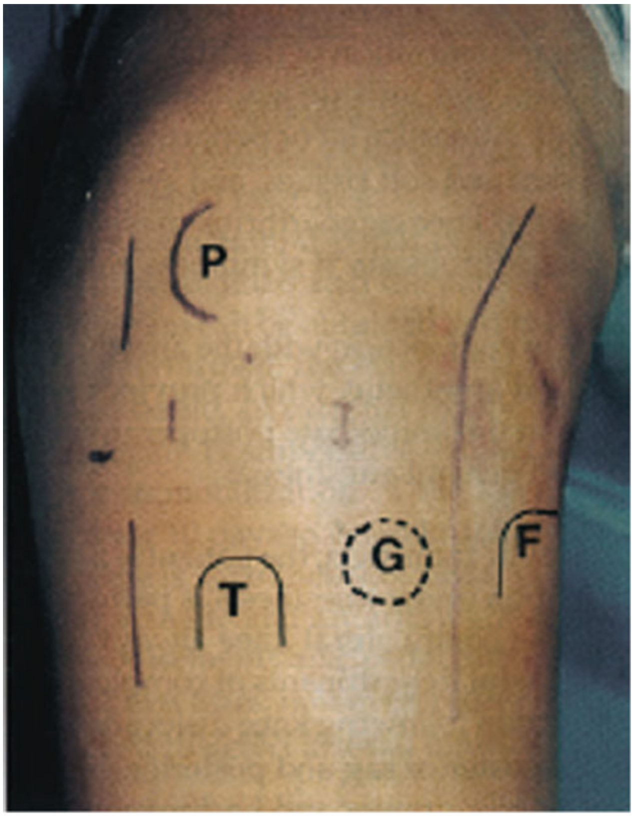


Fig. 35.6 Skin incisions for open lateral or posterolateral reconstruction combined with arthroscopic reconstruction of the anterior and posterior cruciate ligaments. F, fibular head; G, Gerdy tubercle; P, patella; T, tibial tubercle. (From L'Insalata JC, Dowdy PA, Harner CD. Multiple ligament reconstruction. In: Harner CD, Vince KG, Fu FH, editors. Techniques in Knee Surgery, Philadelphia, Lippincott Williams & Wilkins, 2000. Reprinted with permission from Wolters Kluwer Health, Inc.)

- A curved medial utility incision allows exposure of the cruciate ligaments, the medial collateral ligament, and the posteromedial corner.
- A posterior L-shaped incision [52] allows exposure of the tibial insertion of the posterior cruciate ligament for repair of an avulsion fracture or for tibial inlay reconstruction.
- Straight medial and lateral incisions allow exposure of the medial and posteromedial and the lateral and posterolateral structures, respectively.
- A straight midline incision allows exposure to all structures.
- Regardless of the approach used, full-thickness skin flaps should be developed and appropriate skin bridges (more than 7 cm) should be maintained.
- Suggested sequence of surgery:

35.7.3 Postoperative Management

- Anticoagulation medication is recommended for approximately for 4 weeks [53].
- Rehabilitation depends on the individual patient and the type and severity of injuries repaired or reconstructed. Patients are counseled that recovery may take 9–12 months.
- Rehabilitation protocol
  - Postoperative knee brace is worn for the first 12 weeks after surgery and is locked for the first 6 weeks.
  - Patient is non-weightbearing for 8 weeks and partially weightbearing for another 4 weeks (weeks 8–12).
  - Range-of-motion exercises are begun the week after surgery unless otherwise indicated.

○ PCL tibial tunnel		PCL tibial tunnel
○ PCL femoral tunnel	OR	ACL tibial tunnel
○ ACL tibial tunnel		ACL femoral tunnel
○ ACL femoral tunnel		PCL femoral tunnel

○ Passage and fixation of PCL graft in femoral tunnel

○ Passage and fixation of ACL graft in femoral tunnel

○ Passage of PCL graft in tibial tunnel

○ Passage of ACL graft in tibial tunnel

○ Tensioning and fixation of PCL graft with knee in 90 degrees of flexion (may require starting from full extension to ensure that joint is congruent)

○ Tensioning and fixation of ACL graft with knee in full extension

○ Repair, augmentation, and reconstruction of collateral ligaments

○ Range of motion and EUA to ensure proper fixation

○ Radiographic confirmation of knee joint reduction

- Range of motion is limited to 0°–90° for the first 6 weeks, then progresses to full range of motion.
- If the ACL has been reconstructed or repaired, no open chain knee extension for 8 weeks.
- If the PCL has been reconstructed or repaired, no open chain prone knee hangs for 8 weeks.
- If the PLC has been reconstructed or repaired, external tibial rotation and external rotation of the foot/ankle are avoided. Open chain hip abduction also is avoided for 8 weeks.
- If the MCL has been reconstructed or repaired, hip adduction is avoided for 8 weeks.
- Return to full activity is allowed at approximately 12 months.

35.8 Outcomes

While surgical reconstruction leads to improved subjective and objective results in patients with ULV dislocations, these patients may have low postoperative activity scores, reflective of their preoperative activity status [15]. Werner et al. evaluated knee dislocations and found that ULV knee dislocations were associated with worse outcomes than high- and low-velocity injuries, with lower Lysholm and VR-36 (health-related quality of life) scores [54]. Additionally, females were noted to have worse outcomes [36]. Vaidya et al. reported that patients treated operatively had better motion, less instability, and higher levels of activity than those treated nonoperatively [28]. Morbidly obese patients who have ligament reconstruction, however, generally have some loss of motion.

Despite improved outcomes with surgery, many patients with ULV knee dislocations do poorly overall. Werner et al. reported that 71% of their patients were “dissatisfied” or “extremely dissatisfied” with their results after ligamentous reconstruction [36]. Average IKDC and Lysholm scores were low, 40 and 42, respectively. Although IKDC, HSS, Lysholm, and Tegner scores were low in all of their 17 patients with ULVKD, Azar et al. found that those with ligamentous reconstruction with emphasis on posterolateral corner repair or reconstruction had better outcomes than those without repair or reconstruction [15].

A BMI over 35 kg/m^2 also has been associated with increased post-traumatic arthritis following reconstruction for knee dislocation, developing in 33% of those with a BMI over 35 kg/m^2 compared to 11% in those with a lower BMI [55].

When comparing treatment costs and inpatient stay, Johnson et al. found that length of stay was not significantly different, but obese and morbidly obese patients had significantly higher initial hospital costs and overall costs when controlling for vascular injury [23].

35.9 Complications

In ULV knee dislocations, complication rates have ranged as high as 47% [15]. These cohorts have reported significantly higher reoperation, wound infection, arthrofibrosis, and DVT rates, along with vascular claudication, diabetic ketoacidosis, gastrointestinal bleeding, cor pulmonale, delayed Achilles contracture, amputation, and death from cardiac arrest [15, 17, 36]. Ridley et al. determined that for every 1-unit increase in BMI, complication rates increased by 9%. Werner et al., in their retrospective review of 215 patients with multiligament injuries, found a significantly higher overall complication rate among heavier patients with ULV injuries (74%) compared with entire patient group with multiligament injuries (21%) [56].

While study sizes of ULV knee dislocations are small and most involve patients who are morbidly obese or super obese, the effect of BMI on other orthopaedic procedures, particularly arthroplasty, has been extensively described [57–59]. Increasing BMI, specifically morbid obesity, has been shown to increase the occurrence of superficial and deep infections, DVT, and renal insufficiency, and to increase operative time and the number of unplanned reoperations in patients undergoing total knee and hip arthroplasty [59]. When BMI is above 50 kg/m^2 (super obese) rates of venous thromboembolism (VTE), infections, and medical complications are increased compared to normal weight, obese and morbidly obese patients undergoing total knee arthroplasty [58]. A review of Medicare patients with TKA identified a dose-response trend that was significant for increasing BMI and 90-day postoperative complications [60]. Morbidly obese patients had twice the number of wound dehiscence complications and hazard ratios between 1.5 and 2.0 for death, deep infection, acute renal failure, and revision when compared to normal weight controls. Super obese patients were at increased risk of infection, wound dehiscence, acute renal failure, death, readmission, and pulmonary embolism compared to morbidly obese patients. Inpatient hospital charges also were 16.5% higher for super obese than for normal weight patients.

35.9.1 Amputation

Like other complications, amputation rates after ULV knee dislocations vary significantly. Among all knee dislocations in a large case series, the rate of amputations was reported to be 9.2%, with an increased risk for open or high-energy injury or arterial injury [55]. Some smaller case series of

ULV knee dislocations in obese patients report amputation rates of 12–28% [15, 17, 61]. Werner et al., however, reported no amputations in their series of 23 ULV knee dislocations in patients with an average BMI of 49 kg/m^2 [36], and the epidemiologic study by Johnson et al. [23] found that, when vascular injury was controlled, the amputation rate for obese and morbidly obese patients was not significantly different from that in nonobese patients.

Rates of DVT in ULV knee dislocations are infrequently reported, but DVT rates of 3.5% have been reported in studies that include all mechanisms of knee dislocation [13]. There is some evidence that DVT is more frequent in patients with ULV knee dislocations [36, 62]. In the study by Scarcella et al., 13% of patients not requiring amputation had a DVT and 2% had a pulmonary embolism [55]. Werner et al. reported rates of 9% for DVT and 4% for pulmonary embolism in patients with ULV knee dislocations [36].

Postoperative thromboprophylaxis has been shown to be effective in patients with knee dislocations. A prospective study that included 136 patients with fractures and knee dislocations treated with external fixation and LMWH reported an approximately 2% rate of DVT [63]. Born et al. reported that only 3 (2%) of 134 patients with all types of knee dislocations developed symptomatic DVT when treated postoperatively with aspirin or LMWH; two patients who had DVT were obese, and one was a smoker with chronic alcohol use [64]. Given the lack of studies evaluating DVT after knee dislocations in general, much less ULV knee dislocations, the classic risk factors of age over 65, obesity (BMI > 30), smoking, oral contraceptive or hormone replacement, chronic venous insufficiency, and previous DVT should be considered risk factors for thromboembolism in patients with ULV dislocations [65]. Lacking more significant risk factors, the Chest guidelines recommend antithrombotic prophylaxis, preferably LMWH for 35 days and use of intermittent pneumatic compression devices during hospital stay [53].

35.9.2 Arthrofibrosis and Loss of Motion

Arthrofibrosis and loss of motion are frequent after ULV knee dislocations in obese patients. Werner et al. reported a reoperation rate of 39% in 23 patients with surgically reconstructed KD-IIIM and KD-IV injuries, most often for implant removal and lysis of adhesions (9 of 17); five patients required reoperation because of postoperative stiffness [36]. Vaidya et al. reported limited range of motion in all 19 patients (21 knees) in their series. Eight patients who had surgical reconstruction and complied with therapy had an average range of motion of 91.4°, while one patient who was noncompliant had flexion limited to 45° [28]. Ten patients who did not have reconstruction had less motion (average 60.5°); two had subsequent lysis of adhesions and two required total knee arthroplasty, one patient bilaterally, for pain and instability [28].

35.9.3 Recurrent Instability

Although persistent or recurrent instability frequently is included in lists of postoperative complications after ULV knee dislocations [36], the number/percentage of patients with this complication rarely is given. Werner et al. [36] reported graft failure and instability in 2 of 17 patients with ULV knee dislocations, and Vaidya et al., in a report of 18 patients, described late ACL reconstruction because of ongoing instability in one patient. Harner et al. reported that postoperative laxity tests demonstrated consistently improved stability in all of their 31 patients.

35.10 Summary

ULV knee dislocations are rare but increasingly common events, and much of what is known about ULV knee dislocations is from case reports or small retrospective studies. These dislocations occur most frequently in obese, morbidly obese, and super obese patients during everyday activities. ULV knee dislocations can be as severe or more severe than high-velocity knee dislocations. There is evidence that increasing BMI correlates with a more significant risk of neurovascular injuries as well as other complications. These patients also have an increased risk of DVT and should be treated aggressively with prophylactic antithrombotic medication, as well as sequential mechanical compression devices. Diagnosis, early reduction, and identification and treatment of vascular injuries are critical to reducing the risk of limb ischemia and possibly amputation. Given the size of the limb, maintenance of reduction in these patients almost always requires external fixation. While surgery may be technically challenging, surgical reconstruction leads to improved subjective and objective results and is recommended. Discussion with the patient should focus on limited expectations and the high rate of complications because of the nature of their injury, as in many cases these are considered salvage procedures.

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36

Multiple Ligament Knee Injuries in Patients 18 Years of Age and Younger

Gregory C. Fanelli and David Fanelli

36.1 Introduction

The purpose of this chapter is to present the senior author's (GCF) experience treating PCL-based multiple ligament knee injuries in patients 18 years of age and younger. This chapter will discuss patient age at the time of surgery, mechanisms of injury, surgical techniques, considerations in patients with open growth plates, a review of the literature, and the author's surgical outcomes in PCL-based multiple knee ligament reconstructions in patients 18 years of age and younger [1, 2].

36.2 Patient Population

Posterior cruciate ligament reconstructions in patients 18 years of age and younger represent approximately 14% of our total posterior cruciate ligament reconstruction experience at a rural tertiary care medical center [3]. This 14% consists of 58 patients in the combined PCL-collateral ligament group, and 25 patients in the combined PCL-ACL-collateral ligament group for a total of 83 patients. Mechanisms of injury in the PCL-collateral ligament group are sports related in 72%, motor vehicle accident related in 25%, and trampoline accidents in 3%. Mechanisms of injury in the PCL-ACL-collateral ligament group are sports related in 39%, motor vehicle accident related in 57%, and trampoline-related accidents in 4%.

The diagnosis of the posterior cruciate ligament based multiple ligament knee injuries in this 18 years of age and under patient population broken down by percentages are: PCL-lateral side 39%, PCL-medial side 1%, PCL-medial-lateral sides 28%, PCL-ACL-lateral side 17%, PCL-ACL-medial side 12%, and PCL-ACL-medial-lateral sides 3%. Ninety-seven percent of the PCL-collateral group was chronic injuries, while 3% were acute injuries. In contrast, 57% of the PCL-ACL-collateral ligament-injured knees were chronic, while 43% of these knee injuries were acute. Forty-nine percent of the PCL-collateral ligament reconstruction group was right knees, and 51% were left knees. Fifty-eight percent of the PCL-ACL-collateral ligament reconstruction group was right knees, and 42% were left knees.

The mean age at the time of surgery in the PCL-collateral ligament reconstruction group was 16.3 years (range 6–18 years). Three percent of the patients in this group were less than 10 years old, 9% were 10–14 years old, and 88% were 15–18 years old. Sixty-seven percent of the PCL-collateral ligament reconstruction group was boys, and 33% of this group was girls. The age groups of the boys who were less than 10 years old 0%, 10–14 years old 8%, and 15–18 years old 92%. The age groups of the girls who were less than 10 years old were 11%, 10–14 years old 11%, and 15–18 years old 78%.

The mean age at the time of surgery in the PCL-ACL-collateral ligament reconstruction group was 16.7 years (range 13–18 years). Zero percent of the patients in this group were less than 10 years old, 4% were 10–14 years old, and 96% were 15–18 years old. Seventy-six percent of the PCL-ACL-collateral ligament reconstruction group was boys, and 24% of this group was girls. The age groups of the boys who were less than 10 years old were 0%, 10–14 years old 0%, and 15–18 years old 100%. The age groups of the girls who were less than 10 years old were 0%, 10–14 years old 17%, and 15–18 years old 83%.

36.3 Preoperative Planning: Special Considerations

The concern in the pediatric and adolescent patient population with open growth plates is the potential for growth arrest and resultant angular deformity about the knee after surgical

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intervention. This risk can be decreased by insuring that no fixation devices or bone blocks cross or damage the physis during ligament reconstruction. Growth remaining and physiologic stage of development of the patient is very important and is considered in the preoperative planning for the treatment of these complex knee ligament injuries [4, 5]. Adults with PCL injuries will often have mid-substance disruptions of the posterior cruciate ligament, while children may have an increased incidence of PCL avulsion type injuries, both cartilaginous and bony in nature leading to the consideration of primary repair, primary repair with augmentation, and reconstruction of the injured ligaments [6]. Additionally, an understanding of the relationships of the posterior cruciate ligament and collateral ligaments to the physis is important when planning the surgical procedure [7].

36.4 Surgical Techniques and Outcomes in the Literature

Many surgeons have described successful surgical techniques to treat posterior cruciate ligament and multiple knee ligament injuries in patients' with open growth plates. These studies are presented for a broad view of the treatment of these complex knee ligament injuries. Kocher et al. reviewed two separate patient groups with adolescent and pediatric PCL injuries: those managed nonoperatively and those treated surgically with ligament reconstruction or direct repair [6]. The group reviewed 26 PCL (1 bilateral) injuries in patients under age 18 over a 16 year period with a mean follow-up time of 27.8 months. Fourteen patients (15 knees) were treated operatively, and the other 11 patients had nonoperative treatment. All patients were evaluated using Tegner, Lysholm, and Pediatric International Knee Documentation Committee (Pedi-IKDC) scores. The group determined that patient outcomes for nonoperative treatment of nondisplaced avulsion injuries or partial PCL tears are viable in pediatric populations. They also concluded that PCL reconstruction or repair is a suitable treatment option for young patients with multiligament injuries or isolated PCL injuries who fail conservative treatment.

Warme and Mickelson present a case report of a 10-year-old boy who sustained an avulsion of the PCL from the insertion site on the tibia [8]. The boy required a PCL reconstruction after failing conservative treatment and a primary repair attempt. The team completed physeal sparing reconstruction using a modified femoral tunnel placement method combined with tibial inlay technique. The presented method prevented transphyseal drilling and also attained favorable anatomic graft placement. This technique also avoided the "killer" turn often associated with a transtibial approach. The boy had complete return to preinjury level of activity.

Solayar and Kapoor present a case report of a pediatric patient with a PCL avulsion off the insertion site of the tibia with an accompanying posterior horn medial meniscal tear from the posterior capsule [9]. The boy was treated with an open reduction and internal fixation of the detached fragment and suture repair for the meniscal tear. Solayar and Kapoor stress the importance of managing associated intra-articular injuries when treating pediatric PCL tibial avulsions.

Kwon et al. present a case of a 13-year-old girl with tibial detachment of the PCL that was surgically treated with arthroscopic reduction and pull-out suture [10]. The procedure left the epiphyseal plate intact by using a posterior transseptal portal. The Kwon group suggests that this alternative treatment to PCL detachment injuries in pediatric patients will avoid injury to the physeal and maintain ligament tension during healing. However, this is yet to be proven in terms of biomechanical benefit.

The Anderson group reports the case of a pediatric patient with posterolateral knee and posterior instability [11]. The patient failed nonoperative treatment and was successfully treated with physeal saving intra-articular PCL reconstruction and extra-articular posterolateral structure reconstruction.

The Bovid group presents the case of an 11-year-old boy with a high-grade intrasubstance posterior cruciate ligament injury [12]. The injury was operatively treated and reconstructed using the all-arthroscopic tibial inlay technique with a modification to minimize physeal injury risk. The patient returned to preinjury level of activity by 17 months follow-up with no posterior sag and a grade 1 posterior drawer. Radiographs did not indicate degenerative changes. Both the distal femoral and proximal tibial physes were widely patent and showed no angular deformity. The operative limb was longer following surgery with a 1-cm leg length discrepancy.

Accadbled et al. present a case report of an 11-year-old boy with a posterior cruciate ligament rupture [13]. He was operatively treated with an arthroscopic posterior cruciate ligament reconstruction employing a single-bundle four-strand hamstring autograft. At 24 months follow-up, the patient had resumed preinjury level of activity with no growth disturbance indicators and a normal clinical examination.

Stadelmaier et al. studied the inhibitive effects of soft tissue grafts on the formation of a bony bridge within drill tunnels across open tibial and femoral growth plates for a canine model [14]. A fascia lata autograft was positioned in tunnels drilled across the proximal tibial and distal femoral physes in four skeletally immature canines. A control group of four additional canines had a similar procedure, but all drill holes were left unfilled. All growth plates were evaluated at either 2 weeks or 4 months following the procedure with high-resolution radiography and histologic study. This study indicates that a soft tissue graft of fascia lata inserted in drill holes across an open growth plate prevents bony bridge formation. These findings support other clinical studies that report no apparent changes to growth plate function following pediatric intra-articular ACL reconstruction.

MacDonald et al. present a case report of a 6-year-old boy with a partial radial tear of the medial meniscus and a chronic PCL tear [15]. He was treated nonoperatively and at 5 years post injury presented with a looseness sensation in the knee and occasional anterior knee pain. The group concluded that additional follow-up will be necessary to determine if instability will develop into arthritic changes.

Shen et al. present a case report of a 5-year-old boy with posterolateral rotatory instability and posterior cruciate ligament injury [16]. The patient was surgically treated and returned to preinjury level of activity by 4-year follow-up. The findings of the Shen group suggest that operative treatment of acute PCL/PLC injuries can be successful in this patient population.

Wegmann et al. present an overview of ACL, PCL, MCL, LCL and posterolateral corner injuries in pediatric populations [17]. Common pathologies, imaging and treatment modalities are discussed for each injury complex. Specifically for PCL injuries, this group suggests reconstruction in patients with grade 3 injuries with accompanying instability but advocates nonoperative treatment for partial PCL tears or nondisplaced avulsion injuries.

Tanwar et al. present a case report of a 5-year-old female who sustained a popliteal artery thrombosis and compound PCL injury secondary to a dog bite [18]. The PCL injury was managed conservatively with external fixation following thrombectomy and debridement of the wound. At 1 year postoperatively range of motion was 10°–110° with no distal neurovascular defects.

Sørensen et al. present results of six pediatric patients with open physes who underwent PCL reconstruction [19]. Average age at the time of surgery was 9 (range 6–14) with an average follow-up time of 50 months (range 41–90) following surgery. Patients were evaluated with radiologic long-axis leg length measurements, KOOS and Tegner scores, and instrumented knee laxity. The median KOOS score was 88 (range 26–98) and the median Tegner score was 6 (range 4–7) at follow-up. KT-1000 the average side-to-side comparison in laxity was 2 mm (range 1–5) at 25° of flexion and the average was 3 mm (range 3–6) at 70° of flexion. The median side-to-side comparison in flexion was 8°. There was one reported leg length discrepancy of 16 mm and all but one patient returned to previous level of activity.

Fanelli and Fanelli present the results of treatment of PCL-based multiple ligament knee injuries in patients 18 years of age and younger [3]. The PCL combined with collateral ligament injury group included 58 patients with a mean age of 16.3 years (range 6–18 years) with 88% of the patients being in 15–18-year-old age group. Post multiple knee ligament reconstruction, 67% of these patients achieved their preinjury level of Tegner function, and 82% of the patients in this group achieved their preinjury level or one grade lower level of Tegner function. The combined PCL, ACL, collateral ligament group (knee dislocation group) included 22 patients with a mean age of 16.7 years (range 13–18 years) with 96% of the patients being in 15–18-year-old age group. Post multiple knee ligament reconstruction, 55% of these patients achieved their preinjury level of Tegner function, and 75% of the patients in this group achieved their preinjury level or one grade lower level of Tegner function. Mean follow-up of 3.5 years (range 1–17 years) in the PCL-collateral ligament group, and mean follow-up of 4.5 years (range 1–10 years) in the PCL, ACL, collateral ligament (knee dislocation) group, revealed no episodes of growth arrest or angular deformity in either group.

36.5 Authors' Surgical Technique

36.5.1 Graft Selection

Our preferred graft for the posterior cruciate ligament reconstruction is the Achilles tendon allograft without bone plug for single-bundle PCL reconstructions, and Achilles tendon allograft without bone plug and tibialis anterior allografts for double-bundle PCL reconstructions. Achilles tendon allograft without bone plug or other all soft tissue allograft are the preferred grafts for the ACL reconstruction when combined PCL-ACL reconstruction is indicated. The preferred graft material for the lateral posterolateral reconstruction is all soft tissue (no bone plugs) allograft tissue combined with a primary repair, and posterolateral capsular shift procedure. Our preferred method for medial side injuries is a primary repair of all injured structures combined with posteromedial capsular shift and all soft tissue allograft (no bone plugs) supplementation-augmentation as needed. All soft tissue grafts adhere to the principles of Stadelmaier [14].

36.5.2 General Concepts

The principles of reconstruction in the posterior cruciate ligament injured knee and the multiple ligament injured knee are to identify and treat all pathology, accurate tunnel placement, anatomic graft insertion sites, utilize strong graft material, mechanical graft tensioning, secure graft fixation, and a deliberate postoperative rehabilitation program [1–3, 20–33]. The concern in the 18 years of age and younger patient population with open growth plates is the potential for growth arrest and resultant angular deformity about the knee after surgical intervention. This risk can be decreased by insuring that no fixation devices or bone blocks cross or damage the physis during ligament reconstruction. Therefore, in patients with open physes, soft tissue allografts without the bone plugs are used, and no fixation devices cross the physis. Patients with closed or nearly closed growth plates may be treated with the same surgical techniques as adults. Our preference is to perform single-bundle posterior cruciate ligament reconstruction in patients with open growth plates, while single-bundle or double-bundle PCL reconstruction have both been successful in patients with closed or nearly closed growth plates. We have had no patients with growth arrest and resultant angular deformity about the knee after surgical intervention.

36.5.3 Posterior Cruciate Ligament Reconstruction

The patient is placed on the operating room table in the supine position, and after satisfactory induction of anesthesia, the operative and nonoperative lower extremities are carefully examined [29–33]. A tourniquet is applied to the upper thigh of the operative extremity, and that extremity is prepped and draped in a sterile fashion. The well leg is supported by the fully extended operating room table which also supports the surgical leg during medial and lateral side surgery. A lateral post is used to control the surgical extremity. An arthroscopic leg holder is not used. Preoperative and postoperative antibiotics are given, and antibiotics are routinely used to help prevent infection in these time consuming, difficult, and complex cases. Allograft tissue is prepared prior to bringing the patient into the operating room to minimize general anesthesia time for the patient, and to facilitate the flow of the surgical procedure. The reader is referred to Chap. 20 of this book for additional information regarding surgical technique.

The arthroscopic instruments are inserted with the gravity inflow through the superolateral patellar portal. Arthroscopic fluid pumps are not used. Instrumentation and visualization are positioned through inferomedial and inferolateral patellar portals, and can be interchanged as necessary. Additional portals are established as needed. Exploration of the joint consists of evaluation of the patellofemoral joint, the medial and lateral compartments, medial and lateral menisci, and the intercondylar notch. The residual stumps of the posterior cruciate ligaments are debrided; however, the posterior cruciate ligament anatomic insertion sites are preserved to serve as tunnel reference points. When a combined PCL-ACL reconstruction is performed, the same principles apply to preparing for the ACL reconstruction, and the notchplasty for the anterior cruciate ligament portion of the procedure is performed at this time. Care is taken throughout the procedure to protect the proximal tibial and distal femoral growth plates.

An extracapsular extra-articular posteromedial safety incision is made by creating an incision approximately 1.5–2 cm long starting at the posteromedial border of the tibia approximately one inch below the level of the joint line and extending distally. Dissection is carried down to the crural fascia, which is incised longitudinally. An interval is developed between the medial head of the gastrocnemius muscle and the nerves and vessels posterior to the surgeon's finger, and the capsule of the knee joint anterior to the surgeon's finger. The posteromedial safety incision enables the surgeon to protect the neurovascular structures, confirm the accuracy of the PCL tibial tunnel, and to facilitate the flow of the surgical procedure. There is no subperiosteal stripping or elevation from the proximal tibia or distal femur.

The curved over-the-top PCL instruments (Biomet Sports Medicine, Warsaw, Indiana) are used to sequentially lyse adhesions in the posterior aspect of the knee, and elevate the capsule from the posterior tibial ridge. This will allow accurate placement of the PCL/ACL drill guide, and correct placement of the tibial tunnel. Care is taken to gently elevate the posterior capsule only, and not to strip or elevate the periosteum or damage the posterior proximal tibial growth plate.

The arm of the PCL/ACL guide (Biomet Sports Medicine, Warsaw, Indiana) is inserted through the inferior medial patellar portal. The tip of the guide is positioned at the inferior lateral aspect of the PCL anatomic insertion site. This is below the tibial ridge posterior and in the lateral aspect of the PCL anatomic insertion site. The bullet portion of the guide contacts the anteromedial surface of the proximal tibia at a point midway between the posteromedial border of the tibia, and the tibial crest anterior at or just below the level of the tibial tubercle away from the proximal tibial physis. This will provide an angle of graft orientation such that the graft will turn two very smooth 45° angles on the posterior aspect of the tibia. The tip of the drill guide, in the posterior aspect of the tibia is confirmed with the surgeon's finger through the extracapsular extra-articular posteromedial safety incision. Intraoperative AP and lateral X-ray may also be used; however, I do not routinely use intraoperative X-ray. When the PCL/ACL guide is positioned in the desired area, a blunt spade-tipped guide wire is drilled from anterior to posterior below the level of the proximal tibial physis. The surgeon's finger confirms the position of the guide wire through the posterior medial safety incision.

The appropriately sized standard cannulated reamer is used to create the tibial tunnel. The surgeon's finger through the extracapsular extra-articular posteromedial incision is monitoring the position of the guide wire. When the drill is engaged in bone, the guide wire is reversed, blunt end pointing posterior, for additional patient safety. The drill is advanced until it comes to the posterior cortex of the tibia.

The chuck is disengaged from the drill, and completion of the tibial tunnel is performed by hand.

Our preference is to perform single-bundle posterior cruciate ligament reconstruction in patients with open growth plates in order to protect the distal femoral growth plate, while single-bundle or double-bundle PCL reconstruction have both been successful in patients with closed or nearly closed growth plates. This is a decision the surgeon will need to make on each case based on the anatomy at the time of surgery, the patient's development, and expected potential growth remaining. The PCL single-bundle or double-bundle femoral tunnels are made from inside out using the double bundle aimers, or an endoscopic reamer can be used as an aiming device (Biomet Sports Medicine, Warsaw, Indiana). The appropriately sized double-bundle aimer or endoscopic reamer is inserted through a low anterior lateral patellar arthroscopic portal to create the posterior cruciate ligament anterior lateral bundle femoral tunnel. The double-bundle aimer or endoscopic reamer is positioned directly on the footprint of the femoral anterior lateral bundle posterior cruciate ligament insertion site. The appropriately sized guidewire is drilled through the aimer or endoscopic reamer, through the bone, and out a small skin incision. Care is taken to prevent any compromise of the articular surface. The double-bundle aimer is removed, and the endoscopic reamer is used to drill the anterior lateral posterior cruciate ligament femoral tunnel from inside to outside.

When the surgeon chooses to perform a double bundle double femoral tunnel PCL reconstruction, the same process is repeated for the posterior medial bundle of the PCL. Care must be taken to ensure that there will be an adequate bone bridge (approximately 5 mm) between the two femoral tunnels prior to drilling. This is accomplished using the calibrated probe, and direct arthroscopic visualization of the posterior cruciate ligament femoral anatomic insertion sites. Once again, care is taken throughout the procedure to protect the proximal tibial and distal femoral growth plates.

The surgical technique of posterior cruciate ligament femoral tunnel creation from inside to outside is preferred for two reasons. First, there is a greater distance and margin of safety between the posterior cruciate ligament femoral tunnel or tunnels and the medial femoral condyle articular surface using the inside to outside method. Second, more accurate placement of the posterior cruciate ligament femoral tunnels is possible, in the senior author's opinion, because the double bundle aimer or endoscopic reamer can be placed on the anatomic footprint of the anterior lateral or posterior medial posterior cruciate ligament insertion site under direct visualization.

A Magellan suture retriever (Biomet Sports Medicine, Warsaw, Indiana) is introduced through the tibial tunnel into the joint and retrieved through the femoral tunnel. The traction sutures of the graft material are attached to the loop of the Magellan suture retriever, and the graft is pulled into position. The graft material is secured on the femoral side using a bioabsorbable interference screw for primary aperture opening fixation, and a polyethylene ligament fixation button for back up fixation.

The cyclic dynamic method of graft tensioning using the Biomet graft tensioning boot (Biomet Sports Medicine, Warsaw, Indiana) is used to tension the posterior and anterior cruciate ligament grafts [30, 33]. This tensioning method is discussed in Chap. 22 of this book. Tension is placed on the PCL graft distally using the Biomet graft tensioning boot (Biomet Sports Medicine, Warsaw, Indiana). Tension is gradually applied with the knee in zero degrees of flexion (full extension) reducing the tibia on the femur. This restores the anatomic tibial step off. The knee is cycled through a full range of motion multiple times to allow pre-tensioning and settling of the graft. The process is repeated until there is no further change in the torque setting on the graft tensioner. The knee is placed in 70°–90° of flexion and fixation is achieved on the tibial side of the PCL graft with a bioabsorbable interference screw placed just inside the cortex of the tibia, and back up fixation with a bicortical screw and spiked ligament washer or polyethylene ligament fixation button. No fixation devices or bone plugs cross or violate the growth plates.

36.5.4 Anterior Cruciate Ligament Reconstruction

When combined posterior and anterior cruciate ligament reconstructions are performed, the PCL reconstruction is performed first followed by the ACL reconstruction. With the knee in approximately 90° of flexion, the anterior cruciate ligament tibial tunnel is created using a drill guide. The senior author's preferred method of anterior cruciate ligament reconstruction is the transtibial femoral tunnel endoscopic surgical technique. The arm of the drill guide enters the knee joint through the inferior medial patellar portal. The bullet of the drill guide contacts the anterior medial proximal tibia externally at a point midway between the posterior medial border of the tibia, and the anterior tibial crest just above the level of the tibial tubercle away from the proximal tibial physis. An approximate one-centimeter bone bridge exists between the PCL and ACL tibial tunnel starting points on the proximal tibia. The guide wire is drilled through the guide and positioned so that after creating the anterior cruciate ligament tibial tunnel, the graft will approximate the tibial anatomic insertion site of the anterior cruciate ligament. A standard cannulated reamer is used to create the tibial tunnel.

With the knee in approximately ninety to one hundred degrees of flexion, an over-the-top femoral aimer is introduced through the tibial tunnel, and used to position a guide wire on the medial wall of the lateral femoral condyle to create a femoral tunnel approximating the anatomic insertion site of the anterior cruciate ligament. The anterior cruciate ligament graft is positioned, and fixation achieved on the femoral side using cortical suspensory fixation with a polyethylene ligament fixation button. No fixation devices or bone plugs cross or violate the growth plates.

The cyclic dynamic method of tensioning of the anterior cruciate ligament graft is performed using the Biomet graft tensioning boot [30, 33] (Biomet Sports Medicine, Warsaw, Indiana). Traction is placed on the anterior cruciate ligament graft sutures with the knee in zero degrees of flexion, and tension is gradually applied reducing the tibia on the femur. The knee is then cycled through multiple full flexion and extension cycles to allow settling of the graft. The process is repeated until there is no further change in the torque setting on the graft tensioner, and the Lachman and pivot shift tests are negative. The knee is placed in approximately thirty degrees of flexion, and fixation is achieved on the tibial side of the anterior cruciate ligament graft with a bioabsorbable interference screw placed just inside the cortex of the tibia, and back up fixation with a polyethylene ligament fixation button. No fixation devices or bone plugs cross or violate the growth plates.

36.5.5 Posterolateral Reconstruction

Our surgical technique for posterolateral reconstruction is the fibular head based figure of eight free graft technique utilizing semitendinosus allograft. This procedure requires an intact proximal tibiofibular joint and the absence of a severe hyperextension external rotation recurvatum deformity. This technique combined with capsular repair and posterolateral capsular shift procedures mimics the function of the popliteofibular ligament and lateral collateral ligament, tightens the posterolateral capsule, and provides strong allograft tissue to reinforce the posterolateral corner. When there is a disrupted proximal tibiofibular joint or severe hyperextension external rotation recurvatum deformity, a two-tailed (fibular head, proximal tibia) posterior lateral reconstruction is performed in addition to the posterolateral capsular shift procedure protecting the proximal tibial and distal femoral growth plates.

36.5.6 Open Growth Plates

Acute cases in patients with open growth plates, primary repair of all lateral side injured structures are performed with suture anchors and permanent sutures through drill holes as indicated when possible. The primary repair is then augmented with an allograft tissue reconstruction. No fixation devices or bone plugs cross or violate the growth plates. Posterolateral reconstruction with the free graft figure of eight technique utilizes semitendinosus allograft. A lateral curvilinear incision is made. Dissection is carried down to the layer 1 fascia level. The peroneal nerve is identified, peroneal nerve decompression is performed, and the peroneal nerve is protected throughout the entire procedure. When the distal femoral growth plates are open, no hardware or drill holes made on the lateral aspect of the knee that violates the distal femoral physis. The common biceps tendon at its insertion into the fibular head is identified. A semitendinosus allograft is looped around the common biceps tendon insertion at the head of the fibula, and sewn with number two permanent braided sutures where the common biceps tendon and fibular collateral ligament insert into the fibular head. Care is taken to not damage the fibular physis.

The iliotibial band is incised in line with its fibers. Dissection is carried down to the anatomic insertion site of the fibular collateral ligament and the popliteus tendon. A longitudinal incision is made posterior and parallel to the fibular collateral ligament. This incision provides access to the posterolateral compartment of the knee to assess capsular insertion sites for primary repair, and to enable the posterolateral capsular shift. Primary repair is performed as indicated. Posterolateral capsular shift is performed with permanent number 2 ethibond suture with the knee in 90° of flexion.

The semitendinosus allograft limb positioned lateral to the common biceps femoris tendon is passed medial to the iliotibial band and parallel to the fibular collateral ligament. This represents the fibular collateral ligament arm of the fibular head-common biceps femoris tendon based figure of eight posterolateral reconstruction. The semitendinosus allograft limb positioned medial to the common biceps femoris tendon is passed medial to the iliotibial band and medial to the fibular collateral ligament, and parallel to the popliteus tendon. This limb represents the force vector of the popliteus tendon and popliteal fibular ligament. The two limbs of the semitendinosus allograft are crossed in figure of eight fashion and sewn into the respective anatomic insertion sites of the fibular collateral ligament and popliteus tendon on the distal lateral aspect of the femur using number two permanent braided suture. The allograft tissue used for the posterolateral reconstruction is also sewn into the underlying fibular collateral ligament, popliteus tendon, midlateral and posterolateral capsule, and the popliteofibular ligament using number two permanent braided ethibond suture. Throughout the procedure, there is protection of both the fibula and the distal femoral physes, and the peroneal nerve. At the completion of the lateral side procedure, the wound is thoroughly irrigated and closed in layers.

36.5.7 Closed Growth Plates

When the growth plates of the proximal tibia and distal femur are functionally closed, the posterolateral reconstruction is carried out as follows. Posterolateral reconstruction with the free graft figure of eight technique utilizes semitendinosus allograft. A curvilinear incision is made in the lateral aspect of the knee extending from the interval between Gerdy's tubercle and the fibular head to the lateral epicondyle and then proximal following the course of the iliotibial band. A peroneal nerve decompression is performed, and the peroneal nerve is protected throughout the procedure. The fibular head is identified and a tunnel is created in an anterior to posterior direction at the area of maximal fibular head diameter. The tunnel is created by passing a guide pin followed by a standard cannulated drill 7 mm in diameter. The peroneal nerve is protected during tunnel creation, and throughout the procedure. The free tendon graft is passed through the fibular head drill hole. An incision is made in the iliotibial band in line with the fibers exposing the lateral femoral epicondyle area of the distal femur. The graft material is passed medial to the iliotibial band for the fibular collateral ligament limb, and medial to the common biceps tendon and iliotibial band for the popliteus tendon popliteofibular ligament limb. The limbs of the graft are crossed to form a figure of eight with the fibular collateral ligament component located lateral to the popliteus tendon component. A 3.2 mm drill hole is made to accommodate a 6.5 mm diameter fully threaded cancellous screw that is approximately 35–40 mm in length. The drill hole is positioned in the lateral epicondylar region of the distal lateral femur so that after seating a 17–20 mm washer with the above-mentioned screw, the washer will precisely secure the two limbs of the allograft tissue at the respective anatomic insertion sites of the fibular collateral ligament and popliteus tendon on the distal lateral femoral condyle. This drill hole is approximately 1 cm anterior to the fibular collateral ligament femoral insertion. A longitudinal incision is made in the lateral capsule just posterior to the fibular collateral ligament in the interval between the midlateral and posterolateral capsule, and the posterolateral capsular shift is performed using number 2 ethibond permanent braided suture. The graft material is tensioned at approximately 40°–45° of knee flexion with a slight valgus force applied and slight internal tibial rotation, and secured to the lateral femoral epicondylar region with a screw and spiked ligament washer at the above-mentioned point. Number two ethibond suture is used to sew the tails of the graft together proximal to the washer to prevent slipping, and also to sew the allograft to the deep capsular layers for additional reinforcement. The iliotibial band incision is closed. The procedures described are designed to eliminate posterolateral axial rotation and varus rotational instability.

