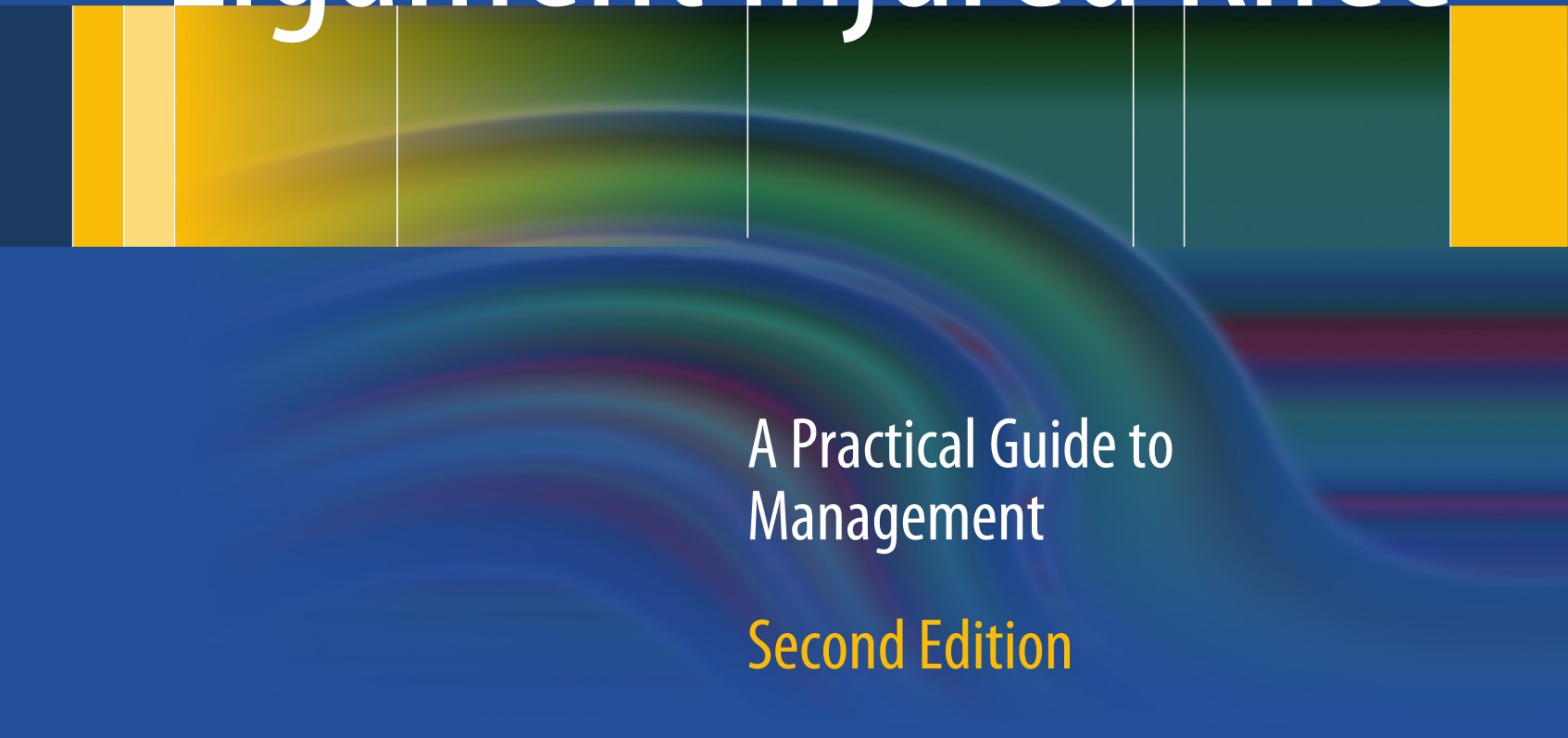
Gregory C. Fanelli
*Editor*

# The Multiple Ligament Injured Knee



## A Practical Guide to Management

Second 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.*

# Preface

Our practice environment largely determines the pathways that our individual orthopaedic 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 complex instabilities of the knee. The purpose of this book is to provide experienced knee surgeons, general orthopaedic surgeons, fellows, residents, medical students, and other health-care 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*, *Second Edition*, is expanded from 18 chapters in the *First Edition* to 35 chapters in the *Second Edition*. The *Second Edition* is composed of nine functional segments with each segment having a number of chapters. New topics in the *Second Edition* include the addition of ACL-based multiple ligament knee injury chapters, mechanical graft tensioning, fracture dislocations, articular cartilage restoration, meniscus transplantation, extensor mechanism restoration, outcomes data, and the editor's 21-year evolutionary experience in the evaluation and treatment of the multiple ligament injured knee. The chapters were organized and written so that they build upon each other, and also 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 21-year experience in the 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 non-surgical 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 33 present methods to evaluate and manage associated complex conditions that occur in treating the multiple ligament injured knee. These include 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, postoperative rehabilitation, special aspects of functional bracing, and complications. Chapter 34 presents the results of treatment of the multiple ligament injured knee from an outcomes data perspective. The final chapter, 35, presents seven 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 launch pad for new ideas to further develop treatment plans and surgical techniques for the multiple ligament injured knee.

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

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# Part I

# Editor’s Experience

# Chapter 1
# PCL-Based Multiple Ligament Knee Injuries: What I Have Learned

**Gregory C. Fanelli**

## 1.1 Introduction

Welcome to the second 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 21 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 orthopedic 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 the 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 children, 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 orthopedic 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 highway 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 orthopedic 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

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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.

## 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 tibiofemoral 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 90° flexed knee leads to posterior tibial displacement with potential arterial contusion and intimal damage [6]. I have also seen posttraumatic deep venous thrombosis in these severe knee injuries.

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 $<0.9$, 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.

## 1.4 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 90° and 30° 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 [8–10]. These are type A (axial rotation instability only), type B (axial rotation instability combined with varus and/or valgus laxity with a firm 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 instabilities 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 aid in determining the correct diagnosis of multiple ligament knee injuries. Knee examination under anesthesia combined with fluoroscopy, stress radiography, and diagnostic arthroscopy also contributes to accurately diagnosing the multiple planes of instability [11, 12]. Once again, recognition and correction of the medial and lateral side instability is the key to successful posterior and anterior cruciate ligament surgery.

## 1.5 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 [13]. 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 [14]. 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 [15]. 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.

## 1.6 Surgical Treatment

Over the past two 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 [16–23].

## 1.7 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 demonstrate that a delayed or staged reconstruction of 2–3 weeks has resulted in less motion loss and arthrofibrosis [16–18, 20–27]. 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 2–4 weeks of the initial injury. Some medial side injuries may be successfully treated with bracing [17, 18, 20].

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 orthopedic 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.

## 1.8 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 posttraumatic 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.

## 1.9 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 [16–20]. 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 [11]. Several studies have shown high rates of medial and lateral side surgical failures with primary repair alone [28–30]. We have had consistently successful results with combined primary repair and reconstruction with allograft or autograft tissue for medial and lateral side injuries [16–23]. 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 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.

## 1.11 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 2–4 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 4–5 weeks after the initial medial or lateral side surgery. When necessary, all ligament repairs and reconstructions are performed as a single-stage open surgical procedure. As always, surgical timing modifiers such as skin condition, vascular status, reduction stability, fractures, and other systemic injuries may alter the course of treatment.

## 1.12 Surgical Technique

The patient is positioned on the fully extended operating room table [22, 25, 31]. 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 double bundle posterior cruciate ligament reconstruction using an Achilles tendon allograft for the anterolateral bundle and a tibialis anterior allograft for the posteromedial bundle. 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 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. 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 Chap. 20 of this text book. The following sections in this chapter will address specific points that contribute to the success of this complex surgical procedure.

## 1.13 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 [32]. 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 primary and backup fixation, and use a slow and deliberate postoperative rehabilitation program.

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, to confirm the accuracy of the tibial tunnel placement, and to facilitate the flow of the surgical procedure [11]. An extracapsular extra-articular 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 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, to 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.

## 1.14 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 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 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 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 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.

## 1.15 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.

## 1.16 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 1-cm 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 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 is achieved on the femoral side using a bioabsorbable interference screw and cortical suspensory backup fixation with a polyethylene ligament fixation button. 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.

## 1.17 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 [33]. 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 opening 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.

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 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-offs, 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 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 backup 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 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 backup fixation with a polyethylene ligament fixation button.

I have found it very important to use primary and backup fixation. During cruciate ligament reconstruction, primary aperture fixation is achieved with bioabsorbable interference screws, and backup 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. Mechanical tensioning of the cruciates at 0° of knee flexion (full extension) and restoration of the normal anatomic tibial step-off at 70–90° of flexion have 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.

## 1.18 Posterolateral Reconstruction

My most commonly utilized surgical technique for posterolateral reconstruction is the free graft 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 [22, 25, 31, 34].

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 semitendinosus 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 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 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. 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 posterolateral capsule that had been previously incised is then shifted and sewn into the strut of figure of eight graft tissue with the knee in 90° of knee flexion to correct posterolateral capsular redundancy. 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 7- or 8-mm drill hole is made over a guide wire approximately 2 cm 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 nonabsorbable sutures at the popliteus tendon anatomic femoral insertion site. The knee is cycled through multiple sets of full flexion and extension cycles and placed in 90° of flexion, the tibia slightly is internally rotated, slight valgus force is applied to the knee, and the graft is 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.

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 [16–19]. 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 [20].

## 1.19 Posteromedial Reconstruction

The surgical leg is 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 [22, 25, 31, 34]. 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 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.

## 1.20 Postoperative Rehabilitation

The knee is maintained in full extension for 5 weeks non-weight bearing. Progressive range of motion occurs during postoperative weeks 6–10. Progressive weight bearing occurs at the beginning of postoperative week 6 progressing at a rate of 20% body weight per week during postoperative weeks 6 through 10. Progressive closed kinetic chain strength training, proprioceptive training, and continued motion exercises are initiated very slowly beginning at postoperative week 11. The long leg range of motion brace is discontinued after the 10th 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 [35, 36]. 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. 32 of this book.

## 1.21 Multiple Ligament Knee Injuries in Children

My experience with multiple ligament knee injuries in children ranges from ages 6 to 16 years. These patients have open growth plates, and their injury mechanisms include trampoline, motorcycle, gymnastics, soccer, automobile, and farming accidents. Posterior cruciate ligament reconstructions have been performed with the single bundle transtibial tunnel technique, and the anterior cruciate ligament reconstructions have been performed with the endoscopic transtibial tunnel surgical technique using allograft tissue. 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. There have been no growth plate arrests in my experience. These severe knee injuries do occur in children and can be a source of significant instability. Surgical reconstruction of the multiple ligament injured knee in children using surgical techniques to preserve the growth plates has resulted in functionally stable knees, and no growth plate arrest in my experience. An example of the management of a PCL-based multiple ligament injured knee is presented in the case studies section of this text book.