36.5.8 Two-Tailed Graft with Open Growth Plates

When there is a disrupted proximal tibiofibular joint, or a hyperextension external rotation recurvatum deformity, a two-tailed (fibular head, proximal tibia) posterior lateral reconstruction is utilized combined with a posterolateral capsular shift. A seven or eight-millimeter drill hole is made over a guide wire approximately two centimeters below the lateral tibial plateau and below the proximal tibial physis. A tibialis allograft is passed through this tibial drill hole and follows the course of the popliteus tendon to its anatomic insertion site on the lateral femoral epicondylar region. Nerves and blood vessels are protected. The tibialis allograft tendon is secured with a suture anchor, and multiple number two braided non-absorbable ethibond sutures at the popliteus tendon anatomic femoral insertion site with no violation of the distal femoral physis. The knee is cycled through multiple sets of full flexion and extension cycles, placed in ninety degrees of flexion, the tibia slightly internally rotated, slight valgus force applied to the knee, and the graft tensioned, and secured in the tibial tunnel with a bioabsorbable interference screw that does not violate the growth plate, and polyethylene ligament fixation button. The fibular head based reconstruction and posterolateral capsular shift procedures are then carried out as described above.

36.5.9 TwoTailed Graft with Closed Growth Plates

When the growth plates of the proximal tibia and distal femur are functionally closed, the posterolateral reconstruction is carried out as follows. A seven or eight-millimeter drill hole is made over a guide wire approximately two centimeters below the lateral tibial plateau. A tibialis allograft is passed through this tibial drill hole and follows the course of the popliteus tendon to its anatomic insertion site on the lateral femoral epicondylar region. Nerves and blood vessels must be protected. The tibialis allograft is secured with a suture anchor and multiple number two braided non-absorbable sutures at the popliteus tendon anatomic femoral insertion site. The knee is cycled through multiple sets of full flexion and extension cycles, placed in ninety degrees of flexion, the tibia slightly internally rotated, slight valgus force applied to the knee, and the graft tensioned and secured in the tibial tunnel with a bioabsorbable interference screw, and polyethylene ligament fixation button. The fibular head based reconstruction and posterolateral capsular shift procedures are then carried out as described above.

36.5.10 Posteromedial Reconstruction

The surgical leg positioned on the extended operating room table in a supported flexed knee position. Posteromedial and medial reconstructions are performed through a medial curved incision taking care to maintain adequate skin bridges between incisions. In acute cases, primary repair of all medial side injured structures is performed with suture anchors and permanent sutures as indicated. The primary repair is then augmented with an allograft tissue reconstruction. Care is taken to make sure that there is no compromise or violation of the proximal tibia or distal femoral growth plates.

In chronic cases of posteromedial reconstruction, the Sartorius fascia is incised and retracted exposing the superficial medial collateral ligament and the posterior medial capsule. Nerves, blood vessels, and the growth plates are protected throughout the procedure. A longitudinal incision is made just posterior to the posterior border of the superficial medial collateral ligament. Care is taken not to damage the medial meniscus during the capsular incision. Avulsed capsular structures are primarily repaired using suture anchors and number two permanent braided sutures. The interval between the posteromedial capsule and medial meniscus is developed. The posteromedial capsule is shifted in an anterior and superior direction. The medial meniscus is repaired to the new capsular position, and the shifted capsule is sewn into the medial collateral ligament using three number two ethibond permanent braided sutures in horizontal mattress fashion, and that suture line is reinforced using a running number two ethibond permanent braided suture.

When superficial medial collateral ligament reconstruction is indicated, this is performed using allograft tissue after completion of the primary capsular repair, and posteromedial capsular shift procedures are performed as outlined above. This graft material is attached at the anatomic insertion sites of the superficial medial collateral ligament on the tibia using a screw and spiked ligament washer or suture anchors. Care is taken to make sure that there is no compromise or violation of the proximal tibia or distal femoral growth plates. The graft is looped around the adductor magnus tendon on the distal medial femur, tensioned, and sewn back to itself using number two ethibond permanent braided sutures. The final graft tensioning position is approximately 30°–40° of knee flexion. Our preference is to secure the tibial insertion site first, and to perform the final tensioning and fixation of the allograft tissue on the femoral side. Number two ethibond permanent braided sutures are used to sew the allograft to the deep capsular layers for additional reinforcement. In patients with closed growth plates, screw and washer fixation may be used if desired on both the tibia and femur to secure the allograft tissue.

36.6 Postoperative Rehabilitation Program

The knee is maintained in full extension for three to five weeks non-weight bearing. Progressive range of motion begins during postoperative week three to five. Progressive weight-bearing occurs at the beginning of postoperative weeks three through five. Progressive closed kinetic chain strength training, proprioceptive training, and continued motion exercises are initiated very slowly beginning at postoperative week twelve. The long leg range of motion brace is discontinued after the tenth week. Return to sports and heavy labor occurs after the ninth to twelfth postoperative month when sufficient strength, range of motion, and proprioceptive skills have returned [34–38]. It is very important to carefully observe these complex knee ligament injury patients, and get a feel for the “personality of the knee”. The surgeon may need to make adjustments and individualize the postoperative rehabilitation program as necessary. Careful and gentle range of motion under general anesthesia is a very useful tool in the treatment of these complex cases, and is utilized as necessary. Our postoperative rehabilitation program is discussed in more detail in Chap. 25 of this book.

36.7 Authors’ Results

We present the results of treatment of 58 patients in the combined PCL-collateral ligament group, and 25 patients in the combined PCL-ACL-collateral ligament (knee dislocation) group for a total of 83 patients [1–3]. Mechanisms of injury in the PCL-collateral ligament group are sports related in 72%, motor vehicle accident related in 25%, and trampoline accidents in 3%. Mechanisms of injury in the PCL-ACL-collateral ligament (knee dislocation) group are sports related in 39%, motor vehicle accident related in 57%, and trampoline-related accidents in 4%.

The diagnosis of the posterior cruciate ligament based multiple ligament knee injuries in this 18 years of age and under patient population broken down by percentages are PCL-lateral side 39%, PCL-medial side 1%, PCL-medial-lateral sides 28%, PCL-ACL-lateral side 17%, PCL-ACL-medial side 12%, and PCL-ACL-medial-lateral sides 3%. Ninety-seven percent of the PCL-collateral group was chronic injuries, while 3% were acute injuries. In contrast, 57% of the PCL-ACL-collateral ligament-injured knees were chronic, while 43% of these knee injuries were acute. Forty-nine percent of the PCL-collateral ligament reconstruction group was right knees, and 51% were left knees. Fifty-eight percent of the PCL-ACL-collateral ligament reconstruction group was right knees, and 42% were left knees.

The mean age at the time of surgery in the PCL-collateral ligament reconstruction group was 16.3 years (range 6–18 years). Three percent of the patients in this group were less than 10 years old, 9% were 10–14 years old, and 88% were 15–18 years old. Sixty-seven percent of the PCL-collateral ligament reconstruction group was boys, and 33% of this group was girls. The age group of boys less than 10 years old was 0%, 10–14 years old 8%, and 15–18 years old 92%. The age groups of the girls who were less than 10 years old were 11%, 10–14 years old 11%, and 15–18 years old 78%.

The mean age at the time of surgery in the PCL-ACL-collateral ligament (knee dislocation) reconstruction group was 16.7 years (range 13–18 years). Zero percent of the patients in this group were less than 10 years old, 4% were 10–14 years old, and 96% were 15–18 years old. Seventy-six percent of the PCL-ACL-collateral ligament reconstruction group was boys, and 24% of this group was girls. The age groups of the boys who were less than 10 years old were 0%, 10–14 years old 0%, and 15–18 years old 100%. The age groups of the girls who were less than 10 years old were 0%, 10–14 years old 17%, and 15–18 years old 83%. All patients in this series received the surgical techniques they required as described above.

It is very important for the reader to understand that the majority of patients in our series were in the 15–18-year-old age group, and that our surgical technique was adjusted to accommodate to the stage of development of the growth plate at the time of surgery as described in the surgical technique section of this article. Postoperatively, the patients were evaluated with range of knee motion, KT 1000 arthrometer, 90° knee flexion posterior tibial displacement stress radiography, Lysholm, Tegner, and Hospital for Special Surgery knee ligament rating scales, X-ray, and physical examination [39–41].

36.7.1 PCL + Collateral Ligament Group

The results of our combined posterior cruciate ligament and collateral ligament reconstruction group (PCL + collateral ligament) are as follows. Fifty-one percent of the patients in this group (29/57) had single-bundle PCL reconstruction, while 49% (28/57) of the PCL-collateral ligament group received a double bundle PCL reconstruction. The mean follow-up for this group of 58 patients was 3.5 years with a range of 1–17 years. The postoperative mean range of motion difference between the surgical knee and the nonsurgical normal knee was a 9.6° loss of terminal flexion with a range of 0°–32° of terminal flexion loss. There were no flexion contractures in this series of patients.

Tibiofemoral displacement measurements were performed using the KT 1000 knee arthrometer (Medmetric Corporation, San Diego, California, USA) and the Telos stress radiography device (Austin Associates, Baltimore, Maryland, USA). Postoperative mean KT 1000 side-to-side difference measurements in millimeters (mm) for the PCL screen, corrected posterior, and corrected anterior were 2.5 mm (range −0.5 to 6.0 mm), 3.3 mm (range −1.0 to 7.0 mm), and 0.1 mm (range −1.5 to 3.0 mm), respectively. The KT 1000 arthrometer 30 lb anterior displacement mean side-to-side difference measurement at 30° of knee flexion was 1.6 mm (range −2.0 to 5.0 mm). Ninety-degree knee flexion stress radiography with a posterior directed force applied to the proximal tibia using the Telos device mean side-to-side difference measurement was 2.5 mm (range −0.4 to 18.1 mm).

Lysholm, Hospital for Special Surgery, and Tegner knee ligament rating scales were used to evaluate the patient outcomes postoperatively. The Lysholm, Hospital for Special Surgery, and Tegner mean postoperative values were 93/100 (range 83–100), 90/100 (range 75–100), and 6/10 (range 3–9), respectively. Sixty-seven percent (32/48) of patients returned to their preinjury Tegner level of function, while 15% (7/48), 6% (3/48), 4% (2/48), and 8% (4/48) of the patients were 1, 2, 3, and 4 Tegner levels below their preinjury Tegner level of function, respectively.

Physical examination tests used to evaluate the postoperative outcomes of the combined PCL-collateral ligament group included the posterior drawer, Lachman, pivot shift, varus stress, valgus stress, and the axial rotation dial tests. All physical examination tests compared the postoperative surgical knee to the normal uninjured nonsurgical knee. The posterior drawer test was normal in 63% (34/54), grade ½ laxity in 9% (5/54), grade 1 laxity in 26% (14/54), and grade 3 laxity in 2% (2/54). The Lachman and pivot shift tests were 100% normal in this intact anterior cruciate ligament group of patients as expected. The varus stress test at 0° and 30° of knee flexion were symmetrical to the normal knee in all patients tested (54/54). The valgus stress test at 0° and 30° of knee flexion were symmetrical to the normal knee in 98% (53/54), and grade 1 laxity in 2% (1/54). The axial rotation dial test at 30° and 90° of knee flexion was symmetrical to the contralateral normal knee in 87% (47/54) of patients, and less external rotation than the contralateral normal knee in 13% (7/54). There were no patients with growth arrest or resultant angular deformity about the knee after surgical intervention in any age group.

36.7.2 PCL + ACL + Collateral Ligament (Knee Dislocation) Group

The results of our combined posterior cruciate ligament, anterior cruciate ligament, and collateral ligament (PCL + ACL + collateral ligament) reconstruction group are presented here. Fifty-nine percent of the patients in this group (13/22) had single-bundle PCL reconstruction, while 41% (9/22) of the PCL-collateral ligament group received a double bundle PCL reconstruction. The mean follow-up for this group of 22 patients was 4.5 years with a range of 1–10 years. The postoperative mean range of motion difference between the surgical knee and the nonsurgical normal knee was an 11.3° loss of terminal flexion with a range of 0°–43° of terminal flexion loss. There were no flexion contractures in this series of patients.

Tibiofemoral displacement measurements were performed using the KT 1000 knee arthrometer (Medmetric Corporation, San Diego, California, USA) and the Telos stress radiography device (Austin Associates, Baltimore, Maryland, USA). Postoperative mean KT 1000 side-to-side difference measurements in millimeters (mm) for the PCL screen, corrected posterior, and corrected anterior were 1.7 mm (range 0.0–3.0 mm), 2.0 mm (range −1.0 to 5.0 mm), and 0.6 mm (range −1.5 to 4.0 mm), respectively. The KT 1000 arthrometer 30 lb anterior displacement mean side-to-side difference measurement at 30° of knee flexion was 2.2 mm (range −1.0 to 5.0 mm). Ninety-degree knee flexion stress radiography with a posterior directed force applied to the proximal tibia using the Telos device mean side-to-side difference measurement was 2.9 mm (range 0.0–12.7 mm).

Lysholm, Hospital for Special Surgery, and Tegner knee ligament rating scales were used to evaluate the patient outcomes postoperatively. The Lysholm, Hospital for Special Surgery, and Tegner mean postoperative values were 93/100 (range 69–100), 89/100 (range 76–96), and 5/10 (range 3–9), respectively. Fifty-five percent (11/20) of patients returned to their preinjury Tegner level of function, while 20% (4/20), 10% (2/20), and 15% (3/20) of the patients were 1, 2, and 3 Tegner levels below their preinjury Tegner level of function, respectively.

Physical examination tests used to evaluate the postoperative outcomes of the combined PCL-collateral ligament group included the posterior drawer, Lachman, pivot shift, varus stress, valgus stress, and the axial rotation dial tests. All physical examination tests compared the postoperative surgical knee to the normal uninjured nonsurgical knee. The posterior drawer test was normal in 65% (13/20), grade 1 laxity in 30% (6/20), and grade 2 laxity in 5% (1/20). The Lachman and pivot shift tests were symmetrical to the normal knee in 95% (19/20), and grade 1 laxity in 5% (1/20). The varus stress test at 0° and 30° of knee flexion was symmetrical to the normal knee in all patients tested (20/20). The valgus stress test at 0° and 30° of knee flexion was symmetrical to the normal knee in all patients tested (20/20). The axial rotation dial test at 30° and 90° of knee flexion was symmetrical to the contralateral normal knee in 100% (20/20) of patients in the PCL + ACL + collateral ligament group. There were no patients with growth arrest or resultant angular deformity about the knee after surgical intervention in any age group.

36.8 Case Presentation

The patient is a 12-year-old boy referred to me three weeks after a right knee injury sustained playing baseball [1]. The patient slid into base and collided with another player and the fixed base with his knee in ninety degrees of flexion. Initial evaluation by another physician revealed a bloody effusion upon aspiration, posterior tibial translation at ninety degrees of flexion, and an MRI study of the right knee demonstrating a posterior cruciate ligament tear. The patient was referred to me for evaluation and treatment.

Physical examination comparing the injured right knee to the uninvolved left knee revealed the skin and neurovascular status to be intact. Range of knee motion was symmetrical to the uninvolved left knee. There was no pain or restriction of motion at the hip or ankle on the involved or normal side. The tibial step offs were decreased, and the posterior drawer test was positive. There were positive posterolateral and posteromedial drawer tests, and the dial test was positive at both thirty and ninety degrees of knee flexion. The knee was stable to valgus stress at zero and thirty degrees of knee flexion, and there was varus laxity at both zero and ninety degrees of knee flexion with a soft endpoint. The hyperextension external rotation recurvatum test was negative, and the heel lift-off test was symmetrical on the injured and noninjured side. The Lachman test and pivot shift tests were both negative.

Initial radiographs taken in the orthopaedic clinic demonstrated open growth plates on the distal femur and the proximal tibia with no fractures (Fig. 36.1). There was no physeal injury noted on stress radiography, or MRI imaging. Magnetic resonance imaging showed a tear of the posterior cruciate ligament, and bone marrow edema without fracture in the anterior tibial epiphysis in the midline. There were no articular cartilage injuries or meniscus tears.

KT 1000 arthrometer testing revealed the following side-to-side difference measurements: PCL screen at ninety degrees of knee flexion six millimeters, corrected posterior measurement at seventy degrees of knee flexion six millimeters, corrected anterior measurement at seventy degrees of knee flexion four millimeters, and the thirty-pound anterior displacement measurement at thirty degrees of knee flexion was one millimeter. Side-to-side difference on stress radiography at ninety degrees of knee flexion with a posterior displacement force applied to the tibial tubercle area of the proximal tibia using the Telos device comparing the involved to the normal knee was ten millimeters (Fig. 36.2).

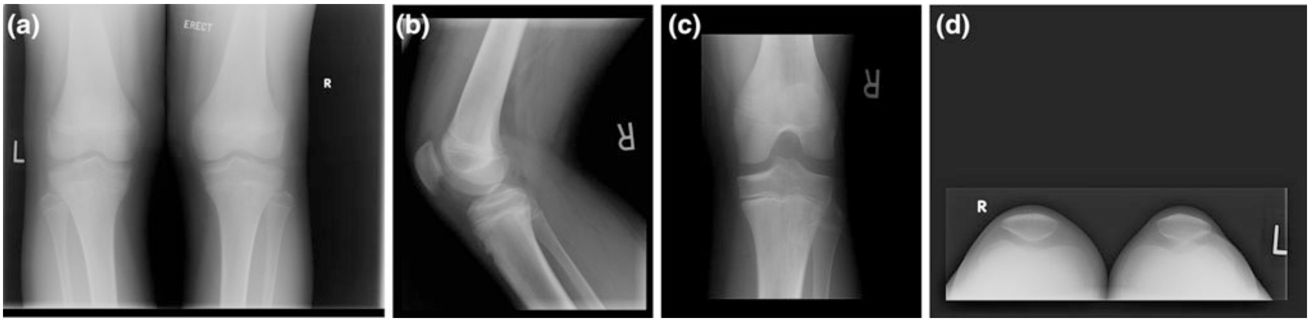


Fig. 36.1 **a–d** Preoperative radiographs in a 12-year-old boy. The diagnosis in this patient is a right knee posterior cruciate ligament based multiple ligaments injured knee with posterior cruciate ligament tear, posteromedial instability type A, and posterolateral instability type B in a patient with open growth plates

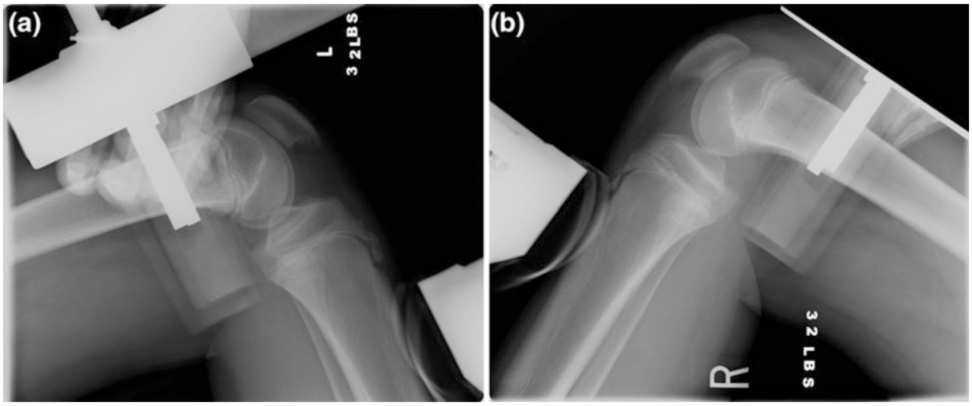


Fig. 36.2 Preoperative stress radiography with a posteriorly directed force applied to the proximal tibia of the normal uninjured knee (**a**) and the PCL, posterolateral, posteromedial injured knee (**b**). These stress radiographs demonstrate increased posterior translation at approximately 90° of knee flexion in the injured knee compared to the normal knee. Side-to-side difference on stress radiography at ninety degrees of knee flexion with a posterior displacement force applied to the tibial tubercle area of the proximal tibia using the Telos device comparing the involved to the normal knee was ten millimeters increased posterior tibial translation compared to the normal knee

Preoperative testing with three knee ligament rating scales revealed the following: Hospital for Special Surgery score was 42/100, Lysholm score was 44/100, and the Tegner activity score was 3 (preinjury, the patient was level 7).

The diagnosis in this patient is a right knee sub-acute posterior cruciate ligament based multiple ligament injured knee with posterior cruciate ligament tear, posteromedial instability type A, and posterolateral instability type B in a patient with open growth plates. The decision was made to proceed with arthroscopic single-bundle transtibial posterior cruciate ligament reconstruction using fresh-frozen Achilles tendon allograft without bone plug combined with fibular head based figure of eight posterolateral reconstruction using fresh frozen semitendinosus allograft. The posterior cruciate ligament reconstruction femoral tunnel crossed the distal femoral physis, and the PCL tibial tunnel was positioned distal to the tibial physis. Cortical suspensory fixation with two stacked polyethylene ligament fixation buttons was used on the femoral side, and a bioabsorbable interference screw and bicortical screw and spiked ligament washer were used on the tibial side fixation. No fixation device crossed the growth plates, and there were no bone plugs on the Achilles tendon allograft tissue, so no bone plug crossed the growth plate (Fig. 36.3).

The posterolateral reconstruction was a fibular head based figure of eight reconstruction using a fresh frozen semitendinosus allograft. The allograft was looped around the common biceps tendon at the fibular head and sewn there using permanent braided suture. The fibular collateral ligament component was passed medial to the iliotibial band, and the popliteofibular popliteus tendon component passed medial to the common biceps tendon and the iliotibial band. The allograft limbs were crossed in figure of eight fashion with the fibular collateral component being lateral to the popliteus

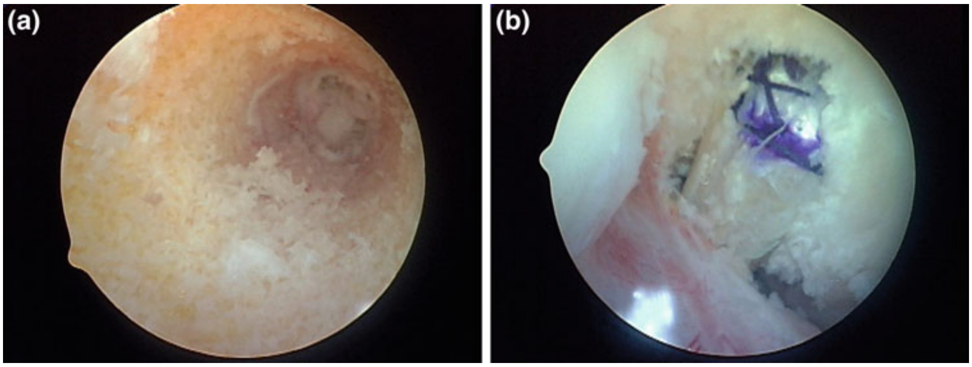


Fig. 36.3 The posterior cruciate ligament reconstruction femoral tunnel crossed the distal femoral physis (**a**), and the PCL tibial tunnel was positioned distal to the tibial physis. Cortical suspensory fixation with two stacked polyethylene ligament fixation buttons were used on the femoral side, and a bioabsorbable interference screw and bicortical screw and spiked ligament washer were used on the tibial side fixation. No fixation device crossed the growth plates, and there were no bone plugs on the Achilles tendon allograft tissue, so no bone plug crossed the growth plate (**b**)

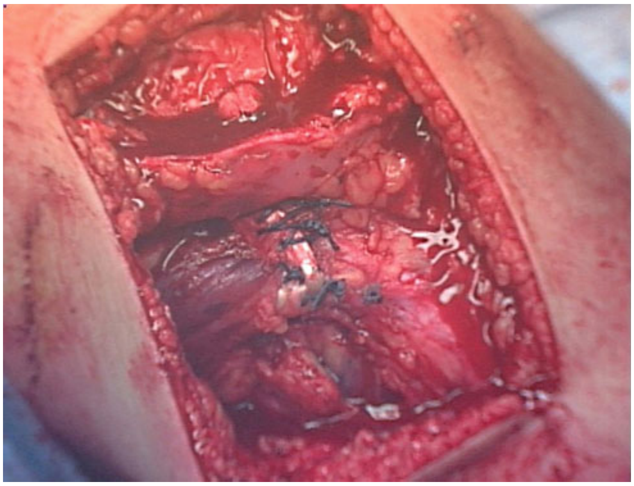


Fig. 36.4 The posterolateral reconstruction was a fibular head based figure of eight reconstruction using a fresh frozen semitendinosus allograft. The allograft was looped around the common biceps tendon at the fibular head and sewn there using permanent braided suture. The fibular collateral ligament component was passed medial to the iliotibial band, and the popliteofibular popliteus tendon component passed medial to the common biceps tendon and the iliotibial band. The allograft limbs were crossed in figure of eight fashion with the fibular collateral component being lateral to the popliteus tendon component. The graft limbs were sewn into their respective anatomic femoral insertion sites with number 2 braided permanent sutures with a slight valgus applied to the knee to close the lateral compartment with the knee in approximately ninety degrees of flexion. The allograft was then sewn to the deep capsular layers for additional reinforcement, and a posterolateral capsular shift was also performed. There were no drill holes through or around the lateral side growth plates

tendon component. The graft limbs were sewn into their respective anatomic femoral insertion sites with number 2 braided permanent sutures with a slight valgus applied to the knee to close the lateral compartment with the knee in approximately ninety degrees of flexion. The allograft was then sewn to the deep capsular layers for additional reinforcement, and a posterolateral capsular shift was also performed. There were no drill holes through or around the lateral side growth plates (Fig. 36.4).

The posteromedial reconstruction was performed using the posteromedial capsular shift technique (Fig. 36.5). This was an all-suture posteromedial capsular advancement procedure performed with the knee in approximately forty-five degrees of flexion as described in Chap. 20 of this textbook. The posterior cruciate ligament reconstruction, the posterolateral reconstruction, and the posteromedial reconstruction procedures were all protective of the growth plates. Postoperatively, the surgical knee was immobilized in a long leg brace locked in full extension, and was non-weight bearing with crutches. Prophylactic preoperative and postoperative antibiotics were utilized. Progressive weight bearing and range of knee motion were gradually initiated according to our postoperative rehabilitation program detailed in Chap. 39 of this textbook.

Six years follow-up postoperative examination of the patient age of 19 reveals equal leg lengths, normal and symmetrical carrying angles, and normal gait during ambulation. Radiographs reveal closed distal femoral and proximal tibial physes that are symmetrical to the normal knee with no malalignment, no evidence of growth arrest, and no degenerative changes (Fig. 36.6). Physical examination of the surgical right knee compared to the normal left knee reveals the posterior drawer is negative, posteromedial and posterolateral drawer tests are negative, and the dial test is symmetrical at 30 and 90° of knee flexion. The Lachman test is negative, the pivot shift test is negative, and the surgical knee is stable to varus and valgus stress throughout the flexion-extension arc.

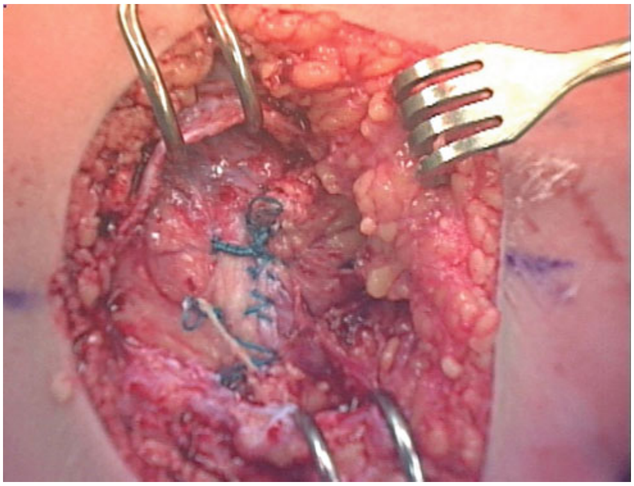


Fig. 36.5 The posteromedial reconstruction was performed using the posteromedial capsular shift technique. This was an all suture posteromedial capsular advancement procedure performed with the knee in approximately forty-five degrees of flexion. A longitudinal incision is made just posterior to the posterior border of the superficial medial collateral ligament. Care is taken not to damage the medial meniscus during the capsular incision. Avulsed capsular structures are primarily repaired using suture anchors and number two permanent braided sutures. The interval between the posteromedial capsule and medial meniscus is developed. The posteromedial capsule is shifted in an anterior and superior direction. The medial meniscus is repaired to the new capsular position, and the shifted capsule is sewn into the medial collateral ligament using three number two ethibond permanent braided sutures in horizontal mattress fashion, and that suture line is reinforced using a running number two ethibond permanent braided suture

The hyperextension external rotation recurvatum and heel lift off tests are symmetrical compared to the normal knee.

Three-year postoperative KT 1000, stress radiography, and knee ligament rating scale measurements reveal the following. Range of motion is 0°–125° on the surgical right knee, and 0°–130° on the uninvolved left knee. Side-to-side difference on KT 1000 measurements on the PCL screen, corrected posterior, and corrected anterior measurements are 2.0, 2.5, and −2.0 mm, respectively. Side-to-side difference on the KT 1000 anterior displacement measurement at 30° of knee flexion is 2.0 mm. Stress X-rays at 90° of knee flexion using the Telos device comparing the surgical to the knee normal knee reveal a 1.8 mm side-to-side difference (Fig. 36.7). The Hospital for Special Surgery, Lysholm, and Tegner knee ligament rating scale scores are 98/100, 99/100, and 7. The patient's preinjury Tegner score was 7 indicating a return to preinjury level of function.

36.9 Summary

The concern in the pediatric and adolescent patient population with open growth plates is the potential for growth arrest and resultant angular deformity about the knee after surgical intervention. This risk can be decreased by insuring that no fixation devices or bone blocks cross or damage the physis during ligament reconstruction. Growth remaining and physiologic stage of development of the patient is very important, and is considered in the preoperative planning for the treatment of these complex knee ligament injuries. Adults with PCL injuries will often have mid-substance disruptions of the posterior cruciate ligament, while children may have an increased incidence of PCL avulsion type injuries, both cartilaginous and bony in nature, leading to the consideration of primary repair, primary repair with augmentation, and reconstruction of the injured ligaments. Additionally, an understanding of the relationships of the posterior cruciate ligament and collateral ligaments to the physis is important when planning the surgical procedure.

The majority of patients in our experience are in the 15–18-year-old age group, and our surgical technique was adjusted to accommodate to the stage of development of the growth plate at the time of surgery as described in the surgical technique section of this chapter. Many surgeons have described successful surgical techniques to treat posterior cruciate ligament and multiple knee ligament injuries in patients' with open growth plates, and these concepts should be incorporated into the surgical planning in patients with open growth plates. Patients with closed or nearly closed growth plates may be treated with the same surgical techniques as adults, while skeletally immature patients require modified surgical techniques outlined in this chapter. Our preference is to perform single-bundle posterior cruciate ligament reconstruction in patients with open growth plates, while single-bundle or double-bundle PCL reconstruction have both been successful in patients with growth plates that are closed or nearly closed [42]. Anterior cruciate ligament and collateral ligament surgery must also respect the stage of development of the physis. Thus, far in the senior author's experience, there have been no patients with growth arrest

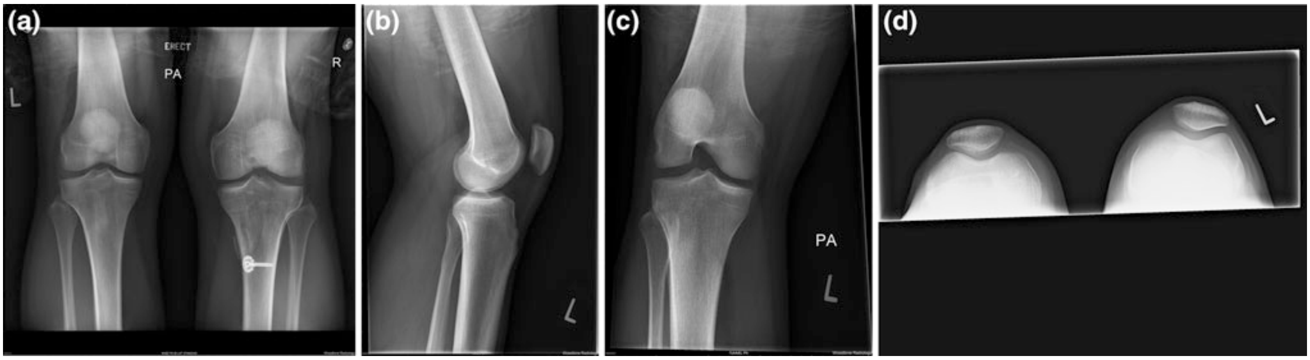
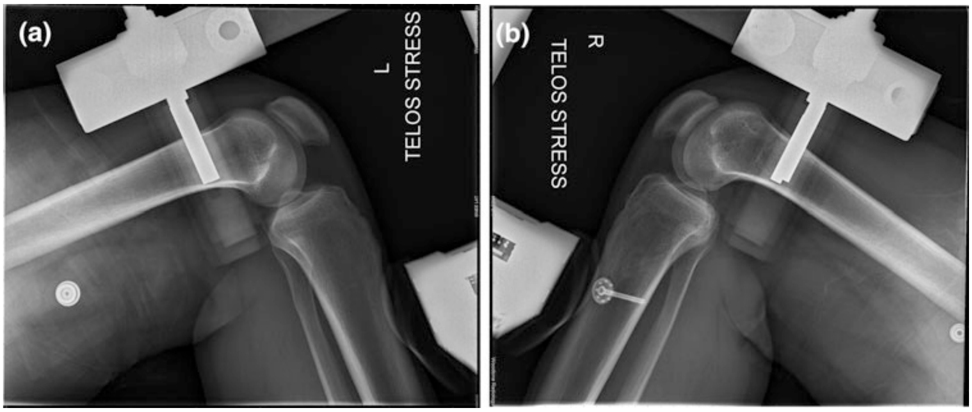


Fig. 36.6 **a**–**d** Six years follow-up postoperative examination of the patient at the age of 19 reveals equal leg lengths, normal and symmetrical carrying angles, and normal gait during ambulation. Radiographs reveal closed distal femoral and proximal tibial physes that are symmetrical to the normal knee with no malalignment, no evidence of growth arrest, and no degenerative changes

Fig. 36.7 Six-year postoperative stress X-rays at 90° of knee flexion using the Telos device comparing the normal knee (**a**) to the surgical knee (**b**) reveal a 1.8 mm side-to-side difference



and resultant angular deformity about the knee after surgical intervention in any age group.

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Anterolateral Complex Reconstruction in the Multiple-Ligament Injured Knee

37

Ryan Wood, Robert Litchfield, and Alan Getgood

Abbreviations

ACL	Anterior cruciate ligament
ACLR	Anterior cruciate ligament reconstruction
ALC	Anterolateral corner
ALL	Anterolateral ligament
ALLR	Anterolateral ligament reconstruction
ALRI	Anterolateral rotatory instability
AMC	Anteromedial complex
BPTB	Bone–patellar tendon–bone
FCL	Fibular collateral ligament
MCL	Medial collateral ligament
MLIK	Multiple-ligament injured knee
PCL	Posterior cruciate ligament
PLC	Posterolateral corner
PMC	Posteromedial corner

37.1 Introduction

The surgical management of the multiple-ligament injured knee (MLIK) revolves around understanding whether one or both of the intra-articular cruciate ligaments (central pivot) are torn, along with the associated extra-articular peripheral structure involvement. It is this decision-making around which the Schenck Knee Dislocation classification was developed [1]. Knowledge of the mechanism of injury combined with a thorough clinical examination, augmented by imaging (static and dynamic radiography and axial slice imaging), assists with clinical decision-making and determination of which of the 'cardinal' points of the knee (Fig. 37.1) are involved. On the lateral side of the knee, injuries to the posterolateral corner (PLC) have tended to be a surgical focus in the world of MLIK. This chapter will focus on the anterolateral complex of the knee, highlighting our current understanding of the biomechanics, techniques for reconstruction and the use of these as an adjunct to anterior cruciate ligament reconstruction (ACLR). Furthermore, we will discuss the indications for their use in the context of MLIK, taking into account some of the additional technical considerations that this may necessitate.

37.1.1 Historical Perspective

Anterolateral rotatory instability (ALRI) of the knee was first described in the early 1970s with Galway and MacIntosh's description of the lateral pivot shift phenomenon in the context of an injury to the anterior cruciate ligament (ACL) [2]. The pioneers of soft tissue knee surgery recognised that both the iliotibial band and, to a lesser extent, the lateral capsular structures, both played a role in limiting internal tibial torsion and when injured led to a pathological state that in the words of Ellison would result in an athlete knowing that 'his career was about to terminate unless the knee is corrected' [3].

In recent years, there has been a resurgence in our understanding of the anatomy of the anterolateral complex (ALC) of the knee. This has led to biomechanical studies which have gone some way towards quantifying the function of the constituent structures and their contribution towards stability in both the native and injured knee. The key role of the iliotibial band (ITB), as recognised more than 40 years ago, remains important along with the contributing roles of many other structures. In many ways, knowledge of this area

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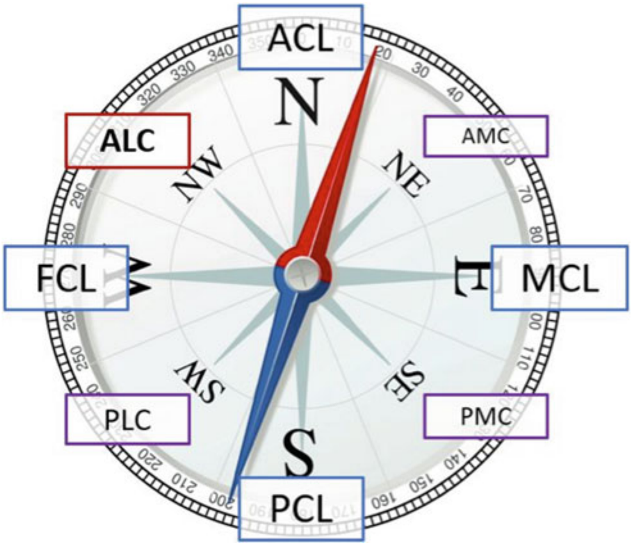


Fig. 37.1 Cardinal points of the knee

of the knee is undergoing a renaissance with the rediscovery of anatomical structures which, over the years, have been described using different terminologies for what was probably the same tissue structure. We will attempt where possible to present consensus opinion on the nomenclature used. We will also present a comprehensive review of the anatomical structures within the ALC and the biomechanical evidence that supports our understanding of their function.

37.2 Anatomy of the ALC

The anatomy of the lateral aspect of the knee was first described using a layered approach by Seebacher [4]. These layers are listed in Box 37.1. Our current understanding is more complex than this original viewpoint. Further anatomical work continues to demonstrate intricate relationships between all of the structures described. There are a number of structures in this anterolateral complex which play a role in the restraint of internal tibial torsion including the ITB and its many layers, joint capsule and anterolateral ligament (ALL), fibular collateral ligament (FCL) and lateral meniscus and its attachments (Fig. 37.2).

Box 37.1. Layered Anatomy of the Lateral Aspect of the Knee

Layer 1: Fascia

1. Iliotibial tract (anterior)
2. Biceps femoris (posterior)

Layer 2: Retinaculum

- Patella retinaculum
- Lateral patellofemoral ligaments

Layer 3: Capsular

- Capsular ligaments
- Superficial and deep capsular laminae.

37.2.1 Iliotibial Band

The ITB arises proximally at the level of the greater trochanter of the hip as a thickening of the investing fascia lata of the leg and the coalescence of the fascial coverings of tensor fascia lata, gluteus medius and gluteus minimus muscles. It has an attachment to the linea aspera of the femur as it runs distally along the lateral border of the femur and inserts distally at the knee onto the patella via the iliopatellar band (IPB) and tibia at Gerdy's tubercle [5].

The complex layered structure of the ITB around the knee was formally described in the 1980s by Terry et al. [6]. Based upon the findings of 17 fresh frozen dissections, as well as a review of the known literature at the time, they were able to delineate a number of layers to the ITB. Further contributions were made by Vieira and colleagues in 2007

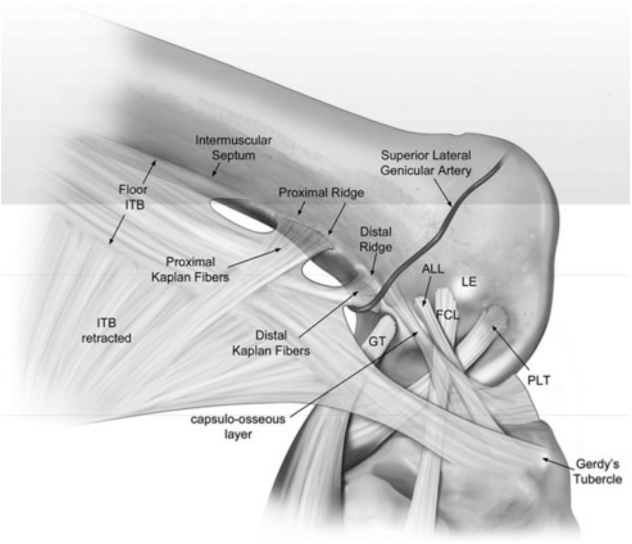


Fig. 37.2 Anatomy of the anterolateral complex of the knee. From Godin JA, et al. [8]. Reprinted with permission from SAGE Publications

[7]. The current view of the anatomy and corresponding function of the ITB describes superficial, middle, deep and capsule-osseous layers.

37.2.1.1 Superficial ITB

The superficial fibres of the ITB are predominately orientated vertically in a proximal to distal fashion and inserted widely into Gerdy's tubercle at their distal attachment. Anteriorly, they arch towards the lateral border of the patella and patella tendon with a condensation known as the iliopatellar band. In the posterior aspect, proximally, the ITB remains attached to the distal aspect of linea aspera and distally it is confluent with the fascia investing the distal aspect of the biceps femoris tendon.

37.2.1.2 Middle ITB

The middle layer is largely seen as a thickening of the superficial layer and they are intimately related. The fibres are orientated more in an oblique fashion from lateral proximal to distal medial and probably serve to strengthen the superficial layer.

37.2.1.3 Deep ITB

The deepest layer of the ITB has been the subject of increased interest in recent years and a number of anatomical studies have sought to delineate its attachments. It lies in the posterior aspect of the ITB, originating distal to the linea aspera attachment and once more becoming confluent with the middle and superficial layers at their attachment to Gerdy's tubercle. The deep layer is anchored to the distal aspect of the femur via proximal and distal Kaplan fibres. The anatomical nature of these fibres was recently revisited and quantified [8]. The proximal insertion travels in a transverse fashion from superficial ITB to distal femur. The distal fibres are orientated in a more oblique direction from proximal lateral to distal medial. Two separate windows are therefore formed, one more proximally between these two bundles of fibres and one distal to this with the capsule-osseous ITB arising at its lower border. The superior lateral geniculate artery was consistently found to travel through this distal window and may form a convenient reference point on advanced imaging studies evaluating the ALC. These attachments via Kaplan's fibres form a distinct and stable functional unit that connects the lateral aspect of the distal femur to the more medial insertion on the tibia at Gerdy's tubercle. The proximal lateral to distal medial orientation of these fibres almost certainly have a large role to play in limiting internal tibial torsion and disruption of this mechanism contributes to the pivot shift phenomenon seen in ACL injuries as well as in the MLIK setting.

37.2.1.4 Capsulo-Osseous ITB

This represents the deepest and most medial layer of the ITB which is only visible once the superficial and deep layers have been reflected away from the femur. It is confluent distally with the deep layer and allows this to extend its insertion proximally and laterally onto the anterolateral capsule and the anterolateral margin of the tibia. Attachments have been described from this layer to all other layers of the ITB and its exact function remains a matter of conjecture. In Terry's original description, he described it as functioning as an 'anterolateral ligament of the knee', a statement re-iterated by Vieira et al. and there is certainly some overlap with other structures to which this name has more recently been applied. A retrograde fibrous tract was also described by Lobenhoffer et al. which connected the deep fibres of the ITB to the lateral tibial plateau [9]. It was postulated that this provided a static stabiliser of the lateral side of the knee. They felt that this was the same structure that had previously been described by Müller as the 'Ligamentum Femero-Tibiale anterius' [10].

37.2.2 Anterolateral Ligament and Joint Capsule

A landmark study in 2013 by Claes et al. sought to describe and clarify the anatomy of the anterolateral aspect of the knee joint capsule and to characterise the anterolateral ligament (ALL) present within this area [11]. The anatomy in this region had previously been well described and its clinical relevance was first alluded to in 1879 with Segond's description of an avulsion fracture of the anterolateral aspect of the tibial plateau in association with forced internal rotation of the knee [12]. He found that this fragment was attached to a 'pearly, resistant, fibrous band' which he postulated would come under extreme tension during internal rotation of the tibial plateau. In a literature search, Claes and colleagues found that a number of structures in this area had been described and termed the 'middle-third of the lateral capsular ligament' [13], 'anterior band of the lateral capsular ligament' [14], 'anterior oblique band' [15] and the anterolateral ligament [7]—a term which they adopted. They also determined that the structures which had variously been described and which they dissected were distinct from the capsule-osseous layer of the ITB, although this is disputed by some authors who might argue that the ALL is a combination of all of these [16].

The ALL as described by Claes is a discrete ligamentous structure in the anterolateral aspect of the knee which arises from a reliable bony attachment proximal and posterior to the popliteus tendon insertion on the lateral femoral epicondyle (Fig. 37.3). It runs in an anterolateral direction to insert on the anterolateral tibia roughly midway between Gerdy's tubercle and the fibular head with firm attachments to the lateral meniscus. Some of the varying descriptions of this anterolateral structure differ in their determination of the femoral origin but there does seem to be agreement as to the

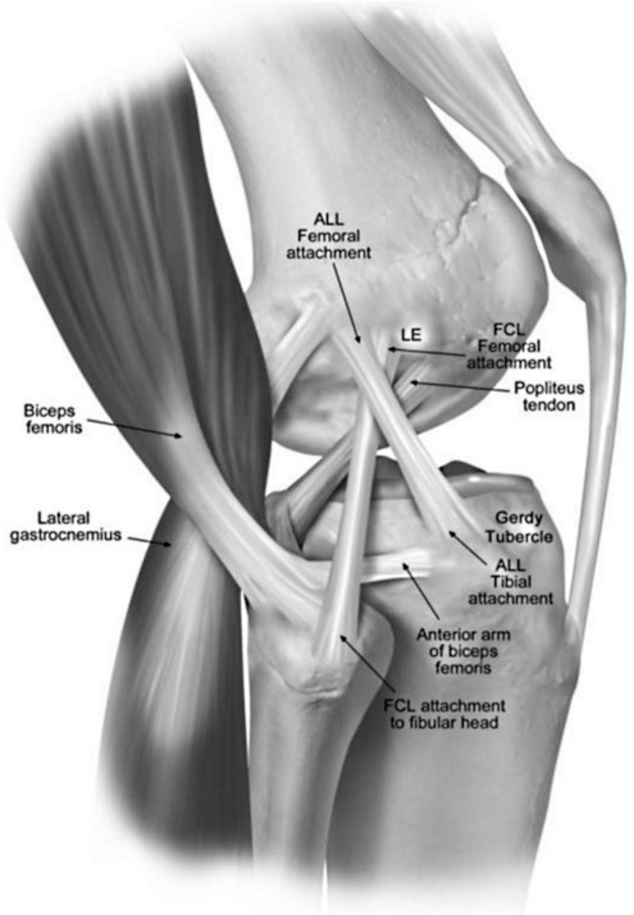


Fig. 37.3 Anatomy of the anterolateral ligament. From Kennedy MI, et al. [17]. Reprinted with permission from SAGE Publications

tibial insertions [17]. Many of the structures already discussed, including the capsulo-osseous ITB probably, have a confluent attachment onto the anterolateral tibia.

37.2.3 Fibular Collateral Ligament

The fibular collateral ligament (FCL) (*syn. lateral collateral ligament)* is a cord-like structure which connects the lateral aspect of the femur and proximal fibula. It is the primary static stabiliser of the knee to varus opening between 0° and 30° of flexion. It is elliptical in cross-section and flattens and fans out in its distal fibular insertion. It arises from a well-defined extra-capsular area just proximal and posterior to the lateral femoral epicondyle and runs distally for approximately 70 mm, inserting on the lateral aspect of the fibular head. At its insertion, it reinforces the peroneus longus fascia and has direct attachments to the lateral aponeurotic expansions of the short head of the biceps femoris tendon [18, 19].

37.3 Biomechanics of the ALC

Anterolateral rotational stability of the proximal tibia is provided by a combination of intra- and extra-articular structures, with the ACL, lateral meniscus, ITB, ALL and anterolateral joint capsule and lateral compartment osteology all probably working in unison [20–23]. The amount that each of these factors contributes towards instability in the MLIK will depend on the patient and the clinical scenario. When considering restoration of knee kinematics following injury, reconstruction of the ACL alone may therefore not be sufficient to correct excessive internal tibial torsion. Ellison described the ACL as ‘the hub of the wheel’, and noted, ‘it is easier to control rotation of a wheel at its rim than at its hub’ [3].

Sectioning studies give us an idea as to the effect of sequential loss of structures on the overall rotational stability of the proximal tibia. The biomechanics of the ALL have been delineated well in recent papers. Parsons et al. sought to understand the biomechanics of the ALL and determined that it was the primary stabiliser of internal rotation of the tibia with the knee in high flexion angles [24]. Sonnery-Cottet et al. showed a similar increase in internal tibial torsion when the ALL was sectioned in both ACL intact and deficient cadaveric specimens, as well as an increase in a simulated pivot shift [21]. Spencer et al. also concluded that the ALL does play a role in assisting the ACL in controlling anterolateral rotation [20]. In their study, serial sectioning of the ACL and ALL demonstrated an increase in anterior translation as well as the clinical grading of the pivot shift test. Sectioning of the ALL also showed a constant increase in internal tibial rotation with the knee in extension in the ACL-deficient knee. Rasmussen et al. showed that ALL deficient cadaveric knees had a significant increase in internal tibial torsion at all flexion angles from 0° to 120°. [25] There is a large degree of heterogeneity in these studies, however, particularly in terms of the state of the iliotibial band in the cadaveric models used. Geeslin et al. looked at combined sectioning of both the ALL and Kaplan’s fibres of the ITB and showed up to 4° of increase in tibial torsion in an ACL-deficient knee compared to the intact state [26]. The overall conclusion of these studies is that the ALL has its greatest effect on controlling internal rotation at flexion angles of greater than 30°. This would lead to the assumption that ALL injury does not necessarily, therefore, completely explain an increase in the pivot shift seen in some ACL-deficient patients—as this clinical test is performed at flexion angles of less than 30°.

Earlier studies have focussed on the role of the ITB alone in determining the presence of a pivot shift in the ACL-deficient knee. In a clinical study, Terry showed that injuries to the ITB rather than the ACL were responsible for a positive pivot shift in 93% of patients with an acute knee injury with the capsule-osseous layer and deep layer implicated in the majority of these patients [27]. Yamamoto et al., however, showed that the ITB had an effect on the pivot shift at similar high flexion angles to those seen in studies investigating the ALL but acknowledges that there is a lack of understanding as to the magnitude of force generated in the clinical scenario [28]. It is still however difficult to fully conclude the individual roles of each of the anatomical structures described in controlling rotation. It may therefore be more prudent going forward to concentrate on clinical outcome studies comparing both anatomic and non-anatomic reconstruction techniques to determine the best clinical solution to increased internal tibial torsion seen in the ACL-injured knee.

37.4 Techniques of LET and ALL Reconstruction

Many different techniques have been described to reconstruct or augment the structures in the anterolateral complex. In the setting of the MLIK, the decision about which method to use will be influenced by a number of factors. These include the pattern of patholaxity, integrity of the FCL, which graft to use, number of existing bony tunnels and surgeon preference.

37.4.1 LET

The LET techniques all share some commonality in that they redirect a strip of the ITB underneath the FCL more proximally. This creates a non-anatomic relationship between the lateral distal femur and the proximal tibia which probably serves to function in the same way as the capsule-osseous layer of the ITB. These techniques clearly rely on the FCL being uninjured. In 1975, Lemaire published the first description of his own extra-articular technique [29]. A 15 cm by 12 mm strip of the posterior ITB is harvested and left attached distally to Gerdy's tubercle. An osseous tunnel is drilled distal and deep to the FCL attachment, exiting on the posterior femoral condyle. The ITB is passed through this tunnel and then back under the proximal FCL and sutured onto itself. The graft is then secured with the knee held in full external rotation.

One year later, MacIntosh described his procedure utilising a 20 cm strip of the ITB, again left attached distally, and routed under the FCL, through a subperiosteal tunnel at the insertion of the lateral intermuscular septum and sutured back onto itself [30]. This technique therefore demands that both the FCL and distal ITB insertions are intact. A combined intra- and extra-articular procedure was subsequently described involving the intra-articular limb of the ACLR being passed 'over the top' and through the knee.

At a similar time, Ellison described a technique that involved taking a strip of ITB that was detached from Gerdy's tubercle with a bony fragment and then routed under the FCL and re-secured just anteriorly to the tubercle [31]. He also included a plication of the middle third capsular ligament—probably what we would now term the ALL, beneath the FCL.

Modern techniques are modifications of the Lemaire and MacIntosh procedures which use a shorter strip of ITB. This is again left attached distally and passed under the FCL more proximally. The strip of tendon can then be secured to the femur either with an interference screw within a bone tunnel or simply with a bone staple (authors' preferred technique). This modified Lemaire technique as performed by the authors is illustrated in Fig. 37.4 [32].

37.4.2 ALL Reconstruction

In recent years, a number of techniques for anatomic reconstruction of the ALL have been described in the literature [33–38]. These have arisen from the renaissance in the anatomical understanding, as well as a concern that the older LETs were both non-anatomic and potentially leading to over-constraint of the lateral compartment. In general, they all share the goal of placing a biological graft (usually gracilis tendon) across the anterolateral aspect of the knee, from just posterior and proximal to the FCL on the femur to a point midway between the fibular head and Gerdy's tubercle on the tibia. These methods are summarised in Fig. 37.5. The exact fixation methods, graft types and anatomical position of the femoral fixation point do differ. There is also considerable variation in the description of how the knee is positioned during graft fixation, with values from extension to 90° of flexion being advised. When considering any of these techniques in the context of the MLIK, a familiarity with numerous methods may allow some flexibility, depending on extent of the reconstruction, other bone tunnels/fixation points required, and autograft and allograft availability and surgical access. These techniques are usually described as an adjunct to simple ACLR but can be adapted when multiple ligaments are damaged.

37.4.3 Biomechanical Studies

The biomechanical effects of ALLR and LET procedures as an adjunct to ACLR are becoming clearer. An attempt has also been made to delineate the isolated ACL injury from a combined ACL/ALC injury—in effect a multi-ligament knee injury—as being different clinical entities.

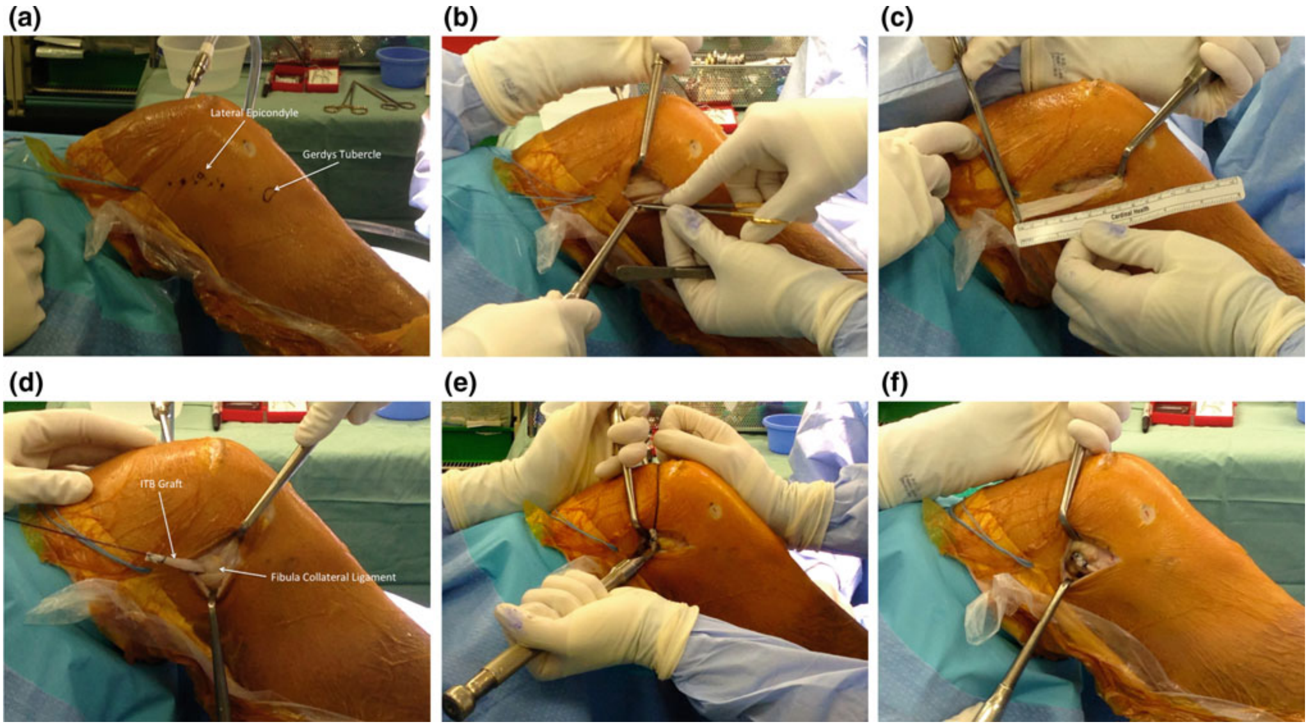
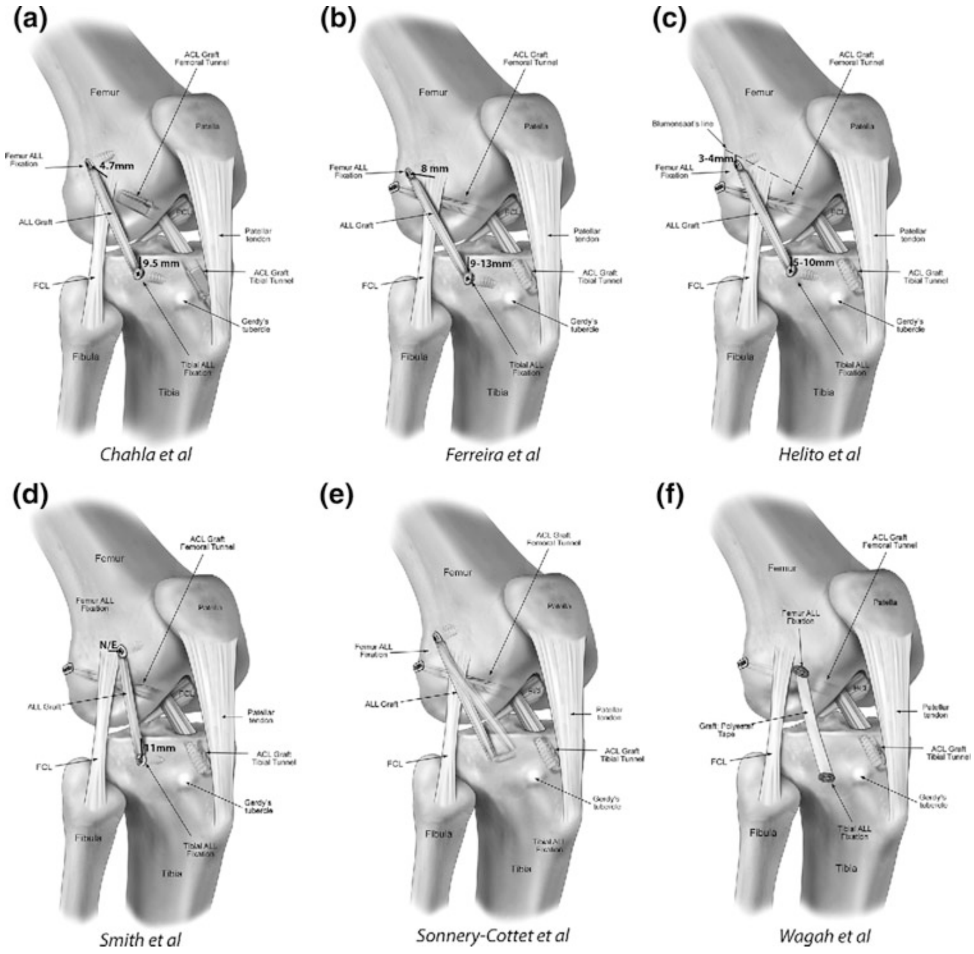


Fig. 37.4 LET surgical technique. A 5 cm curvilinear incision is placed just posterior to the lateral femoral epicondyle (**a**). The posterior border of the ITB is identified and the ITB is cleared of any superficial soft tissue distally to Gerdy's tubercle (**b**). An 8 cm long x 1 cm wide strip of ITB is harvested from the middle third of the ITB, ensuring that the posterior Kaplan fibres and the capsulo-osseous layer remain intact (**c**). This strip remains attached distally at Gerdy's tubercle and is released proximally. A #1 vicryl whip stitch is placed in the free end of the graft. The FCL is then identified. Small capsular incisions are made anterior and posterior to the proximal portion of the ligament and dissecting scissors are placed deep to the FCL, remaining extra-capsular, to bluntly dissect out a tract for graft passage. The ITB strip is then passed beneath the FCL from distal to proximal (**d**). The proximal attachment site is identified just anterior and proximal to the lateral gastrocnemius tendon. Any soft tissue and periosteum are cleared using a cob and electrocautery on the metaphyseal flare of the lateral femoral condyle (**e**). Care is taken not to damage any ACL graft femoral fixation as suspensory devices are often found close to this location. The graft is then held taught but not over tensioned, with the knee at 60° flexion and the foot in neutral rotation to avoid lateral compartment over-constraint. The graft is secured using a small bone staple and then folded back distally and sutured to itself using the #1 vicryl whip stitch (**f**). The wound is irrigated, haemostasis is confirmed and closure is performed in layers. Our preference is to close the defect in the ITB only as far as the distal fibres of vastus lateralis, to avoid over-tightening of the lateral patellofemoral retinaculum. Post-operative rehabilitation is the same as for any ACL reconstruction and weight-bearing and range of motion is dictated by additional procedures that may have been performed

Inderhaug and colleagues compared this important clinical difference and were able to demonstrate that a combined lesion led to significantly increased instability when an anterior translation force, internal rotation force and combined forces were applied [39]. They went on to look at the effect of two types of LET procedure and an ALLR on restoring the knee kinematics in a cadaveric model. Their results would lead us to believe that in the combined injury, ACLR alone was insufficient in restraining anterior tibial translation at lower flexion angles and internal tibial torsion and various flexion ranges. The modified Lemaire procedure described in this chapter and MacIntosh LET procedure were both able to restore native knee kinematics when combined with ACLR.

This study echoed the results of earlier work by Spencer et al. in 2015 [20]. They demonstrated that the ALL did play a role in assisting the ACL in controlling rotation of the proximal tibia but that the magnitude of this effect was small. They were also able to echo the above findings in that the ALLR used in their study did not control rotation in addition to an ACLR, although they acknowledge that ALLR graft position may play a role, particularly regarding some variation in reported femoral origins.

Geeslin et al. also used a robotic cadaveric model to compare a modified Lemaire LET with the ALLR described previously by Dr LaPrade's group [26, 40]. They once more concluded that isolated ACL injury behaves differently to ACL injury combined with either ALL or Kaplan's fibres being sectioned. Their conclusion was that the LET and ALLR were equivalent in restoring knee kinematics in combination with ACLR and felt they were unable to choose between the two procedures.



Chahla et al *Ferreira et al* *Helito et al*

Smith et al *Sonnery-Cottet et al* *Wagah et al*

Fig. 37.5 ALL reconstruction techniques. From DePhillipo et al. [33]. Reprinted with permission from Elsevier

37.5 Clinical Outcomes of ALLR/LET

No literature currently exists to evaluate the use of ALC reconstruction techniques in the setting of the MLIK. We therefore must draw conclusions from the substantial body of evidence which exists when describing these procedures as an adjunct to ACLR. This clinical evidence base is, however, a very heterogeneous group. Many of the longer term studies are reporting on historical techniques which have largely been abandoned in favour of modified techniques. There is also a large degree of variability in the choice of graft and technique of ACLR that make comparisons difficult. Non-randomised, comparative studies looking at ACLR alone vs ACLR with an additional procedure have also suffered from an inherent bias in that the adjunctive procedures were often added in patients with more severe injuries and laxity and were compared with patients who had suffered an isolated ACL injury. As discussed in this chapter, these probably represent two very distinct clinical entities.

37.5.1 LET

Weber et al. recently summarised the clinical studies looking at LET as an adjunct to ACLR [41]. They conclude that there are conflicting outcomes. Some of this is related to the factors as discussed above. They found it difficult to make a conclusion one way or the other on the longer term clinical benefits of LET in addition to ACLR. Hewison et al. performed a meta-analysis of the existing literature in 2015, with inclusion of 29 studies according to their criteria [42]. They concluded that combined ACLR plus LET procedure showed a statistically significant benefit in reducing the pivot shift, but no difference in IKDC scores or anterior tibial translation. Further understanding is contributed by other authors who have systematically reviewed the literature. Song et al. looked at the literature regarding ACLR with LET in addressing the pivot shift phenomenon [43]. They found that in longer term outcomes (greater than 2 years follow-up), the addition of a LET did prove effective in eliminating the high-grade pivot shift phenomenon, but this did not correlate to an improvement in clinical outcome scores. In a meta-analysis with eight included studies, Rezende et al. also failed to demonstrate an improvement in knee function or in complications but did acknowledge a marginal improvement in objective knee stability as assessed by Lachman's test and the Pivot shift [44]. Devitt et al. in their most recent meta-analysis similarly found no clinical improvements, particularly in acute primary ACLR but stated that there may be some benefit in patients presenting with chronic ruptures [45].

In our institution, we will shortly be reporting the 2-year outcomes on a randomised clinical trial comparing ACLR using an anatomic single bundle technique and hamstring autograft with and without an adjunctive modified Lemaire type LET (STAbiLiTY Study: ClinicalTrials.gov #NCT02018354).

37.5.2 ALL Reconstruction

Given that this is a relatively new technique that has only been described in the last few years, there is a paucity of outcome data on its use. The first clinical study was presented by Sonnery-Cottet et al. [46]. In their prospective case series of 83 patients with combined ACLR with ALLR they demonstrate results no worse than contemporary outcome studies looking ACLR alone or with LET. The population investigated in this study is, however, mixed and less than half of those studied had a grade 2 or 3 pivot shift on presentation.

Zhang et al. publish a comparative study looking at single bundle anatomic ACLR versus double bundle and single bundle with additional ALLR [47]. Sixty patients in total were examined and they found that both the double-bundle anatomic technique and single bundle with ALLR gave improved clinical tests of stability including internal rotation and the pivot shift. Their results only reflected 1 year of follow-up and the small numbers make drawing broader conclusions a challenge [47].

A further study by the SANTI study group published in 2017 looked at a pooled series of 502 patients [48]. They concluded that in a high-risk population of young patients participating in pivoting sports, the rate of graft failure with quadrupled hamstring tendon grafts with ALLR was less than both bone–patellar tendon–bone reconstructions and quadrupled hamstring graft reconstructions. The rate of return to pre-injury level of sport was also superior to hamstring tendons alone and equivalent to the patellar tendon group.

It is therefore difficult to draw conclusions on the efficacy of this procedure. The body of evidence is expanding as clinical data from proponents worldwide is published and early signs are that there may be some benefits. As always, identification of patients who will stand to benefit from this additional and potentially more costly procedure will become paramount.

37.6 Indications for ALC Reconstruction

All indications for ALLR or LET have been described in the context of the ACL-deficient knee, focusing on demographic, clinical and occasionally radiographic indications. It is difficult to extrapolate these to the MLIK scenario, especially in the more extreme cases of knee dislocation as patient expectations may need to be moderated post-operatively and the goals of reconstruction may be different to those from an uncomplicated ACLR. Similarly, the clinical test used to evaluate internal tibial rotation laxity —namely the pivot shift—is more difficult to interpret in light of collateral ligament and/or ITB injury. MRI and ultrasound scanning have been evaluated in terms of their ability to detect injuries in the anterolateral complex but in the acute or chronic MLIK are going to be much more open to interpretation. It is important to note that there is no absolute consensus despite the more defined scenarios encountered in ACL deficiency rather than in the case of MLIK.

Box 37.2. Indications for ALLR/LET in ACL-deficient Knee

Strong

- Grade 3 pivot shift
- Revision ACLR with no prior technical error
- Return to pivotal/contact sports

Moderate

- Age <25 years
- Radiographic evidence of anterolateral injury
- Chronic ACL deficiency
- Grade 2 pivot shift
- Generalised ligamentous laxity
- Concomitant meniscal pathology
- Low velocity/non-contact mechanism of injury.

Most sources would agree on a number of indications for adjunctive lateral augmentation in the ACL-deficient knee. These are summarised in Box 37.2. The strongest indication is presence of a grade 3 pivot shift and there appears to be the strongest consensus on this examination factor being present. Pivot shift grading is summarised in Box 37.3. This can be a difficult test to interpret, however, particularly in the presence of generalised hyperlaxity, collateral ligament injuries, meniscal tears and an increase in the tibial posterior slope [49–51]. No studies have validated this test in the MLIK context. Given this difficulty, careful clinical examination and consideration of the mechanism of injury by an experienced clinician are important. Examination of the proximal tibia for tenderness anterior to the fibula and distal to the joint line may be beneficial in the acute setting. In a more chronic scenario, direct comparison of rotational laxity of the tibia with the contralateral side may be performed with the knee in varying degrees of flexion. With bi-cruciate and collateral deficient knees, establishing a set point of the knee with axial loading can be helpful with the knee in full extension but is more challenging in flexion. Chronicity of presentation may also have a bearing on the examination findings. Some evidence exists to suggest that secondary stabilising structures may become attenuated in the face of long-standing ACL deficiency (greater than 6 months), with chronic ACL-deficient patients being more likely to have a positive pivot shift test [52].

Box 37.3. Pivot Shift Grading

Grade 0: Normal
Grade 1: Pivot glide
Grade 2: Jerk with subluxation or clunk
Grade 3: Significant clunk with locking.

In the MLIK, the decision as to whether to perform an anterolateral adjunctive procedure will depend on many more factors than just the clinical presentation. Surgical factors will include which other structures require reconstruction, predicted graft requirement and availability of autograft and allograft, planned tunnel and fixation placement as well as possible cost considerations accompanying all these factors. A focal, residual internal tibial rotational deficit is going to be a rare occurrence and consideration in more severe multi-ligament injuries and the priorities of initial surgery will be re-establishing the coronal and sagittal set points of the knee. Re-addressing additional instabilities later is an option but runs the risk of additional damage being accrued within the knee.

As such, in the authors' experience of being a tertiary referral centre for MLIK, it is extremely rare for us to perform an ALC reconstruction in the case of a MLIK. This has never been performed in an acute setting, and only rarely performed in the setting of a chronic lateral injury with high-grade rotational patholaxity.

37.6.1 Case Example

We present a case example of a 16-year-old athletic female who sustained a direct blow to the anteromedial aspect of her knee whilst playing basketball. The probable mechanism of injury was hyperextension, varus and some degree of tibial torsion. She had significant early pain and swelling followed by ongoing episodes of instability and lack of trust in the knee coupled with an inability to restore her pre-injury level of activity. Physical examination revealed generalised hyperlaxity with 15° of genu recurvatum (c.f. 10° on contralateral knee). She exhibited a grade 3B Lachman's test and a grade 3 pivot as well as a subtle reverse pivot shift and a positive dial test at 30° (but not at 90). Her FCL was grossly intact. Plain radiography was unremarkable, and an MRI scan of the knee confirmed complete ACL tear. Repeated clinical examination confirmed a persistent increase in hyperextension and posterolateral rotatory laxity. Varus stress radiography revealed only a 1 mm side-to-side difference in lateral opening. She therefore underwent arthroscopic assessment of the knee which confirmed a complete rupture of the ACL with intact chondral surfaces and uninjured menisci. We performed an ACLR using BPTB autograft along with popliteus tendon reconstruction (popliteal limb of LaPrade technique [53]) and LET using the modified Lemaire procedure described in this chapter. Post-operatively she was placed in a range of movement knee brace set at 0–90° with partial weight-bearing for the first 6 weeks, followed by a standard ACL rehabilitation protocol. At her 2-year follow-up clinic visit, it was noted that she had symmetrical hyperextension, stable knee to Lachman testing, no significant external rotatory laxity and no pivot shift. Post-operative radiographs are shown in Fig. 37.6.

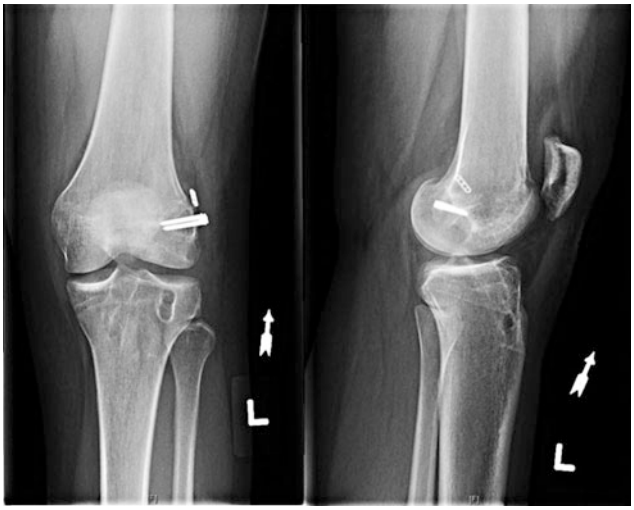


Fig. 37.6 Post-operative radiographs

Box 37.4. Technical Considerations, Pearls and Pitfalls

1. The pattern of injury within the knee will determine the surgical strategy. Careful clinical examination will assist in the decision-making and is often much more important than imaging, particularly in the chronic presentation.
2. In the acute setting of an MLIK, an ALC reconstruction is not indicated. Careful repair of torn capsular and ITB structures along with reconstruction of the central pivot and repair/reconstruction of the collaterals will suffice.
3. In the chronic MLIK, posterolateral-sided injuries are much more likely to exhibit patholaxity than anterolateral complex injury. If significant ALC patholaxity is encountered, the choice of reconstruction technique may be determined by the integrity of the FCL. If the FCL is intact, LET or ALLR may be appropriate. If the FCL is injured and required reconstruction, an ALLR would be a preferred option if deemed to be indicated.
4. If performing an ALC reconstruction along with central pivot and PLC, it is vital to first restore the central pivot followed by tensioning and fixation of the PLC. Only then should the ALC be performed and fixated to limit the risk of fixed posterolateral translation of the tibia and subsequent lateral compartment over-constraint. Caution is advised in this scenario.
5. If using an ALLR, be aware of the potential for tunnel coalition, particularly if addressing the ACL and PLC concurrently.
6. At present, there is no clinical evidence to guide decision-making with respect to ALC reconstruction in MLIK.

37.7 Summary

Structures within the anterolateral complex of the knee play an important role in the rotational stability of the knee. Along with the central pivot and collateral ligaments, the anterolateral corner of the knee can be part of the injury complex in the MLIK. Careful clinical examination, the pattern of injury and surgical expertise will guide the decision-making process when determining whether augmentation or reconstruction of structures in this corner of the knee is required. In practice, these procedures are only rarely indicated in the MLIK.

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Part IX

Postoperative Care

Brace Considerations in Posterior Cruciate Ligament (PCL) Instability and the Multiple-Ligament Injured Knee

38

Eileen A. Crawford and Edward M. Wojtys

38.1 Introduction

Isolated partial and some complete ruptures of the posterior cruciate ligament (PCL) have a high probability of successful treatment using nonoperative means [1–4]. In most cases, patients with these injuries can expect a stable and functional knee because of the superior healing potential of the PCL in comparison to the anterior cruciate ligament (ACL), which has been attributed in part to its better synovial coverage and vascularity [1, 3]. Multiple-ligament knee injuries, in contrast, typically warrant surgical repair or reconstruction of one or more of the damaged ligaments [5, 6]. Whether surgical or nonsurgical treatment is utilized, the knee must be positioned to heal in a reduced and stable orientation to minimize the risks of ligament stretching. Achieving this goal has proven challenging, as even surgical reconstruction is often associated with residual hyperlaxity and high rates of post-traumatic osteoarthritis [1, 7–9].

Historically, immobilization in a cast was the standard treatment for ligamentous knee injuries [10] to promote healing by limiting stress on the ligament and maintaining proper knee orientation. Favor has since shifted toward early range of motion, as research revealed the deleterious effects of immobilization on the mechanical and structural properties of the ligament–bone complex. Woo et al. [11] demonstrated in a rabbit model of the MCL that immobilization of 9–12 weeks greatly decreased the load-to-failure and altered the histologic appearance of the normal ligament–bone interface. Remobilization of equal duration restored the mechanical integrity, but normalization of structural properties of the ligament–bone interface took up to a year [11]. Many experts continue to treat isolated PCL injuries with initial cast immobilization, but the cast is replaced with a brace after 3–4 weeks to regain knee motion [1, 12]. Multiligamentous knee injuries resulting from knee dislocations may be an exception to the early motion strategy, as strict immobilization in a cast or external fixator is often utilized for protection of vascular repairs and severely traumatized soft tissues, or for polytrauma patients who are unstable for acute knee ligamentous reconstructions [9].

Although most patients who have a PCL or multiligamentous knee injury will wear a brace for a portion of their recovery, there has been limited investment by the orthopedic and orthotic communities in the development and evaluation of braces specific to these types of injuries. Most braces that are marketed as PCL braces are simply modified from preexisting ACL braces [3], understandably given the much higher incidence of ACL injuries. Despite the lower numbers of PCL and multiligamentous knee injuries, however, orthopedic sports medicine surgeons will still encounter a number of these injuries in their practice. The variety of available manufactured braces, the expense of these braces, and the lack of an objective tool for evaluating their efficacy make selecting an appropriate brace a challenge [13, 14]. Understanding the nuances of bracing is critical for proper management and for providing the best chance for a stable, functional, and pain-free knee in the long term. This chapter will review such nuances and perhaps stimulate more critical thinking on how to improve the current nonoperative and postoperative management of PCL and multiligamentous knee injuries.

38.2 Biomechanics

38.2.1 PCL

Braces intended to protect the PCL while healing must be designed with the complexity of PCL biomechanics in mind. The length and tension of the intact PCL vary throughout the normal arc of motion of the knee [3]. As the knee flexes under a load from 0° to 90°–105°, the length of the PCL

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increases and the in situ force increases [15]. The elongation plateaus between 105° and 120°, and then the PCL shortens from 120° to 135° [3, 16] (Fig. 38.1). The PCL also internally rotates 80°–84° around its long axis as the knee flexes from full extension to 90° [15, 16] (Fig. 38.2). This rotation of the PCL fibers increases the in situ axial force on the PCL with increasing flexion. Likewise, the reactive force of the PCL pulling the distal femur posteriorly and proximal tibia anteriorly changes with the degree of knee flexion [3].