## 1.22 Outcomes and Results of Treatment

Our results of multiple ligament injured knee treatment without mechanical graft tensioning are outlined below [18]. 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. 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 Sports Medicine graft-tensioning boot was used in this series of patients (Biomet Sports Medicine, Warsaw, Indianna).

Postoperative physical examination results revealed normal posterior drawer/tibial step-off in 16/35 (46%) of knees and 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. Thirty-degree varus stress testing was normal in 22/25 (88%) of knees and grade 1 laxity in 3/25 (12%) of knees. Thirty-degree 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 pounds 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.

This study demonstrates that combined ACL/PCL instabilities can 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 [20]. 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. PCs were reconstructed with allograft Achilles tendon in all 15 knees. ACLs 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 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 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 pounds 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 [21–23]. 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, and 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 double bundle PCL-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 were 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 were 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 were 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 were 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 were 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 were 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.

## 1.23 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 <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. 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 primary and backup 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 reconstructions 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.

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# Part II

# Anatomy and Biomechanics

# Chapter 2
# Anatomy and Biomechanics of the Cruciate Ligaments and Their Surgical Implications

**Christopher Kweon, Evan S. Lederman, 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 composed of two bundles that are named based on their relative attachments on the femur and tibia: 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 with 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].

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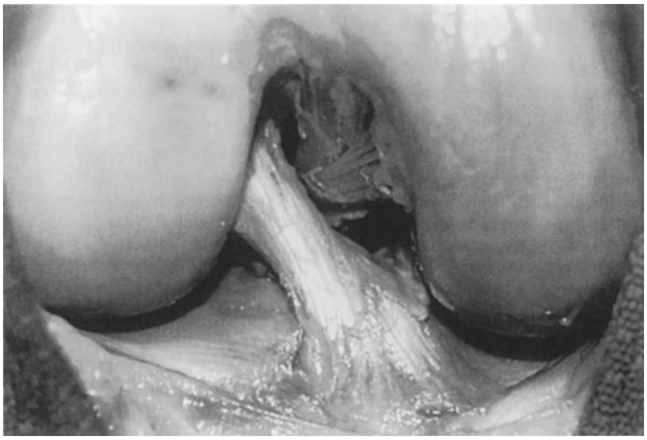


**Fig. 2.1** Human anatomic specimen showing the complex helical arrangement of the ACL and its broad attachment (Figure 1.3 of 1st edition)

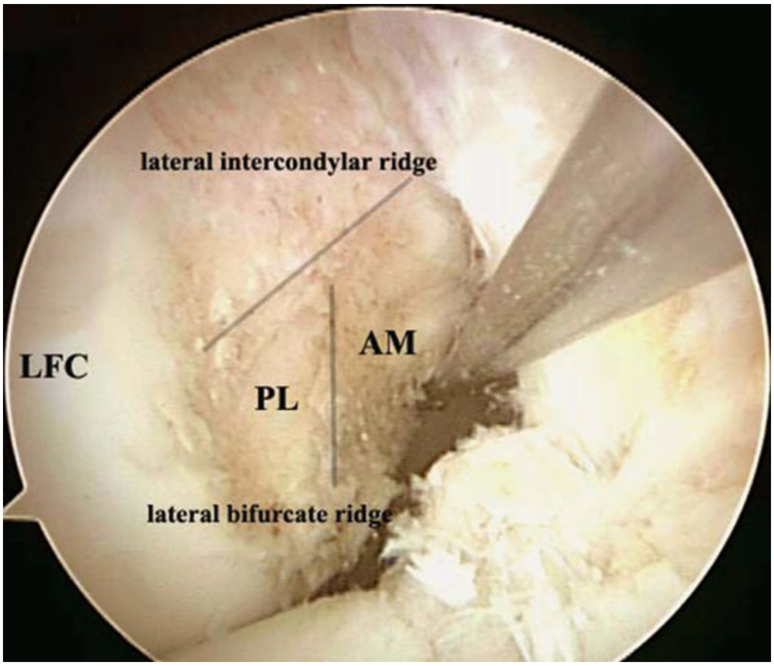


**Fig. 2.2** Arthroscopic view of the lateral notch demonstrating the femoral attachment sites of the anteromedial (AM) and posterolateral (PL) bundles of the ACL in relation to cruciate ridge and resident's ridge. Springer images

Anatomic studies have shown that the ACL ranges from 31 to 38 mm in length and 10 to 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 two bundles of the ACL attachments are 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 diffusion through its synovial sheath [8]. The innervation of the ACL consists of mechanoreceptors derived from the tibial nerve and contributes to its proprioceptive role [9, 10]. 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 [11].

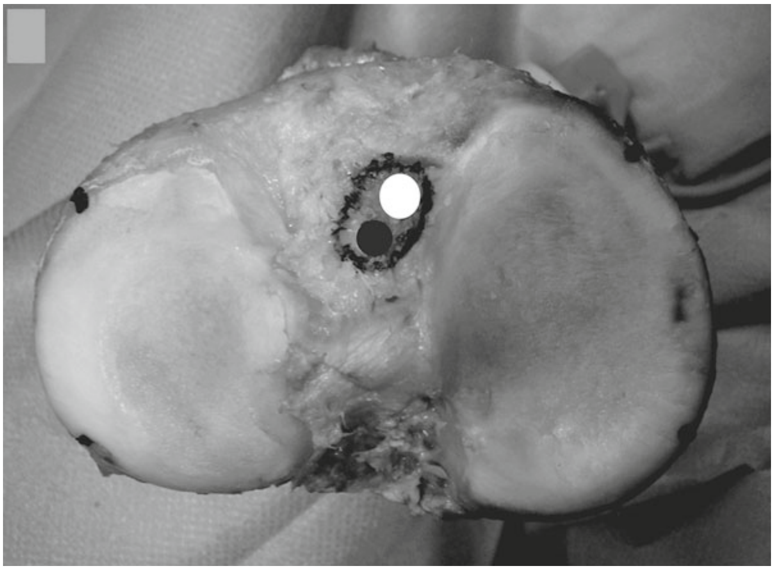


**Fig. 2.3** Cadaveric specimen showing the attachment points of each bundle of the ACL onto the tibia. Springer images

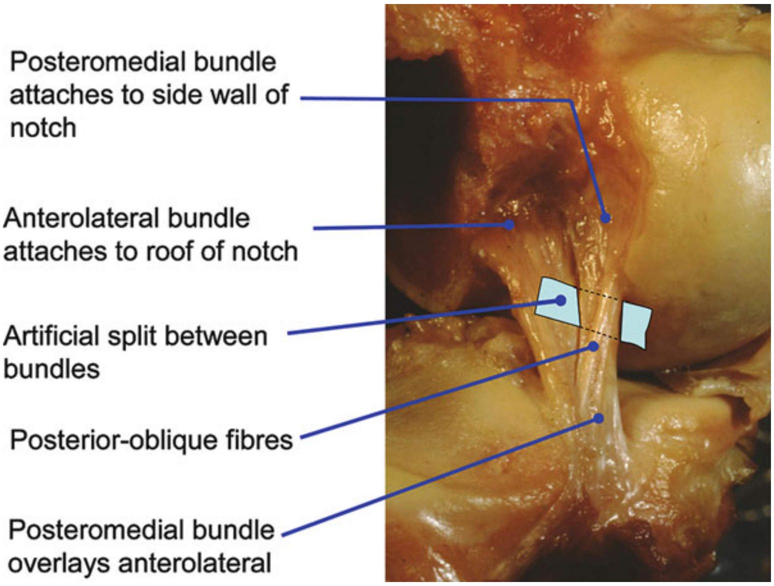


**Fig. 2.4** Anterior view of cadaveric specimen showing the two bundles of the PCL and the attachment sites on the femur. Springer images

### 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) [12, 13]. Its average length and width at its midportion, as reported by Girgis et al., are 38 and 13 mm, respectively [14]. 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 [12]. 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 [12]. They serve as secondary stabilizers to posterior tibial translation (Fig. 2.5).

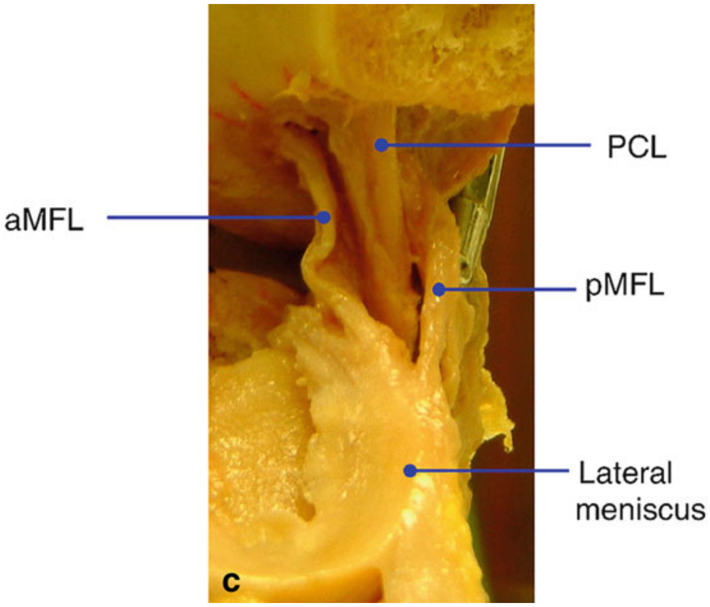


**Fig. 2.5** Posterior view of knee showing the PCL attachment on the tibia and accessory ligaments located posteriorly. Springer images

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 the anterolateral portion measuring 118 mm$^2$ and posteromedial insertion measuring 90 mm$^2$ [15]. 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 [16].

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 [17]. The innervation of the PCL is from the tibial and obturator nerves. As with the ACL, this serves primarily as a proprioceptive function [9].

### 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 [17]. 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) [23].

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.