The dysfunction and instability seen in the PCL-deficient knee reflect this characteristic of varying force through the arc of motion. The posterior slope of the tibia causes an anterior-directed force with weight-bearing, thus stabilizing the PCL-deficient knee [17]. However, the degree of knee flexion and interaction of the quadriceps and hamstrings while weight-bearing also affect the stability. When the PCL is sectioned in cadaveric knees, posterior translation increases from 2.4 mm in full extension to 10.1 mm in 90° of knee flexion [18]. For most athletic activities, knee flexion is less than 60°, however, posterior translation still averages 9 mm at 60° of flexion [18]. Indeed, posterior translation typically exceeds 5 mm once the knee flexes to 20°–30°, so instability may be experienced even in terminal stance with normal gait [10, 18]. Some patients will experience instability with stair descent, which occurs in the early swing phase when the tibia is unloaded and the hamstrings are more active than the quadriceps [17]. Posterior sag of the tibia in a PCL-deficient knee (Fig. 38.3) also affects the mechanical disadvantage of the extensor mechanism and may lead to anterior (patellofemoral) knee pain in patients with PCL insufficiency [10].

The ideal brace for PCL-deficient knees would thus provide an anterior force on the proximal tibia that increases in magnitude as the knee flexes to 90°. Similarly, postoperative braces following PCL injury and reconstruction should increase support with increasing knee flexion to relieve stress on the reconstructed ligament as it heals. Braces should be worn for ambulation as well as rehabilitative exercises until the early stages of healing are complete, so comfort, and ease of use are also important considerations in brace design.

38.2.2 Multiple-Ligament Injured Knee

The biomechanics of the multiple-ligament injured knee clearly depends on which and how many ligaments are compromised. As with the PCL, the knee flexion angle affects which structures are most active in resisting translational and rotatory forces. Femoral rollback of 8–9 mm and internal tibial rotation of 15–20° occurs as the knee flexes from 0° to 120° [19]. There is no single ideal brace for the multiple-ligament injured knee, but the combination of a thorough knee ligamentous examination and knowledge of the function of the various stabilizing structures will assist in selecting an appropriate brace for the instability pattern involved.

The medial and lateral knee structures each include multiple primary stabilizers. The superficial medial collateral ligament (MCL), deep MCL, and posterior oblique ligament (POL) comprise the primary medial knee stabilizers. Valgus stability is primarily provided by the proximal division of the superficial MCL, with secondary support from the deep MCL and POL. The distal division of the superficial MCL functions mainly in resisting internal and external rotation forces. The deep MCL and POL are most important in

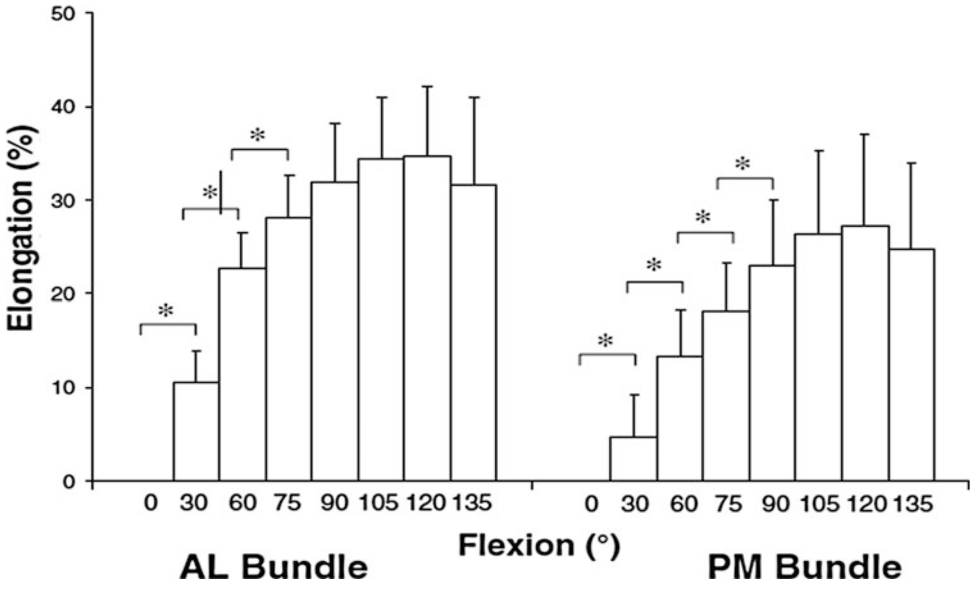

Fig. 38.1 Elongation of the anterolateral (AL) and posteromedial (PM) bundles of the PCL with weight-bearing knee flexion from 0° to 135°. Papannagari et al. [16], ©2007. Reprinted by permission of SAGE Publications

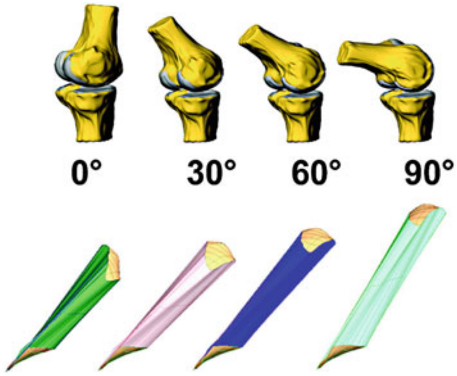

Fig. 38.2 Schematic representation of the relative length and orientation of the PCL with varying degrees of knee flexion. DeFrate et al. [15], ©2004. Reprinted by permission of SAGE Publications

internal rotation stability [20]. The primary stabilizers on the lateral side of the knee include the lateral collateral ligament (LCL), popliteus tendon, and popliteofibular ligament (PFL). While there are as many as 28 distinct lateral knee stabilizers, these three have been the focus of surgical reconstructions [21]. As a group, these primary lateral stabilizers resist varus, external rotation, internal rotation, and posterolateral tibial translation. The LCL provides stability in response to varus, internal rotation, and external rotation loads. The popliteus tendon and PFL function primarily in resisting external rotation loads [21].

In ACL-deficient knees, weight-bearing accentuates anterior instability due to the posterior slope of the tibia—just the opposite of its effect on the PCL-deficient knee [22]. When anterior tibial translation exceeds 5 mm, the mechanical state of the knee transitions from low stiffness to high stiffness, due to the tension of the ACL. Pierrat et al. [13] tested three off-the-shelf knee braces in ACL-deficient knees showing that they counteract anterior translation only in the low stiffness state (<5 mm). They recommended that braces be developed to increase the resistive force with increasing tibial translation [13]. Wojtys et al. [23] showed that commercially available knee braces can reduce anterior translation approximately 30–40% when the surrounding musculature is relaxed and approximately 70–85% when the muscles are contracted. The quick transitions between muscle activation and relaxation and weight-bearing and non-weight-bearing during athletic activities can therefore create frequent fluctuation in tibial translation even in the braced knee. These changes may lead to the common sensation of knee buckling or shifting in the ACL-deficient knee. Beynnon et al. [22] tested a variety of braces in ACL-deficient subjects and found that none was able to restore the physiologic translation seen in the transition from non-weight-bearing to weight-bearing in an ACL-intact knee.

38.3 Indications for Bracing

For all types of orthopedic injuries, bracing falls into different categories. Braces may be rehabilitative, functional, or prophylactic. Rehabilitative braces are intended to protect the surgically reconstructed ligament(s) or to provide a stable environment for the native torn ligament(s) to heal by limiting femorotibial translation and rotation. Functional braces may provide external stability in the setting of ligamentous insufficiency allowing patients to complete daily activities and progress to higher level athletic pursuits. The goal of prophylactic braces is to prevent or limit the severity of future injuries, particularly in knees that have been injured or experienced excessive forces with certain activities [3, 10, 24].

Most braces will be prescribed for rehabilitative purposes, either for initial nonoperative treatment or in the postoperative period. Range of motion parameters can be controlled with many of these braces, allowing gradual advancement of motion and restriction to a “zone of safety” in the early

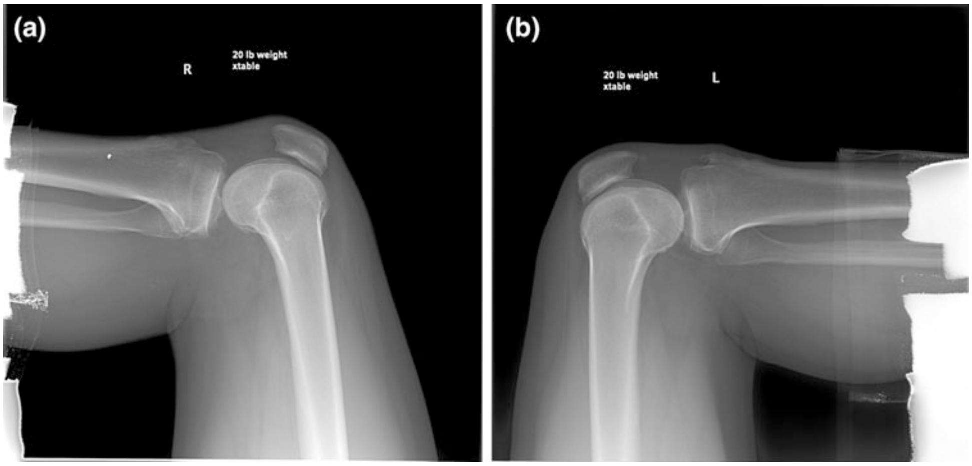

Fig. 38.3 Posterior sag of the right tibia **a** compared to the normal left knee **b** as seen on stress X-ray with a 20 lb weight placed over the patient’s anterior tibia while the hip and knee are each flexed to 90°

recovery period. Rehabilitative braces are particularly important for PCL injuries because gravity exerts a constant stress on the PCL in the supine position. Therefore, PCL rehabilitative braces should reduce the posterior translation of the tibia by applying an anteriorly directed force to the proximal tibia so that the healing ligament or graft does not elongate [3]. In addition to protecting the healing ligament, rehabilitative braces are used by some surgeons to reduce postoperative pain and assist in regaining terminal knee extension, despite a lack of supporting evidence for these claims. They generally should not be worn once the patient returns to active sports participation [25].

Functional knee braces were originally intended to provide support for a knee with ligamentous insufficiency, but currently they are often used following ligament reconstruction when the patient returns to high-level activities. In this sense, they are being utilized more like a prophylactic brace and are only worn while performing those activities [26]. They are designed to prevent excessive anterior–posterior and varus–valgus motions while still allowing enough mobility to complete quick and complex maneuvers [27]. DeVita et al. [27] tested functional knee braces in normal knees and found an immediate alteration in angular impulses at the hip and ankle during walking and running, suggesting that the biomechanical adaptations seen in ACL-injured individuals may be at least partially related to bracing. Since there is a lack of clear evidence to suggest a benefit, some surgeons choose not to use a functional brace postoperatively, even for multiligamentous knee injuries, as long as the knee is stable to examination and has been fully rehabilitated [28]. The benefit of functional bracing in nonoperative management is also unclear. For example, there is no evidence that bracing for PCL insufficiency reduces the development of osteoarthritis. Osteoarthritis following nonoperative treatment of PCL insufficiency occurs in as much as 78% of patients, with the medial and patellofemoral compartments most susceptible [3].

Evidence to support the routine use of prophylactic braces is also limited. While some studies have demonstrated a reduction in MCL injuries with prophylactic bracing, others have reported an increased rate of knee and ankle injury with their use [14, 29, 30]. The potential benefit may also be restricted to athletes engaged in specific positions or sports, such as football linemen and elite skiers [29, 30]. Anderson et al. [14] determined in a cadaveric study that the greatest control of translation and rotation occurred with the combination of athletic taping and prophylactic bracing. However, uninjured or fully rehabilitated athletes often dislike prophylactic knee braces because the added weight and restriction are perceived to impair performance [30].

In theory, braces can control anterior–posterior tibial translation and even varus–valgus angulation relatively well as long as the braces are adequately rigid [24]. Internal and external tibial rotation, on the contrary, will not be well controlled without the hip and ankle included in the brace [24]. Therefore, standard braces may not be sufficient in the multiligament-injured knee. Biomechanical testing of the Lenox Hill brace placed on cadaveric knees with sectioning of the ACL and MCL demonstrated only a 20% reduction in anterior–posterior translation [14]. An in vivo study by Jonsson and Kärrholm [31] found a reduction in anterior–posterior translation by approximately one-third using the Lenox Hill and ECKO braces for ACL-deficient knees. The Lenox Hill brace also controlled external rotatory laxity, but not internal rotatory laxity [31]. Biomechanical testing of PCL-specific braces is needed to understand if the current braces can achieve comparable reductions in abnormal tibial translation and rotation for PCL injuries.

Knee braces are not completely benign in their impact on athletic performance. During exercise, oxygen-rich blood flows to the muscles between contractions as the muscle relaxes. External compressive forces on the muscles from wearing a brace increase the resting intramuscular pressure and can impair blood flow to the muscles, leading to earlier muscle fatigue [19]. Studies have demonstrated increase in oxygen consumption, heart rate, and blood lactate associated with brace use in athletes [32–34]. Avoiding over-tightening of the straps can limit these effects without compromising knee stability as long as the brace remains secure on the knee [19]. While knee braces can improve involuntary quadriceps muscle reaction times, presumable due to their proprioceptive enhancement, they slow muscle reaction time in voluntary hamstring contraction. This combination is undesirable when there is concern for primary or recurrent ACL injury [23].

38.4 Brace Specifications

Selecting the proper brace for a patient depends on matching various brace specifications to both the injury and the individual. This thoughtful attention will increase the likelihood of the brace achieving its desired goals.

The first decision is choosing between static and dynamic braces. Static braces rest passively on the leg in a position that resists pathologic motion. Their countering force is only applied when the pathologic motion is encountered [10, 24]. An example of a static PCL brace would be a device that has additional padding between the calf and the posterior tibial support to counteract the posterior translation of the proximal tibia in the supine position (Fig. 38.4). In contrast, dynamic braces are constantly applying a force or preload that resists the undesired motion [10, 24]. This may be accomplished with springs, as with the PCL-Jack brace (Albrecht, Stephanskirchen, Germany) (Fig. 38.5) [3]. While dynamic braces are considered superior in their ability to

Fig. 38.4 Padding added to the posterior tibial support of a static knee brace. This figure was published in Noyes' Knee Disorders: Surgery, Rehabilitation, Clinical Outcomes by Frank R. Noyes, Rehabilitation of posterior cruciate ligament and posterolateral reconstructive procedures, p. 634, ©2009 Elsevier

Fig. 38.5 The PCL-Jack brace. From: Jansson et al. [3]. Reprinted with permission from Springer

resist tibial translation, they may create abnormal forces on the knee [24]. As discussed above, the anterior–posterior translational forces in the knee vary with range of motion. Similar to the PCL, the in situ force on the ACL changes throughout the arc of motion. The ACL experiences its peak force at low flexion angles between 15° and 30°, with a significant drop in force by 45° of flexion [35, 36]. Therefore, a constant anterior force on the proximal tibia from a dynamic PCL brace may increase strain on the intact ACL in a non-physiologic pattern, whether or not the force generated by the brace is enough to stress the ACL remains to be seen. A potential solution to this problem is a brace that applies a varying load across the arc of motion. The Rebound ACL and Rebound PCL braces (Ossur Inc., Foothill Ranch, CA, USA) (Fig. 38.6) attempt this goal with a tensioned cable and pulley system. LaPrade et al. [37] performed a kinematic study comparing the Rebound PCL brace to the PCL-Jack brace to confirm that the anterior force on the tibia increases with increasing flexion angle for the Rebound PCL brace. Contrary to the description above, these authors characterized the PCL-Jack brace as a static brace, because the force applied to the tibia was constant over the arc of motion, and the Rebound PCL brace as a dynamic brace [37].

The strength and rigidity of the brace will determine the degree of unintended motion and the resistance to high loads. Straps should interlock with the brace struts to provide the best support. Braces with bilateral hinges and hard-shell supports are more rigid than those with unilateral hinges and soft-shell supports [24]. Rehabilitative braces typically have longer struts than functional braces since greater control of the joint is desired in the early recovery phase. Condylar pads (Fig. 38.7) that center at the joint line enhance motion control [24]. Hinge mechanisms with a shear pin stop may limit unintended motion [10]. Hinges of rehabilitative braces most commonly have a single axis of rotation, which causes the brace axis of rotation to deviate from the knee axis of rotation as femoral rollback occurs with increasing knee flexion. Functional braces often use polycentric or eccentric cam-type hinges to better approximate normal knee joint motion [38]. A four-point leverage system is used to counteract abnormal motion in braces designed for cruciate ligament injuries with anteroposterior forces applied to the

Fig. 38.7 A knee brace with condylar pads. Image courtesy Össur, Inc

femur and tibia (Fig. 38.8) [38]. A three-point leverage system is used to off-load the medial or lateral joint in braces designed for collateral ligament injuries (Fig. 38.9). In multiple-ligament injuries, the cruciate ligament braces will provide static support of the collateral ligaments from the brace struts [38]. Straps and components may be attached with Velcro, rivets, stitching, or glue, and the quality of these attachments should be inspected prior to use of a particular brace. As braces will typically be worn for several weeks, normal wear and tear of the brace should be expected and monitored so that the brace can be replaced as needed [10].

Regardless of the strength and sophistication of the brace, an improperly fitted brace will not adequately protect the patient's knee. Careful attention to placement of the hinges in relation to the joint line and femoral condyles is important to ensure that the brace allows proper knee motion while providing effective control [39]. The tightness of fit must be balanced to prevent slippage without compromising circulation and lymphatic drainage. The brace should also be appropriately padded over bony prominences to prevent irritation to the underlying skin and soft tissues [10]. Even with a secure fit, braces tend to allow more motion than indicated by the hinge stops. Cawley et al. [26] found that during ambulation, patients could achieve 15°–20° more extension than the amount set by the extension stop. The amount of adipose tissue between the bone and the brace will also affect how well the brace can limit motion [10]. Similarly, as the patient regains muscle girth during rehabilitation, the fit of the brace will need to be adjusted [24]. The proprioceptive enhancement that may come with a brace incorporates muscle recruitment for additional knee stability [13, 14]. Proper fit is essential to take advantage of the proprioceptive benefits. For all these reasons, a brace should always be fitted by a provider with knowledge and experience regarding brace use, and the principles of brace fit should be explained to the patient.

Finally, comfort and ease of use are important factors to the patient, who will ultimately determine if the brace is to be worn as prescribed. Patients commonly complain of brace slippage, which is not only annoying but also compromises the effectiveness of the brace [14]. Custom braces may provide a more comfortable fit since they can be specifically contoured to the patient's anatomy. However, they are more expensive and may become loose as swelling subsides or tight as the muscles regain their normal size. Longer braces will provide more leverage for applied forces, but are often less tolerated by the patient and more difficult to achieve a snug fit with rigid struts [24]. Dynamic braces tend to be bulkier and may become too restrictive as the patient progress in activity level. For example, the PCL-Jack brace limits knee flexion from 0° to 90°–110°, and hinge mechanisms at both the knee and the ankle make it cumbersome for athletic participation [3].

A single type of rehabilitative brace may not be satisfactory for all patients with a specific knee ligament injury, and individual patients may need more than one type of brace over the course of recovery and rehabilitation. However, braces are costly and more complex designs are not always better. Attention to the needs of the patient and the brace specifications can help to provide optimal chances for successful treatment without incurring unnecessary costs.

38.5 Duration of Bracing

38.5.1 PCL

There is no clear evidence supporting a particular duration for bracing knees with PCL injuries as part of nonoperative management. Studies on PCL bracing report various length of time in a brace, ranging from 4 weeks to 6 months [2–4]. Some authors report that their selected duration for bracing was chosen somewhat "arbitrarily" [2], though it is based on the current understanding of ligament and soft tissue healing. During the first 2–3 weeks following injury, fibroblasts enter the zone of injury and collagen fibers proliferate [4]. Protection of the healing ligament during this time is critical, so it is necessary to brace or even immobilize the knee in a cast or splint.

For postoperative care of a reconstructed PCL, a total of 6 weeks of bracing has been recommended to allow for sufficient biological healing [3, 40]. However, bracing beyond 6 weeks has been justified by the concept that ligament healing and remodeling continues for over a year [3]. Kim et al. [40] performed a systematic review of studies that described the postoperative rehabilitation protocol

Fig. 38.8 A brace that uses a four-point leverage system applies force to the distal femur against a thigh anchor and to the proximal tibia against a lower leg anchor

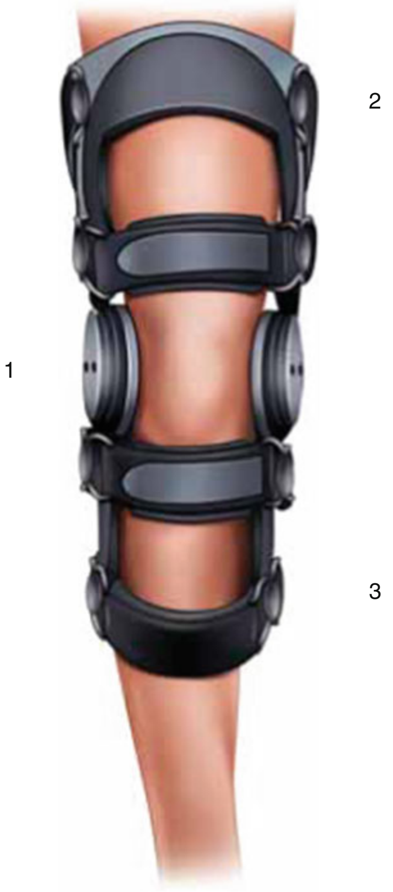

Fig. 38.9 A brace that uses a three-point leverage system applies force above (2) and below (3) the fulcrum (1), which is positioned adjacent to the injured ligament to limit tension on the ligament as it heals

following PCL reconstruction. They determined that most authors used a protocol of bracing for the first 6 to 8 weeks following surgery, with restricted weight-bearing during the first 6 weeks [40]. Li et al. [41] preferred a longer 12-week course of bracing with the brace locked in full extension for 4 weeks, then unlocked three times per day for progressive range of motion exercises over the next 8 weeks. Patients were kept non-weight-bearing for the first 6 weeks following surgery [41].

In both operative and nonoperative situations, bracing must be accompanied by proper rehabilitation. Guided motion should start soon after the injury or surgery to encourage appropriate organization of the collagen fibers, as well as to minimize the negative effects of immobilization on cartilage, muscle, and bone [4]. Within the first 2 weeks, patients may perform range of motion exercises from 0° to 30° in the prone position with little harm because posterior force is minimal in this arc. At knee flexion angles less than 30°, the anterior force produced by the quadriceps mechanism overpowers any posterior shear force created by the hamstrings [40]. After 2 weeks, a gradual increase of 15° of flexion per week will allow the patient to get to 90° of flexion by 6 weeks [40]. Fanelli [42] advocates for slower progression of postoperative PCL rehabilitation in order to optimize the chances for a successful outcome. The use of a brace during early mobilization can support proper positioning of the knee, limit excessive motion, and provide some protection against the stresses that the PCL experiences in simple activities of daily living.

The additional support of a brace may be especially important when the quadriceps muscle is weak from immobilization and disuse. The quadriceps mechanism provides a dynamic anterior tibial force that is synergistic with the intact PCL [40]. When the PCL is injured or reconstructed, the quadriceps becomes even more important in counteracting the posterior forces of the hamstrings and ACL on the proximal tibia. Focused quadriceps strengthening helps to prevent posterior joint subluxation and protect the PCL while it is healing [40]. Quadriceps strengthening exercises should be performed at knee flexion angles less than 70°, the so-called quadriceps neutral angle (Fig. 38.10) [43]. Beyond this degree of flexion, quadriceps contraction creates a *posterior* force on the proximal tibia because of the orientation of the patellar tendon [43]. Electrical stimulation of the quadriceps also may be used to counteract the tendency for quadriceps atrophy during this early postoperative phase [7].

38.5.2 Multiple-Ligament Injured Knee

In certain multiple-ligament knee injuries, a course of preoperative bracing is warranted to allow healing of partially torn ligaments. The most common scenario is the combined ACL–MCL injury. High-grade MCL tears treated with 6 weeks of rehabilitative bracing may heal sufficiently to allow isolated ACL reconstruction following the course of bracing [28, 44, 45]. However, residual laxity of 4 mm or more after 6 weeks of rehabilitative bracing requires MCL reconstruction or advancement in addition to ACL reconstruction [44]. Delaying surgical treatment of more extensive three- or four-ligament knee injuries in order to nonoperatively treat the MCL with 6 weeks of bracing does not appear to negatively impact outcomes based on the study by Fanelli and Edson [46].

Controversy exists regarding early immobilization versus early range of motion for multiple-ligament knee injuries [47, 48]. A systematic review on multiple-ligament knee injuries showed that when surgery was performed acutely, early mobilization resulted in better stability, range of motion, return-to-work percentage, and outcome scores compared to immobilization [47]. The superiority of early motion was not demonstrated in chronic cases, however [47]. Braces with locking mechanisms and stops can be used for both immobilization and guided mobilization. For combined ACL–PCL reconstructions, with or without medial and lateral ligament reconstructions, Fanelli and Edson [48] recommend 10 weeks of bracing with the knee locked in full extension for the first 4–5 weeks. Weight-bearing is not permitted sooner than 6 weeks following surgery, and at 10 weeks the patient is transitioned to a functional knee brace for all activities [48]. A cast or splint may even be used in the first few weeks following surgery if there are concerns over patient compliance with wearing a brace full time. Use of a functional brace for activities after completion of a full rehabilitation program is optional. For surgeons and patients who choose to use one, wearing the functional brace for sports more than 18 months after surgery is unnecessary [38].

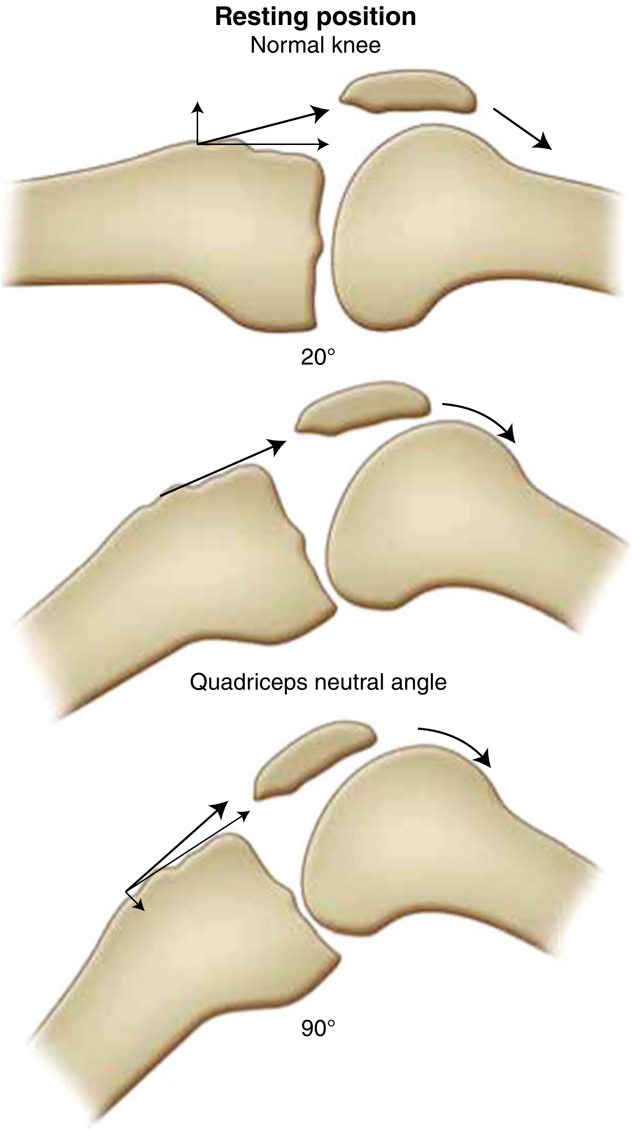

Fig. 38.10 Demonstration of the force vectors created by the pull of the patellar tendon with quadriceps contraction. The quadriceps neutral angle is the knee flexion angle at which there is no force vector perpendicular to the tibial plateau

In setting a plan for the duration of bracing during rehabilitation, the physician must take patient compliance into consideration. Continuous wear of the brace is more critical for PCL injuries and combined PCL injuries than for other ligamentous injuries. Unstrapping a PCL brace in the early postoperative period just while lying on the couch will transfer the force of gravity to the healing ligament [2]. Therefore, strict compliance during the early stages of healing may be more important than the overall duration of bracing.

Achieving a high level of compliance depends on the patient understanding the role of the brace and the potential consequences of not using it properly. The physician or his or her designee should be responsible for communicating this to the patient in terms that he or she can understand. In order to function properly, the brace may feel restrictive, bulky, and uncomfortable to the patient, particularly the more complex dynamic braces [2, 10, 24]. Patients need encouragement to continue to wear the brace, and limiting the duration of bracing can make the process more tolerable.

Tailoring the brace type and specifications to the individual patient can also improve compliance. Older and less active patients will appreciate a lower profile brace that is easy to apply (Fig. 38.11). Young, active patients will need a more restrictive brace to account for their more physically demanding lifestyle (Fig. 38.12). Either way, patients should understand that bracing is only one part of the recovery process. Without lifestyle modifications and dedicated rehabilitation, bracing will not be sufficient to reach the optimal outcome [10, 24].

Fig. 38.11 The Rebound Dual knee brace provides support for various ligament instabilities in a low-profile construct. Image courtesy Össur, Inc

Fig. 38.12 The Rebound PCL brace has a larger posterior tibial support and a more sophisticated force application system, but the brace is bulkier and may be less tolerable to less active patients. Image courtesy Össur, Inc

38.6 Bracing Outcomes

38.6.1 PCL

Outcome studies of bracing PCL injuries are rare, and the variety of protocols applied in these studies makes it difficult to form a consensus on how to achieve the best functional results. The primary dichotomy in these studies is whether or not there is a period of cast immobilization prior to bracing. Clinical outcome studies comparing static and dynamic PCL braces are lacking, so the clinical benefit of dynamic braces that mimic the native PCL biomechanics has yet to be proven [37]. Static PCL braces are associated with superior knee laxity measurements and functional outcome scores compared to standard knee braces not specific to PCL injuries [41].

Jung et al. [49] described a long initial period of casting of 6 weeks with acute PCL injuries. The cylinder cast with posterior tibial support was applied once edema from the injury started to resolve, and the cast was changed as needed over the 6 weeks to maintain a good fit. Subjects were then transitioned to a brace with a posterior tibial support for another 6 weeks. They reported very good objective and functional outcomes, with improvement of radiographic posterior translation from 7.4 mm pre-immobilization to 3.5 mm at the minimum 2-year follow-up. Mean KT-1000 scores for side-to-side differences were 6.2 mm pre-immobilization and 2.97 mm at final follow-up. The also reported that 100% of subjects had a normal or nearly normal IKDC grade [49].

Ahn et al. [1] reported less favorable outcomes using a protocol of a shorter period of cast immobilization. In this retrospective study of 38 patients with acute isolated PCL injury, subjects were treated with the same protocol: 3 weeks in a long leg cast once the swelling subsided, followed by a limited-motion brace with a posterior tibial support for 6 weeks with 0 to 30° of knee flexion permitted and transition to full weight-bearing by 8 weeks from the injury. At a mean of 52 months, they reported that only 29% of subjects improved a grade of posterior laxity and the mean KT-1000 posterior translation decreased from 6.7 to 5.2 mm. MRI evidence of ligament continuity with low signal at a minimum of 6 months post-injury correlated with greater improvements in posterior laxity and KT-1000 translation. Functional scores were modest, with 66% of subjects having a satisfactory IKDC score and an overall decrease in the mean Tegner activity level [1].

Respective times for casting and bracing were further evaluated in a prospective randomized study by Yoon et al. [12]. Patients who had chronic grade III PCL injuries underwent surgical reconstruction of the PCL with postoperative bracing. Both groups were initially immobilized in a splint for 1 week following surgery. The cast group was then placed in a long leg cast and allowed to put full weight on the operative leg. After 4 weeks in the cast, they were transitioned to a brace for another 7 weeks and started gradually increasing knee motion. The brace group went from the splint to a brace locked in full extension with no weight-bearing on the operative leg for 2 weeks. Motion and weight-bearing were gradually increased during the subsequent 9 weeks in the brace, with a goal of reaching full weight-bearing by 6 weeks from surgery. The cast group had better IKDC grade and greater improvement in posterior translation on stress radiographs at 1 and 2 years postoperative. However, there were no differences between groups in range of motion, Lysholm score, overall IKDC score, or Tegner score at 1 or 2 years postoperative [12].

When cast immobilization is used for PCL injuries, the cast should be applied in a prone position to eliminate posterior sag while the cast hardens. A benefit of casting is that it is rigid enough to allow early weight-bearing. Weight-bearing facilitates maintenance of reduction due to the posterior slope of the tibial plateau, which creates an anterior force on the proximal tibia when axially loaded [12]. The downside of prolonged casting is muscle atrophy and interference with activities such as bathing, working, and driving [49]. If a brace is used early in the recovery period, locking the brace in full or near-full extension will limit the stress on the PCL, which increases with flexion up to 90°.

A dynamic brace well designed for PCL injuries is the PCL-Jack brace (Albrecht GmbH, Stephanskirchen, Germany). It has been tested with acute, isolated grade I and II PCL injuries [2]. The brace was worn for 4 months with full weight-bearing and ROM from 0° to 110° allowed from the outset. They reported improvement in posterior sag based on arthrometry, from 7.1 mm at presentation to 2.3 mm at 12 months and 3.2 mm at 24 months from injury. Likewise, the posterior sag measured on radiographs decreased from 8.1 to 3.1 mm at 12 months and 3.4 mm at 24 months post-injury. While 95% of subjects had good or excellent results on Lysholm score, there was small but significant decrease on IKDC, Lysholm, and Tegner scores from pre-injury to 12 and 24 months post-injury. Complications associated with this brace included two minor skin abrasions and one subject experiencing exacerbation of his preexisting patellofemoral osteoarthritis [2].

A couple of smaller series evaluated return to sports in athletes who sustained an acute isolated PCL injury and were treated with bracing only. Parolie and Bergfeld [50] assessed subjects within 24 h of the injury, placed them in a Lenox Hill brace, and allowed early motion with a vigorous rehabilitation protocol. At a mean of 6.2 years follow-up, all of the athletes returned to full sports participation and were satisfied with the function of their knees [50]. Iwamoto et al. [18] treated two professional baseball players with acute PCL injury by immobilizing them in a brace in full extension for 3 weeks while focusing on quadriceps strengthening exercises. Both were able to return to their prior level of participation for at least 2 years, although they had 5 mm to 8 mm of posterior tibial subluxation and one was still experiencing instability with running [18].

Finally, Strobel et al. [51] studied preoperative bracing for patients with a fixed posterior subluxation from isolated or combined PCL injury. Subjects wore a posterior tibial support brace (medi Bayreuth, GmbH, Bayreuth, Germany) during the night and a functional PCL brace (DonJoy, Carlsbad, California) during the day prior to their surgical PCL reconstruction. Of those who had anterior stress radiographs performed ($n = 59$ of 109), 85% had reduction of the fixed posterior subluxation prior to surgery, and in 59% it was reduced to less than 3 mm. Subjects who had a grade III fixed posterior subluxation were less likely to achieve reduction with preoperative bracing [51]. Preoperative correction of the fixed posterior subluxation makes anatomic reconstruction of the PCL possible without releasing other tissues.

38.6.2 Multiple-Ligament Injured Knee

Bracing strategies are typically more conservative in the multiple-ligament injured knee than in isolated ligament injuries, especially for those caused by knee dislocation. Prolonged cast immobilization is rarely indicated due to the risk of significant arthrofibrosis. It may be necessary in morbidly obese or medically unstable patients who are not surgical candidates.

Noyes and Barber-Westin [52] reported on 11 subjects treated with bicruciate ligament reconstructions for knee dislocations with a mean follow-up of 4.8 years. Postoperatively, patients were immobilized in a split cylinder cast for the first 4 weeks. This was removed for range of motion exercises from 10° to 90° 6–8 times per day. After 4 weeks, the cast was replaced with a rehabilitative brace during the day and soft extension brace at night. Range of motion was gradually increased over the next 8 weeks. Of those treated acutely, 86% had AP translation within 3 mm of the contralateral knee on arthrometric testing at 20° and 70° of flexion. In the chronic group, 100% had AP translation within 3 mm of the contralateral knee at 20° of flexion, but only 50% maintained that stability at 70° of flexion. Twelve percent of ligament reconstructions failed (2 PCL, 1 ACL, and 1 LCL/PLC). At final follow-up, 9 of 11 subjects achieved normal range of motion and only 1 subject had a contracture greater than 10°, though manipulations under anesthesia with or without surgical lysis of adhesions were common in the acute group [52].

Another study on bicruciate ligament reconstructions for knee dislocations done by Shapiro and Freedman [53] described outcomes for seven patients treated acutely with allograft reconstruction and immediate postoperative bracing. Range of motion from 0° to 70° was permitted from the outset, and a continuous passive motion device was used during the inpatient hospitalization. Weight-bearing was supported with crutches until 4–6 weeks from surgery. At a mean follow-up of more than 4 years, 57% had achieved full extension and the remainder had less than 5° flexion contracture. Mean terminal knee flexion was 118°, with all subjects reaching at least 105°. Manipulation under anesthesia with or without surgical lysis of adhesions was required in four patients (57%) to achieve these results. The average postoperative Lysholm score was 74.7, and the average Tegner score decreased from 7.1 pre-injury to 5 postoperatively. Arthrometric testing at 20° of knee flexion demonstrated a mean difference in AP translation of 3.3 mm compared to the contralateral side [53].

These studies show that arthrofibrosis is common after surgical treatment of knee dislocations despite early knee mobilization in a brace. Fortunately, a functional range of motion can still be achieved with scar tissue release and manipulation under anesthesia, but patients should be counseled regarding this risk. Results were similar for residual knee laxity whether a brace was used immediately or with a preceding course of a removable cast.

Fanelli et al. [54] reported minimum 2-year outcomes for 21 subjects who underwent combined PCL and posterolateral complex (PLC) reconstructions. The knee was immobilized in full extension in a brace for 3 weeks, and protected weight-bearing with crutches was permitted. Progressive range of motion was started at week 4, and the brace was continued until week 10. Postoperative posterior drawer testing was rated as normal in 10 subjects, grade I in 10 subjects, and grade II in 1 subject. Posterolateral stability—measured by reverse pivot shift, posterolateral drawer, and external rotation thigh–foot angle—was corrected in all subjects. Arthrometric testing improved significantly from preoperative to postoperative values, with final KT-1000 measurements within 3 mm of the contralateral side. Full extension was achieved in all subjects, and the mean terminal flexion loss was 10°. Only one subject required surgical lysis of adhesions with manipulation under anesthesia. The mean Lysholm, Tegner, and HSS knee ligament scores improved significantly on postoperative testing [54].

Most clinical outcome studies addressing combined ACL–MCL injuries involve preoperative bracing for the MCL injury. Sankar et al. [45] studied 12 adolescent athletes with ACL–MCL injuries. Subjects were placed in a hinged knee brace for a mean of 33 days before ACL reconstruction. At 5 years mean follow-up, all had stable knees on physical examination and had returned to their previous level of play [45]. Nakamura et al. [44] reported outcomes in combined ACL and grade III MCL injuries initially treated with 6 weeks of bracing. In these complete MCL tears, only 65% demonstrated valgus laxity of less than 4 mm on stress X-rays at 0° of extension at the time of delayed ACL reconstruction. The remaining 35% underwent ACL reconstruction with MCL repair or reconstruction [44].

38.7 Summary

Bracing plays a prominent role in the management of PCL and multiple-ligament knee injuries. The majority of isolated PCL partial and some complete injuries can be treated nonoperatively in a brace, and those that do warrant surgery will typically require a course of bracing in the perioperative period. Multiple-ligament knee injuries almost always require surgical treatment, and bracing may be used preoperatively and/or postoperatively. Braces for knee ligament injuries come in a variety of designs, each with advantages and disadvantages that should be appropriately matched to the individual patient and course of recovery. Unfortunately, the existing evidence regarding the specific clinical benefits of bracing, the recommended duration of bracing, and the necessity of functional and prophylactic bracing is still inconclusive. Current guidelines for brace use would greatly benefit from additional comparative clinical outcome studies. However, there is agreement that regardless of the bracing protocol used, patient compliance is crucial and dependent on ongoing communication between the patient and the treating physician.