### 2.2.4 *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 is well described, combined multiligament 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. The majority of ACL injuries involve complete rupture of both bundles with a 12% showing a completely intact posterolateral bundle [18]. Injury patterns of the

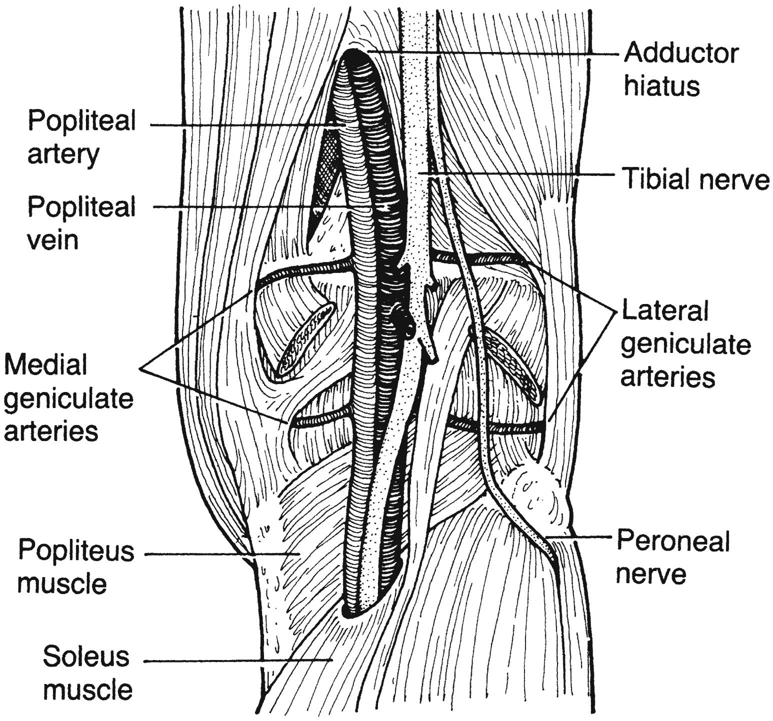


**Fig. 2.6** The vasculature of the knee viewed posteriorly (Figure 1.5 of the 1st edition)

PCL are not as well described in the literature but can consist of injury to the posteromedial, anterolateral, or both bundles. The surgical implications of single- versus double-bundle reconstruction as it relates to the discrete injury patterns have become increasingly more important as our understanding of cruciate anatomy has increased.

## 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 [23]. 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 [24]. 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 [25]. 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 [24]. 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 [26, 27]. In full extension, the ACL absorbs 75% of the anterior translation load and 85% between 30 and 90° of flexion [28]. 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 anterior bundles (both medial and lateral) have higher maximum stress and strain than the posterior bundles [29]. The tensile strength of the ACL is approximately 2,200 N but is altered with age and repetitive loads [19, 23, 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*

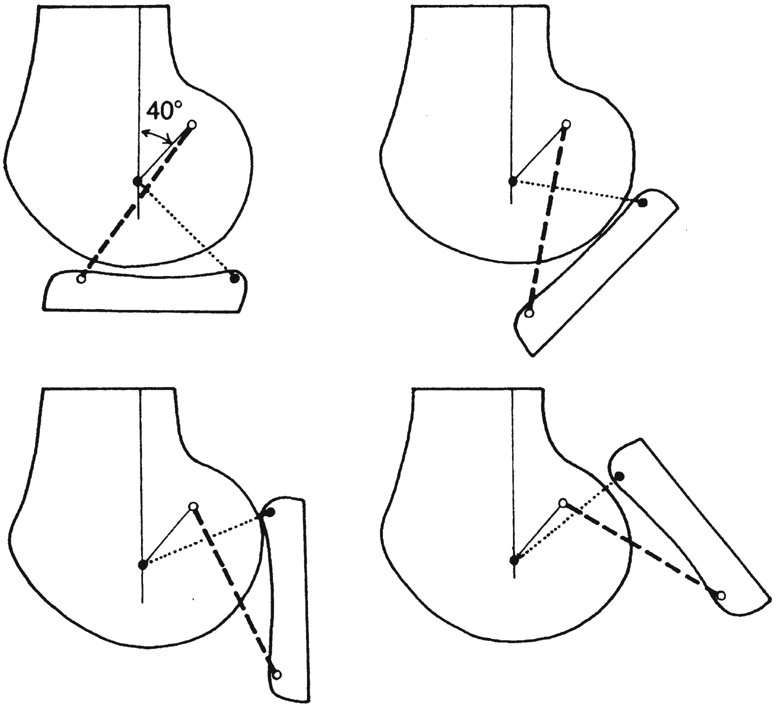
The primary function of the PCL is to resist posterior translation of the tibia on the femur at all positions of knee flexion [31]. It is a secondary stabilizer against external rotation of the tibia and excessive varus or valgus angulation at the knee [32]. The anterolateral band is tight in flexion 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 [33, 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; they do not greatly alter tibial rotation or varus/valgus angulation, however, 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 [12]. 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° [37]. 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% [38].

**Fig. 2.7** The four-bar cruciate linkage system (Figure 1.9 of the 1st edition)



### 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 [24, 39]. This interplay between ACL and PCL is often referred to as the four-bar cruciate linkage system (Fig. 2.7) [40]. 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 [41]. 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 [24].

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

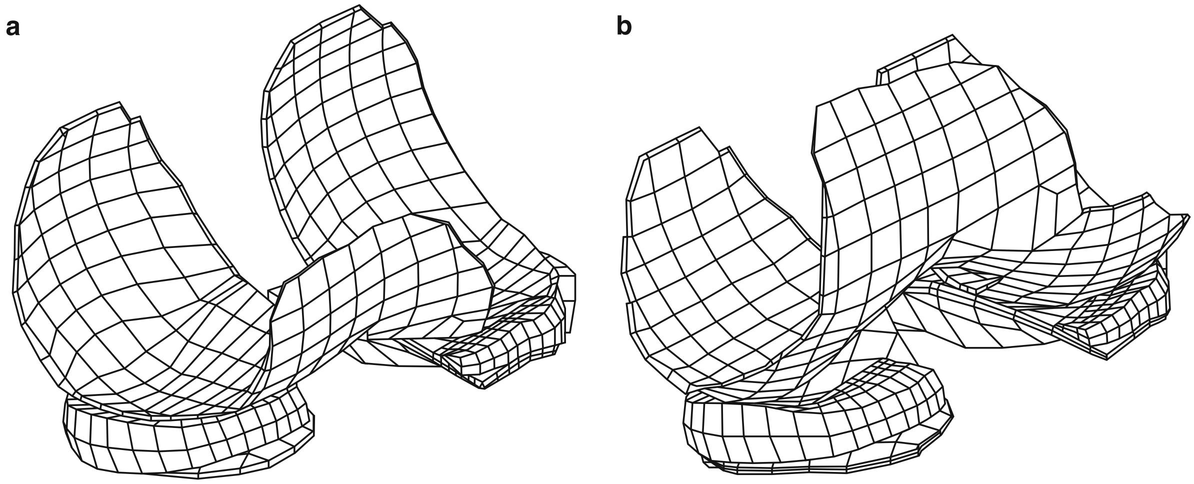


**Fig. 2.8** Depiction of the knee in 0 (*left*) and 30 (*right*) degrees of flexion illustrating femoral rotation related to the tibia in early flexion. From Moglo KE, Shirzi-Adl A. Cruciate coupling and screw-home mechanism in passive knee joint during extension-flexion. J Biomech 2011;38:1075–83. Reprinted with kind permission from Elsevier

leads to an increase in joint reactive forces and, ultimately, stressed or injured supporting structures [42]. 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 become atrophied after an ACL rupture, the extensor pull on the tibia lessens, decreasing the stresses placed on the secondary stabilizers.

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 [39].

## 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. have 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 [37, 38]. 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 [19]. The specific surgical treatments of ACL- and PCL-based multiple ligament injured knees and treatment approaches are reviewed in following chapters.

### *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 1,725 and 2,500 N. Many studies have found the PCL to have significantly more tensile strength than the ACL, but this is controversial [19, 20].

Cooper et al. have shown that the tensile strength of grafts taken from the central third of the patellar tendon averages 4,389 N for grafts 15 mm wide and 2,977 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 [21]. See Table 2.1 for comparison of mechanical strength of native cruciates and commonly utilized autografts (Table 2.1).

**Table 2.1** Tensile strength comparison

| Material | Maximum load (N) |
|---|---|
| Anterior cruciate ligament | 2,000 |
| Posterior cruciate ligament | 4,000 |
| Bone-patellar tendon-bone (10 mm) | 2,900 |
| Semitendinosus and gracilis (2-strand) | 1,900 |
| Semitendinosus and gracilis (4-strand) | 2,800 |

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

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].

### 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 [43–49]. 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.

### 2.4.4 *Tunnel Placement for Cruciate Reconstruction*

Cadaver and computed tomography studies have lead 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, 15, 16]. The existence of two discrete attachment points of each of the bundles for both the ACL and PCL is now well understood and has brought to focus the surgical implications of reconstructing injured cruciate ligaments anatomically and the resultant functional outcome from surgery.

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 [50–52]. 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 the anterior and PCLs more anatomically utilizing double-bundle techniques and creating multiple tunnels when reconstructing multiple ligament injured knees. These techniques are increasing in use and have been well described [6, 7, 26]. 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. Continued clinical outcome studies are currently underway to further assess the efficacy and safety of anatomic reconstructions of the cruciate ligaments utilizing double-bundle techniques.

## 2.5 Conclusion

Knee dislocations are severe injuries because they may result in disruption of multiple ligaments, surrounding musculature, and neurovascular structures [53]. Diagnosis and acute treatment can be difficult, and the varying techniques that are utilized to reconstruct the anterior and PCLs 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 translations and angulations 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 entire knee as well as the anterior and PCLs. 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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# Chapter 3
# Anatomy and Biomechanics of the Lateral and Medial Sides of the Knee and the Surgical Implications

**Andrew G. Geeslin and Robert F. LaPrade**

## 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 1,147.1 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.

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 [3–11]. 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) [6]. The anatomy of these three 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, 6]. 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 [6].

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G.C. Fanelli (ed.), *The Multiple Ligament Injured Knee: A Practical Guide to Management*,
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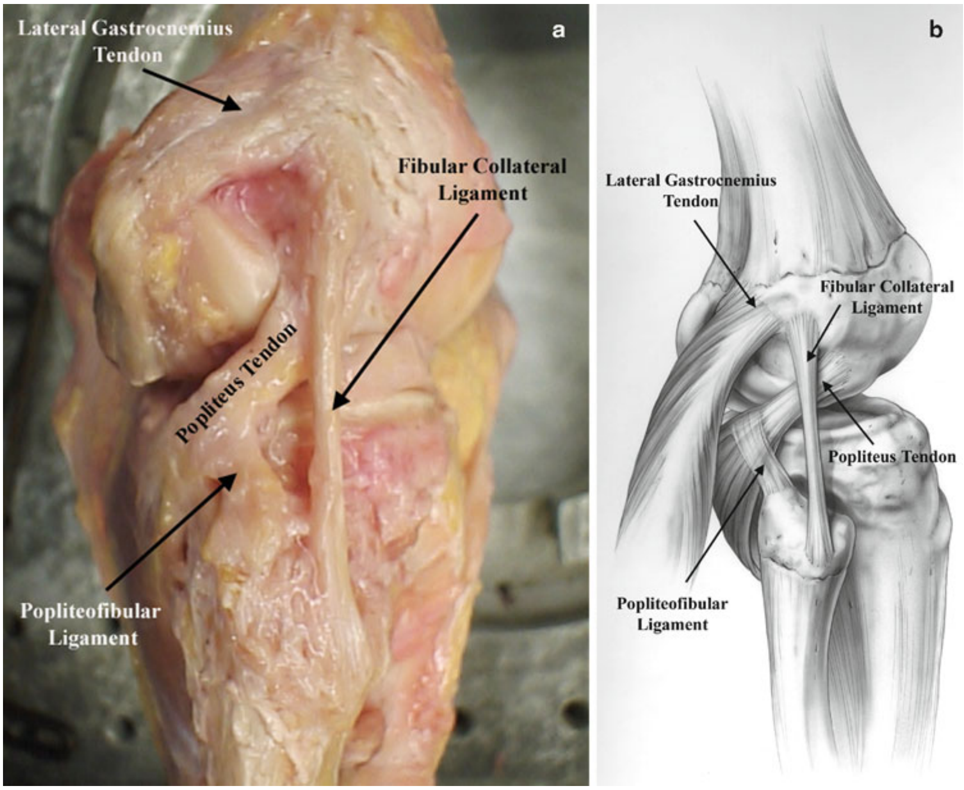


**Fig. 3.1** *Right knee* (**a**) dissection and (**b**) illustration demonstrating the fibular collateral ligament, popliteofibular ligament, popliteus tendon, and lateral gastrocnemius tendon. Figure used with permission from LaPrade RF, Ly TV, Wentorf FA, et al. The posterolateral attachments of the knee: a qualitative and quantitative morphologic analysis of the fibular collateral ligament, popliteus tendon, popliteofibular ligament, and lateral gastrocnemius tendon. Am J Sports Med. 2003;31(6):854–860

#### 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 [6]. The popliteus tendon courses around the posterolateral aspect of the lateral femoral condyle, becomes intra-articular, and attaches to the anterior portion 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 [6].

#### 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 [6]. 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.

### *3.2.2 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 [12–17]. Recently, detailed anatomical investigations have demonstrated the radiographic and quantitative surface anatomy of this region [18, 19].

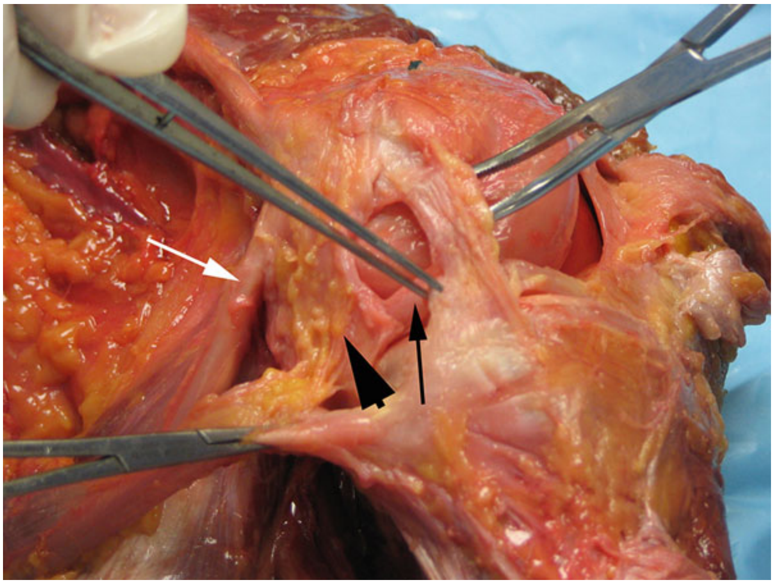
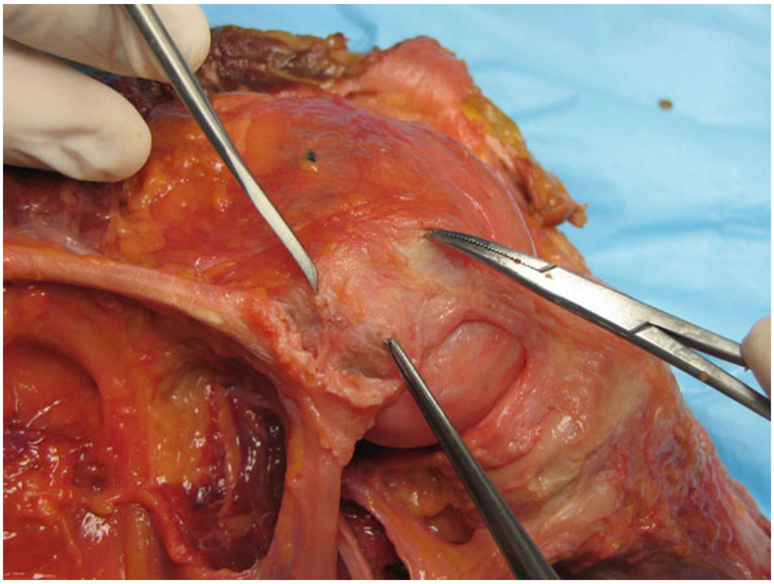


**Fig. 3.2** A photograph of a dissection of the medial aspect of the *left knee* is shown. The meniscofemoral portion of the deep medial collateral ligament is seen elevated by the curved hemostat, and the meniscotibial portion is grasped by the forceps. The central arm of the posterior oblique ligament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



#### 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 [18].

#### 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 capsular ligament [18]. 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) [18].

#### 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 [13, 18, 20]. 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 [18].

## 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 [4, 12]. 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 [21]. 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 [5, 22].

#### 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 [23]. Its role in stability specifically against external rotation has also been demonstrated [4, 5, 24, 25]. In addition, the popliteus complex has been shown to share posterior tibial loads with the posterior cruciate ligament (PCL) [26].

#### 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 [27–29].

#### 3.3.1.4 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 [30]. Other studies have demonstrated a similar phenomenon for PCL grafts [31, 32]. 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 [33].

#### 3.3.1.5 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 [34]. 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 [35]. 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 [12, 36–38]. It has also been reported to be a primary medial knee restraint to external rotation of the tibia [39]. 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 [40].

#### 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 [39, 41, 42]. 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 [39, 41].

#### 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 [12, 20, 40–43]. 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 [16, 39, 43]. 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 [43–45]. 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 [33]. 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 [46]. 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 [43].

#### 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 [34, 38, 47]. A radiographic technique has also been developed to objectively quantify the amount of medial joint line opening with valgus stress [48]. 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 [49]. 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 [35, 48]. High-resolution magnetic resonance imaging will allow assessment of injury to individual structures of the lateral [50] and medial knee, femoral and tibial articular surfaces for bone bruises [2, 29], 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 [51, 52].

## 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 [53–56]. As such, it is recommended that these injuries are treated surgically in order to restore the function of this region of the knee. 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 [57–59]. 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 [55, 56, 60]. With the aim of reproducing the stabilizing function of the PLC structures, several nonanatomic reconstruction techniques have been described [61–66]. 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 [54, 67, 68].

**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

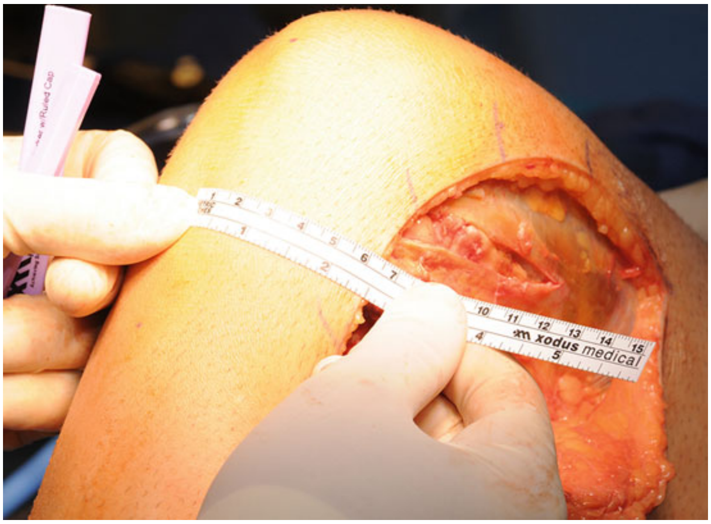


**Fig. 3.5** An intraoperative photograph demonstrating a planned 6-cm skin bridge is shown. This technique is utilized for patients with a planned patellar tendon autograft harvest for anterior cruciate ligament reconstruction

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, 54, 67, 69]. 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).

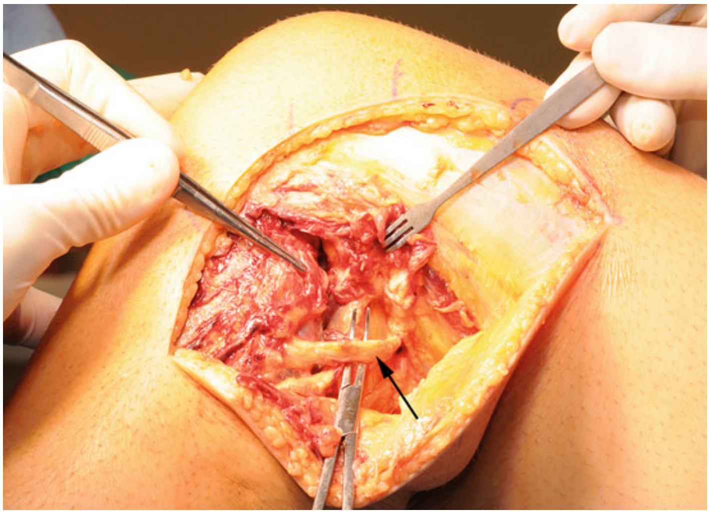


**Fig. 3.6** An intraoperative photograph of the lateral side *left knee* is shown. The common peroneal nerve (*arrow*) is visualized following neurolysis

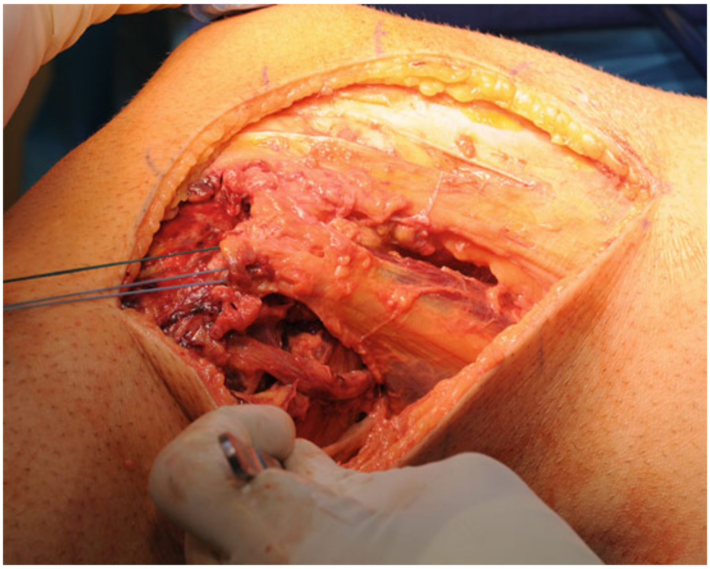


**Fig. 3.7** An intraoperative photograph of the lateral side of the *left knee* is shown in a patient with an avulsion of the biceps femoris tendon. A tag stitch was placed in the distal aspect of the tendon to allow a proximal release and reapproximation to its distal attachment

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 [6]. 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 [6]. Next, the nearby popliteus tendon attachment in the anterior aspect of the popliteus sulcus is identified approximately 18.5 mm anterodistal to the FCL [6].