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Postoperative Rehabilitation of the Multiple-Ligament Injured Knee

39

Craig J. Edson and Gregory C. Fanelli

39.1 Introduction

During the past several years, advancement in the surgical techniques and rehabilitation for the multiple-ligament injured knee has allowed patients to return to a higher level of function than previously considered possible following this devastating knee injury. This chapter will provide guidelines for developing a rehabilitation program based on current scientific theories and experience gained over the past 21 years treating this challenging patient population [1, 2]. It is not intended as the final word but as the blueprint for implementing rehabilitation programs that can be modified depending on each individual patient's need. Communication between the surgeon and the rehabilitation specialist is essential to assure that patients are able to progress steadily without compromising the healing surgically treated structures.

Rehabilitation following multiple knee ligament reconstructions requires a precarious balance between restoring range of motion and function to the knee without compromising the static stability and integrity of the grafted tissues. It is imperative that the patient is aware of the time commitment and the likelihood that the entire rehabilitation process will take a full year before returning to full activity. In addition, when the PCL is involved, a 10°–15° loss of terminal flexion is common. Finally, the guidelines for return to activity will often differ for the industrial athlete versus the athlete planning to return to a specific sport. Knowing this information prior to surgery often improves patient compliance and the final outcome.

39.2 Postoperative Program Rationale

The determination of the optimum rehabilitative approach following multiple knee ligament reconstructions will often be at the discretion of the surgeon. The program should be adaptable to accommodate individual variances and specific patient needs. This approach will be more conservative than those principles and techniques utilized following ACL reconstruction [3]. For instance, allowing weight-bearing during the immediate postoperative period is likely more deleterious to the PCL since it is considered the primary static stabilizer of the knee [4]. Combine this with the prospect that multiple-ligament reconstruction often involves both medial and lateral repairs or reconstructions, and then the cyclic motion of the knee during ambulation needs to be minimized to avoid overstressing of these structures. It is encouraging that there are a growing number of studies that have analyzed the effects of exercises and daily activities on the reconstructed PCL [5–9], especially since in vivo measurements of the forces and strains on the reconstructed grafts are currently impractical. With these concepts in mind, it remains imperative to design a rehabilitation program that protects the graft during the early healing phase and provides the patient with a knee that allows them to return to their desired level of function. This rehabilitation program is designed to accommodate combined posterior cruciate ligament, anterior cruciate ligament, lateral posterolateral ligament, and/or medial posteromedial ligament reconstructions and repairs.

39.3 Postoperative Rehabilitation Program: Table 39.1

The postoperative rehabilitation program following multiple-ligament knee surgery is divided into the maximum protection phase (postoperative weeks 1 through 5), the moderate protection phase (postoperative weeks 6 through 10),

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Table 39.1 Rehabilitation guidelines following multiple-ligament reconstruction involving the posterior cruciate ligament

Phase 1—Surgery to 8-week post-op	
Rehabilitation goals	Maximize protection of surgical grafts
	Control effusion
	Quadriceps strengthening
	Maintain full extension
Guidelines	Brace is locked in full extension and worn 24/7 for 3 weeks—may use an immobilizer for showering
	Non-weight-bearing with crutches for 3–4 weeks—may bear full weight when standing in place
	Brace unlocked 0° to full flexion at 3–4 weeks—D/C nighttime use
	Begin PWB gait and increase by 25% each week for 4 weeks
	Begin ROM once brace is opened—active-assisted or passive only
	No isolated hamstring exercises. May do light stretching
Exercises	Patella mobilization
	Quad sets
	SLR with brace locked
	Electrical stimulation for quadriceps re-education (optional)
	Initiate closed-chain exercises in standing once allowed weight-bearing
	Stationary bike for AAROM when indicated
End-phase goals	Full weight-bearing at end of week 7–8
	Knee flexion to 90° or greater and full extension
	Quadriceps control during functional activities (stairs, level surfaces)
	Discontinue brace
Phase 2–8 to 16-week post-op	
Rehabilitation goals	Knee flexion to 125° or greater by end of week 16
	Functional proprioceptive skills including single-leg balance
	Quadriceps strength of 4/5 or greater by end of week 16
	Good proximal hip strength
Guidelines	Avoidance of open-chain or isolated hamstring strengthening
	Avoidance of open-chain quadriceps strengthening if ACL is involved
	Increased flexion should be patient driven only after 110°
	Proper gait mechanics and symmetrical stride length
Therapeutic exercises	Continue with stationary bike for ROM with gradual resistance
	Resistive closed-chain exercises in 0°–60° range
	Bilateral resistive exercises with progression to single-leg (squats, lunges, leg press for example)
	Progressive hip and core strengthening
	Moderate intensity isometric quadriceps strengthening at 70°
End-phase goals	Active knee flexion of at least 110°
	Single-leg stance of 20 s or greater
	Resolution of swelling and pain level of 0–2/10 with ADLs
Phase 3–4 to 8 months	
Rehabilitation goals	Maximize knee flexion. 10° terminal flexion deficit is not unusual
	Quadriceps strength 80–90% of contralateral limb
	Initiate monitored jogging (for athletic population)
Guidelines	Jogging should be performed on a flat, predictable surface and treadmill
	Running should be minimized or avoided
	Avoid isolated hamstring exercises until end of post-op month 6

(continued)

Table 39.1 (continued)

Phase 3–4 to 8 months	
	Open-chain quadriceps exercises are permitted with light resistance
	Single-leg jump test is to be 80% or greater on the contralateral limb before initiating plyometrics (when indicated)
Therapeutic exercises	Progressive resistive closed-chain quadriceps strengthening
	Hamstring curls against gravity at end of post-op month 5
	Progressive hip, core, and proprioceptive training in multiple planes
	Low resistance, isolated hamstring strengthening at end of post-op month 6
	Plyometric and agility exercises after post-op month 8 (if indicated)
End-phase goals	Preparation for aggressive sport-specific training and drills
	Full, functional knee flexion
Phase 4–9 months to 1 year	
Rehabilitation goals	Quadriceps symmetry
	Completion of plyometric or "Jump" program
	Return to sports at the end of 1 year if all criteria are met
Guidelines	Patient to demonstrate symmetry with single-leg hop test for distance
	Single-leg proprioceptive skills equal to the contralateral limb
	Functional brace fitting prior to return to sports
Therapeutic exercises	Continuation and progression of strengthening and agility training
	Sport-specific drills at 50% intensity with progression to full participation
	Aggressive cutting, change of direction, stop and go, and sprinting activities at end of phase 4
End-range goals	Safe, monitored return to sports without restrictions
	Follow-up with surgeon for KT-1000 testing, X-ray, and functional outcomes

The above guidelines and specific therapeutic exercises are designed to establish a template for the postoperative management following multiligament reconstruction. They are certainly not all-inclusive, and adjustments may be necessary based on individual differences and other variables that may occur. It is imperative that there is open communication between the surgeon and the rehabilitation specialist to address any changes or modifications that are deemed necessary. In addition, return to sports is a controversial issue with regard to the timing and the clinician's ability to determine when a patient can safely engage in sports without risk of re-injury. Much of the literature is based on isolated ACL reconstruction, and yet there is ongoing debate on when to return individuals to competition. # The decision for returning the multiligament injured athlete becomes further complicated by the number of ligaments involved, the period of initial immobilization, and the arduous task of restoring quadriceps strength. It may be idealistic to believe that these individuals will meet all the requirements established for the safe return to sports

the strength and motion achievement phase (postoperative weeks 11 through 26), and the preparation for return to activity phase (postoperative weeks 27 through 52).

39.4 Maximum Protection Phase

The goals of the maximum protection phase of the postoperative multiple-ligament reconstructive knee rehabilitation program include maximizing protection of the ligament grafts, maintaining patellar mobility, minimizing quadriceps atrophy, maintaining full passive extension, and controlling pain and swelling. The maximum protection phase following multiple knee ligament reconstructions involves 3–4 weeks of non-weight-bearing (NWB) ambulation with the knee in full extension in a knee range of motion brace locked in 0° of flexion. This phase begins in the operating room when the knee brace is applied locked in extension and continues through postoperative week 4. The patient wears this brace 24 h per day. When ambulating, the surgical extremity is strictly non-weight-bearing. This eliminates compression and distraction forces across the knee ligament reconstructions. This position has been shown to minimize forces on the PCL [10] and prevents the development of an early flexion contracture. When standing still, the patient is permitted to bear weight equally on each leg. This enables the patient to have better static balance when standing on both legs and minimizes the risk of falls. Controlled static weight-bearing will provide stress loading to stimulate the bones of the lower extremity and may stimulate tunnel healing and graft incorporation. Intermittent weight-bearing may also promote the production of synovial fluid to enhance articular cartilage nourishment. The brace allows access to the patella, and patients are encouraged to perform self-patella mobilization once the postoperative dressings have been removed. Electrical stimulation may be utilized for quadriceps reeducation. Quadriceps inhibition and atrophy is a difficult but crucial factor to control in the immediate post-op phase. Swelling is a significant contributor to atrophy and also is to be minimized [11]. Exercises that are recommended during this maximum protection phase include quadriceps sets; gastrocnemius, soleus, and hamstring stretching; and ankle pumps. These exercises promote improved blood flow and, may to some degree, inhibit atrophy. The application of ice on a routine basis is encouraged to combat swelling; however, a water-resistant barrier is recommended until the incisions are fully healed. Once the incisions have closed, scar massage is also encouraged.

Our experience has shown that completely eliminating repetitive and cyclic range of motion during the first 4 postoperative weeks has resulted in the most predictable healing of the reconstructed grafts and restoring static stability to these severely injured knees. A small percentage of patients will fail to regain flexion resulting in the need for manual controlled range of knee motion under anesthesia and possible arthroscopic debridement of scar tissue [12]. Our experience has been that allowing patients to perform early repetitive cyclic range of motion exercises leads to detrimental effects on static stability. This occurs at the posterior cruciate ligament reconstruction and also at the medial and/or lateral sides when reconstruction of these structures is involved. There is a delicate balance in the postoperative rehabilitation between stability and stiffness. Both stability and range of motion are essential for optimum performance of the knee. It is critically important for the surgical rehabilitation team to carefully monitor these patients to maintain this balance and to make adjustments in the program as necessary.

39.5 Moderate Protection Phase

The moderate protection phase begins with postoperative week number 5 and continues through postoperative week number 8. The goals during the moderate protection phase of the postoperative rehabilitation program are to initiate progressive weight-bearing, progressively and gradually increase knee flexion achieving 90°–100° of knee flexion, improve quadriceps tone and strength, improve proprioception, and avoid isolated quadriceps and hamstring contractions against resistance.

The postoperative range of motion brace is unlocked and opened to allow full range of motion at the beginning of postoperative week number 4 or 5. The patient is no longer required to sleep in the long-leg brace. Prone hangs are used several times per day to prevent a flexion contracture from developing. The patient is also allowed to begin partial weight-bearing with the crutches. The patient is instructed to bear approximately 25% of their body weight on the involved extremity; however, we do not expect this to be a precise amount. The 25% body weight per week program serves simply as a means to introduce progressive and gradual weight-bearing forces to the surgical grafts. Continued use of the crutches and protective weight-bearing minimizes the patient's risk of falling due to quadriceps atrophy and weakness. The patient progresses their weight-bearing by 25% each week so that they have attained full weight-bearing by the end of postoperative week 8 when the crutches and the long-leg brace are discontinued assuming the patient has adequate quadriceps control to minimize fall risks.

Passive flexion exercises are used to improve knee range of motion. This can be accomplished with several techniques including a "stair stretch" in which the patient places the involved leg on a stair and gently rocks forward, thus allowing the knee to bend. The patient can also perform passive-assisted heel slides as long as the knee is maintained in neutral alignment. This consists of using the uninvolved leg to gently push the knee into flexion while the surgical leg is resting on a towel and on a smooth surface. Once a flexion stretch is felt, the patient should use the nonsurgical leg to extend the knee back to neutral. Other techniques of passive knee range of motion may be utilized as long as they are done without any active hamstring involvement or imparting varus or valgus stress to the surgical knee when the medial and/or lateral sides are involved. Isolated hamstring strengthening is completely avoided to increase knee flexion. Electrical stimulation may be used for quadriceps strengthening with the knee in 0° of flexion.

Knee flexion must progress gradually. This allows the grafts and soft tissue structures to adapt slowly to changes in length. If the patient or therapist attempts to regain and force flexion too quickly, the grafts may be compromised. There have been instances when a posterior cruciate ligament graft has been torn simply by being too aggressive in achieving flexion during the early phase of healing. The patient is encouraged to gradually attain approximately 90°–100° of flexion by the end of postoperative week 8.

39.6 Strength and Motion Achievement Phase

The strength and motion achievement phase occurs during postoperative weeks 9 through 26 (approximately postoperative months 4–6). The goals of this phase of the postoperative rehabilitation program are to increase knee flexion to at least 120° by the end of postoperative month number 6, progress the closed-chain exercise strengthening program, initiate open-chain quadriceps strengthening exercises during postoperative month number 5, and begin to improve cardiovascular endurance. The patient may achieve these goals with a self-regulated program or utilize the help of a physical therapist or other rehabilitation specialist. This decision is made between the patient and surgeon.

The focus of the rehabilitation program during this phase is improving range of motion and lower extremity strength. The patient is now full weight-bearing and is able to be instructed on proper gait mechanics and proprioception exercises. Katonis [13] determined that the native PCL contained numerous mechanoreceptors that communicated with the central nervous system. They determined that the loss of these receptors contributed to joint laxity as well as muscle dysfunction. Similar findings have been reported for the ACL as well [14]. It is crucial to train the surrounding mechanoreceptors so that joint proprioception is restored during gait and daily activities. Closed-chain exercises are now utilized to further assist proprioception. Lutz [14] has shown that there is a decrease in shear forces at the tibiofemoral joint during these exercises due to the axial orientation of the applied force as well as muscular co-contraction. Initially, closed-chain exercises are done with only body weight for resistance; however, as strength and volitional control improve, resistive exercises using weights are implemented. The patient is advised to limit knee flexion to 60° during these exercises. Wilk [15] has shown that quadriceps and hamstring ratios are similar during the first 60° of flexion, thus minimizing tibial translation in anterior and posterior directions. Restoring quadriceps strength is easily the largest hurdle to minimizing pain and swelling, as well as improving joint function. In a recent study, Palmieri-Smith et al. [11] suggested that quadriceps weakness was not solely a result of disuse or lack of adequate exercise intensity but also a result of arthrogenic muscle inhibition. This was theorized to be a result of reflex activity in which altered afferent signal originating from the injured joint leads to a diminished efferent motor drive to the muscles. This indicates that the patient is unable to volitionally recruit sufficient muscle fibers to increase strength, regardless of the amount of resistance applied. To combat this inhibition, they suggest minimizing joint effusion, utilizing cryotherapy, and incorporating TENS and/or neuromuscular stimulation. All of these techniques can be beneficial in allowing the patient to regain quadriceps recruitment and strength. Reflexive inhibition is only one component of quadriceps atrophy and weakness. When beginning resistive exercises, eccentric exercises play an important role in improving strength. Gerber [16] found that negative resistance training in combination with standard concentric exercises had a twofold greater increase in quadriceps peak cross-sectional area and volume when compared to patients receiving standard rehabilitation only following ACL reconstruction.

One final component of improving quadriceps strength is the use of open kinetic chain (OKC) exercises. These have been shown to create larger anterior shear forces than do closed-chain exercises. Consequently, these exercises are avoided for the first 4 months. Since these types of exercises may challenge the quadriceps more effectively than closed-chain exercises, they are implemented gradually and with regard to patient's subjective reports. We have found that one risk to these exercises is the potential development of anterior knee pain, specifically patellar tendonitis. This may be a result of excessive force on these structures that, over time, causes them to break down and become inflamed. Close monitoring of the patient's response to these exercises and use of cryotherapy after exercising can reduce the incidence of this potential complication.

As the patient is advanced through progressive resistive exercises and proprioceptive training, more challenging activities can be implemented. The patient is allowed straight-line jogging at the end of post-op month 5 or 6 assuming that quadriceps strength is adequate to permit this activity. The patient's running gait is monitored, and the patient is allowed to continue only when they can do so without altered mechanics or other obvious dysfunction. The patient also performs more single-leg strengthening exercises. Escamilla [6] has shown that PCL forces were significantly lower in one-leg squat exercises up to 70° compared to a bilateral-leg squat to 90°. Dynamic stabilization, proximal strengthening, and core exercises play an important role at this point as a measure to improve overall strength and conditioning. There are several techniques to achieve this goal and are too numerous to address individually for the purpose of this chapter. They are intended to provide the patient with overall stability to allow progression to more aggressive linear and nonlinear activities. At the end of postoperative month number 6, the patient's knee flexion range of motion ideally would be approximately 120°.

A summary of the exercise program during weeks 9 through 26, the strength and motion achievement phases, includes the progressive resistance closed kinetic chain exercises avoiding flexion beyond 70° of knee flexion, the introduction of isolated quadriceps strengthening exercises during postoperative month number 5, the introduction of single-leg proprioception exercises on an unsteady surface, and the addition of hip progressive resistance exercises. Additionally, straight-line running may begin during postoperative month number 6, and low-intensity plyometrics may be introduced at the end of postoperative month number 6. Failure to gain motion occasionally occurs. Gentle manipulation may be considered if the range of motion greater than 90° of knee flexion is not achieved by the end of postoperative month number 4.

39.7 Preparation for Return to Activity Phase

The preparation for return to activity phase occurs during postoperative weeks 27 through 52 (postoperative months 7 through 12). The goals during the preparation for return to activity phase of the postoperative rehabilitation program include increasing range of motion, achieving quadriceps strength of 90% or greater compared to the nonsurgical lower extremity, advancing to sport-specific activities, and returning to sports and physically demanding occupations during postoperative months 10 through 12.

It is during this phase of the postoperative rehabilitation program that the rehabilitation exercises are directed toward sport- or work-related activities. This includes progression of strengthening, conditioning, agility exercises, and incorporating a progressive plyometric proprioceptive program. When the patients are traditional athletes, running in nonlinear directions and low-intensity cutting activities are initiated. Low-level plyometrics are incorporated, including bilateral- and single-leg exercises. Emphasis is placed on proper landing mechanics and the ability to maintain this position for 2–5 s once the jump is concluded. These training programs have been reported in the literature as both postoperative and preventative techniques for the ACL [16–21]. The plyometric program duration is 6 weeks, and the patient is progressed through the individual stages based on successful completion of the prior stage. The program is designed to progressively increase load and enhance the functional abilities with minimal exposure to potential injury risk positions. The patient is monitored carefully for signs of increased joint soreness or swelling and appropriate measures are taken to avoid any progression of these symptoms. Ideally, the completion of this program coincides with the end of post-op month 9 at which time a return to sports or heavy manual labor is considered. Isolated hamstring exercises are also initiated at this time, but they are done without additional resistance. We do not find hamstring weakness and/or atrophy to be a common finding in our patients. Prior to this point, the detrimental effects of isolated hamstring exercises on the posterior cruciate ligament reconstruction seem to outweigh the benefits they provide.

The return to sports and high physical demand industrial occupations is a multifactorial decision. A careful balance of the patient's desire to return based on their perceived readiness versus objective measures of their actual function and lingering impairments must be considered. There does not appear to be a functional testing "gold standard" that best determines an athlete's ability to return to sports or an industrial athlete's ability to return to a physically demanding occupation. Bjorklund [21] examined various functional tests for validity and accuracy in determining performance at two separate post-op intervals following ACL reconstruction (4 and 8 months). They developed a series of eight tasks; three consisted of bilateral tests, while five consisted of single-leg activities. The patients rated their outcomes utilizing the International Knee Documentation Committee (IKDC) form, and objective criteria were developed to assess the patient's performance during the eight functional tests. The authors determined that these tests were reliable and appropriate for assessing a patient's functional ability following ACL reconstruction. One possible obstacle to this assessment is the inclusion of clinical assessment of a patient while performing functional tests. Certainly, it is possible that, based on a clinician's experience and expertise, there could be a wide range of differences when attempting to objectively quantify a functional test. It appears that the most effective method to assess a patient's skill and tolerance to functional tests is to include objective and measurable criteria. For example, single-leg hop for distance, single-leg timed hop for distance, shuttle runs, and single-leg vertical jumps for height, to name a few. In addition, many facilities now include testing utilizing force plates to assess not only the knee but also the hip and ankle function in the sagittal plane. A functional movement screen and lower quarter Y balance test are also useful adjuncts to testing and require very little equipment. A patient should be within 10% of the uninvolved leg with all functional tests to be considered for return to physically demanding activities. As stated initially, a full year is recommended before returning an athlete to there desired sporting activity. In many instances, this time frame is impractical as the athlete has not acquired the necessary strength, proprioception, and explosive "burst" to safely participate. There are current studies that question the timing to return athletes to their pre-injury level following ACL reconstruction [22, 23], and the rehabilitation programs are much less restrictive when compared to multiligament reconstruction. The athlete and medical teams need to be realistic in their assessment of safely returning to play.

Prophylactic bracing is a controversial issue and one that will not be analyzed within this chapter. We recommend that the patients utilize a functional brace during sports or other activities that could place the knee at risk. This is done until the patient reaches postoperative month 18 at which time the use of the brace becomes optional.

39.8 Results

Multiple-ligament knee injuries are devastating injuries that result from high- or low-energy trauma. The goal of treatment is to enable these patients to return to their pre-injury level of function within a reasonable period of time. The results and outcomes of our treatment of posterior cruciate ligament-based multiple-ligament knee reconstructions indicate that our patients have achieved static stability of the reconstructed knee in a majority of patients as documented with physical examination, stress radiography, arthrometer testing, and three different knee ligament rating scales [12, 24–32]. The return to pre-injury level of activity and function in our patients has been between 73 and 86% in the complex cases. These statistics include both traditional athletes and industrial athletes. While restoring a traditional athlete to competitive status is rewarding for both the patient and the physician, restoring an industrial athlete to their pre-injury level of work status is rewarding to the patient, their family, the physician, the therapist, and to the economic community at large.

39.9 Summary

The previously outlined program serves as a blueprint for developing a postoperative rehabilitation program and presents the guidelines that are utilized in our practice following multiple knee ligament reconstructions. We have attempted to describe the scientific rationale behind our rehabilitation program. Modifications and adaptations can be applied to account for individual needs and variances. For example, it might not be feasible for someone who performs heavy work to remain off work for the recommended amount of time that is usually required to insure an optimum outcome. In this case, once the person has met a reasonable level of strength and proprioception, it may be necessary to send them back to work to avoid potential financial hardships. They should utilize a brace at all times and make any possible modifications in their job to avoid re-injury. Communication between the patient's employer and the medical staff is also crucial to determine the best environment for the worker to perform his job while minimizing forces on the surgically repaired knee. This approach has resulted in a high level of patient satisfaction as well as the ability to return to their desired level of function in the majority of cases.

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Part X

Outcomes

Complications Associated with the Treatment of the Multiple Ligament Injured Knee

40

David C. Johannesmeyer, Dustin L. Richter, Robert C. Schenck Jr., and Daniel C. Wascher

40.1 Complications Associated with the Treatment of the Multiple Ligament Injured Knee

Knee dislocations are rare injuries but are being seen with increasing frequency. These injuries are usually caused by high-energy mechanisms. Associated cerebral and visceral injuries are common [1]. Neurovascular injury in the involved extremity can result in long-term disability. The incidence of popliteal artery injury has ranged between 7 and 48% [2–7]. Most studies show the risk to be approximately 2–5% with modern understanding of bicruciate injuries and in the largest population study of 8050 knee dislocations in North America revealed an incidence 3.3% [8]. Failure to identify a vascular injury may lead to devastating complications. Studies have shown that delayed recognition of an occlusive injury beyond 8 h is likely to result in amputation [7, 9, 10]. This risk is coupled with the clinician's responsibility to utilize an evidence-based protocol that includes an initial palpation of pedal pulses and at least one of the following: angiography, duplex ultrasonography, ankle-brachial index (ABI), or repeated physician documented physical exam over a minimum 24 h observation period [8, 11, 12]. Nerve injury is also common in knee dislocations and can result in significant morbidity. The common peroneal nerve is the most frequently injured peripheral nerve. Most studies have reported the incidence of peroneal nerve injury in conjunction with knee dislocations to range from 25 to 35% [7, 13–16]. The tibial nerve is less commonly involved, and all reported cases have had concomitant peroneal nerve injuries [1, 17–19]. The mechanism of injury to the common peroneal nerve is usually from a bicruciate injury with a varus stress causing traction or stretch to the nerve. The superficial location and immobility of the nerve make the common peroneal nerve susceptible to injury. It is critical that the treating physician performs a thorough examination of the whole patient with particular emphasis on the neurovascular structures in the injured extremity in order to avoid complications associated with missed injuries.

Historically, there has been a paucity of good quality evidence to formulate the optimal treatment. Early interventions varied from immobilization [20] to surgical repair [21]. Currently advances in operative techniques have demonstrated good mid- to long-term outcomes with open [22] as well as with modern arthroscopic techniques, which are becoming the standard of care [23–27]. Complications related to ligamentous knee surgery have been shown to decrease patient satisfaction [28, 29]. While complications can result from the initial trauma or from a delayed or missed diagnosis, this chapter will focus on complications that may result from the treatment of the multiple ligament injured knee.

40.2 Popliteal Artery Injury

Subclinical popliteal artery injury does occur and may present with a normal physical exam. Arteriography can be helpful in identifying intimal injury of the popliteal artery; however, it cannot be relied upon conclusively. McDonough reported on three patients that had normal pulse exam and arteriograms interpreted as normal prior to ligament reconstruction with subsequent arterial injuries [12]. Immediately after release of the tourniquet, two of three patients had absent pulses that required immediate revascularization. In both patients, large intimal flaps were found with resultant chronic thrombi. The third patient had developed a pseudoaneurysm of the popliteal artery sometime following the knee dislocation. If an intimal injury is diagnosed on a preoperative angiogram, it may be prudent to delay surgical reconstruction of the knee [1, 5, 13, 30–32]. The orthopedic

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surgeon performing a multiligament reconstruction should have a heightened awareness of the possibility of vascular obstruction from a known or unrecognized intimal popliteal artery injury. A careful neurovascular examination is mandatory immediately after every multiligament knee reconstruction. Any abnormality requires urgent vascular surgery consultation. Figure 40.1 is an example of a patient with a popliteal artery injury.

Iatrogenic vascular injury of a dislocated knee can occur from disruption of a previously repaired popliteal injury or damage to an intact artery. Traditionally, an injured popliteal artery in the multiligament injured knee has been treated with emergent saphenous vein bypass grafting with associated stabilization of the knee joint [27]. Application of a spanning external fixator helps protect the vascular repair from undue stresses from the unstable knee joint. There is debate over whether the spanning external fixator should be placed prior to or after revascularization [33]. Advocates of initial fixation prior to revascularization express concern that fixation performed after vascular repair may jeopardize the repair. Immediate external fixation allows the vascular repair to be performed in a controlled environment which protects the completed repair from disruption [34]. On the other hand, advocates of performing the vascular repair prior to lower extremity fixation argue that reversal of limb ischemia is the most important factor in limb survival and should take precedence. Prior studies have demonstrated that the vascular repair was able to withstand longitudinal traction during fracture fixation of the tibia or femur and that no disruption of the vascular repair occurred in these series [35–37]. A meta-analysis performed by Fowler et al. identified 14 articles with patients that had sustained either femoral fracture, tibial fracture, or knee dislocation, with associated vascular injury [38]. These studies consisted of patients that underwent fracture fixation or knee stabilization prior to a revascularization procedure and those patients that underwent revascularization prior to fracture fixation with amputation as an outcome measurement. The data showed no statistical difference in regard to the incidence of amputation between lower extremity fixation prior to revascularization and revascularization prior to fracture fixation. Unless the ischemic time is close to 8 h, we have found it best to apply a spanning external fixator with the knee joint held reduced in 20° flexion prior to vascular repair. This can be achieved rapidly while the vascular surgeon is harvesting the contralateral saphenous vein. The fixator allows adequate exposure to the popliteal artery through a posteromedial approach and protects the subsequent vascular repair.

Tourniquet use during ligamentous reconstruction following a vascular repair is a topic of controversy and uncertainty. Use of a tourniquet on a revascularized limb puts the vascular repair at risk for complications including thrombosis or damage to the repair itself [39]. To minimize these risks, recommendations include using a well-padded tourniquet positioned high on the thigh and keeping the tourniquet time as short as possible. In consultation with our vascular surgeons, we have typically delayed ligament reconstruction for a minimum of 6 weeks following revascularization in order to allow the vascular repair to mature and decrease the risk of thrombosis. In cases where the

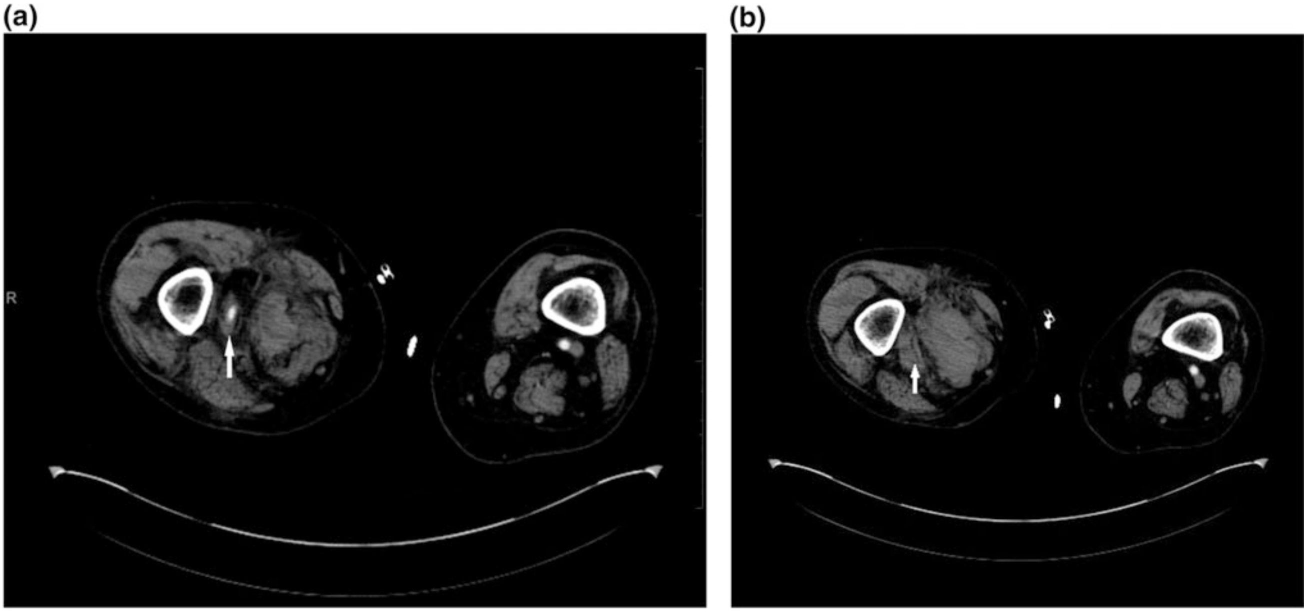

Fig. 40.1 CT angiogram of a patient with popliteal artery injury with pseudoaneurysm [(**a**) *white arrow*], contrast extravasation, and inability to identify artery on distal images [(**b**) *white arrow*]

pulses remained diminished 6 weeks after revascularization, repeat vascular evaluation and consultation are necessary before proceeding with a knee reconstruction.

Finally, a normal popliteal artery can be injured when performing a posterior cruciate ligament reconstruction. With a transtibial technique, the popliteal artery can be injured with the passage of a guide pin or when drilling the tibial tunnel [40]. Matava et al. have shown that the distance from the PCL tibial attachment to the popliteal artery averages 7.2 mm in the sagittal plane from full extension to 100° flexion with a maximum distance of 9.3 mm at 100° [41]. Commercially available PCL tibial guides are designed to provide some protection from the guide pin penetrating the posterior capsule. Fluoroscopic imaging with a perfect lateral projection of the tibial plateau can aid in preventing inadvertent popliteal artery injury. However, we recommend direct viewing of the guide pin exiting the PCL tibial footprint. The PCL tibial footprint can be visualized by placing the 70° arthroscope through an accessory posteromedial portal. Once the guide pin has been successfully positioned, a curette or commercially available pin shield should be placed over the guide pin while tunnel reaming is performed. Appropriate visualization, capping the pin, and careful reaming can avoid inadvertent penetration of the popliteal space and arterial injury.

The tibial inlay technique for PCL reconstruction has also been used to help minimize popliteal artery injury. In this approach, the PCL tibial footprint is approached through a posterior or posteromedial incision. The medial head of the gastrocnemius is retracted laterally to expose the PCL footprint and protect the popliteal structures. A burr is then used to create a trough in the PCL footprint where the graft will be fixed. However, even with this approach, there is the potential for popliteal artery injury from vigorous retraction or joint subluxation. The surgeon must always have a keen awareness of the risk of popliteal artery injury in any multiligament reconstruction.

40.3 Nerve Injury

Nerve injuries can occur at the time of injury or from treatment of knee dislocation. The common peroneal nerve is the nerve most often injured at the time of a knee dislocation, although the tibial nerve is also at risk. Peroneal nerve injuries occur most commonly when the posterolateral corner structures are disrupted [7, 14, 42]. Several anatomic factors predispose the common peroneal nerve to injury. The nerve is superficial and relatively tethered around the fibular head in close proximity to the biceps tendon. Peroneal nerve injury can range from a stretch injury to a complete transection of the nerve. A case report involving peroneal palsy following knee dislocation noted the possibility that a short segment or limited neurolysis at the time of surgery may not allow full appreciation of the involvement of the peroneal nerve injury, as the zone of injury is often rather extensive [7, 18]. Some authors have advocated early exploration of an injured peroneal nerve and performing a nerve repair or neurolysis [7, 43, 44]. Full return of peroneal nerve function is uncommon and can take many months or years, regardless of treatment [45–47]. However, early treatment can provide improved outcomes as a delay may result in contractures or pressure ulcers or may hinder postoperative rehabilitation [7].

Nerve injury can also result from treatment of the dislocated knee [48, 49]. With surgical approaches to reconstruct the lateral collateral ligament and posterolateral corner, the surgeon must employ great care to clearly identify and protect the common peroneal nerve as injuries can occur in as many as 2% of surgeries [49]. The peroneal nerve should be identified and marked early in the surgical dissection as it is at risk if bone tunnels need to be drilled in the fibular head for a posterolateral corner reconstruction or biceps femoris tendon repair. The nerve is best identified proximal to the fibular head at the posterior aspect of the biceps femoris tendon [50]. As the nerve courses toward the fibular head, there are numerous fascial bands encompassing both the biceps femoris tendon and peroneal nerve [51]. Once identified, a vessel loop can be placed around the nerve to serve as a constant visual reminder as to the location of the nerve. A hemostat should be avoided to avoid any possible chance of a traction injury to the nerve. The fascial plane posterior to the biceps femoris should not be closed in order to prevent the nerve from being compressed by postoperative swelling and in releasing the peroneal nerve, the surgeon should consider performing a short release (5 mm) of the fascia of the peroneus longus muscle.

The effects of tourniquet use on a patient with concomitant peroneal nerve injury have not been well documented [39]. Pneumatic tourniquets are known to cause conduction abnormalities related to mechanical compression of the nerves beneath and under the edges of the tourniquet, including ischemic changes distal to the tourniquet [52]. The degree of injury is related to the amount of pressure and the length of time the tourniquet is inflated. It is unknown whether or not using a tourniquet on an extremity with a concomitant peripheral nerve injury increases the likelihood of permanent nerve injury [39]. Similar to precautions in tourniquet use following vascular repair, the tourniquet should be well padded, placed proximal to the injured section of nerve, inflated to an appropriate pressure, and used for as brief a period of time as possible [39]. We recommend that the tourniquet not be inflated continuously for longer than 120 min. If additional tourniquet use is required, the tourniquet should be deflated for 10–15 min to allow reperfusion of the nerve prior to reinflation.

The saphenous nerve can also be injured during surgical exposure. The saphenous nerve lies beneath the sartorius muscle and the gracilis tendon. The main branch of this nerve, the sartorial branch, travels distally to supply sensation to the medial aspect of the calf. The sartorial branch can be injured when creating a posteromedial arthroscopy portal, when harvesting the pes anserine tendons, or when performing a medial collateral ligament repair or reconstruction. If the sartorial branch is cut, the patient will experience numbness over the anteromedial aspect of the calf. A painful neuroma can occur. Transillumination of the saphenous vein with a 70° arthroscope through the notch and keeping the posteromedial portal anterior to the vein will minimize risk to the nerve. Careful retraction of the pes anserine tendons and a flexed knee position during medial knee exposure can also assist with protecting the saphenous nerve in open medial reconstructions. Use of gabapentin or similar agents postoperatively when such neuritic symptoms occur is often indicated and successful.

The infrapatellar branch of the saphenous nerve is at risk for injury when establishing a medial arthroscopic portal and usually is transected in anteromedial incisions of the knee. When this nerve is cut, the patient will have numbness over the anterolateral aspect of the knee. Occasionally, a painful neuroma can occur. When an anteromedial incision is planned, the surgeon should explain to the patient preoperatively that after surgery, they will have a numb area lateral to the incision. The numb area usually decreases and is less noticeable with time [53–55].

40.4 Deep Venous Thrombosis

The incidence of deep venous thrombosis (DVT) in patients with a knee dislocation is unknown. However, many patients who sustain a knee dislocation fulfill Virchow's triad: endothelial injury, venous stasis from immobilization, and hypercoagulability associated with trauma. Following injury, many patients with knee dislocations are immobilized and kept non-weight bearing. Other patients are treated with a spanning external fixator. Likewise, after surgical reconstruction, most patients are kept non-weight bearing with restricted range of motion for up to 6 weeks. These factors argue for the use of chemoprophylaxis to minimize the risk of DVT in patients being treated for a knee dislocation.

Studies have shown the incidence of symptomatic DVT following reconstruction of a multiligamentous knee injury to be between 2 and 3.5% despite treatment with chemoprophylaxis [23, 56]. These findings are consistent with other published studies regarding low molecular weight heparin (LMWH) use following ACL reconstruction and use of external fixation devices for lower extremity trauma [57].

Our approach has been to place patients presenting with knee dislocations on LMWH or aspirin until they are full weight bearing with a near-normal range of motion. The risk of severe bleeding complications from coexisting injuries (head trauma, pelvic injuries, etc.) may preclude the use of pharmacological intervention; mechanical prophylaxis and occasionally Greenfield filters should be utilized in these patients. Following surgical reconstruction of the knee ligaments, the patient's anticoagulation is continued or restarted and maintained until the patients are full weight bearing. Leg swelling or calf pain should be evaluated with a duplex scan to determine if a DVT is present. Any DVT detected in the postoperative period will need longer term anticoagulation. Use of vascular consultation for both arterial and venous management pre- and postoperatively is often helpful.

40.5 Compartment Syndrome and Fluid Extravasation

Significant capsular disruption and fascial defects occur in knee dislocations. These capsular tears can predispose to fluid extravasation if arthroscopy is performed soon after the injury. Extravasation of arthroscopic fluid has the potential to cause a compartment syndrome [58–62]. Postponing surgery for several weeks can allow time for the capsular injury to heal and decrease the risk of extravasation. However, the delay may increase the difficulty of surgical dissection of the medial and lateral structures. Other strategies for avoiding extravasation are utilizing a low-flow pump, using gravity flow, or performing the reconstruction with open techniques. Regardless of the timing of surgery, if arthroscopy is performed, the surgeon must remain vigilant to the possibility of extravasation by palpating the compartments frequently during the operation. If the compartments are swelling, the arthroscopy should be abandoned, compartment pressures measured, and, if necessary, emergent fasciotomies performed.

40.6 Wound Problems and Infection

Superficial and deep wound infections can occur following surgical treatment of the dislocated knee. Many patients with knee dislocations have a severely traumatized soft tissue envelope around the knee. Excessive tension on the skin from an unreduced dislocation or from the invagination that occurs in a posterolateral dislocation can lead to skin necrosis. The dislocated knee should be reduced promptly to minimize the risk of skin necrosis. Open knee dislocations require emergent debridement and intravenous antibiotics.