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 [70]. 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 [49]. Concurrent meniscal tears are repaired when indicated; however, a partial meniscectomy is performed if tears are not 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.

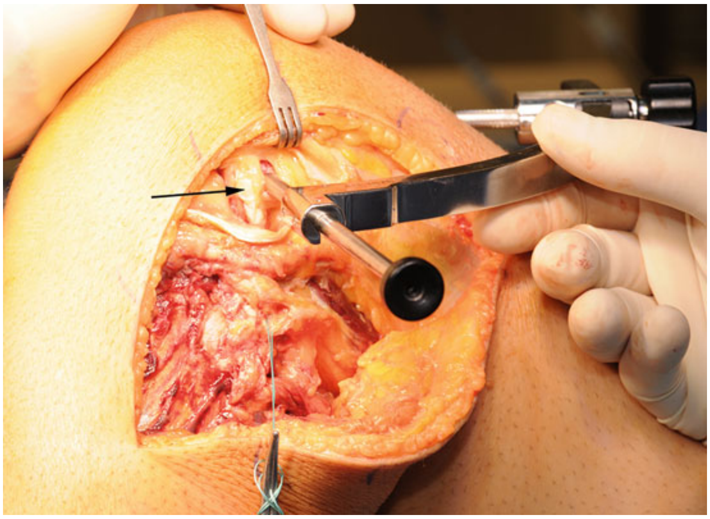


**Fig. 3.8** An intraoperative photograph of the lateral side of the *left knee* is shown. A tag stitch was placed in the distal aspect of the fibular collateral ligament (FCL); the free end is wrapped around a curve hemostat, and traction is used to allow visualization of the femoral attachment of the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

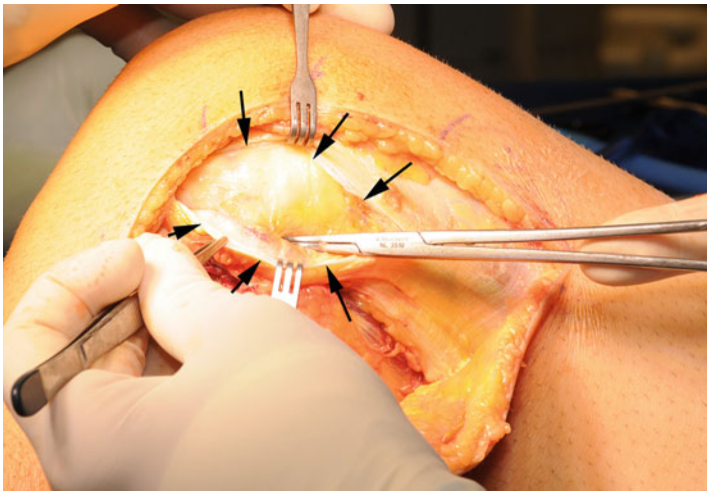


**Fig. 3.9** An intraoperative photograph of a splitting incision of the iliotibial band is shown. The anterior and posterior borders (*arrows*) of the iliotibial band incision are retracted with surgical rakes

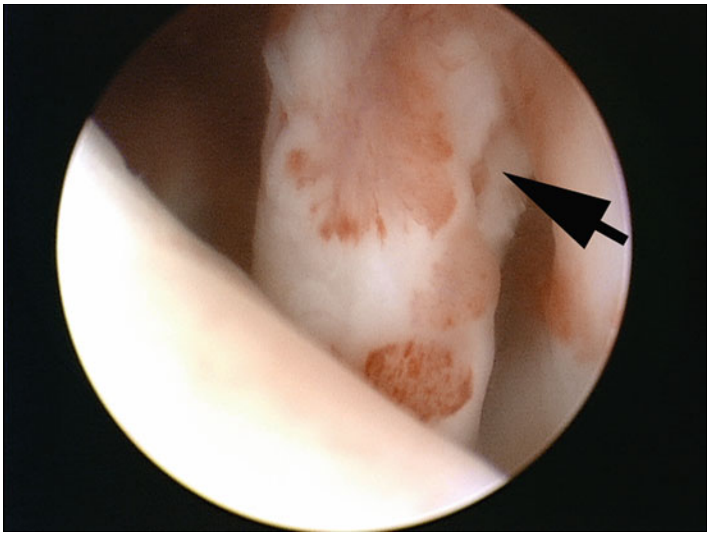


**Fig. 3.10** An arthroscopic photograph of a torn popliteus tendon (*arrowhead*) is demonstrated

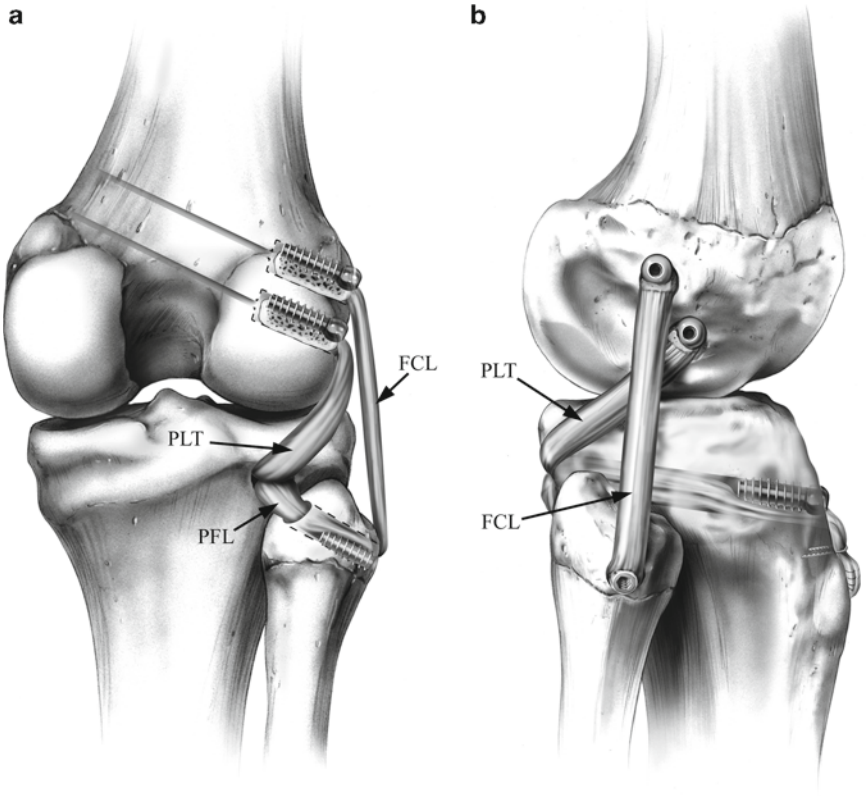


**Fig. 3.11** An illustration of a (**a**) posterior view and (**b**) lateral view of an anatomic posterolateral corner reconstruction is shown. The two femoral tunnels with the fibular collateral ligament (FCL) and popliteus tendon (PLT) grafts with bone blocks and the interference screws are demonstrated. 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 RF, Johansen S, Wentorf FA, et al. An analysis of an anatomical posterolateral knee reconstruction: an in vitro biomechanical study and development of a surgical technique. Am J Sports Med. 2004;32(6):1405–1414

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 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 [54, 67].

A reconstruction of the FCL is planned for midsubstance tears and substantial intrasubstance stretch injuries [67, 68]. 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 [64, 71]. If evaluation of the popliteus tendon reveals a substantial intrasubstance stretch injury, midsubstance tear, or musculotendinous avulsion, a reconstruction of this structure is planned [25, 67]. 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 [25, 72]. However, when these two structures are concurrently torn and nonrepairable, an anatomic PLC reconstruction is performed using an Achilles tendon allograft (Fig. 3.11) [54, 67]. Bone tunnels for reconstruction of either the FCL or popliteus tendon, or for all 3 main PLC structures are placed according to established anatomic reconstruction techniques [25, 54, 72]. 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*" [67, 73].

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) [64, 71]. The femoral attachment site of the popliteus tendon is identified by previously described anatomic

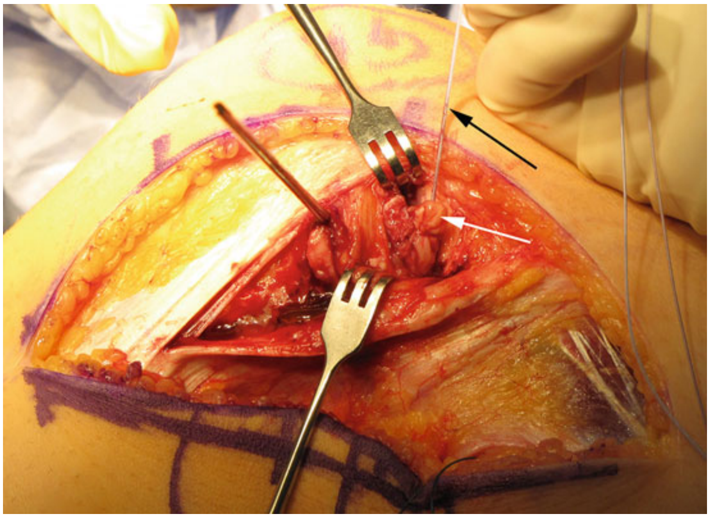


**Fig. 3.12** An intraoperative *right knee* photograph is shown with a splitting incision of the iliotibial band for exposure of the femoral attachments of the fibular collateral ligament and popliteus tendon. The avulsed popliteus tendon (*white arrow*) and passing sutures (*black arrow*) are demonstrated.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

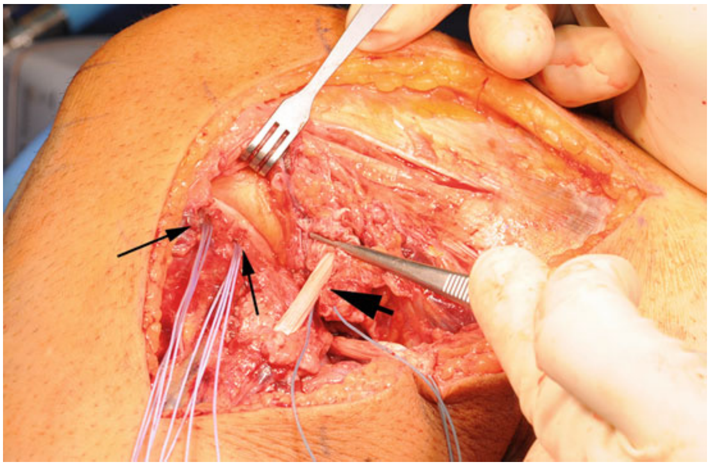


**Fig. 3.13** An intraoperative photograph of a suture anchor repair (*arrows*) of a lateral capsule tear off tibia is shown. A fibular collateral ligament reconstruction graft is also visualized (*arrowhead*)

landmarks [6], 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 [50, 74]) 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, 75], are 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 distal to the fracture edge. The fracture is then reduced, and the sutures are tied with the knee in extension.

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

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 [54, 76]. 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 [54, 67, 73].

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 [77, 78]. A K-wire is drilled to this point from the flat spot slightly distal and medial to Gerdy’s tubercle [54], 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 [6]. 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 through the popliteal hiatus along the anatomic path of the popliteus tendon and

**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

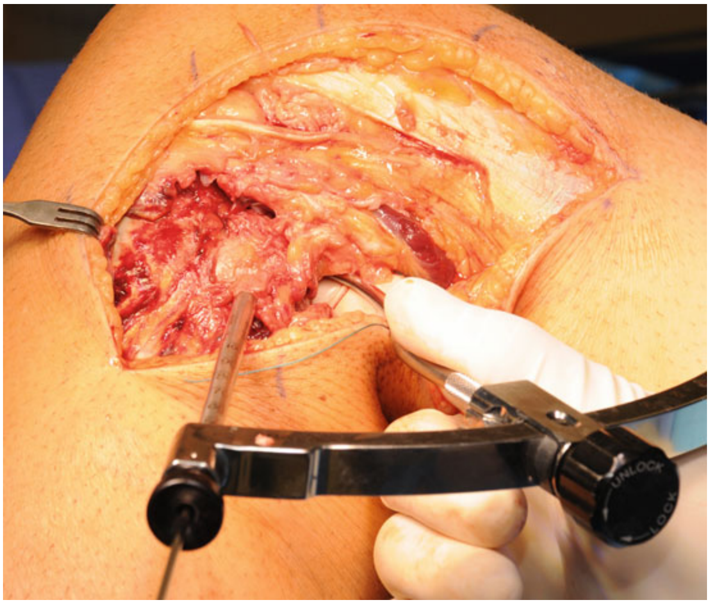
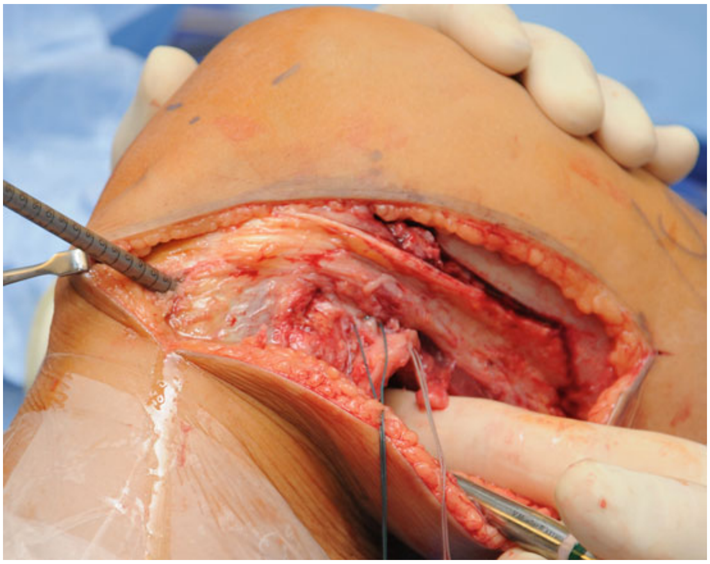


**Fig. 3.16** An intraoperative photograph of a *left knee* is shown. A 9-mm reamer is used to create the tibial tunnel for a posterolateral corner reconstruction. Posteriorly, the neurovascular bundle is protected



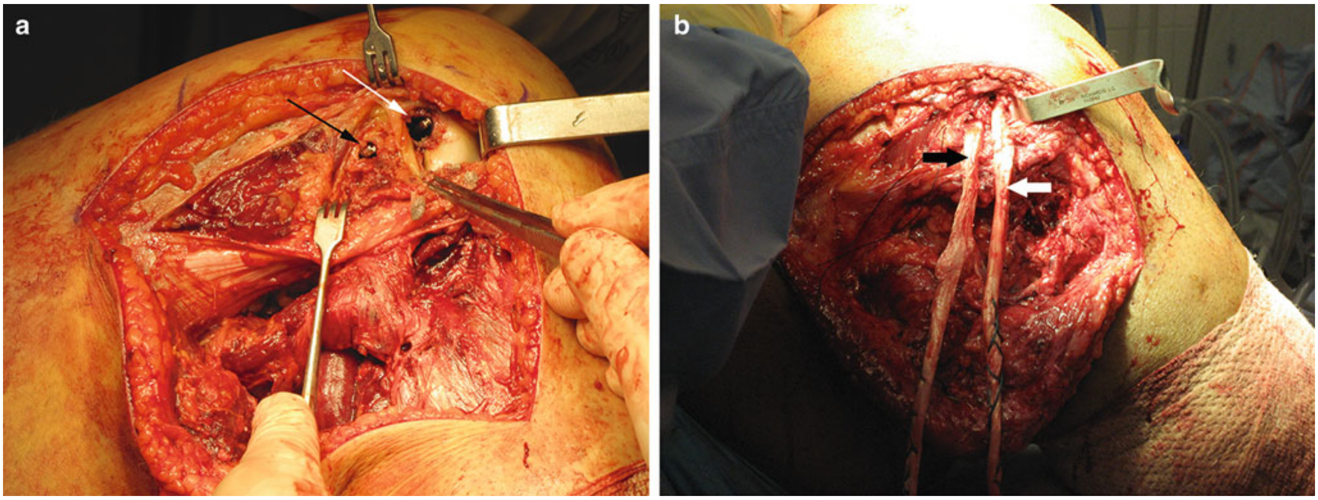


**Fig. 3.17** Intraoperative photographs of a *right knee* posterolateral corner reconstruction are shown. (**a**) Eyelet pins are shown in the femoral attachment sites of the popliteus tendon (*white arrow*, reamed) and fibular collateral ligament (*black arrow*, not yet reamed). (**b**) The popliteus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

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 [79]. 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. The nonoperative treatment for MCL injuries is well defined [80–85] 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 [86]. 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 [18] of the sMCL is identified by blunt dissection.

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

In preparation for reconstruction, the sMCL and POL tibial attachments are identified [18, 86]. Utilizing anatomic landmarks, the femoral attachments of the sMCL and POL are further identified [19]. 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.

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

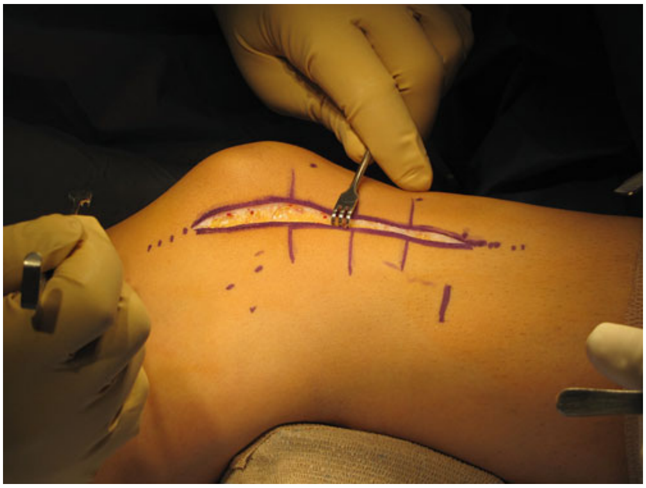


**Fig. 3.19** A photograph of the 16- and 12-cm grafts for reconstruction of the superficial medial collateral ligament and posterior oblique ligament, respectively, is shown. The tendons are sized for 7-mm tunnels and tubularized with nonabsorbable suture at each end

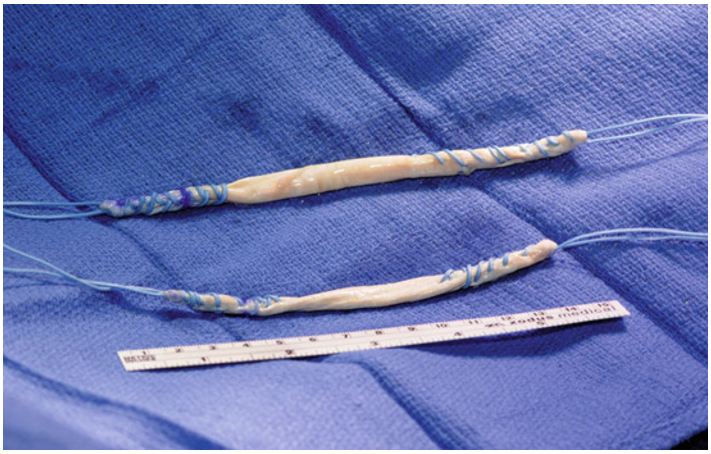
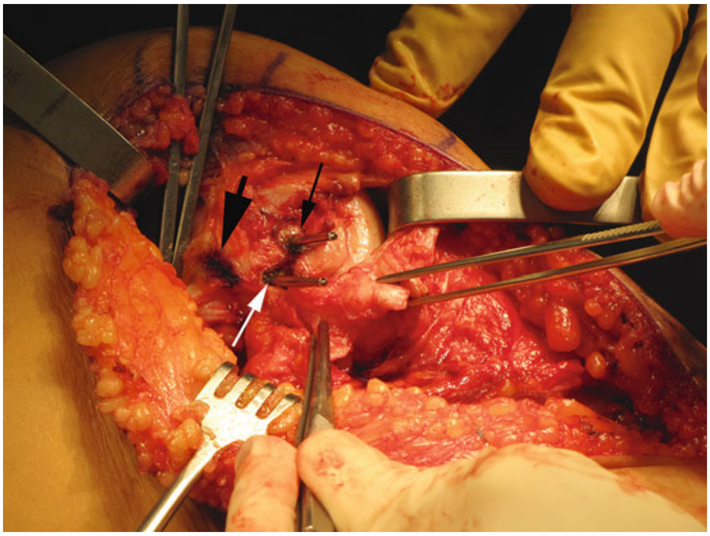


**Fig. 3.20** An intraoperative photograph of the medial aspect of *left knee* is shown. The pins placed in the planned locations for the superficial medial collateral ligament (*black arrow*) and posterior oblique ligament (*white arrow*) tunnels are visible. Also, the location of the adductor tubercle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



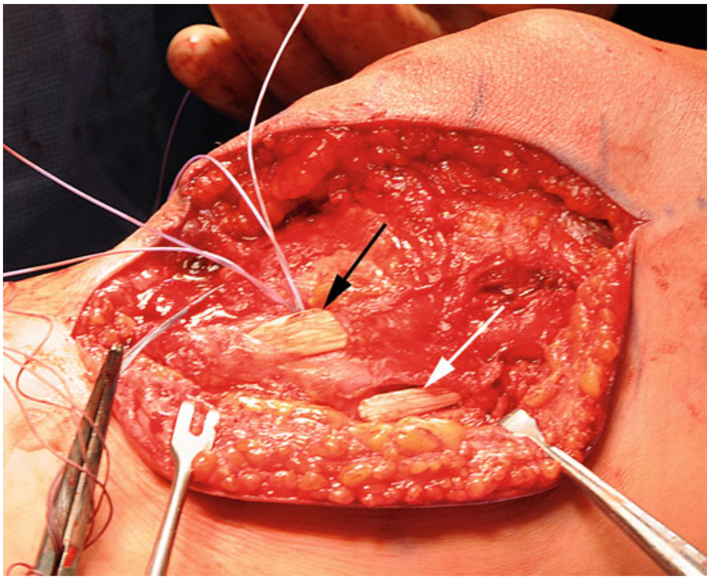


**Fig. 3.21** An intraoperative photograph of the medial aspect of the *right knee* is shown. The superficial medial collateral ligament (*black arrow*) and posterior oblique ligament (*white arrow*) grafts are demonstrated

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 2 divisions of the tibial portion of the sMCL is performed utilizing a suture anchor placed through the anterior arm of the semimembranosus, just distal to the joint line (Fig. 3.21).