Any surgical reconstruction should be delayed until the wound is healed with no signs of infection. Likewise, if the skin is significantly swollen and ecchymotic, surgery should be postponed to allow the soft tissue envelope time to recover. The metabolic demands of polytrauma, as well as preexisting patient factors (age > 50 years, the presence of systemic illnesses, corticosteroid use, previous scars, obesity, etc.), can also negatively impact wound healing [51, 63, 64].

In scenarios where the knee is grossly unstable, but wounds or soft tissue swelling necessitate a delay in surgical treatment, application of a spanning external fixator is useful. This provides stability to the knee joint while allowing access for skin assessment and wound care. It is important to place the fixator pins away from planned future incisions. While no studies exist that report specifically on infection following external fixation for multiligamentous knee injuries, we know that pin site infections can occur in as much as 15% of lower extremities undergoing external fixation following trauma [65]. Treatment would include antibiotics and removal of external fixation pins.

At the time of surgical reconstruction, the surgeon should take several measures to minimize the risk of wound complications. The surgeon should avoid incisions that cross previous scars. Excessive undermining of skin flaps should be avoided. The surgeon should avoid using an extended anterior "total knee" incision. A sufficient skin bridge (>10 cm) should be maintained between incisions. We have found that an anteromedial arthrotomy and an extensile lateral incision give adequate exposure to all injured areas of the knee without jeopardizing the integrity of the skin. We utilize perioperative intravenous antibiotics for all patients undergoing knee ligament reconstructions. Appropriate hemostasis before wound closure is critical to prevent hematoma formation as postoperative hematoma is a leading cause of skin necrosis and infection [63]. Finally, the surgeon should also ensure that there is no excessive tension on the wound at the time of closure. Elevation and cold therapy can help minimize early postoperative swelling. The surgical wounds need to be closely monitored the first few weeks after surgery. If the wound shows any erythema or drainage, antibiotic treatment should be initiated. Surgical debridement is required for grossly infected wounds. Prompt recognition of a wound infection can prevent the need to remove ligament grafts and hardware.

40.7 Arthrofibrosis

Arthrofibrosis is a common complication in the treatment of multiligament knee injuries. Prior to 1970, most knee dislocations were treated with cast immobilization. Taylor et al. found an unacceptably high rate of stiffness in knees that were immobilized greater than 6 weeks [20]. As surgical treatment of the multiligament knee has become more popular, arthrofibrosis still remains a common complication. The mean incidence of arthrofibrosis in surgically treated knee dislocations is 29% (5–71%) [66]. A retrospective study by Wong et al. compared closed immobilization with surgical treatment following knee dislocations. The 11 patients in the closed treatment group were treated with casting or a spanning external fixator. The 15 patients in the surgical group underwent surgical repair and/or reconstruction of the injured ligaments. At final follow-up, the operated patients had better stability and better overall International Knee Documentation Committee (IKDC) scores than the immobilized group. There was no difference in the mean total range of motion between the immobilized group (137°) and the surgically treated group (128°). However, the authors did note a higher degree of flexion contracture in patients who underwent operative treatment (5.7 mm vs. 1.8 mm) [67].

Some authors have suggested that multiligament reconstructions should be avoided for 3 weeks after injury because of a high risk of arthrofibrosis with the early intervention [68–71]. Other authors have found improved outcome measures in patients who underwent reconstruction within 3 weeks of injury [22, 72–74]. A systematic review by Hohmann et al. [66] identified eight studies that compared early versus delayed surgery [22, 51, 72–74]. Early surgery was defined as less than 3 weeks with delayed surgery anytime beyond 3 weeks and averaged 51 weeks after injury. This review found significantly better outcomes for early intervention and a trend towards improved range of motion [66]. However, there is the potential for substantial bias regarding the timing of surgery. These studies were not randomized, and surgery may have been delayed for patients with more severe knee injuries or systemic trauma [26]. Our approach has been to perform surgery as soon as the soft tissue envelope around the knee has recovered from the acute trauma and when the overall condition of the patient allows participation in a rehabilitation program. If surgery needs to be delayed, the knee can be stabilized in a spanning external fixator or a hinged knee brace depending on the stability of the knee and the overall condition of the patient. However, concomitant injuries such as bucket handle meniscus tears, significant avulsion injuries amenable to repair, and irreducible knee dislocations like those seen with medial collateral ligament (MCL) invagination may warrant more urgent operative intervention.

Decreased range of motion following treatment of the dislocated knee can range from mild loss of end range motion to severe arthrofibrosis. Cosgarea et al. noted that arthrofibrosis is a spectrum of involvement ranging from localized anterior intra-articular scar to global intra-articular and extra-articular involvement [75]. Paulos coined the term infrapatellar contraction syndrome (IPCS) for knees in which there is decreased flexion and extension in combination with decreased patellar mobilization [76]. Prevention strategies for arthrofibrosis include minimizing surgical trauma by utilizing arthroscopic techniques where possible and limiting the harvesting of autograft tissue from the injured knee. Minimizing postoperative swelling with rest, ice, compression, and elevation may also be helpful. Range of motion exercises should be started as early as possible depending on the pattern of injury, graft choices, and fixation of the ligaments. However, if aggressive motion exercises are begun too early, there is a risk of stretching the healing grafts. After multiligamentous knee reconstructions, the surgeon must balance the risk of recurrent laxity with that of arthrofibrosis. An individualized rehabilitation protocol must be developed for every patient and communicated to the therapist. Our general practice has been to immobilize the knee near full extension for approximately 2 weeks before initiating range of motion exercises; allografts tolerate longer periods of immobilization better than autografts. Hyperextension, flexion >90°, and weight bearing are avoided for 6 weeks in order to protect the reconstructed ligaments during the early healing phase.

Treatment of motion loss following reconstruction of the dislocated knee is difficult. We have modified an algorithm developed by Cosgarea et al. for treating stiff knees [75]. When recognized early in the rehabilitation course, treatment consists of range of motion exercises and patellar mobilization along with anti-inflammatory and pain management measures. Weight-bearing exercises can help with gaining complete extension. If the patient continues to have significant motion restrictions at 3 months, we perform a closed manipulation under anesthesia followed by an aggressive physical therapy program. An indwelling epidural catheter can be used if pain is limiting the patient's ability to participate in therapy. Surgical intervention is reserved for recalcitrant cases particularly those with significant flexion contractures. Surgical intervention for arthrofibrosis involves performing an arthroscopic lysis of adhesions and fat pad debridement as seen in Fig. 40.2. Occasionally a limited arthrotomy is required to excise anterior scar tissue. Utilizing this technique, Cosgarea et al. demonstrated significant gains in both flexion and extension. However, ultimate functional outcomes were compromised. Radiographic findings demonstrated that 89% had osteophyte formation in at least one compartment and 20% had joint space narrowing. Results were worse in patients with severe motion loss and long-standing symptoms (>6 months). Paulos also found markedly improved range of motion but significant pain and functional limitations in his series of patients who underwent treatment for IPCS [76]. These authors make it clear that arthrofibrosis is best treated with prevention or early intervention.

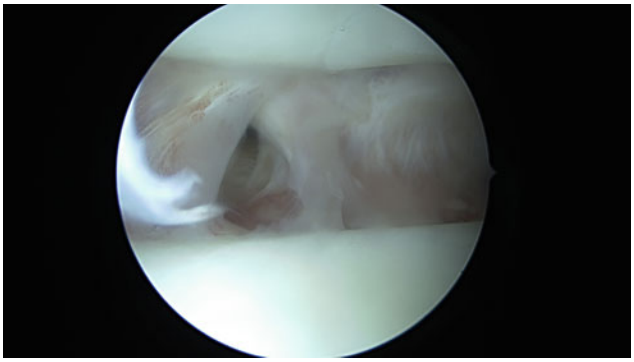

Fig. 40.2 Arthroscopic image of suprapatellar pouch showing arthrofibrosis. Surgery was performed 10 weeks prior to arthroscopic lysis of adhesions in a patient that had range of motion of 0°–60° with a firm endpoint

40.8 Heterotopic Ossification

Heterotopic ossification (HO) is another potential cause of decreased range of motion following surgical treatment of the dislocated knee. The incidence of symptomatic heterotopic ossification following treatment has ranged from 26 to 45%. Proposed risk factors for the development of HO include time to surgery, degree of soft tissue trauma, and high Injury Severity Scores. In a study done by Whelan et al., they looked at risk factors for HO development following surgical treatment of multiligamentous knee injuries. The only independent risk factor found for the development of HO was PCL reconstruction [77].

In patients with significant risk factors for the development of HO, prophylaxis with indomethacin can be utilized. Radiation has been used for HO prophylaxis in other conditions but we are not aware of it being used in patients with knee dislocations. If heterotopic ossification is seen on follow-up radiographs but is not symptomatic, no treatment is indicated. Treatment of symptomatic heterotopic ossification can be difficult and usually involves excision of the heterotopic bone. If the heterotopic bone is near neurovascular structures, great care must be exercised during the surgical dissection to avoid injury to those structures. Following HO removal, early range of motion should be initiated and prophylaxis with indomethacin should be employed (Fig. 40.3).

40.9 Recurrent Instability

Recurrent or persistent instability is also a common complication of treatment of multiligament knee injuries. Residual instability has been reported in 42% of patients in at least one plane [66]. Factors that will affect the stability of

Fig. 40.3 X-ray of patient who developed HO following 3 ligament MLK injury reconstruction (*white arrow*). Subsequently underwent manipulation under anesthesia. Also had injury-related peroneal nerve palsy

the knee joint include the severity of the initial injury, identification of all injuries within the knee, type of treatment selected, quality of the treatment performed, postoperative rehabilitation program, and additional traumatic events. Furthermore, pathology present at the time of index surgery, such as limb malalignment, meniscal incompetence, and cartilage lesions can predispose a patient to recurrent instability requiring revision surgery [78]. Chronic instability predisposes knees to further injury to the menisci and articular cartilage. In a series by Noyes [79], the incidence of significant articular or meniscal damage requiring treatment was 75% in patients presenting with chronic instability, compared to no meniscal or articular cartilage damage in patients treated with early surgery. Treatment of the injured ligaments can include immobilization, repair of injured structures, reconstruction of the torn ligaments, or some combination thereof. As previously noted, nonoperative treatment is more likely to result in decreased stability and lower functional scores [67]. Repair versus reconstruction of the involved structures in a multiligamentous knee injury is a topic of debate. Primary repair offers the advantage of anatomic restoration of the injured ligaments especially when the injury is at a bony attachment site. However, primary repair is difficult to perform more than 3 weeks after injury, and the quality of the injured tissues may preclude successful primary repair. In their systematic review, Levy et al. found that direct repair of the cruciate ligaments resulted in a greater degree of flexion loss, a higher rate of PCL instability, and a lower rate of return to the preinjury activity level compared to cruciate ligament reconstructions [80]. Similarly, a comparison of direct repair versus reconstruction of the posterior lateral corner demonstrated a much higher failure rate after primary repair compared with reconstruction [49]. Our approach is to attempt a primary repair for bony avulsions and for the collateral ligaments when surgery is able to be performed in the first few weeks after injury. If collateral ligaments are injured midsubstance or if surgery is performed on a delayed basis, we perform an anatomic reconstruction of the medial and/or lateral sides.

Surgical technique is critical to the outcome for multiligament reconstructions. The surgeon must first accurately identify all injured structures in order to prepare for a comprehensive reconstruction and avoid postoperative instability [68]. Plain radiographs can identify bony avulsions. Magnetic resonance imaging is useful for diagnosing injured ligaments as well as the site of the injury. An examination under anesthesia at the time of reconstruction is critical to evaluate all pathologic laxity. The surgeon must have a thorough understanding of knee anatomy in order to be able to restore knee anatomy. Multiple allograft and autograft options are necessary and may include patellar, quadriceps, semitendinosus, gracilis, tibialis anterior, or Achilles tendons with or without bone plugs. The surgeon must have available a variety of fixation techniques. Technical errors that can result in residual pathologic laxity include failure to identify and treat an injured ligament, use of a structurally weak graft, nonanatomic placement of ligament grafts, and inadequate graft fixation.

Finally, the postoperative rehabilitation program is critical to the success of multiligament knee reconstructions. In general, the course of rehabilitation is slower after surgical treatment of the dislocated knee than it is with an isolated ACL reconstruction. Stretching of the graft during the postoperative rehabilitation program is not uncommon [81]. However, allowing the surgically repaired knee to heal must be balanced with starting a rehabilitation protocol that allows improved patient outcomes and reduces the risk of postoperative loss of range of motion [82]. Protocols, though, must be patient specific as limitations and allowances can change based on the structures requiring surgical repair. The major factors that contribute to the risk of graft failure in the early postoperative period are the need to utilize allografts and damage to the secondary stabilizers. Hyperextension, varus or valgus loads, and rotational forces can place high loads on healing ligaments. We routinely brace our patients for a minimum of 6 weeks following reconstruction. Open chain exercises can cause high loads in the reconstructed cruciate ligaments and may lead to graft elongation if started too early. We avoid open chain exercises in our patients with multiligament reconstructions for 3 months. Running is not initiated until the patient has full range of motion, no effusion, and good muscle control, which usually takes at least 4 months to attain. Pivoting activities are begun between 6 and 9 months, and we generally avoid return to any sporting activity for at least 1 year. The risk of graft failure from too aggressive rehabilitation must be balanced against the risk of arthrofibrosis from a therapy program that is too restrictive.

The postoperative protocol must be individualized for each patient, and there must be continuous communication between the surgeon, patient, and therapist.

40.10 Conclusion

Patients with multiligament injured knees present the surgeon with the difficult task of restoring stability to the knee without causing major complications. A thorough understanding of knee anatomy and biomechanics, combined with careful surgical planning and execution, can minimize the risk of serious complications. Careful postoperative follow-up is required to identify complications that can occur. Early recognition and prompt treatment will result in a satisfactory outcome in most patients.

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Results of Treatment of the Multiple-Ligament-Injured Knee

41

Niv Marom and Robert G. Marx

41.1 Introduction

Knee dislocations have been described in the literature since the eighteenth century. The term knee dislocation has been defined to include not only truly dislocated knees but also knees with rupture of two or more of the four major knee ligaments, usually involving bicruciate ligament injury. They are rare injuries, but are among the most serious of all traumatic extremity injuries. Many of these injuries reduce spontaneously, leaving the true incidence of knee dislocation unknown. The potential limb-threatening nature of knee dislocations mandates that every orthopaedic surgeon be familiar with the assessment and treatment of knee dislocations. Initial assessment of vascular status is critical due to the potential for injury of the popliteal artery, associated with approximately 32% of all knee dislocations [1, 2]. Late complications include decreased range of motion (ROM), instability, pain, inability to return to previous employment, and inability to return to previous activities and sport.

Given the rarity and heterogeneity of this injury, high-quality clinical studies and randomized clinical trials are largely lacking to help guide treatment. Continued areas of debate surrounding the operative treatment of knee dislocations include early versus delayed reconstruction, repair versus reconstruction of the posterolateral corner (PLC), and preferred treatment of the medial side or medial collateral ligament (MCL) in the multi-ligament-injured knee.

41.2 Operative Versus Nonoperative Management

Dramatic advances in the improvement of short- and long-term outcomes after knee dislocation have evolved over the past 250 years. In the early nineteenth century, Sir Astley Cooper proposed that "there are scarcely any accidents to which the body is liable which more imperiously demand immediate amputation than these" [3]. Amputation has undoubtedly become the treatment of last resort; historically, studies favored conservative or nonsurgical approaches. The recent trend has favored operative treatment.

Repair of midsubstance ligamentous tears has been generally unsuccessful, although better results have been reported following reattachment after ligament avulsion from their insertions [4, 5]. In order to establish the current basis upon which we treat the multi-ligament-injured knee, we will briefly discuss the evidence to support the operative management of the multiple-ligament-injured knee.

A meta-analysis of operative versus nonoperative treatment of knee dislocations by Dedmond and Almekinders [6] lends substantial support to the use of surgical treatment. They included 15 studies with an average follow-up between 2 and 5 years. Statistically significant better outcomes were found in ROM (means 123° vs. 108°, $p < 0.001$), degree of flexion contracture (means 0.54° vs. 3.5°, $p < 0.05$), and Lysholm score (means 85.2 vs. 66.5, $p < 0.001$) for the surgically treated patients. Moreover, the ability to return to the same level of employment (58% vs. 50%) or athletic activities (31% vs. 14%) tended to be better in the surgically treated group.

Wong et al. [7] retrospectively compared the functional outcome of 15 patients treated operatively with 11 patients treated with closed immobilization after knee dislocation. There was no statistical difference in overall knee ROM (mean difference 8.5°, $p = 0.20$); however, the operated group had significantly greater flexion contracture (mean difference 3.9°, $p = 0.002$). The operated group had better

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stability (mean difference in anteroposterior stability 4.8 mm, $p = 0.001$) and better overall knee function as measured by the IKDC score (mean difference 12.1, $p = 0.005$). Subjectively, knee instability among the operated group was reported in 26.7% ($n = 4$) of patients as compared to 90.9% ($n = 10$) in the closed immobilization group ($p = 0.002$).

Richter et al. [5] retrospectively evaluated 89 patients treated for traumatic knee dislocation. Sixty-three patients underwent repair or reconstruction, and 26 patients were treated nonsurgically with either a cast or external fixation for 6 weeks. At an average follow-up of 8.2 years, the mean Lysholm (78.3 vs. 64.8, $p = 0.001$) and Tegner activity scores (4.0 vs. 2.7, $p < 0.001$) were significantly better in the surgical group as compared to the nonsurgical group. Mean mm translation during Lachman examination was significantly lower in the surgically treated group (5.1 vs. 8.2, $p < 0.001$). Moreover, a greater percentage of patients were able to resume working and sports activities in the operatively treated group. Overall, prognostic factors associated with improved outcomes included patients 40 years of age or younger, injuries sustained secondary to sports rather than motor vehicle accidents, and the use of functional rehabilitation as opposed to immobilization.

Levy et al. [8] published in 2009 their systematic review combining data from four studies of which three were discussed above [5–7] and found that patients receiving operative treatment had higher Lysholm scores (80 vs. 57), higher International Knee Documentation Committee (IKDC) scores (58 vs. 20), they were more likely to return to work earlier than those that where managed non-operatively (72% vs. 52%) and also return to playing sport earlier (29% vs. 10%). However, there was not much difference on posttreatment range of motion (ROM) between these two groups (126° vs. 123°).

Peskun and Whelan [9] performed an evidence-based review of studies comparing operative and nonoperative treatment in the decade up to 2011. Thirty-one articles for operative treatment were compared to only four articles of nonoperative management. The operative cohorts had significantly higher Lysholm scores (84.3% vs. 67.2%), a significantly greater rate of return to work (80.9% vs. 57.8%) and a significantly greater rate of return to sport (50.0% vs. 22.2%).

Based on the presented data, operative management of the multiple-ligament-injured knee is considered the preferred management for this type of injury [10–12].

41.3 Allograft Use in the Treatment of the Multiple-Ligament-Injured Knee

There is no unique combination of graft types that has proven superiority to any other for multiple-ligament reconstruction [13]. The decision regarding grafts choice should be based on the specific pattern of injury, the experience of the surgeon, discussion with the patient and graft availability. Allograft tissue has become increasingly important for those orthopaedic surgeons treating the multiple-ligament-injured knee. Some of the advantages of allograft use over autograft tissue include no donor site morbidity, multiple graft size options, and less tourniquet time [13, 14]. However, there may be some tissue strength and infection concerns depending on allografts processing technique. Additionally, allografts are more available in some countries than others and can be expensive. The literature supports arthroscopically assisted ACL and PCL reconstructions with appropriate collateral ligament surgery using allograft tissue as a reproducible procedure with improved postoperative knee stability (Table 41.1) [15–18].

41.4 Results of Early Versus Delayed Reconstruction

The optimal surgical timing for the multiple-ligament-injured knees is considered controversial. Specific factors to be taken into account that could change the preferred time to repair of collateral and cruciate injury include vascular status, reduction stability, other traumatic injuries, and skin condition. Although not standardized, the generally accepted time frame for acute intervention is prior to 3 weeks post-injury, while reconstruction is considered chronic or delayed by most authors if it occurs more than 3 weeks after injury. Several authors report improved outcomes with early surgical intervention of all ligamentous structures [19–21]. Others recommend immobilization followed by delayed surgery [22, 23]. The major complication following early reconstruction is arthrofibrosis, in many instances requiring manipulation under anesthesia (MUA) or lysis of adhesions (LOA), whereas instability to both cruciate and collateral ligament stresses was more commonly encountered with delayed reconstruction [19, 23]. Although there seems to be more recent evidence supporting the acute reconstruction of knee dislocations, the specific structures injured dictate whether acute or chronic reconstruction is preferred.

Shelbourne et al. [23] reported on 21 patients with low-velocity knee dislocations. They recommended delayed PCL reconstruction with bone–patellar tendon–bone autograft and repair of the medial structures with conservative management of the ACL tear. Reconstruction was delayed until the patient had greater than 90° of flexion, full extension, and good strength. Their rationale for reconstruction technique was that arthrofibrosis associated with acute management of all injured ligaments would be avoided with delayed reconstruction of the PCL and repair of the MCL with conservative management of the ACL. They reported satisfactory results in nine patients treated with this delayed

Table 41.1 Use of allograft in the treatment of the multiple-ligament-injured knee

Study (year)	Injuries[a] (number patients, avg f/u)	Lysholm score (avg)	Functional grading	AP side-to-side difference (avg in mm)	Miscellaneous
Shapiro and Freedman [15]	ACL/PCL (*n* = 7, 51 mos)	74.7	E-3, G-3, F-1	3.3	MUA: *n* = 4 at avg 16.8 weeks; avg flexion arc 118°
Wascher et al. [16]	ACL/PCL (*n* = 13, 3 years)	88	IKDC: 6 NN, 5 AbN, 1 GAbN	4.5 at 20°; 5.0 at 70°	6 Full unrestricted sports; 4 modified sports; MUA: *n* = 2; avg extension loss 3°; avg flexion loss 5°
Shi et al. [17]	ACL/PCL (*n* = 15, 38 mos)	90	IKDC: 9 N, 5 NN	4.8 at 25° and 4.2 at 70°	Avg loss of extension 1.5°; avg loss of flexion 3.9°; 2 patients exhibited 8 and 10 mm of anterior laxity, respectively
Fanelli et al. [18[b]]	ACL/PCL (*n* = 15, 2 years)	86.7		1.6 (PCL screen); 1.6 (corrected posterior); 0.5 (corrected anterior)	Normal PDT in 86.6%; normal Lachman in 86.6%; normal pivot shift test in 93.3%

ACL anterior cruciate ligament, *PCL* posterior cruciate ligament, *PLC* posterolateral corner, *E* excellent, *G* good, *F* fair, *N* normal, *NN* nearly normal, *AbN* abnormal, *GAbN* grossly abnormal, *MUA* manipulation under anesthesia, *PDT* posterior drawer test

[a] All included studies used allograft reconstructions exclusively for cruciate reconstructions

[b] Allograft multiple-ligament knee reconstructions using the Arthrotek (Warsaw, IN) mechanical graft-tensioning device

reconstruction with overall extension losses of 3° and flexion losses of 15°. Only 19% of the patients returned to their preoperative level of activity. In a follow-up on the treatment of low-velocity knee dislocations in sports injuries, Shelbourne and Klootwyk [24] advocated nonoperative management of all MCL injuries, nonoperative management of the PCL if the posterior drawer is 2+ or less, delayed ACL reconstruction, and acute repair of lateral structures.

Also advocating delayed reconstruction were Fanelli et al. [25] who reported 2-year minimum follow-up on 21 arthroscopically assisted PCL/PLC reconstructions in 15 male patients and 6 female patients. Their patients were divided into acute reconstructions between 2 and 4 weeks post-injury versus chronic reconstructions between 6 months and 16 years post-injury. Acute and chronic reconstructions were compared using the Tegner, Lysholm, and HSS knee ligament rating scales with no significant differences found. There was no significant difference between the corrected anterior and posterior KT-1000 measurements between the acute and chronic PCL/PLC reconstructions. The mean postoperative PCL side-to-side difference (STSD) was significantly less in the chronic reconstructions (mean 0.8 mm) as compared to the acute reconstructions (mean 2.5 mm) ($p = 0.0315$), although both fell within the normal range. Overall, the authors recommend delayed reconstruction at 2–3 weeks to allow for decreased swelling and protected ROM.

Fanelli et al. [22] also reported on ten patients acutely treated and ten patients chronically treated for knee dislocations with ACL and PCL reconstructions. They found that there were significant differences between preoperative and postoperative Tegner, Lysholm, and HSS knee ligament rating scales ($p = 0.0001$), yet there were no differences between acute and chronic reconstructions. There were no differences between acute or chronic reconstructions based on KT-1000 measurements. They recommended that reconstruction of the ACL, PCL, and PLC be delayed for at least 2–3 weeks and that reconstruction of the ACL, PCL, and low-grade MCL tears be delayed for 6 weeks to allow the MCL to heal prior to cruciate ligament reconstruction.

While there does exist evidence supporting delayed reconstruction, more studies exist that advocate acute reconstruction. Harner et al. [19] reported on their results for the surgical treatment of knee dislocations. Nineteen of 31 patients were treated acutely (less than 3 weeks) and 12 were treated chronically. The acutely reconstructed knees had improved Lysholm (mean 91 vs. 80, $p = 0.07$), Knee Outcome Survey Activities of Daily Living (mean 91 vs. 84, $p = 0.07$), and Sports Activities Scale (89 vs. 69, $p = 0.04$) scores. There was a trend towards improved Meyers functional ratings in the acute reconstruction group ($p = 0.14$). There was no difference in ROM between the acutely or chronically treated patients, but four of the acutely treated knees required manipulation due to loss of flexion. Significantly fewer patients in the acute reconstruction group ($n = 3$) as compared to the chronic reconstruction group ($n = 6$) had 2+ laxity with Lachman testing ($p = 0.04$).

Liow et al. [20] reported on 21 patients with 22 knee dislocations treated early (<2 weeks post-injury) or chronically (>6 months post-injury). Follow-up was a mean of 32 months. Lysholm scores (87 vs. 75) and Tegner activity scores (5 vs. 4.4) were both higher in the acute reconstruction group. There were no significant differences in IKDC and knee stability outcomes between groups. They concluded that reconstruction within 2 weeks resulted in better overall function and outcome.

Noyes et al. [26] reviewed the results of 11 patients who underwent allograft ACL and PCL reconstruction. Seven were treated acutely (7–28 days) and four were treated chronically (13–31 months). The overall rating, based on patient perception scale and pain scale, resulted in poor outcomes in all four patients in the chronically treated group as compared to one excellent, two good, one fair, and three poor outcomes in the acutely treated group. They also reported more subjective difficulties, especially with sports, in the delayed reconstruction group as compared to the acute reconstruction group.

Wascher et al. [16] reported on 13 patients who underwent simultaneous reconstruction of the ACL and PCL either acutely (<3 weeks post-injury, $n = 9$) or chronically (>3 weeks post-injury, $n = 4$). Mean Lysholm scores were higher in the acute reconstruction group.

Tzurbakis et al. [21] reported on 48 patients with either ACL and medial-sided knee injuries ($n = 12$), ACL or PCL with PLC injuries ($n = 11$), or ACL and PLC injuries ($n = 25$) who were treated either acutely (<3 weeks post-injury) or chronically. Thirty-eight patients were treated acutely and ten were treated chronically. They found that acute surgical management resulted in better Lysholm scores (88.3 vs. 81.7, $p = 0.15$), Tegner rating (4.37 vs. 5.17, $p = 0.003$), and IKDC overall rating (77.1% vs. 55.5%, $p = 0.15$).

Mook et al. [27] reported a systematic review of the timing of operative intervention and rehabilitation in multi-ligament-injured knees. They found that acute treatment (<3 weeks post-injury) resulted in residual anterior instability ($p = 0.018$), more flexion deficits ($p = 0.004$), and significantly more joint stiffness as compared to chronic treatment (>3 weeks post-injury) ($p < 0.001$).

The most recent evidence is the systematic review and meta-analysis evaluating the optimal timing of surgery reptorted by Hohmann et al. [28]. They included 8 studies (total of 260 patients) in their analysis and showed that early surgical intervention in multi-ligament injuries of the knee produces a significantly superior clinical outcome (lysholm scores and IKDC-categorical outcome), compared to late reconstruction. Although an overall trend of improved total range of knee motion was also demonstrated in the early surgical intervention, this was very small and unlikely to be clinically relevant. The authors mentioned the fact that demographic and clinical differences between the early and late group may have affected the clinical outcome substantially, especially when considering significant soft tissue swelling, late referrals from other centers, necessary management of other concomitant orthopaedic and non-orthopaedic injuries as a cause of delayed intervention. All of these may contribute to inferior outcomes in the delayed reconstruction group.

Overall, literature has shown that both delayed and acute reconstructions can have good outcomes with more recent publication supporting early surgical intervention for the multi-ligament injured knee when possible. However, the lack of prospective, randomized controlled trials, the heterogeneous cohorts of patient and the highly variable nature of this injury lead to difficulty generalizing and highlight the need for stronger evidence.

41.5 Outcomes After Combined Anterior and Posterior Cruciate Ligament Reconstruction

The literature reviewing outcomes after surgical treatment of knee dislocations is difficult to assess and is inconclusive due to several factors, including limited number of subjects, the lack of objective measures, the heterogeneity of the injury patterns, and varying surgical procedures utilized. In this section, we will focus on outcomes after combined ACL and PCL reconstruction in the multiple-ligament-injured knee. Outcomes specific to the medial side of the knee and the PLC as it relates to the multiple-ligament-injured knee will be discussed in later sections.

Fanelli and Edson [29] reported the 2- to 10-year results of 35 arthroscopically assisted combined ACL/PCL reconstructions. Postoperative physical examination revealed a normal posterior drawer test (PDT) in 46% (16/35). A normal Lachman and pivot shift test was found in 94% (33/35). Postoperative KT-1000 arthrometer mean STSD measurements were 2.7 mm (PCL screen), 2.6 mm [29] (corrected posterior), and 1.0 mm (corrected anterior), which were statistically significant as compared to the preoperative assessment. Telos stress radiographic STSD at 90° of knee flexion and 32 lb of posteriorly directed proximal force were 0–3 mm in 11 (52.3%) of 21 knees. Postoperative Lysholm score mean value was 91.2, which also represented a statistically significant improvement.

Fanelli et al. [18] subsequently published their data representing 2-year follow-up results of 15 arthroscopically assisted ACL/PCL reconstructions using the Biomet Sports Medicine (Warsaw, IN) graft-tensioning boot. Both cruciate ligaments were reconstructed with Achilles tendon allograft in all 15 knees. Postoperatively, the PDT was normal in 86.6% (13/15 knees). Lachman test was normal in 86.6% of knees, and the pivot shift test was normal in 93.3% (14/15). Postoperative KT-1000 arthrometer mean STSD was 1.6 mm (PCL screen), 1.6 mm (corrected posterior), and 0.5 mm (corrected anterior). All were a significant improvement from preoperatively. Telos stress radiographic

STSD were 0–3 mm in 66.7% (10/15), 4 mm in 26.7% (4/15), and 7 mm in 1 knee (6.67%). Mean Lysholm score was 86.7 postoperatively. Their findings demonstrate the efficacy of using a mechanical graft-tensioning device in single-bundle, arthroscopically combined ACL and PCL reconstructions.

Wascher et al. [16] reviewed the results in 13 patients who underwent simultaneous allograft ACL/PCL reconstruction after knee dislocation. At a mean of 38 months, only one patient described their reconstructed knee as normal. The average extension loss was 3° (range, 0°–10°) and the average flexion loss was 5° (range, 0°–15°). The KT-1000 arthrometer measurements with 133 N anterior–posterior tibial load showed a mean STSD of 4.5 mm (range, 0–10) at 20° and 5.0 mm (range, 0–9) at 70°. The mean Lysholm score was 88. Only six patients had an IKDC rating of nearly normal. MUA was required for two patients postoperatively.

Noyes and Barber-Westin [26] evaluated 11 patients with ACL/PCL reconstructions and immediately protected knee motion after knee dislocations at a mean of 4.8 years postoperatively. The failure rates included 2 out of 11 (18%) PCL reconstructions and 1 (9%) ACL reconstruction. Arthrometric testing at 20° of flexion showed 10 knees with less than 3 mm of increased total anteroposterior displacement and 1 knee with 7 mm of increased translation. At 70° of flexion, nine knees had <3 mm of increased displacement and two knees had > 6 mm of increased translation. Five patients (all acute injuries) required treatment for decreased knee ROM. Nine patients had full ROM. Even though an early protected knee motion rehab protocol was used in this cohort, five patients required MUA or arthroscopic LOA for knee stiffness.

Lo et al. [30] evaluated their series of 11 consecutive patients treated with combined ACL/PCL reconstructions using hamstring (ACL) and quadriceps tendon (PCL) autografts in a single operation at a mean follow-up time of 55 months. 91% of patients (10/11) exhibited good or excellent results. Eighty-two percent (9/11) patients subjectively rated their knee function as normal or nearly normal as compared to the preoperative status. Knee ROM was normal in 8 of the 11 patients (73%). Ninety-one of knees had normal Lachman and pivot shift test results. Postoperatively all patients had either a normal PDT or a grade I PDT (a decrease of 5 mm in tibial step-off). KT-1000 arthrometric testing revealed a postoperative STSD of 0.9 mm (corrected anterior), 2.5 mm (corrected posterior), and 2.6 mm (PCL screen). All were a statistically significant improvement from the preoperative values. Mean Lysholm score postoperatively was 88 (preoperative 34, $p = 0.008$).

Strobel et al. [31] evaluated the clinical outcome in 17 patients after one-stage reconstructions of the ACL, PCL, and PLC using autogenous hamstring grafts. Grafts were obtained from the ipsilateral and contralateral limbs. Mean follow-up was 2 years. Mean postoperative total anteroposterior STSD with KT-1000 arthrometer testing was 2.0 mm (range, −4 to 7 mm). IKDC was nearly normal in four patients (29.8%), abnormal in ten patients (58.8%), and grossly abnormal in two patients (11.8%). Mean postoperative subjective IKDC score was 71.8. This study demonstrates that although normal tibiofemoral kinematics are variably restored, most patients can recover a functionally stable knee and have substantially improved knee function based upon subjective and objective parameters as compared to their preoperative status.

Zhao et al. [32] evaluated their results of simultaneous double-bundle ACL and PCL reconstruction with autogenous hamstring tendons in 21 patients at a minimum of 2-year follow-up. All patients were reported to have normal knee extension. One had a 10° flexion limitation, and four had a 5° flexion limitation. KT-1000 arthrometer testing revealed STSD in overall anteroposterior laxity at 70° of knee flexion of 0–2 mm in 16 patients, 3–5 mm in four patients, and 6–10 mm in one patient. At 25° of knee flexion anteroposterior laxity measurements were 0–2 mm in 14 patients, 3–5 mm in 6 patients, and 6–10 mm in 1 patient. The mean Lysholm score was 91.9 at latest follow-up. IKDC grading was normal in 13 patients (61.9%), nearly normal in seven patients (33.3%), and abnormal in 1 patient (4.8%). This study reveals that simultaneous double-bundle ACL and PCL reconstruction with autogenous hamstring tendons can yield normal or nearly normal results in >95% of patients at 2 years.

41.6 Return to Pre-injury Activity Level

Return to pre-injury level of activity is not reliable following reconstruction for knee dislocations. Mariani et al. [33] reported on combined hamstring autograft ACL and bone–patellar tendon–bone PCL reconstructions in 15 patients. Pre-injury, pre-reconstruction, and postsurgical activity levels were evaluated by the Tegner score. Seven patients (50%) returned to pre-injury level of the sport with two patients (14.3%) returning to competitive sports (Tegner nine). They suggested that autografts yield adequate stability and moderate return to sports.

Fanelli et al. [22] reported Tegner activity scores on a cohort of 20 patients treated with arthroscopically assisted combined bicruciate ligament reconstruction with a minimum 2-year follow-up. Mean preoperative Tegner score for 20 knees was 1.9 (range, 0–7). The mean postoperative Tegner score for the 20 knees was 5.6 (range, 3–9). This is a statistically significant improvement from preoperative to postoperative values ($p = 0.0001$). Fanelli and Edson [29] also reported statistically significant improvements

($p = 0.001$) in Tegner scores for 35 arthroscopically assisted combined ACL/PCL reconstructions at 2- to 10-year follow-up. The mean preoperative Tegner score for 30 knees was 1.4 (range, 0–7). The mean postoperative Tegner score for 35 knees was 5.3 (range, 3–7).

Zhao et al. [32] performed simultaneous one-stage double-bundle ACL and PCL reconstructions in 21 patients with hamstring autografts and reported a 19% return to pre-injury level. Khanduja et al. [34] reported 68% return to pre-injury level of activity on a retrospective review of arthroscopic PCL reconstructions and open PLC reconstructions in chronic multi-ligament-injured knees. Wascher et al. [16] reported on 13 patients (nine treated acutely and four treated delayed) with ACL and PCL reconstructions. Seven had MCL injuries and six had PLC injuries. Return to the unrestricted sport was 46% while return to modified sport was 31%. Tzurbakis et al. [21] evaluated patients with ACL and MCL injuries, ACL or PCL injuries with PLC injury, or ACL and PCL injuries. All patients' activity significantly decreased postoperatively with only those in the ACL and MCL injury group returning to any activities. Additionally, there were no differences in return to activity between those reconstructed acutely or delayed.

Mook et al. [27] performed a review of 24 retrospective studies categorizing surgical timing as acute, chronic, or staged. Return to work rate was 89%, 100%, and 100% respectively and return to athletics rate was 43.6%, 68.8%, and 90%, respectively. Patient activity level was not specified.

In the athletic population, Hirschmann et al. [35] reported on 24 elite athletes who underwent surgery for multi-ligament knee injuries which were sustained during sports activity and found a 79% return to sport rate following surgery, though only 33% of the athletes were able to perform at pre-injury levels.

In a different high demand population, Barrow et al. [36] retrospectively evaluated 46 military service members who had sustained a multi-ligament knee injury during combat activity. The primary clinical outcome measure was the ability to return to active military duty. The most common ligament injury pattern ($n = 9$; 20%) was combined disruption of all four major ligaments: the anterior cruciate ligament, posterior cruciate ligament, posterolateral corner, and medial collateral ligament. Return to duty rate was 41% (19/46). High-energy mechanism, neurovascular injury, compartment syndrome, traumatic knee arthrotomy, and intra-articular femur fracture were all more prevalent in subjects who were unable to return to duty ($p < 0.05$). Number of ligaments injured was not associated with return to duty status.

Overall, the return to activity following knee dislocation and reconstruction is unpredictable with varying rates influenced by many factors such as the population of patients, machnism of injury, concomitant injuries, injury characteirstics, surgery timing and technique and more. The available literature is mainly based on small case series with significant heterogeneity in injury mechanism, injury complexity, and management.

41.7 Repair Versus Reconstruction of the Posterolateral Corner

The surgical treatment options for an unstable PLC include repair and reconstruction. The data overall supports reconstruction except in the setting of a significant avulsion fracture that is amenable to internal fixation. Several authors recommend anatomic repair of the PLC if performed within 2–3 weeks of the injury [37–40]. In addition to timing of surgery, other variables that impact the success of PLC repair include tissue quality, severity of surrounding soft tissue damage, associated ligamentous injuries, and the location of the PLC damage. The popliteus is frequently torn at the musculotendinous junction thereby precluding repair [37].

Shelbourne et al. [41], in treating knee dislocations, reported on a technique to repair the disrupted lateral-sided structures, including the PLC, "en masse" while reconstructing the ACL and treating the PCL nonoperatively. Seventeen patients were objectively evaluated at a mean 4.6 years and 21 subjectively evaluated at 5.6 years postoperatively. Lateral laxity was normal in 15 patients, and the overall objective grade was normal in ten patients and nearly normal in the rest. The mean subjective IKDC score was 91.3, modified Noyes score was 93.0, and activity score was 8.0. Of the 16 patients injured during sports, 13 (81%) returned to the same level of activity. They concluded that this "en masse" technique resulted in excellent subjective and objective scores especially for repairs occurring within 4 weeks of injury.