## 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 [87]. 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 [87] and medial [13, 20, 80, 83, 85, 88, 89] knee literature.

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# Part III

# Diagnosis and Evaluation of the Multiple Ligament Injured

# Chapter 4
# Initial Assessment in the Acute and Chronic Multiple-Ligament-Injured Knee

**Christopher Peskun and Daniel B. Whelan**

## 4.1 Physical Examination

Physical examination of a patient with a suspected knee dislocation ideally takes place urgently following injury. These patients routinely sustain multisystem trauma and should be triaged utilizing the Advanced Trauma and Life Support protocol [1, 2]. Following initial resuscitation and stabilization, a thorough exam of the involved extremity should begin with inspection to rule out any evidence of active bleeding, gross malalignment, open injury, ecchymosis, skin mottling, or blisters. The presence of a "dimple sign" overlying the medial aspect of the knee frequently signifies buttonholing of the medial femoral condyle through the anteromedial joint capsule following a posterolateral rotatory type mechanism (Fig. 4.1). This is an important physical finding as it can be a predictor of a dislocation that may require an open reduction [3–5]. Open knee dislocations occur with an incidence of between 19% and 35% and must be identified early in the physical examination [6]. These injuries have a greater surgical urgency and overall higher complication rate [7].

The physical examination continues with an evaluation of the vascular status of the lower extremity. The options for vascular assessment include physical examination alone, physical examination with measurement of ankle–brachial index (ABI), or routine arteriography. Hard signs of frank vascular injury, including active hemorrhage, distal ischemia, and expanding hematoma, should alert the treating surgeon to the need for emergent vascular imaging and involvement of a vascular surgeon. Softer signs of vascular injury, such as limb color and capillary refill, have been described for vascular assessment; however, their reliability and clinical utility remain unclear [8]. In all circumstances, the surgeon should palpate for the presence of both the dorsalis pedis and posterior tibial pulses. Although there has recently been published evidence to suggest that the presence of normal distal pulses rules out clinically significant vascular injury with 100% sensitivity [9, 10], many surgeons strongly advocate that an ABI be performed in all patients suspected of having a knee dislocation [11]. The ABI is a fast and reliable test with relatively no associated morbidity to the patient. The ABI is measured with the use of a Doppler ultrasound probe by measuring the systolic pressure in the affected leg at a level just proximal to the ankle and dividing this value by the systolic pressure in the ipsilateral arm. An ABI value of >0.9 has been shown to be a reliable marker of normal arterial patency [12]. This calculated value may be less reliable in patients suffering from peripheral vascular disease with vessel calcification [13]. Further investigation in the form of arteriography, or imaging with vascular reconstructions, is warranted in the setting of an abnormal physical exam and ABI <0.9.

Assessment of neurological function in the setting of knee dislocation can be challenging, as patient compliance is frequently compromised by head injury or intoxication. The peroneal nerve is the most commonly injured nerve with less frequent injury to the tibial nerve [14]. Both the motor and sensory function of these peripheral nerves must be evaluated as they can be affected independently [15]. Accurate documentation of neurological status is particularly important when a knee joint reduction maneuver is planned as iatrogenic injury is a possibility.

Although difficult to perform in the acutely injured knee, a complete examination includes assessment of the ligamentous structures of the knee, in particular the ACL, PCL, MCL, LCL, posterolateral, and posteromedial corners. Ideally, the assessment

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**Fig. 4.1** Dimple sign in an irreducible knee dislocation

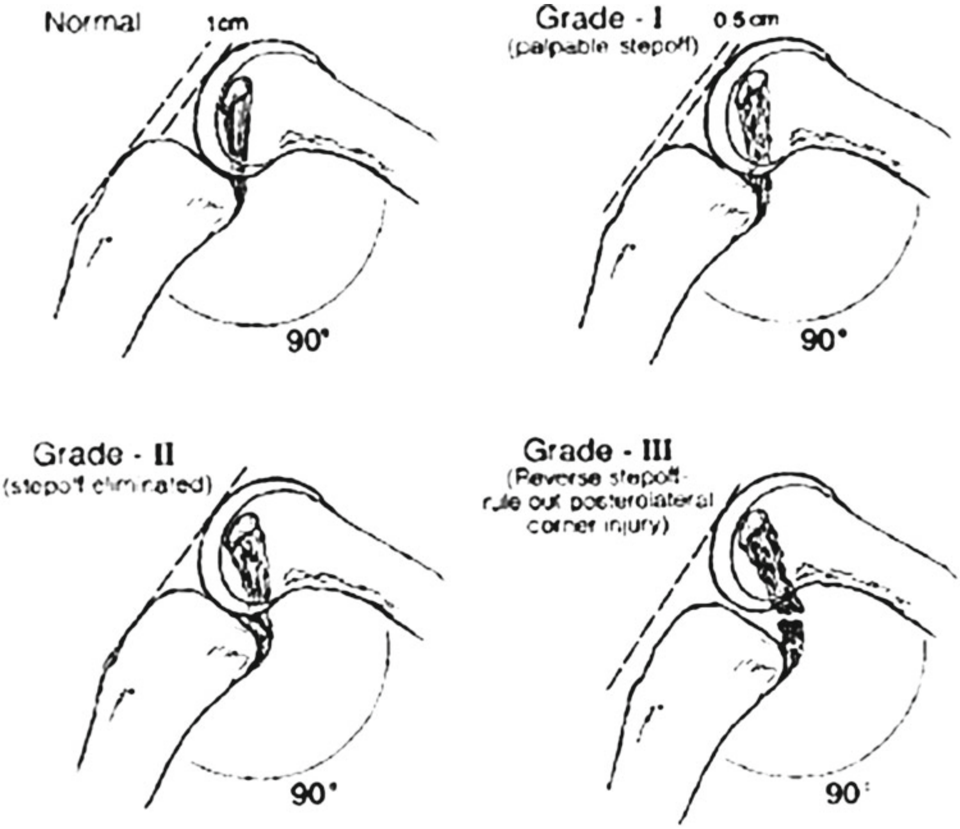

**Fig. 4.2** Assessment of cruciate unstable knee. From Petrie RS, Harner CD. Evaluation and management of the posterior cruciate injured knee. Oper Tech Sports Med. 7(3);1999:93–103. Reprinted with kind permission from Elsevier

is performed only once by a surgeon with specialty training in the management of multiligament knee injuries. This assessment should be performed in a gentle fashion so as to not induce excessive pain or further injury to an already compromised knee joint.

The Lachman's test and the posterior drawer test are the most sensitive tests for isolated ACL and PCL injuries, respectively [16]. In the scenario of a multiligament knee injury, the anterior and posterior drawer tests may be difficult to perform and interpret. Particular attention must be paid to the step-off between the medial tibial plateau and medial femoral condyle (Fig. 4.2) [17]. The MCL and LCL are assessed by imparting a valgus and varus force, respectively, through the knee. This is best accomplished with the knee first in full extension and then 30° of flexion. Comparison to the contralateral uninjured limb is important for identifying pathologic laxity. The final component of the soft tissue assessment of the knee involves a test for the competence of the extensor mechanism. Although injuries to the extensor mechanism are rare [18], the high morbidity associated with loss of active knee extension necessitates early diagnosis and treatment. Competence of the extensor mechanism is assessed by direct palpation or a straight leg elevation test.

In order to complete the physical examination, the fascial compartments of the lower leg should be palpated, as compartment syndrome may occur with or without concomitant vascular injury. In the setting of an obtunded or noncompliant patient with abnormally tense compartments, consideration should be given to invasive compartment pressure measurement.

## 4.2 Imaging Studies

Following the clinical diagnosis and closed reduction of a knee dislocation, adjunctive imaging should be obtained. Plain radiographs of the knee assist in identifying the direction of dislocation as well as the presence of fractures; however, in the setting of suspected vascular injury, arteriography, or cross-sectional imaging with vascular reconstructions, should be considered. The role of arteriography, whether performed preoperatively or intraoperatively, remains controversial [19]. The first generation of management algorithms for knee dislocations called for routine arteriography in all cases, yet recently the benefits of this approach have been proven to be limited. In addition, the potential risks to the patient and resource-intensive nature of the procedure have necessitated the consideration of other options.

The role of computed tomography (CT) in the setting of multiligament knee injury continues to evolve. The ability to clearly define the location and characteristics of associated fractures as well as the ability to perform concomitant CT angiography has increased its utility, especially in cases of suspected vascular injury (Fig. 4.3) [20]. Moreover, CT angiography requires only antecubital venous cannulation, whereas traditional arteriography necessitates femoral artery cannulation, along with its higher associated morbidity and complication rate [21].

Magnetic resonance imaging is of the utmost importance in the management of multiligament knee injury. The prolonged time for acquisition necessitates stabilization of the patient before performing the study. The ability of MRI to identify associated tendon, ligament, and meniscal injury is unparalleled compared with other imaging modalities (Fig. 4.4). Furthermore, the specific site of ligamentous injury (proximal/distal) can be clearly defined, which can impact the need for and specific type of surgical treatment [22]. Magnetic resonance angiography may also allow for vascular assessment, negating the need for routine angiography. The accuracy of MRI for detecting the extent or site of ligamentous injury, in the setting of knee dislocation, has been demonstrated to be 85–100%. This range is significantly higher than the accuracy of physical examination, namely, 53–82% [23].

## 4.3 Surgical Timing

Although in the past, prolonged immobilization in a splint or hinge brace was the standard form of definitive treatment for multiligament knee injuries [24], the present day goal of definitive management is anatomic repair or reconstruction of the knee ligaments and menisci to facilitate a painless, stable, and functional knee. The timing of surgical management of the multiligament knee-injured patient depends on the anatomic characteristics of the injury, systemic status of the patient, and presence of concomitant injuries. Associated vascular injury, open injury, compartment syndrome, irreducible dislocation, or grossly unstable dislocation requires emergent surgical management.