Most authors report improved outcomes with acute reconstruction of the PLC as opposed to repair after knee dislocation [42, 43]. Stannard et al. [43] reported on the results of repair versus reconstruction in a level III prospective trial of 57 knees with 24-month minimum follow-up. Forty-four (77%) of those knees had injuries to multiple ligaments. Patients were not randomized to treatment but were selected for repair if they presented for surgery within 3 weeks of injury, and the tissue at surgery was deemed adequate to support a repair. If those criteria were not met, the patients underwent reconstruction with a modified two-tailed technique using a tibialis allograft to reconstruct the popliteus, popliteofibular ligament, and the lateral collateral ligament. The patients underwent an early motion rehab protocol. The failure rate for the repair group was 37% which is significantly higher than the 9% failure rate for the reconstruction group. The clinical exam for stability was also significantly in favor of reconstruction ($p < 0.05$). The authors strongly advocate reconstruction rather than repair for all cases of PLC disruption with the only exception being PLC avulsion fractures amenable to screw internal fixation.

Levy et al. [42] reported on a cohort of 45 patients with minimum 2-year follow-up who underwent repair versus reconstruction of the fibular collateral ligament (FCL) and PLC in the setting of a multi-ligament knee reconstruction. Ten patients underwent acute repair of the PLC followed by staged ACL/PCL reconstruction. Eighteen patients underwent PLC reconstructions at the time of ACL/PCL reconstruction. Reconstruction of the FCL and PCL was performed with an Achilles tendon allograft. Failure rate was significantly worse in the repair group (40% vs. 6%, $p = 0.04$). After revision reconstructions there was no difference in IKDC subjective scores. There was no correlation with tear site and failure, but overall higher failure rates with repairs. These results are to be accepted with caution due to the small sample size in the repair group. Overall, the authors found that reconstruction of the FCL/PLC is a more reliable option than repair alone in the setting of a multi-ligament-injured knee.

Bonanzinga et al. [44] evaluated in a systematic review the management of combined anterior ACL and PLC injuries. They included a total of six studies involving 95 patients who were managed either without surgery, with primary repair or with reconstructions. In the reconstruction group, 67 of the 72 patients who underwent a PLC reconstruction were assessed for anteroposterior laxity, with a mean side-to-side difference of 1.5 ± 1.1 mm. Additionally, 88% of patients in this group were graded as good/excellent (A/B) on the IKDC form. In the early repair group, three patients (33%) were graded as good/excellent (A/B) on the IKDC form and 56% graded as +1 for varus laxity on physical examination. In the non-operative group, the only clinical score available was the subjective IKDC score, with a mean value of 80.5. The authors concluded that combined ACL and PLC reconstruction seems to be the most effective approach to these combined injuries and they also mentioned the paucity of literature focused on the management of these combined injuries.

41.8 Treatment of the Medial Side/MCL in the Multi-ligament-Injured Knee

There is limited information in the literature regarding treatment of the injured medial side in the multi-ligament-injured knee. Thus, ideal treatment, whether conservative, repair, or reconstruction, of the MCL remains controversial. Fanelli and Edson [29] reported on 35 patients with acute and chronically treated ACL/PCL reconstruction, 15 of whom had injuries involving the MCL. Seven were treated nonoperatively, and eight were treated with reconstruction and posteromedial capsular advancement. All seven in the operative group and seven of eight in the nonoperatively treated group were stable to 30° valgus stress test. Their overall treatment decisions were based on the expected degree of medial-sided damage although they did not distinguish by grade of MCL tear. Fanelli et al. [22] recommended that in multi-ligament knee injuries, reconstruction of the ACL and PCL, when present with concomitant MCL injury, be delayed for 6 weeks with appropriate brace treatment to allow for healing of the MCL.

Kovachevich et al. [45] performed a systematic review of the literature regarding MCL treatment in the setting of a multi-ligament knee injury. They concluded that repair or reconstruction in the setting of a multi-ligament knee injury results in satisfactory outcomes based on the available literature, yet caution that further level I evidence and outcome-based studies are needed.

Mook et al. [27] reported in their systematic review that valgus laxity was more prevalent in patients treated acutely although the difference was not significant. However, patients treated acutely and immobilized postoperatively showed higher rates of laxity as compared to those patients rehabilitated with early mobilization (26% vs. 2%). No data was published based on actual treatment of the medial side. Grades I and II MCL injuries have been reported to reliably heal and provide stability after nonoperative treatment when found in isolation [46–49] or when found with concomitant cruciate ligament injury [50]. Low-grade MCL injuries combined with a bicruciate ligament injury may benefit from 4 to 8 weeks of nonoperative management followed by cruciate ligament reconstruction [22, 29, 51].

Bicruciate ligament injuries associated with high-grade MCL injuries have less clear results. Several authors [26, 52, 53] report better results with repaired medial structures at the time of the cruciate ligament reconstruction as primary repair of the collateral ligaments is less predictable when delayed. Concomitant MCL repair may increase the risk of postoperative stiffness as demonstrated by repair with ACL reconstructions [54–56]. For midsubstance MCL injuries or when repaired tissue results in persistent laxity, augmentation procedures are often required commonly using autologous semitendinosus or gracillis graft [57–59].

41.9 Conclusion

Knee dislocations are complex and rare injuries, but the potential limb-threatening nature of knee dislocations mandates that every orthopaedic surgeon be familiar with the assessment and treatment of these injuries. The mechanism of injury is usually one of high-energy trauma, yet knee dislocations are also encountered in sports injuries. Most Orthopaedic Surgeons performing multiple-ligament surgeries would agree that early surgical treatment when possible is the preferred management based on recent literature, however, controversies still exist with regard to timing and stageing surgeries, repair versus reconstruction of the PLC, and the preferred method of treatment of concomitant MCL injuries. We found the data lacking in high-quality clinical studies and randomized clinical trials to make many strong recommendations guiding treatment, yet it is reasonable to conclude that multiple-ligament surgeries, when performed well and address all deficits, generally result in good clinical outcome and return to daily activities in the majority of cases. As far as return to pre-injury level of sport activity, it is unpredictable based on current literature and probably also significantly influenced by the different characteristics of the patient and the injury.

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Part XI

Clinical Case Studies

Selected Case Studies in the Treatment of the Multiple Ligament Injured Knee

42

Gregory C. Fanelli

42.1 Introduction

This section in *The Multiple Ligament Injured Knee: A Practical Guide to Management, Third Edition,* presents selected cases in treatment of the multiple ligament injured knee that are representative of my practice. I have written this chapter in first person to provide a more personal approach to presenting these topics. These selected cases represent real-life management examples in the treatment of difficult knee ligament instability problems. The format followed will be the same for each case study to provide consistency in the presentation, and is outlined as follows: history, physical examination, imaging study findings, surgical timing, graft selection, surgical technique, postoperative rehabilitation program, and results. Details of the surgical technique will not be presented in this section since the surgical technique was performed as I have described in Chaps. 1, 20, 22, and 36 in this textbook. Specific topics presented in this chapter of selected case studies include nonsurgical treatment, open growth plates, multiple ligament knee injuries in young athletes and middle-aged adults, extensor mechanism disruption, complex knee ligament instability in the obese patient, revision multiple knee ligament surgery, and peroneal nerve injury. The purpose of this case study chapter is for the reader to gain insight into management and treatment strategy decisions in these complex knee ligament injuries. The following is a list of the cases presented in this chapter:

Case Study 1: Acute ACL-PCL-High-Grade Medial Side Injury with Entrapped Medial Capsule
Case Study 2: Acute PCL, ACL, Medial and Lateral Side Injuries, Patellar Tendon Avulsion
Case Study 3: Pediatric Combined PCL Posterolateral Instability
Case Study 4: Fracture Dislocation
Case Study 5: Bilateral Knee Dislocations With Vascular Injury
Case Study 6: Chronic PCL, ACL, Posterolateral, Posteromedial Instabilities After Left Knee Dislocation
Case Study 7: 17 Year Follow-Up Chronic PCL, ACL, Posterolateral, Posteromedial Instabilities
Case Study 8: Minimally Displaced PCL Tibial Insertion Site Bony Injury
Case Study 9: PCL, Posteromedial, and Posterolateral Instability in a 12-Year-Old Boy With Open Growth Plates
Case Study 10: Acute Combined Posterior Cruciate Ligament Tear With Posterolateral Instability in a 17-Year-Old Gymnast
Case Study 11: Acute Combined Posterior Cruciate Ligament Tear With Posteromedial Instability in a 52-Year-Old Woman
Case Study 12: Acute Combined PCL, ACL, Posterolateral Instability in a 47-Year-Old Man With 15 Year Outcomes
Case Study 13: Acute Combined PCL, ACL, Posterolateral Instability, Patella Tendon Rupture in a 21-Year-Old Man
Case Study 14: Subacute Combined PCL, ACL, Posteromedial Instability in 32-Year-Old Woman With a Body Mass Index of 50
Case Study 15: Acute Combined Posterior Cruciate Ligament Tear, Anterior Cruciate Ligament Tear, Posterolateral Instability, and Peroneal Nerve Injury
Case Study 16: Revision Posterior Cruciate Ligament, Anterior Cruciate Ligament, and Posteromedial Reconstruction.

42.2 Case Study 1: Acute ACL-PCL-High-Grade Medial Side Injury with Entrapped Medial Capsule

This patient is a 17-year-old male American football player who sustained a right knee direct contact and twisting injury. The patient's right foot was stuck in the turf, and forced

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valgus, external rotation, and flexion forces were applied to the patient's knee resulting in a posterior tibia–femoral dislocation, and pain and deformity of the right knee. The right lower extremity was splinted on the field, and the patient was transported from the scene of the accident to the community hospital where closed reduction of the dislocated knee was attempted. The patient was then transported to our facility. Dorsalis pedis pulses in the injured right lower extremity were ½ compared to 2/2 in the normal left lower extremity. Posterior tibial pulses were intact and symmetrical. Peroneal and tibial nerve function for motor and sensation were intact and symmetrical to the uninvolved left lower extremity.

Physical examination of the knee revealed grade 3+ anterior–posterior laxity of the knee at 25° and 90° of knee flexion. The tibial step offs were negative. There was grade 3 + laxity of the knee to valgus stress at 0° and 30° of knee flexion, and a palpable defect in the medial retinaculum. The lateral and posterolateral ligament complex were stable to examination with varus stress at 30° and 0° of knee flexion, and the posterior lateral drawer test was negative. The patient was able to straight leg raise, and the patella femoral joint was stable with flexion and extension. There was medial skin indentation; however, the skin was intact with no lacerations. Post-reduction X-rays revealed the tibia to still be displaced posterior and lateral to the distal femur.

Ankle–brachial index, arterial duplex, and CT angiogram were all normal, and there was no imaging study evidence of an intimal flap tear of the popliteal artery. There was no clinical evidence of venous insufficiency.

Magnetic resonance imaging study revealed complete disruption of the ACL, PCL, and medial collateral ligament-medial capsular ligament complex. There was also peripheral detachment of the medial meniscus, and the medial capsule entrapped within the medial compartment of the knee.

The assessment of this patient revealed a knee with complete disruption of the ACL and PCL with a high-grade medial side injury, medial meniscus avulsion, and the medial capsule entrapped within the medial compartment of the knee resulting in incomplete reduction. Dislocated knees with high-grade medial side injuries seem to be associated with a higher risk of stiffness, and heterotopic ossification. My treatment strategy was to obtain reduction of the tibia–femoral joint by removing the entrapped medial capsule thereby protecting the skin, and reduce the risk of arthrofibrosis and heterotopic ossification by doing a two-staged surgical procedure.

The patient was taken to surgery two days post-injury for stage one surgical procedure where open reduction of the tibia–femoral dislocation was performed. Primary repair of the medial meniscus and all medial side injured structures was performed using suture anchors and permanent number two suture. Medial side augmentation/reconstruction was performed using Achilles tendon allograft. Postoperatively, the patient was immobilized in a brace locked in full extension until the second stage surgical procedure, and remained non-weight bearing on crutches. The stage two surgical procedure was performed five weeks after the stage one surgical procedure, and consisted of an arthroscopic combined posterior and anterior cruciate ligament reconstruction using allograft tissue. A double-bundle PCL reconstruction was performed during this surgical procedure. Postoperatively, the patient was immobilized in a long leg brace locked in full extension and non-weight bearing for approximately five weeks. The postoperative rehabilitation program that was followed is described in detail in Chap. 39 of this textbook.

This patient's postoperative Tegner, Lysholm, and Hospital for Special Surgery knee ligament rating scale scores two years post reconstruction were 5, 94/100, and 80/100, respectively. KT 1000 arthrometer side-to-side difference values for the PCL screen, corrected posterior, and corrected anterior measurements were 1.0, 0.5, and 0.5 mm, respectively. The KT 1000 side-to-side difference measurements at 30° of knee flexion was 1.0 mm. Telos stress radiographic side-to-side difference measurement at 90° of knee flexion with a posteriorly directed force applied to the tibial tubercle area to assess PCL reconstruction stability was 4.6 mm. The Lachman test was normal, pivot shift negative, tibial step off normal, posterior drawer negative, valgus stress test symmetrical to the nonsurgical knee, and range of motion 0°–110° of knee flexion (nonsurgical side range of motion 0°–125°), with a stable extensor mechanism. Follow-up radiographs show no indication of heterotopic ossification or degenerative joint disease. The patient has achieved his preinjury level of function.

42.3 Case Study 2: Acute PCL, ACL, Medial and Lateral Side Injuries, Patellar Tendon Avulsion

This patient is a 40-year-old female who was riding her motorcycle when she was hit by a pickup truck. The patient was transported to a community hospital where a diagnosis of a left posterior knee dislocation with patellar tendon avulsion from the tibial tubercle insertion was made. The dislocation was reduced in the emergency room. Initial evaluation of the patient's knee revealed anterior and posterior laxity at 30° and 90° of knee flexion with no firm end point. There was varus and valgus laxity with no end point at 0°, 30°, and 90° of knee flexion. The patient was not able to perform a straight leg raise, and with hamstring contraction, the proximal tibia dislocated posterior to the distal femur. There was bruising on the skin of the proximal medial tibia. The peroneal and tibial nerve function was intact with respect to sensory and motor function. The dorsalis pedis and posterior tibial pulses were intact, and symmetrical to the uninvolved right lower extremity. There were no other systemic or orthopaedic injuries. CT angiogram revealed the popliteal artery to be intact with no evidence of intimal flap tear. There was no clinical evidence of venous insufficiency. Reduction of the knee was maintained in plaster splints.

Plain radiographs demonstrated a reduced tibia–femoral joint, and a patella displaced in a superior direction. There were no fractures. MRI demonstrated complete tears of the anterior and posterior cruciate ligaments, avulsion of the medial, and lateral capsular structures from the proximal tibia which included the peripheral attachments of the medial and lateral menisci. Avulsion of the patellar tendon from the tibial tubercle insertion site was also identified on MRI. The patient was transferred to our facility for treatment.

This patient had a severe multiple ligament left knee injury with extensor mechanism disruption that involved both cruciates, the medial and lateral side capsule and ligament structures, the medial and lateral menisci, and skin injury over the proximal medial tibia. The concerns with this patient are the severity and magnitude of the ligament injuries, the extensor mechanism disruption, the potential skin injury and compromise, and the risk of heterotopic ossification and arthrofibrosis. The decision was made to perform a single stage open surgical procedure for repair and reconstruction of the involved structures within the first week following the patient’s injury through a midline longitudinal skin incision. The severe capsular and extensor mechanism disruption required open and not arthroscopic surgery.

The posterior and anterior cruciate ligaments were reconstructed with Achilles tendon allograft tissue using single bundle surgical techniques. The medial and lateral side meniscus, capsular, and ligament structures underwent primary repair with suture anchors, transosseous sutures, and allograft augmentation as needed. The patellar tendon avulsion received primary repair with number 5 suture through drill holes in the tibial tubercle area, and tibialis anterior allograft augmentation. The patient was immobilized postoperatively in plaster splints in full extension with non-weight bearing using crutches for approximately four to five weeks. Progressive range of motion, weight bearing, and physical therapy were then initiated.

There was proximal medial skin breakdown in the postoperative period in the area of skin trauma that occurred during the accident. This was treated with dressing changes and antibiotics with complete healing. There was no infection, and skin grafting was not required. The patient developed arthrofibrosis resulting in a range of motion from 0° to 20° of knee flexion. At the fourth postoperative month, the patient underwent arthroscopic debridement and manipulation. This did not result in improved range of motion. At the eighth postoperative month, the patient underwent open debridement, lateral release, and manipulation. Postoperative wound healing was uneventful, and the patient was advanced in physical therapy and activity.

At postoperative year seven at age 47, the patients involved left knee range of motion is 0°–109° compared to 0°–140° on the uninvolved right knee. The Hospital for Special Surgery, Lysholm, and Tegner knee ligament rating scale scores are 87/100, 88/100, and 4. The patient’s preinjury Tegner score was also 4 indicating a return to preinjury level of function. KT 1000 arthrometer side-to-side difference values for the PCL screen, corrected posterior, and corrected anterior measurements were 2.0, 1.0, and 0.0 mm, respectively. The KT 1000 side-to-side difference measurements at 30° of knee flexion was 1.0 mm. Stress radiographic side-to-side difference measurement at 90° of knee flexion with a posteriorly directed force applied to the proximal to assess PCL reconstruction stability was 2.0 mm. The Lachman test was negative, pivot shift negative, tibial step off equal to the uninvolved side, posterior drawer negative, valgus and varus stress test symmetrical to the nonsurgical knee at 0° and 30° of knee flexion. The extensor mechanism is stable, and the patient has no extensor lag compared to the normal knee. Follow-up radiographs show early degenerative joint disease.

42.4 Case Study 3: Pediatric Combined PCL Posterolateral Instability

The patient is a 6-year-old female who was injured in a trampoline accident resulting in a posterior cruciate ligament tear of the left knee. The patient was initially seen at a community hospital and treated with long leg casting with the injured knee in extension for approximately six weeks. After cast removal, the patient was advanced in physical therapy and increasing activity. The patient went on to develop functional instability with activities such as running, pivoting, and twisting types of maneuvers. The patient was referred to me approximately 5 months after her initial injury for evaluation and treatment of a left knee posterior cruciate ligament tear with functional instability.

Physical examination revealed the injured left knee compared to the normal right knee to have negative tibial step offs, a grade 3 posterior drawer, positive posterolateral drawer, negative posteromedial drawer, no valgus laxity at 0° and 30° of knee flexion, varus laxity at 0° and 30° of knee flexion of approximate 10 mm of increased lateral joint line opening compared to the normal knee. The dial test was positive with the left thigh-foot angle being greater than 10° increased at 30° and 90° of knee flexion compared to the normal lower extremity. The Lachman test and pivot shift tests were negative, and the extensor mechanism was stable. Range of motion was symmetrical to the uninvolved side. When having the patient run, pivot, and twist in the clinic, she would experience instability when twisting on the planted involved left foot causing her to fall. Plain radiographs revealed open distal femoral and proximal tibial growth plates that were symmetrical on both knees.

The diagnosis in this patient in chronic posterior cruciate ligament tear combined with posterolateral instability type B with resultant functional instability in a 7-year-old child with open growth plates. The decision was made to proceed with arthroscopic single-bundle transtibial posterior cruciate ligament reconstruction using fresh frozen looped semitendinosus allograft combined with posterolateral fibular based figure of eight reconstruction using fresh frozen tibialis posterior allograft. The posterior cruciate ligament reconstruction femoral tunnel crossed the distal femoral physis, and the PCL tibial tunnel was positioned distal to the tibial physis. Cortical suspensory fixation with a polyethylene ligament fixation button was used on the femoral side, and a bioabsorbable interference screw and bicortical screw and spiked ligament washer were used on the tibial side fixation.

The posterolateral reconstruction was a fibular-based figure of eight reconstruction using a fresh frozen tibialis posterior allograft. The allograft was looped around the common biceps tendon at the fibular head and sewn there using permanent braided suture. The fibular collateral ligament component was passed medial to the iliotibial band, and the popliteofibular popliteus tendon component passed medial to the common biceps tendon and the iliotibial band. The allograft limbs were crossed in figure of eight fashion with the fibular collateral component being lateral to the popliteus tendon component. The graft limbs were sewn into their respective anatomic femoral insertion sites with number 2 braided permanent sutures. The allograft was then sewn to the deep capsular layers for additional reinforcement, and a posterolateral capsular shift was also performed. Both the posterior cruciate ligament reconstruction and the posterolateral reconstruction procedures were protective of the growth plates.

Five and one-half years follow-up postoperative examination reveals equal leg lengths, normal and symmetrical carrying angles, and normal gait during ambulation. Radiographs reveal open distal femoral and proximal tibial physes that are symmetrical to the normal knee with no malalignment, and no evidence of growth arrest. Range of motion is 0°–113° on the surgical left knee, and 0°–130° on the normal right knee. Side-to-side difference on KT 1000 measurements on the PCL screen, corrected posterior and corrected anterior measurements are 2.5, 3.5, and 0.0 mm, respectively. Side-to-side difference on the KT 1000 anterior displacement measurement at 30° of knee flexion is 2.0 mm. Stress X-rays at 90° of knee flexion comparing the surgical to the knee normal knee reveal a negative 0.3 mm side-to-side difference.

Physical examination of the surgical left knee compared to the normal right knee reveals the tibial step offs are equal to the normal knee, the posterior drawer is negative, posteromedial and posterolateral drawer tests are negative, and the dial test is symmetrical at 30° and 90° of knee flexion. The Lachman test is negative, the pivot shift test is negative, and the surgical knee is stable to varus and valgus stress throughout the flexion–extension arc. The Hospital for Special Surgery, Lysholm, and Tegner knee ligament rating scale scores are 90/100, 89/100, and 6. The patient's preinjury Tegner score was 7 indicating a return to nearly preinjury level of function.

42.5 Case Study 4: Fracture Dislocation

The patient is a 34-year-old man who fell from a height of approximately 50 ft and sustained a closed posterolateral fracture dislocation of the right knee. Initial evaluation revealed gross deformity and swelling of the right knee. Dorsalis pedis pulse in the involved extremity was diminished; however, the foot was adequately perfused. Sensory and motor exam of the right lower extremity was intact and symmetrical to the uninvolved left lower extremity. X-rays of the involved knee and lower extremity revealed a right comminuted medial tibial plateau fracture with articular surface comminution, and a posterolateral dislocation of the tibia under the femur. The diagnosis is a right knee closed tibial plateau fracture dislocation. Closed fracture reduction was performed in the emergency department, and a well-padded long leg splint was applied. Post-reduction, the dorsalis pedis pulse was restored and was symmetrical to the uninvolved lower extremity. Sensation and motor function remained intact and symmetrical to the uninvolved left lower extremity.

Open reduction and internal fixation of the right proximal tibia and tibial plateau fractures and meniscal and capsular repair were performed on post-injury day number one. The patient was referred to me for evaluation and treatment of multiple ligament instability of the right knee. Clinical examination, plain radiography, and MRI evaluation revealed a well fixed and well aligned proximal tibia fracture with reduced and aligned tibiofemoral and patellofemoral joints. There was anterior and posterior laxity at 30° and 90° of knee flexion, and varus and valgus laxity at 0° and 30° of knee flexion with very soft end points. The clinical examination impression was posterior and anterior cruciate ligament instability, posterolateral instability type B, and posteromedial instability type B. These findings were confirmed with MRI examination.

The treatment decision was to enable the fractures to completely heal, confirm that normal lower extremity alignment was achieved with fracture fixation and healing and that no osteotomy would be required. When complete fracture healing was achieved, and normal lower extremity alignment confirmed, the internal fixation hardware was removed approximately 7 months after open reduction internal fixation of the fracture. The patient underwent right knee combined PCL, ACL, posterolateral, and posteromedial reconstruction approximately nine months post-injury after complete wound healing from the hardware removal surgical procedure.

The knee ligament reconstructions were performed using fresh frozen allograft tissue all from the same tissue bank. The double-bundle arthroscopic PCL reconstruction was performed with an Achilles tendon allograft for the anterolateral bundle and a tibialis anterior allograft for the posteromedial bundle. The arthroscopic ACL reconstruction utilized a tibialis anterior allograft. The posterolateral reconstruction was performed with a fibular head based figure of eight semitendinosus allograft combined with a posterolateral capsular shift and peroneal nerve neurolysis. The medial posteromedial reconstruction was performed with tibialis posterior allograft combined with a posteromedial capsular shift procedure. Postoperatively, the patient was immobilized in a long leg brace locked in full extension and non-weight bearing for approximately five weeks. The postoperative rehabilitation program that was followed is described in detail in Chap. 39 of this textbook.

This patient's postoperative Tegner, Lysholm, and Hospital for Special Surgery knee ligament rating scale scores 10 years post reconstruction at age 45 were 4, 90/100, and 89/100, respectively. KT 1000 arthrometer side-to-side difference values for the PCL screen, corrected posterior, and corrected anterior measurements were 1.0, 2.0, and −2.0 mm, respectively. The KT 1000 side-to-side difference anterior displace measurement at 30° of knee flexion was 2.0 mm. Stress radiographic side-to-side difference measurement at 90° of knee flexion with a posteriorly directed force applied to the proximal to assess PCL reconstruction stability was 3.4 mm. The Lachman test was normal, pivot shift negative, tibial step off equal to the uninvolved knee, posterior drawer negative, posterolateral, and posteromedial drawer negative, anterolateral and anterior medial drawer negative, dial test right equals left at 30° and 90° of knee flexion, varus and valgus stress test symmetrical to the nonsurgical knee at 0° and 30° of knee flexion, and range of motion 0°–115° of knee flexion (nonsurgical side range of motion 0°–130°), with a stable extensor mechanism. Follow-up radiographs show mild degenerative joint disease. The patient has achieved his preinjury level of function with respect to work and recreational sports, however, he does have a slight limp, some exertional pain, and some impairment with stair climbing and squatting.

42.6 Case Study 5: Bilateral Knee Dislocations with Vascular Injury

The patient is a 17-year-old female involved in a motor vehicle accident who sustained a closed head injury; right PCL based multiple ligament knee injury, and a left knee dislocation with popliteal artery rupture and peroneal nerve injury. The left knee dislocation was reduced in the emergency department; however, the patient had diminished dorsalis pedis and posterior tibial pulses on the left lower extremity compared to the right lower extremity even after the reduction. An emergent arteriogram was obtained which identified a left popliteal artery segmental occlusion at the tibial plateau. The right multiple ligament injured knee had intact neurological and vascular examination, and the right lower extremity was immobilized in full extension in a brace. The right knee also had an angiogram performed that was a normal study. The patient was taken to the operating room for emergent left popliteal artery repair with saphenous vein patch angioplasty by the vascular surgeons. Upon completion of the vascular repair, the left knee joint posterior capsule that was torn at the time of the dislocation was repaired by the orthopaedic surgery team. The knee was placed in an immobilizer locked in full extension postoperatively. The patient's popliteal artery repair healed uneventfully.

The right knee ligament injuries were disruption of the posterior cruciate and anterior cruciate ligaments, and the medial side structures diagnosed by physical examination, plain radiography, and MRI study. The left knee ligament injuries were disruption of the posterior and anterior cruciate ligaments, and the lateral and posterolateral structures. The vascular surgeons preferred a six-week minimum time frame from left lower extremity arterial repair until subsequent left knee surgery that would require manipulation of the left knee or instrumentation in the posterior aspect of the left knee as would be done with posterior cruciate ligament reconstruction. The treatment decision was to proceed with staged reconstruction performing the right knee surgery on post-injury day 22, and the left knee surgery approximately 10 weeks post-injury and popliteal artery repair. This enabled the patient to recover from her closed head injury, and for the vascular repair to heal adequately.

The right knee ligament reconstruction consisted of an arthroscopic single-bundle posterior cruciate ligament reconstruction using an Achilles tendon allograft, an arthroscopic single-bundle anterior cruciate ligament reconstruction using an Achilles tendon allograft, and a medial posteromedial reconstruction using an Achilles tendon allograft. The left knee ligament reconstruction consisted of an arthroscopic single-bundle posterior cruciate ligament reconstruction using an Achilles tendon allograft, an arthroscopic single-bundle anterior cruciate ligament reconstruction using an Achilles tendon allograft, a fibular collateral ligament and popliteus tendon primary repair, a lateral posterolateral reconstruction using an Achilles tendon allograft combined with a posterolateral capsular shift, and a Peroneal nerve neurolysis. The details of the surgical procedure are similar to the techniques described in Chap. 20 of this textbook. Postoperatively, the patient was immobilized in a long leg brace locked in full extension and non-weight bearing for approximately five weeks. Careful follow-up was performed after each surgical segment to evaluate for heterotopic ossification and arthrofibrosis so that appropriate intervention could be initiated as necessary. The postoperative rehabilitation program is discussed in Chap. 39 of this textbook.

Thirteen years post right and left knee multiple knee ligament reconstructions at age 30, this patient's postoperative Tegner score was level 5/6 (preinjury level 5/6). Postoperative Lysholm score was 89/100, and the Hospital for Special Surgery knee ligament rating scale score was 95/100. KT 1000 arthrometer side-to-side difference values for the PCL screen, corrected posterior and corrected anterior measurements were 1.0, 1.0, and 1.0 mm, respectively. The KT 1000 side-to-side difference anterior displacement measurement at 30° of knee flexion was 1.0 mm. Stress radiographic side-to-side difference measurement at 90° of knee flexion with a posteriorly directed force applied to the proximal tibia to assess PCL reconstruction stability was 0 mm. The Lachman tests were normal, pivot shift tests negative, tibial step offs equal in both knees, posterior drawer negative in both knees, posterolateral, and posteromedial drawer tests negative, anterolateral, and anterior medial drawer tests negative, dial test right equals left at 30° and 90° of knee flexion, varus and valgus stress tests are stable and symmetrical at 0° and 30° of knee flexion, and range of motion 0°–134° of knee flexion on the right, and 0°–134° of knee flexion on the left, with stable extensor mechanisms. Follow-up radiographs show no indication of heterotopic ossification or degenerative joint disease. The patient has achieved her preinjury level of function with respect to work and recreational activities.

42.7 Case Study 6: Chronic PCL, ACL, Posterolateral, Posteromedial Instabilities After Left Knee Dislocation

The patient is a 19-year-old male college student who is a competitive wrestler. The patient sustained a left foot planted severe external rotation twisting mechanism of injury to his left knee resulting in a posterolateral tibiofemoral knee dislocation. The patient was initially seen in an outside hospital emergency department where closed reduction of the tibiofemoral knee dislocation was performed. Neurological and vascular examination of the involved left lower extremity was normal and symmetrical to the uninvolved right lower extremity. Imaging studies revealed no abnormality of the popliteal vessels or the common peroneal nerve. MRI study at the time of injury revealed posterior cruciate and anterior cruciate ligament tears, medial collateral ligament and medial capsule tears, medial patellofemoral ligament tears, fibular collateral ligament tear, and lateral and posterolateral capsular sprains. The patient was treated with immobilization followed by progressive increase in activity level. The patient was referred to me four months after his index injury for functional instability of his left knee with pivoting and twisting activities, walking on uneven ground, and other activities of daily living. The patient was not able to participate in sports or other physically demanding activities. Also of note, the patient had a prior ACL reconstruction on the uninvolved right knee.

Physical examination of the involved left knee compared to the right knee upon presentation to my clinic demonstrated range of motion of 0–140 in each knee. There was no effusion, the skin is in good condition, the extensor mechanism is intact, and the neurological and vascular examinations were normal and symmetrical to the uninvolved side. The Lachman test and pivot shift tests were positive. The anterolateral and anteromedial drawer tests were positive. The tibial step offs were negative at 90° of knee flexion, and the posterior drawer, posterolateral drawer, and posteromedial drawer tests were positive. There was valgus laxity at 0° and 30° of knee flexion. The knee is stable to varus stress. The dial test was positive at 30° and 90° of knee flexion. Gait is normal with no valgus or varus thrust. Preoperative KT 1000 side-to-side difference measurements on the PCL screen, corrected posterior, and corrected anterior measurements were 10.0, 10.0, and 1.5 mm, respectively. The KT 1000 side-to-side difference measurement at 30° of knee flexion was 1.0 mm. Telos stress radiographic side-to-side difference measurement at 90° of knee flexion with a posteriorly directed force applied to the tibial tubercle area to assess PCL stability was 11.7 mm. This patient's preoperative Tegner, Lysholm, and Hospital for Special Surgery knee ligament rating scale scores were 3, 80/100, and 37/100, respectively, and the IKDC score is 61.

The patient's diagnosis was chronic posterior and anterior cruciate ligament instability, lateral posterolateral instability type A, and medial posteromedial instability type B. The patient has a functionally unstable knee with his desired level of activity. Plain radiographs show a well reduced well aligned tibiofemoral joint with some calcification near the fibular collateral ligament and popliteus femoral insertion sites.

Six months after the patient's left knee dislocation surgical reconstruction of his knee ligaments was performed for chronic functional instability using fresh frozen allograft tissue all from the same tissue bank. The double bundle arthroscopic PCL reconstruction was an Achilles tendon allograft for the anterolateral bundle and a tibialis anterior allograft for the posteromedial bundle. The arthroscopic ACL reconstruction utilized Achilles tendon allograft. The lateral posterolateral reconstruction was performed with a fibular head based figure of eight semitendinosus allograft combined with a posterolateral capsular shift and peroneal nerve neurolysis. The medial posteromedial reconstruction was performed with semitendinosus allograft combined with a posteromedial capsular shift procedure. Postoperatively, the patient was immobilized in a long leg brace locked in full extension and non-weight bearing for approximately five weeks. The postoperative rehabilitation program is described in detail in Chap. 39 of this textbook.

This patient's postoperative Tegner, Lysholm, and Hospital for Special Surgery knee ligament rating scale scores three years post reconstruction at age 22 were 5, 90/100, and 89/100, respectively. KT 1000 arthrometer side-to-side difference values for the PCL screen, corrected posterior, and corrected anterior measurements were 2.0, 0, and −2.0 mm, respectively. The KT 1000 side-to-side difference anterior displacement measurement at 30° of knee flexion was −5.0 mm (the patient had a prior ACL reconstruction on the right knee). Stress radiographic side-to-side difference measurement at 90° of knee flexion with a posteriorly directed force applied to the proximal tibia to assess PCL reconstruction stability was 3.5 mm. The Lachman test was normal, pivot shift negative, tibial step off equal to the uninvolved knee, posterior drawer negative, posterolateral and posteromedial drawer negative, anterolateral and anterior medial drawer negative, dial test right equals left at 30° and 90° of knee flexion, varus and valgus stress test negative and symmetrical to the nonsurgical knee at 0° and 30° of knee flexion, and range of motion 0°–126° of knee flexion (nonsurgical side range of motion 0°–148°), with a stable extensor mechanism. Follow-up radiographs show no indication of heterotopic ossification with mild degenerative joint disease. The patient has achieved his noncompetitive sports preinjury level of function with respect to work and recreational sports; however, he has chosen not to return to competitive wrestling.

42.8 Case Study 7: 22 Year Follow-up Chronic PCL, ACL, Posterolateral, Posteromedial Instabilities

This patient is a 36-year-old woman who injured her right knee when her right foot struck a stationary object while snow sledding. At the time of impact, the right knee sustained forced valgus, flexion, and external rotation of the tibia with respect to the femur. The patient's dorsalis pedis and posterior tibial pulses were intact and symmetrical to the uninvolved extremity, and motor and sensory neurologic function of the involved extremity were intact and symmetrical to the uninvolved lower extremity at the time of presentation. The skin was in good condition with no open wounds. Physical examination of the involved right knee compared to the normal left knee demonstrated range of motion of 10°–90° in the injured knee, and 0°–120° in the normal knee. The extensor mechanism was intact. The Lachman test and pivot shift tests were positive. The anterolateral and anteromedial drawer tests were positive. The tibial step offs were negative at 90° of knee flexion, and the posterior drawer, posterolateral drawer, and posteromedial drawer tests were positive. There was valgus laxity at 0° and 30° of knee flexion. The knee was stable to varus stress. The dial test was positive at 30° and 90° of knee flexion. Plain radiographs demonstrated a well reduced well aligned tibiofemoral joint. MRI imaging demonstrated posterior and anterior cruciate ligament tears, as well as medial and lateral side injuries. The diagnosis was posterior and anterior cruciate ligament instability, lateral posterolateral instability type A, and medial posteromedial instability type B. The patient was initially treated with splinting in extension followed by progressive range of motion. Surgical treatment consisting of single-bundle PCL reconstruction with Achilles tendon allograft, ACL reconstruction using bone patellar tendon bone autograft, posterolateral reconstruction using biceps femoris tendon transfer, and medial side reconstruction using a posteromedial capsular shift was performed approximately ten weeks post-injury. Postoperatively, the patient was immobilized in a long leg brace locked in full extension and non-weight bearing for approximately five weeks followed by progressive range of motion and weight bearing. The postoperative rehabilitation program that was followed is described in detail in Chap. 39 of this textbook.

This patient's postoperative Tegner, Lysholm, and Hospital for Special Surgery knee ligament rating scale scores 17 years post reconstruction were 3, 83/100, and 86/100, respectively. KT 1000 arthrometer side-to-side difference values for the PCL screen, corrected posterior, and corrected anterior measurements were 2.0, 3.0, and 1.0 mm, respectively. The KT 1000 side-to-side difference measurement at 30° of knee flexion is 3.0 mm. Telos stress radiographic side-to-side difference measurement at 90° of knee flexion with a posteriorly directed force applied to the tibial tubercle area to assess PCL reconstruction stability was -2.2 mm indicating that the PCL reconstruction side has less posterior tibial translation than the uninvolved knee. The Lachman test was negative, pivot shift negative, tibial step offs equal to the uninvolved knee, posterior drawer negative, posterolateral and posteromedial drawer negative, anterolateral and anterior medial drawer negative, dial test right equals left at 30° and 90° of knee flexion, varus and valgus stress test negative and symmetrical to the nonsurgical knee at 0° and 30° of knee flexion, and range of motion 0°–110° of knee flexion (nonsurgical side range of motion 0°–122°), with a stable extensor mechanism. Follow-up radiographs show progressive degenerative joint disease.

The patient's Tegner preinjury level of function was level 5, and at 17 years postoperative follow-up it is level 3. The patient walks with a slight limp, does have some knee pain with exercise, and is slightly impaired with stair climbing and squatting. Her knee is very stable with all activities, and there is no locking or giving way episodes. The patient's decreased Tegner level of function may be due to the degenerative changes in her knee, as well as being 17 years older than at the time of injury.

Twenty-two years post reconstruction at age 58, the patient's degenerative joint disease had progressed to the point of needing a total knee replacement. At the time of total knee replacement surgery all knee ligaments were intact and stable to physical examination and visual inspection. Press fit non-constrained posterior stabilized total knee components without patella resurfacing were used for the total knee replacement.

42.9 Case Study 8: Minimally Displaced PCL Tibial Insertion Site Bony Injury

This patient is a 44-year-old manual laborer who had a fall on to the anterior aspect of his flexed knee while working. This was a low energy injury from a standing height. The patient felt pain but continued to work. The patient developed an effusion and a limp with ecchymosis on the posterior aspect of his popliteal fossa area and calf which caused him to seek medical attention approximately ten days post-injury.

Physical examination of the lower extremities comparing the injured knee to the uninjured knee revealed the neurovascular status and the skin to be intact. A mild effusion was present, and there was no gross deformity of the lower extremity. The tibial step offs were equal with the knees at 90° of flexion, and the involved knee had approximately five millimeters of increased excursion of the posterior drawer test with a soft endpoint compared to the normal knee. The anterior cruciate ligament, the medial and lateral collateral ligaments, the posteromedial and posterolateral corners, and the extensor mechanism were all stable to physical examination.

Plain radiographs obtained in the orthopaedic clinic on the day of consultation demonstrated normal alignment of the patellofemoral and tibiofemoral joints, and no evidence of fractures. MRI of the injured knee demonstrated a minimally displaced tibial avulsion fracture at the posterior cruciate ligament insertion, and no other structural injuries in the knee. Venous Doppler studies that were ordered because of the patient's calf pain were negative for deep or superficial venous thrombosis.

This patient had an isolated posterior cruciate ligament injury with a minimally displaced fracture at the PCL tibial insertion site. This was a low energy injury with less than five millimeters of posterior tibial excursion during posterior drawer testing. It was determined that this injury had excellent healing potential, and would be treated nonsurgically. The patient was placed in a hinged range of motion brace locked in extension with weight bearing as tolerated for approximately four to six weeks. At approximately eight weeks post-injury, the long leg brace was discontinued. Physical examination after completion of brace treatment for the above described posterior cruciate ligament injury revealed symmetrical knee range of motion comparing to the uninvolved knee. Equal tibial step offs and a negative posterior drawer test. No varus or valgus laxity, and negative Lachman and pivot shift tests. The posteromedial and posterolateral corners were stable. The patient resumed his preinjury level of activity, with no subsequent knee instability.

42.10 Case Study 9: PCL, Posteromedial, and Posterolateral Instability in a 12-Year-Old Boy with Open Growth Plates

The patient is a 12-year-old boy referred to me three weeks after a right knee injury sustained playing baseball. The patient slid into base and collided with another player and the fixed base with his knee in 90° of flexion. Initial evaluation by another physician revealed a bloody effusion upon aspiration, posterior tibial translation at 90° of flexion, and an MRI study of the right knee demonstrating a posterior cruciate ligament tear. The patient was referred to me for evaluation and treatment.

Physical examination comparing the injured right knee to the uninvolved left knee revealed the skin and neurovascular status to be intact. Range of knee motion was symmetrical to the uninvolved left knee. There was no pain or restriction of motion at the hip or ankle on the involved or normal side. The tibial step offs were decreased, and the posterior drawer test was positive. There were positive posterolateral and posteromedial drawer tests, and the dial test was positive at both 30° and 90° of knee flexion. The knee was stable to valgus stress at 0° and 30° of knee flexion, and there was varus laxity at both 0° and 30° of knee flexion with a soft endpoint. The hyperextension external rotation recurvatum test was negative, and the heel lift-off test was symmetrical on the injured and non injured side. The Lachman test and pivot shift tests were both negative.

Initial radiographs taken in the orthopaedic clinic demonstrated open growth plates on the distal femur and the proximal tibia with no fractures. There was no physeal injury noted on stress radiography, or MRI imaging. Magnetic resonance imaging showed a tear of the posterior cruciate ligament, and bone marrow edema without fracture in the anterior tibial epiphysis in the midline. There were no articular cartilage injuries or meniscus tears.

KT 1000 arthrometer testing revealed the following side-to-side difference measurements: PCL screen at 90° of knee flexion six millimeters, corrected posterior measurement at 70° of knee flexion six millimeters, corrected anterior measurement at 70° of knee flexion four millimeters, and the thirty pound anterior displacement measurement at 30° of knee flexion was one millimeter. Side-to-side difference on stress radiography at 90° of knee flexion with a posterior displacement force applied to the tibial tubercle area of the proximal tibia using the Telos device comparing the involved to the normal knee was ten millimeters.

Preoperative testing with three knee ligament rating scales revealed the following: Hospital for Special Surgery score was 42/100, Lysholm score was 44/100, and the Tegner activity score was 3 (preinjury, the patient was level 7).

The diagnosis in this patient is a right knee subacute posterior cruciate ligament based multiple ligament injured knee with posterior cruciate ligament tear, posteromedial instability type A, and posterolateral instability type B in a patient with open growth plates. The decision was made to proceed with arthroscopic single-bundle transtibial posterior cruciate ligament reconstruction using fresh-frozen Achilles tendon allograft combined with fibular head based figure of eight posterolateral reconstruction using fresh frozen semitendinosus allograft, and posteromedial reconstruction using the posteromedial capsular shift procedure as described in Chap. 36 of this textbook. The posterior cruciate ligament reconstruction femoral tunnel crossed the distal femoral physis, and the PCL tibial tunnel was positioned distal to the tibial physis. Cortical suspensory fixation with two stacked polyethylene ligament fixation buttons were used on the femoral side, and a bioabsorbable interference screw and bicortical screw and spiked ligament washer were used on the tibial side fixation. No fixation device crossed the growth plates.

The posterolateral reconstruction was a fibular head based figure of eight reconstruction using a fresh frozen semitendinosus allograft. The allograft was looped around the common biceps tendon at the fibular head and sewn there using permanent braided suture. The fibular collateral ligament component was passed medial to the iliotibial band, and the popliteofibular popliteus tendon component passed medial to the common biceps tendon and the iliotibial band. The allograft limbs were crossed in figure of eight fashion with the fibular collateral component being lateral to the popliteus tendon component. The graft limbs were sewn into their respective anatomic femoral insertion sites with number 2 braided permanent sutures with a slight valgus applied to the knee to close the lateral compartment with the knee in approximately 90° of flexion. The allograft was then sewn to the deep capsular layers for additional reinforcement, and a posterolateral capsular shift was also performed. There were no drill holes through or around the lateral side growth plates.

The posteromedial reconstruction was performed using the posteromedial capsular shift technique. This was an all-suture posteromedial capsular advancement procedure performed with the knee in approximately 45° of flexion as described in Chap. 15 of this textbook. The posterior cruciate ligament reconstruction, the posterolateral reconstruction, and the posteromedial reconstruction procedures were all protective of the growth plates. Postoperatively, the surgical knee was immobilized in a long leg brace locked in full extension, and was non-weight bearing with crutches. Prophylactic preoperative and postoperative antibiotics were utilized. Progressive weight bearing and range of knee motion were gradually initiated according to our postoperative rehabilitation program detailed in Chap. 36 of this textbook.

Six years follow-up postoperative examination of the patient at the age of 19 reveals equal leg lengths, normal and symmetrical carrying angles, and normal gait during ambulation. Radiographs reveal closed distal femoral and proximal tibial physes that are symmetrical to the normal knee with no malalignment, no evidence of growth arrest, and no degenerative changes. Physical examination of the surgical right knee compared to the normal left knee reveals the posterior drawer is negative, posteromedial and posterolateral drawer tests are negative, and the dial test is symmetrical at 30° and 90° of knee flexion. The Lachman test is negative, the pivot shift test is negative, and the surgical knee is stable to varus and valgus stress throughout the flexion–extension arc. The hyperextension external rotation recurvatum and heel lift-off tests are symmetrical compared to the normal knee.

Three year postoperative KT 1000, stress radiography, and knee ligament rating scale measurements reveal the following. Range of motion is 0°–125° on the surgical right knee, and 0°–130° on the uninvolved left knee. Side-to-side difference on KT 1000 measurements on the PCL screen, corrected posterior, and corrected anterior measurements are 2.0, 2.5, and −2.0 mm, respectively. Side-to-side difference on the KT 1000 anterior displacement measurement at 30° of knee flexion is 2.0 mm. Stress X-rays at 90° of knee flexion using the Telos device comparing the surgical to the knee normal knee reveal a 1.8 mm side-to-side difference. The Hospital for Special Surgery, Lysholm, and Tegner knee ligament rating scale scores are 98/100, 99/100, and 7. The patient's preinjury Tegner score was 7 indicating a return to preinjury level of function.

Nine year postoperative KT 1000, stress radiography, and knee ligament rating scale measurements at age 22 reveal the following. Range of motion is 0°–120° on the surgical right knee, and 0°–133° on the uninvolved left knee. Side-to-side difference on KT 1000 measurements on the PCL screen, corrected posterior, and corrected anterior measurements are 2.0, 3.0, and 1.0 mm, respectively. Side-to-side difference on the KT 1000 anterior displacement measurement at 30° of knee flexion is 1.0 mm. Stress X-rays at 90° of knee flexion comparing the surgical to the normal knee reveal a 5.8 mm side-to-side difference. The Hospital for Special Surgery, Lysholm, and Tegner knee ligament rating scale scores are 94/100, 94/100, and 4. The patient, now out of high school and college, no longer plays competitive baseball which accounts for the decreased Tegner score.

42.11 Case Study 10: Acute Combined Posterior Cruciate Ligament Tear with Posterolateral Instability in a 17-Year-Old Gymnast

The patient is a 17-year-old competitive gymnast who had a missed landing during a gymnastics event injuring her left knee. At the time of injury, the patient had a hyperextension and varus force applied to her knee with the right foot planted firmly on the ground. The patient developed immediate pain and swelling, and was unable to continue participation in the athletic competition. The patient's initial presentation upon reporting to the emergency department included a right knee effusion with posterior and lateral right knee pain. Neurovascular status of the involved right lower extremity was intact, and the skin was intact. There was anterior–posterior and varus laxity with guarding by the patient. The patient was referred to me for evaluation and treatment of the knee injury.

Initial evaluation of this patient in our clinic revealed nearly symmetrical range of motion of both knees with minimal effusion of the injured left knee. The neurovascular examination of the involved left lower extremity was symmetrical to the normal right lower extremity, and the skin was intact on both legs. Physical examination comparing the injured left knee to the normal right knee revealed negative tibial step offs with the proximal tibia dropped back posterior to the distal femur with the knee at 90° of knee flexion, a grade three posterior drawer test, positive posterior lateral drawer test, and varus laxity at 30° and 0° of knee flexion with 10 mm of increased lateral joint line opening compared to the normal knee, but with a firm end point. The dial test was positive at both 30° and 90° of knee flexion, and the posteromedial drawer test was negative. The knee was stable to valgus stress throughout the flexion–extension arc, and the Lachman and pivot shift tests were negative. The hyperextension external rotation recurvatum and heel lift off tests were symmetrical. The extensor mechanism was stable.

Plain radiographs demonstrated symmetrical positioning of the tibiofemoral and patellofemoral joints compared to the patient's normal knee. Stress radiography at 90° of knee flexion with a posterior directed force applied to the proximal tibial comparing the injured left knee to the normal right knee revealed 12 mm more posterior tibial displacement of the injured knee. MRI study of the left knee revealed a medial femoral condyle bone bruise, complete posterior cruciate ligament tear, and disruption of the posterolateral structures of the knee.

The diagnosis, in this case, is an acute posterior cruciate ligament tear combined with posterolateral instability type B in a 17-year-old competitive athlete. The plan was to proceed with reconstruction of the posterior cruciate ligament, primary repair of the posterolateral structures, and posterolateral reconstruction at approximately three to four weeks post-injury. Preoperatively the patient achieved full range of motion of the injured knee. There was a complete disruption of the posterior cruciate ligament, and PCL reconstruction was performed using the single-bundle arthroscopically assisted transtibial tunnel technique using an Achilles tendon allograft to reconstruct the anterolateral bundle of the PCL. The injury complex on the lateral side of the knee consisted of femoral insertion site avulsion of the fibular collateral ligament and popliteus tendon, and attenuation of the midlateral and posterolateral capsule. Primary repair of fibular collateral ligament and popliteus tendon injuries was performed combined with a posterolateral capsular shift procedure, and a posterolateral reconstruction using a fibular head based figure of eight posterolateral reconstruction technique. Postoperatively, the surgical knee was immobilized in a long leg brace locked in full extension, and was non-weight bearing with crutches. Prophylactic preoperative and postoperative antibiotics were utilized. Progressive weight bearing and range of knee motion were gradually initiated according to our postoperative rehabilitation program detailed in Chap. 39 of this textbook.

Ten years postoperatively the patient's range of motion is 0°–135° on the surgical left knee, and 0°–150° on the uninvolved right knee. The posterior drawer is negative, posteromedial and posterolateral drawer tests are negative, and the dial test is symmetrical at 30° and 90° of knee flexion. The Lachman test is negative, the pivot shift test is negative, and the surgical knee is stable to varus and valgus stress throughout the flexion–extension arc. The hyperextension external rotation recurvatum and heel lift-off tests are symmetrical compared to the normal knee.

Side-to-side difference on KT 1000 measurements on the PCL screen, corrected posterior, and corrected anterior measurements are 3.5 mm, 2.0 mm, and −2.0 mm, respectively. Side-to-side difference on the KT 1000 anterior displacement measurement at 30° of knee flexion is 1.0 mm. The Hospital for Special Surgery, Lysholm, and Tegner knee ligament rating scale scores are 94/100, 94/100, and 5. Five year postoperative stress X-rays at 90° of knee flexion using the Telos device comparing the surgical to the knee normal knee reveal a 0.5 mm side-to-side difference.

42.12 Case Study 11: Acute Combined Posterior Cruciate Ligament Tear with Posteromedial Instability in a 52-Year-Old Woman

The patient is a 52-year-old woman who slipped and fell on an icy deck twisting her left knee. The patient was initially evaluated by her primary care doctor who obtained an MRI that was read by the radiologist as a complex lateral meniscus tear, posterior cruciate ligament tear, partial anterior cruciate ligament tear, and a disruption of the medial collateral ligament with tearing of the medial patellar retinaculum and tear with elevation of the vastus medialis obliques. The patient was referred to me for evaluation and treatment.

Physical examination of the injured left knee compared to the normal right knee revealed a mild effusion, and nearly symmetrical range of motion. The neurovascular examination of the involved left lower extremity was symmetrical to the normal right lower extremity, and the skin was intact on both legs. Comparing the injured left knee to the normal right knee revealed negative tibial step offs with the proximal tibia dropped back posterior to the distal femur with the knee at 90° of knee flexion, a grade three posterior drawer test, positive posterior medial drawer test, and valgus laxity at 30° and 0° of knee flexion with 10–15 mm of increased medial joint line opening compared to the normal knee with a soft endpoint. The dial test was positive at both 30° and 90° of knee flexion, with the anteromedial tibial plateau rotating forward and the anterolateral tibial plateau maintaining its normal anatomic relationships. The knee was stable to varus stress throughout the flexion–extension arc, and the Lachman and pivot shift tests were negative. The hyperextension external rotation recurvatum and heel lift-off tests were symmetrical. The extensor mechanism had increased lateral patellar excursion with the knee at 30° of knee flexion. Plain radiographs demonstrated symmetrical positioning of the tibiofemoral joint, however, the injured knee demonstrated lateral patellar tilting on the 30° axial view of the patella compared to the uninjured knee.

The diagnosis, in this case, is an acute posterior cruciate ligament tear combined with posteromedial instability type B/C, lateral patellar subluxation instability, and a lateral meniscus tear in a 52-year-old woman with a physically demanding job. The plan was to proceed with reconstruction of the posterior cruciate ligament, primary repair of the posteromedial structures and the extensor mechanism, address the lateral meniscus tear, and perform a posteromedial reconstruction at approximately four weeks post-injury. Preoperatively the patient achieved full range of motion of the injured knee. Surgical findings demonstrated a complete disruption of the posterior cruciate ligament, and PCL reconstruction was performed using the single bundle arthroscopically assisted transtibial tunnel technique with an Achilles tendon allograft to reconstruct the anterolateral bundle of the PCL. The injury complex on the medial side of the knee consisted of femoral insertion site avulsion of the deep medial collateral ligament, and the medial patellar retinaculum and medial patellofemoral ligament. Primary repair of the injured medial side structures was performed using suture anchors. The primary medial side repair was combined with a posteromedial capsular shift procedure, and a posteromedial reconstruction using a looped tibialis anterior allograft surgical technique. Postoperatively, the surgical knee was immobilized in a long leg brace locked in full extension, and was non-weight bearing with crutches. Prophylactic preoperative and postoperative antibiotics were utilized. Progressive weight bearing and range of knee motion were gradually initiated according to our postoperative rehabilitation program detailed in Chap. 39 of this text book.

Four years postoperatively at age 56 the patient's range of motion is 0°–120° on the surgical left knee, and 0°–132° on the uninvolved right knee. The posterior drawer is negative, posteromedial and posterolateral drawer tests are negative, and the dial test is symmetrical at 30° and 90° of knee flexion. The Lachman test is negative, the pivot shift test is negative, and the surgical knee is stable to varus and valgus stress throughout the flexion–extension arc. The hyperextension external rotation recurvatum and heel lift off tests are symmetrical compared to the normal knee.

Side-to-side difference on KT 1000 measurements on the PCL screen, corrected posterior, and corrected anterior measurements are 3.0, 3.5, and −0.5 mm, respectively. Side-to-side difference on the KT 1000 anterior displacement measurement at 30° of knee flexion is 2.0 mm. Postoperative stress X-rays at 90° of knee flexion comparing the surgical knee to the normal knee reveal a 3.4 mm side-to-side difference. There is no X-ray evidence of degenerative joint disease in the injured knee. The Hospital for Special Surgery, Lysholm, and Tegner knee ligament rating scale scores are 89/100, 93/100, and 3. The patient has achieved her preinjury Tegner activity scale level, and has returned to her regular job. X-rays reveal no degenerative joint disease in the injured knee.

42.13 Case Study 12: Acute Combined PCL, ACL, Posterolateral Instability in a 47-Year-Old Man with 15 Year Outcomes

The patient is a 47-year-old man involved in an all terrain vehicle (ATV) accident that is very active in sports, recreational activities, and has a physically demanding occupation. The patient was initially seen in a community hospital emergency room after his ATV accident, and the diagnosis was made of a multiple ligament injured left knee. X-rays obtained upon initial evaluation demonstrated well aligned tibiofemoral and patellofemoral joints. It is important to recognize that this was a tibiofemoral knee dislocation with spontaneous reduction. Vascular studies demonstrated no injury to the arterial or venous system of the injured left lower extremity, and the patient had no other injuries. The patient was transferred to our facility for evaluation and treatment of a multiple ligament injured left knee.

Magnetic resonance imaging showed tears of the posterior and anterior cruciate ligaments, and injury to the lateral and posterolateral structures. Physical examination of the injured left knee and lower extremity compared to the uninjured right knee and lower extremity revealed negative tibial step offs with the proximal tibia dropped back posterior to the distal femur with the knee at 90° of knee flexion. There was a grade three posterior drawer test, positive posterior lateral drawer test, and varus laxity at 30° and 0° of knee flexion with 10 mm of increased lateral joint line opening compared to the normal knee with a soft endpoint. The dial test was positive at both 30° and 90° of knee flexion. The knee was stable to valgus stress throughout the flexion–extension arc with a negative posteromedial drawer test. The Lachman and pivot shift tests were positive. The hyperextension external rotation recurvatum and heel lift-off tests were symmetrical. The extensor mechanism was stable to physical examination. Plain radiographs demonstrated symmetrical positioning of the patellofemoral and tibiofemoral joints.

The diagnosis, in this case, is a left knee acute posterior and anterior cruciate ligament tears combined with posterolateral instability type B in a 47-year-old man with a physically demanding job who is also an avid sportsman and recreational athlete. The plan was to proceed with reconstruction of the posterior and anterior cruciate ligaments, perform a primary repair of the posterolateral structures, and posterolateral reconstruction at approximately four weeks post-injury.

Preoperatively the patient achieved full range of motion of the injured left knee. Surgical findings demonstrated a complete disruption of the posterior and anterior cruciate ligaments, and PCL reconstruction was performed using the single bundle arthroscopically assisted transtibial tunnel technique with an Achilles tendon allograft to reconstruct the anterolateral bundle of the PCL. Anterior cruciate ligament reconstruction was performed using the single bundle endoscopic transtibial femoral tunnel technique with Achilles tendon allograft. The injury complex on the lateral side of the knee consisted of attenuation of the fibular collateral ligament, popliteus tendon, and midlateral and posterolateral capsule with proximal and distal insertion sites of these structures remaining intact. Retensioning of the fibular collateral ligament and popliteus tendon was performed in conjunction with a posterolateral capsular shift procedure. In addition, a posterolateral reconstruction was performed using a fibular head based figure of eight posterolateral reconstruction technique with semitendinosus allograft. Postoperatively, the surgical knee was immobilized in a long leg brace locked in full extension, and was non-weight bearing with crutches. Prophylactic preoperative and postoperative antibiotics were utilized. Progressive weight bearing and range of knee motion were gradually initiated according to our postoperative rehabilitation program detailed in Chap. 39 of this text book.

Seventeen year postoperative follow-up at age 64 demonstrated the patient's range of motion is 0°–112° on the surgical left knee, and 0°–135° on the uninvolved right knee. The posterior drawer is negative, posteromedial and posterolateral drawer tests are negative, and the dial test is symmetrical at 30° and 90° of knee flexion. The Lachman test is negative, the pivot shift test is negative, the surgical knee is stable to varus and valgus stress throughout the flexion–extension arc, and the hyperextension external rotation recurvatum and heel lift-off tests are negative. All physical examination tests are compared to the uninjured knee.

Side-to-side difference on KT 1000 measurements on the PCL screen, corrected posterior, and corrected anterior measurements are 1.0, 0, and 0 mm, respectively. Side-to-side difference on the KT 1000 anterior displacement measurement at 30° of knee flexion is 1.0 mm. Postoperative stress X-rays at 90° of knee flexion comparing the surgical knee to the normal knee reveal a 2.9 mm side-to-side difference. There is no X-ray evidence of degenerative joint disease in the injured knee. The Hospital for Special Surgery, Lysholm, and Tegner knee ligament rating scale scores are 96/100, 97/100, and 7. The patient has achieved his preinjury Tegner activity scale level, and has returned to his regular job as well as all his recreational activities.

42.14 Case Study 13: Acute Combined PCL, ACL, Posterolateral Instability, Patella Tendon Rupture in a 21-Year-Old Man

The patient is a 21-year-old male college student that fell from a height and sustained a closed fracture of his right tibia and fibula and a closed patellar tendon rupture, posterior and anterior cruciate ligament tears, and posterolateral instability of his left knee. X-rays obtained upon initial evaluation of the left knee demonstrated a reduced tibiofemoral joint, and a high riding patella consistent with a patella tendon rupture. Vascular studies demonstrated no injury to the arterial or venous system of the multiple ligament knee injured left lower extremity.

The plan was to perform immediate fracture care and to perform a staged approach to the multiple ligament injured knee. The right lower extremity fractures were treated with closed reduction and casting, and the left patella tendon rupture was primarily repaired and augmented with allograft tissue within 24 h of the injury. The left knee ligament injuries were treated with bracing. The right tibia and fibula fractures and the left patellar tendon augmented primary repair healed uneventfully, and the patient successfully completed rehabilitation programs for the injuries to the right and left lower extremities. Stage two was to return the patient to the operating room for surgical reconstruction of the multiple ligament injured left knee.

Magnetic resonance imaging showed tears of the posterior and anterior cruciate ligaments, and injury to the lateral and posterolateral structures. Physical examination of the multiple ligament injured left knee and lower extremity compared to the uninjured right knee revealed negative tibial step offs with the proximal tibia dropped back posterior to the distal femur with the knee at 90° of knee flexion, a grade three posterior drawer test, positive posterior lateral drawer test, and varus laxity at 30° and 0° of knee flexion with 10 mm of increased lateral joint line opening compared to the normal knee with a soft endpoint. The dial test was positive at both 30° and 90° of knee flexion. The knee was stable to valgus stress throughout the flexion–extension arc with a negative posteromedial drawer test. The Lachman and pivot shift tests were positive. The hyperextension external rotation recurvatum and heel lift-off tests were symmetrical to the normal knee. The extensor mechanism was stable to physical examination, with symmetrical range of motion to the opposite knee, and restoration of active physiologic extension and hyperextension indicating successful extensor mechanism repair. Plain radiographs demonstrated symmetrical positioning of the patellofemoral and tibiofemoral joints compared to the opposite knee. The diagnosis in this case is a left knee acute posterior and anterior cruciate ligament tears combined with posterolateral instability type B complicated by an ipsilateral patellar tendon rupture, and a contralateral fracture of the right tibia and fibula in a 21-year-old man.

Six months post-injury, the patient returned to the operating room for surgical reconstruction of the multiple ligament injured left knee. Preoperatively, the patient achieved full range of motion of the injured left knee. Surgical findings demonstrated a complete disruption of the posterior and anterior cruciate ligaments, and PCL reconstruction was performed using the single bundle arthroscopically assisted transtibial tunnel technique with an Achilles tendon allograft to reconstruct the anterolateral bundle of the PCL. Anterior cruciate ligament reconstruction was performed using the single bundle endoscopic transtibial femoral tunnel technique with Achilles tendon allograft. The injury complex on the lateral side of the knee consisted of attenuation of the fibular collateral ligament, popliteus tendon, and midlateral and posterolateral capsule with proximal and distal insertion sites of these structures remaining intact. Retensioning of the fibular collateral ligament and popliteus tendon was performed in conjunction with a posterolateral capsular shift procedure. In addition, a posterolateral reconstruction was performed using a fibular head based figure of eight posterolateral reconstruction technique with Achilles tendon allograft. Postoperatively, the surgical knee was immobilized in a long leg brace locked in full extension, and was non-weight bearing with crutches. Prophylactic preoperative and postoperative antibiotics were utilized. Progressive weight bearing and range of knee motion were gradually initiated according to our postoperative rehabilitation program detailed in Chap. 39 of this textbook.

Six year postoperative follow-up evaluation demonstrated the patient's range of motion is 0°–110° on the surgical left knee, and 0°–130° on the uninvolved right knee. The posterior drawer test is negative, posteromedial and posterolateral drawer tests are negative, and the dial test is symmetrical to the right lower extremity at 30° and 90° of knee flexion. The Lachman test is negative, the pivot shift test is negative, the surgical knee is stable to varus and valgus stress throughout the flexion–extension arc, and the hyperextension external rotation recurvatum and heel lift off tests are negative. All physical examination tests are compared to the uninjured knee.

Side-to-side difference on KT 1000 measurements on the PCL screen, corrected posterior, and corrected anterior measurements are 2.0, 4.5, and 0.5 mm, respectively. Side-to-side difference on the KT 1000 anterior displacement measurement at 30° of knee flexion is negative 3.0 mm. Postoperative stress X-rays at 90° of knee flexion using the Telos device comparing the surgical knee to the normal knee reveal a 2.5 mm side-to-side difference. There is no X-ray evidence of degenerative joint disease in the injured knee. The Hospital for Special Surgery, Lysholm, and Tegner knee ligament rating scale scores are 90/100, 94/100, and 4, respectively. The patient has achieved his preinjury Tegner activity scale level.

42.15 Case Study 14: Subacute Combined PCL, ACL, Posteromedial Instability in 32-Year-Old Woman with a Body Mass Index of 50

The patient is a 32-year-old woman with a body mass index of 50 who was a pedestrian hit by an automobile sustaining an injury to the right knee and right upper extremity. The patient was seen by an orthopaedic surgeon who immobilized the knee in full extension with full weight bearing, and referred the patient to me approximately four weeks post-injury for evaluation and treatment of the right knee injury. Plain X-rays obtained in the immobilizer at the time of my initial evaluation revealed well reduced and well aligned tibiofemoral and patellofemoral joints and no fractures. MRI of the injured right knee was read by the radiologist as having an anterior horn medial meniscus tear, anterior and posterior cruciate ligament tear, tear of the medial collateral ligament, and lateral femoral condyle and lateral tibial plateau bone bruising.

My initial physical examination of the injured right knee compared to the normal left knee revealed a very stiff knee since it had been immobilized in extension for almost five weeks. There was valgus laxity at full extension; however, the patient was not able to bend the knee enough to assess anterior–posterior tibial translation with respect to the femur. There was no varus laxity on physical examination. The patient was converted to a hinged range of motion brace to provide valgus stability, and physical therapy instituted to achieve range of motion so that an adequate physical examination of the injured knee could be performed and a surgical treatment plan developed.

My second examination of the patient's injured knee compared to the normal knee revealed range of motion from 0° to 115° of knee flexion. The skin was in good condition, and the neurovascular examination was intact and symmetrical to the uninjured left lower extremity. The knee was stable to varus stress at 0° and 30° of knee flexion, and there is valgus laxity at 0° and 30° of knee flexion with 10 mm of medial joint line opening and a firm end point. The posterior drawer test was positive, and the Lachman and pivot shift tests were also positive. The posteromedial and anteromedial drawer tests were positive, but the posterolateral and anterolateral drawer tests were negative. The extensor mechanism was stable. The diagnosis in this patient is subacute posterior and anterior cruciate ligament tears combined with posteromedial instability type B in a patient with a body mass index of 50.

The patient's right knee ligament reconstructive surgery was performed approximately 3 months after her initial injury. The surgery consisted of an arthroscopically assisted transtibial tunnel double-bundle posterior cruciate ligament reconstruction using Achilles tendon allograft for the anterolateral bundle, and a tibialis anterior allograft for the posterior medial bundle. The anterior cruciate ligament reconstruction was an arthroscopically assisted single bundle transtibial femoral tunnel technique using an Achilles tendon allograft. The posteromedial reconstruction was performed using a posteromedial capsular shift surgical technique. Postoperatively, the surgical knee was immobilized in a long leg brace locked in full extension, and was non-weight bearing with crutches. Prophylactic preoperative and postoperative antibiotics were utilized. Progressive weight bearing and range of knee motion were gradually initiated according to our postoperative rehabilitation program detailed in Chap. 39 of this text book.

Eight year postoperative follow-up evaluation of the patient's surgical right knee demonstrated the patient's range of motion is 0°–118° on the surgical right knee, and 0°–133° on the uninvolved left knee. The posterior drawer test is negative, posteromedial and posterolateral drawer tests are negative, and the dial test is symmetrical to the normal left lower extremity at 30° and 90° of knee flexion. The Lachman test is negative, the pivot shift test is negative, the surgical knee is stable to varus and valgus stress at 0° and 30° of knee flexion, and the hyperextension external rotation recurvatum and heel lift-off tests are negative, and symmetrical to the uninjured knee. All physical examination tests of the surgical right knee are compared to the uninjured left knee. The patient's body mass index at 8 year follow-up is 53.

Side-to-side difference on KT 1000 measurements on the PCL screen, corrected posterior, and corrected anterior measurements are 2.0, 0.0, and 0.0 mm, respectively. Side-to-side difference on the KT 1000 anterior displacement measurement at 30° of knee flexion is 3.0 mm. Postoperative stress X-rays at 90° of knee flexion using the Telos device comparing the surgical knee to the normal knee reveal a 0.0 mm side-to-side difference. There is X-ray evidence of degenerative joint disease in the injured knee. The Hospital for Special Surgery, Lysholm, and Tegner knee ligament rating scale scores are 60/100, 54/100, and 2, respectively. The patient's knee is functionally and objectively stable; however, she does have knee pain and her knee ligament rating scale scores are decreased secondary to her degenerative joint disease.

42.16 Case Study 15: Acute Combined Posterior Cruciate Ligament Tear, Anterior Cruciate Ligament Tear, Posterolateral Instability, and Peroneal Nerve Injury

The patient is a 30-year-old man who injured his left knee jumping on a trampoline. The mechanism of injury was an out of control landing resulting in a varus stress to the left knee from a forced figure of four position of the patient's left lower extremity under the patient's body weight. Evaluation in the emergency department revealed a multiple ligament injured left knee with pulses symmetrical to the uninjured lower extremity. Vascular studies confirmed intact arterial and venous systems in the injured lower extremity, and no arterial intimal flap tear. The patient was unable to dorsiflex the toes, foot, and ankle on the injured left lower extremity. Plain radiographs demonstrated the patellofemoral and tibiofemoral joints to be reduced; however, there was widening of the lateral compartment in the anteroposterior radiographic view. Magnetic resonance imaging study of the injured left knee demonstrated complete tears of the anterior and posterior cruciate ligaments, posterolateral corner injury with complete disruption of the fibular collateral ligament and biceps tendon at the head of the fibula, and injury to the popliteofibular ligament, midlateral, and posterolateral capsule.

Physical examination of the injured left knee and lower extremity compared to the uninjured right lower extremity revealed the proximal tibial step offs to be negative accompanied by a grade three posterior drawer test. The posterolateral drawer test was positive, and the posteromedial drawer test was negative. The dial test was positive at both 30° and 90° of knee flexion, and there was varus laxity at both 0° and 30° of knee flexion with no discernible endpoint. The knee was stable to valgus stress, the Lachman test positive, the pivot shift test positive, and the extensor mechanism stable. The patient was unable to dorsiflex the toes, foot, and ankle on the injured left lower extremity. The diagnosis in this patient is an acute posterior cruciate ligament tear, anterior cruciate ligament tear, posterolateral instability Type C, and a peroneal nerve injury.

The patient had surgical reconstruction of the posterior and anterior cruciate ligaments, primary repair and reconstruction of the posterolateral corner structures, and peroneal nerve neurolysis approximately three to four weeks post-injury. The posterior cruciate ligament reconstruction was an arthroscopically assisted double bundle PCL reconstruction using a fresh-frozen Achilles tendon allograft for the anterolateral bundle of the PCL, and a fresh frozen tibialis anterior allograft for the PCL posteromedial bundle. The anterior cruciate ligament reconstruction was an arthroscopically assisted transtibial femoral tunnel reconstruction using a fresh-frozen Achilles tendon allograft.

Before beginning any surgical repair or reconstruction on the lateral side of the knee, a peroneal nerve neurolysis was performed, and the nerve protected throughout the procedure. The peroneal nerve was in continuity; however, it had been severely stretched and was attenuated. The midlateral and posterolateral capsule were avulsed from the proximal tibia, and were primarily repaired using suture anchors. The fibular collateral ligament, popliteofibular ligament, and the common biceps tendon that were avulsed from the fibular head were primarily repaired with number 2 and number 5 permanent braided sutures through the posterolateral reconstruction drill hole made through the head of the fibula. Posterolateral reconstruction was performed with the fibular head based figure of eight technique using fresh frozen semitendinosus allograft tissue to augment and reinforce the lateral posterolateral primary repair.

Postoperatively, the surgical knee was immobilized in a long leg brace locked in full extension, and was non-weight bearing with crutches. Prophylactic preoperative and postoperative antibiotics were utilized. Progressive weight bearing and range of knee motion were gradually initiated according to our postoperative rehabilitation program detailed in Chap. 39 of this textbook. An ankle-foot orthosis was used to prevent foot drop and subsequent heel cord contracture.

There was no recovery of peroneal nerve function documented by physical examination, and by serial electromyograms and nerve conduction studies. Six-month post left multiple knee ligament reconstruction the patient underwent posterior tibial tendon transfer to restore dorsiflexion function to the left foot and ankle that resulted from the peroneal nerve injury.

Two year postoperative follow-up evaluation of the patient's surgical left knee demonstrated the patient's range of motion is 0°–110° on the surgical left knee, and 0°–120° on the uninvolved right knee. The posterior drawer test is negative, posteromedial and posterolateral drawer tests are negative, and the dial test is symmetrical to the normal right lower extremity at 30° and 90° of knee flexion. The Lachman test is negative, the pivot shift test is negative, the surgical knee is stable to varus and valgus stress at 0° and 30° of knee flexion, and the hyperextension external rotation recurvatum and heel lift-off tests are negative, and symmetrical to the uninjured knee. All physical examination tests of the surgical left knee are compared to the uninjured right knee. The patient has active dorsiflexion of the left foot and ankle, does not have drop foot, and does not need to use an ankle–foot orthosis indicating successful tendon transfer.

Side-to-side difference on KT 1000 measurements on the PCL screen, corrected posterior, and corrected anterior measurements are 3.0, 1.0, and 0.0 mm, respectively. Side-to-side difference on the KT 1000 anterior displacement measurement at 30° of knee flexion is 3.0 mm. Postoperative stress X-rays at 90° of knee flexion using the Telos device comparing the surgical left knee to the normal right knee reveal a 2.9 mm side-to-side difference. There is X-ray evidence of degenerative joint disease in the injured knee. The Hospital for Special Surgery, Lysholm, and Tegner knee ligament rating scale scores are 77/100, 88/100, and 5, respectively. The patient's knee is functionally and objectively stable, and there is good function of the left foot and ankle. The patient has returned to his preinjury level of activity with respect to work and recreational activities.

42.17 Case Study 16: Revision Posterior Cruciate Ligament, Anterior Cruciate Ligament, and Posteromedial Reconstruction

The patient is a 40-year-old man who sustained a right knee tibiofemoral knee dislocation with button holing of the medial femoral condyle through the medial capsule in a snow mobile accident. The patient was treated by another orthopaedic surgeon who performed open reduction of the knee, primarily repaired the medial capsule, and applied a spanning external fixator. Wound healing occurred uneventfully, and the external fixator was removed three weeks after its application, the knee was manipulated to restore range of motion, and the knee placed in a hinged range of motion brace for protection. Physical examination of the knee under anesthesia confirmed the diagnosis of posterior cruciate and anterior cruciate ligament tears, posterolateral instability type A, and posteromedial instability type B.

The patient's right knee ligament reconstructive surgery was performed approximately 4–5 weeks after his initial injury. The surgery consisted of an arthroscopically assisted transtibial tunnel double-bundle posterior cruciate ligament reconstruction using fresh-frozen Achilles tendon allograft for the anterolateral bundle, and a fresh frozen tibialis anterior allograft for the posterior medial bundle. The anterior cruciate ligament reconstruction was an arthroscopically assisted single bundle transtibial femoral tunnel technique using a fresh-frozen Achilles tendon allograft. The posterolateral reconstruction was performed using a fibular head based figure of eight posterolateral reconstruction technique with fresh frozen semitendinosus allograft. The posteromedial reconstruction was performed using a posteromedial capsular shift surgical technique. Postoperatively, the surgical knee was immobilized in a long leg brace locked in full extension and was non-weight bearing with crutches. Prophylactic preoperative and postoperative antibiotics were utilized. Progressive weight bearing and range of knee motion were gradually initiated according to our postoperative rehabilitation program detailed in Chap. 39 of this textbook.

Approximately 4 months post reconstruction; the patient was doing heavy manual labor against medical advice and reinjured his knee. This resulted in tears of the posterior cruciate ligament, anterior cruciate ligament, and posteromedial reconstructions with resultant functional instability. The patient underwent revision PCL, ACL, and medial posteromedial reconstruction 5 months after his primary reconstruction. The surgery consisted of an arthroscopically assisted transtibial tunnel double-bundle posterior cruciate ligament reconstruction using fresh-frozen Achilles tendon allograft for the anterolateral bundle, and a fresh frozen tibialis anterior allograft for the posterior medial bundle. The anterior cruciate ligament reconstruction was an arthroscopically assisted single bundle transtibial femoral tunnel technique using a fresh-frozen Achilles tendon allograft. The posteromedial reconstruction was performed using a posteromedial capsular shift surgical technique combined with a fresh frozen tibialis anterior allograft reconstruction of the superficial medial collateral ligament.

No tunnel bone grafting was required in this case since there was no tunnel osteolysis, or tunnel malposition. Cases where either tunnel osteolysis, or tunnel malposition exist will require bone grafting and a staged revision reconstruction procedure. Postoperatively, the surgical knee was immobilized in a long leg brace locked in full extension, and was non-weight bearing with crutches. Prophylactic preoperative and postoperative antibiotics were utilized. Progressive weight bearing and range of knee motion were gradually initiated according to our postoperative rehabilitation program detailed in Chap. 39 of this textbook.

Twelve year postoperative follow-up evaluation of the patient's surgical right knee at age 52 demonstrated the patient's range of motion is 0°–128° on the surgical right knee, and 0°–135° on the uninvolved left knee. The posterior drawer test is negative, posteromedial and posterolateral drawer tests are negative, and the dial test is symmetrical to the normal left lower extremity at 30° and 90° of knee flexion. The Lachman test is negative, the pivot shift test is negative, the surgical knee is stable to varus and valgus stress at 0° and 30° of knee flexion, and the hyperextension external rotation recurvatum and heel lift-off tests are negative, and symmetrical to the uninjured knee. All physical examination tests of the surgical right knee are compared to the uninjured left knee.

Side-to-side difference on KT 1000 measurements on the PCL screen, corrected posterior, and corrected anterior measurements are 4.0, 5.0, and −1.0 mm, respectively. Side-to-side difference on the KT 1000 anterior displacement measurement at 30° of knee flexion is 0 mm. Postoperative stress X-rays at 90° of knee comparing the surgical knee to the normal knee reveal a 1.8 mm side-to-side difference. There is X-ray evidence of minimal degenerative joint disease in the injured knee. The Hospital for Special Surgery, Lysholm, and Tegner knee ligament rating scale scores are 78/100, 81/100, and 4, respectively. The patient's knee is functionally and objectively stable, and the patient has returned to his preinjury level of function both at manual labor in the road construction industry, and his recreational activities.

42.18 Summary

This section in *The Multiple Ligament Injured Knee: A Practical Guide to Management, Third Edition,* presents selected cases in treatment of the multiple ligament injured knees that are representative of my practice. These selected cases represent real-life management examples in the treatment of difficult knee ligament instability problems. The details of the surgical techniques, while not presented in this section, are described in Chaps. 1, 20, 22, and 36 in this textbook. The purpose of this case study chapter has been for the reader to gain insight into management, treatment strategy, and outcomes of treatment in these complex knee ligament injuries.

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