Vascular injury in association with knee dislocation requires expedient diagnosis and management. Treatment including arterial reconstruction with a contralateral reverse saphenous vein graft is the standard of care. Primary arterial repair is usually not possible as the tissue disruption is due to a traction injury, leaving the injured artery with ragged and uneven ends. Involvement of a vascular surgeon and prepping and draping of the contralateral limb are preoperative necessities.

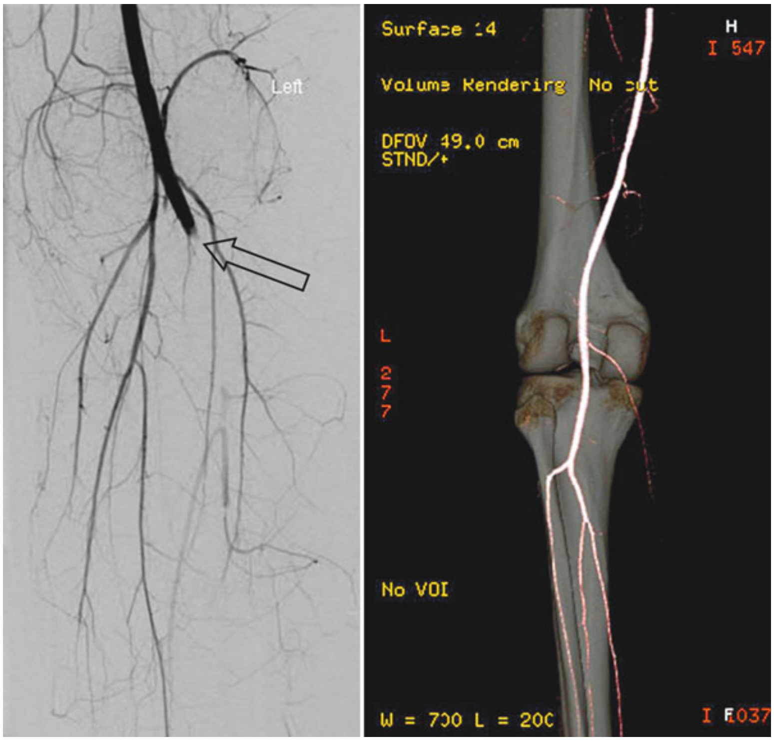

**Fig. 4.3** Comparison of computed tomography angiogram and conventional angiography

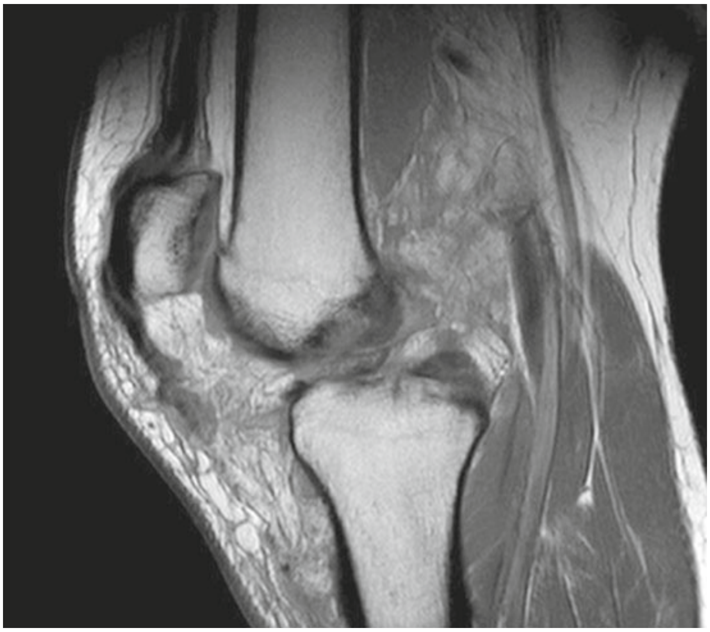

**Fig. 4.4** Bicruciate injury with patellar tendon rupture

To protect the reconstruction against recurrent injury and to facilitate tissue maturation, the knee joint should be temporarily stabilized with an external fixator (Fig. 4.5) [25]. Expedient patient treatment is paramount when considering vascular reconstruction, as a delay may be associated with higher rates of procedural failure and reperfusion injury, with the potential for systemic complications [26–28]. When the dysvascular time period approaches 6 h, one option is to temporize with vascular shunting while harvesting of the contralateral saphenous vein graft is performed [29, 30]. Four-compartment fasciotomies of the involved lower leg should be considered when revascularization has taken place >6 h post injury.

**Fig. 4.5** Vascular exploration with external fixator in place

In addition, fasciotomy should be performed anytime there is a clinical suspicion of a frank or evolving compartment syndrome [31, 32].

Open knee dislocation requires immediate reduction with irrigation and debridement. Antibiotic treatment, repeated irrigation and debridement, and definitive wound coverage assist in decreasing the risk of complications. These initial measures may delay definitive management and potentially compromise patient functional outcome; however, the risk for deep infection and wound complications preclude early definitive management. An irreducible dislocation, often seen with a posterolateral mechanism, is managed via an urgent open reduction. An immediate ligamentous repair in this situation is one option, although this approach likely increases the risk of arthrofibrosis [33].

In the absence of a diagnosis requiring urgent surgical management, most surgeons prefer to delay surgery for multiligament knee injury for a minimum of 10–14 days, although this issue remains controversial [34]. This latency period allows for a reduction in soft tissue swelling, improvement in quadriceps function, and partial reconstitution of the knee joint capsule. Capsular reconstitution allows an arthroscopic technique to be utilized for cruciate ligament reconstruction with a decreased risk of iatrogenic compartment syndrome. Surgery performed prior to 3 weeks following injury has shown better clinical stability and increased functional outcome scores when compared to delayed surgery [35–37]. Moreover, the intraoperative and postoperative complications arising from scar tissue formation are more commonly seen in reconstructions performed >3 weeks following injury. One potential downside to immediate surgical reconstruction is the development of arthrofibrosis. Ideally, the cruciate ligaments are reconstructed arthroscopically with the posterolateral and posteromedial corners, medial collateral ligament, and lateral collateral ligament repaired with an open technique [34].

Occasionally, due to delay in patient presentation or a prolonged period of systemic instability precluding early ligament reconstruction, surgery must be performed in a delayed or chronic fashion. Several studies have examined the outcome of chronic multiligament knee reconstructions [38–41]. Overall, the results indicate a decreased range of motion and increased rate of residual laxity when compared to acute reconstructions. The operative considerations for chronic multiligament knee reconstruction include the increased need for autograft and allograft tissue as repair is usually not possible or advisable, and the increased amount of scar tissue which can complicate both open and arthroscopic approaches.

## 4.4 External Fixation

In general, external fixator application can be avoided as part of the management of knee dislocations, provided the joint is relatively stable post reduction. The associated complications, such as pin site colonization and infection, damage to the quadriceps mechanism, and joint stiffness, make the use of an external fixator undesirable [42].

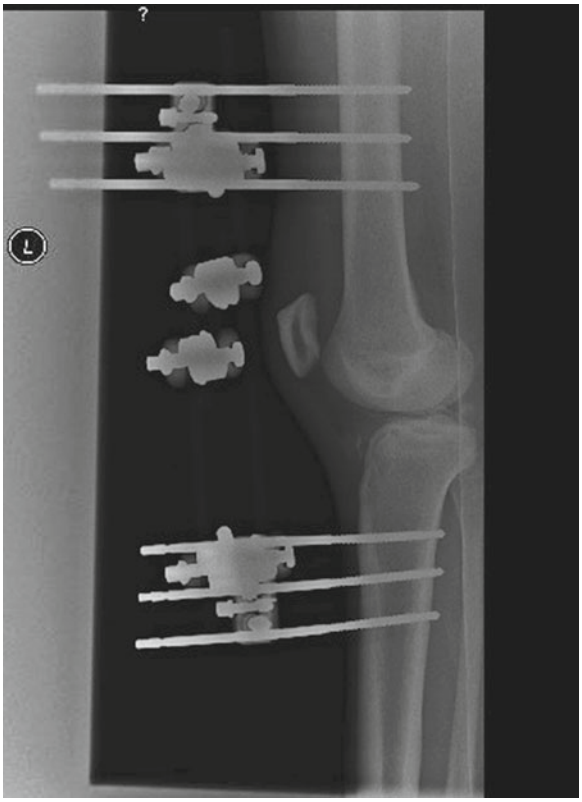

**Fig. 4.6** Subluxed knee with external fixator in place

However, the use of an external fixator is indicated in the setting of a knee dislocation, or multiligament knee injury, when there is an associated vascular repair, open injury, fasciotomy, or grossly unstable reduction that cannot be maintained with the use of a hinged brace [43]. An additional relative indication for external fixator use is patient obesity, which often causes intolerance or fitting difficulty of a hinge knee brace. External fixation has three main advantages compared to cast bracing. Namely, it allows the direct monitoring of the soft tissues, simplifies repeated vascular assessments, and facilitates transportation and mobilization of patients. Soft tissue monitoring is particularly important when there is an associated open injury or the concomitant fasciotomy wounds.

Application of a knee-spanning external fixator is performed with placement of multiple pins in both the femur and tibia. The pins should be placed in such a fashion as to avoid the area of injury and planned area of surgical reconstruction. The femoral pins may be placed directly anterior or lateral, each of which has relative benefits and drawbacks. Although anterior pin placement is technically straightforward, one disadvantage is the risk for quadriceps tethering, which can cause muscle defunctioning and compromised rehabilitation. Lateral pin placement allows for the quadriceps muscle to largely be avoided but may decrease the stability of the construct. Most surgeons apply the external fixator in a biplanar orientation with pins placed laterally in the femur and anteromedially in the tibia. This pin configuration limits the degree of soft tissue violation, thereby lowering the potential for pin site infection and subsequent loosening, but still allows for a mechanically stable construct. The external fixator should be applied with the knee in either full extension or a small amount of flexion, for example, if a vascular reconstruction has been performed. Regardless of the specific configuration or method of implementation, it is paramount that reduction of the knee joint be confirmed at the time of fixator application so as to avoid the complications associated with an inappropriately placed construct (Fig. 4.6).

There has been concern in the past that placement of a spanning knee external fixator may increase compartment pressures around the knee, although this seems to be a transient phenomenon with minimal risk of progression to frank compartment syndrome [44]. External fixation has been used in the past for definitive management of knee dislocations, although chronic laxity can result and compromise outcomes. In the scenario of temporary external fixation, the surgeon must be aware of the balance between stiffness and laxity based on the amount of time the fixator is left in place [45, 46]. The external fixator is traditionally left in place for a total of 6–8 weeks. It is usually removed in the operating room with the benefit of a general anesthetic, which is also an opportune time for an examination under anesthesia and possible knee manipulation.

## 4.5 Arthroscopic Versus Open Cruciate Surgery

Multiligament knee injuries frequently involve injuries to both the ACL and PCL, with a high rate of concomitant injuries to the collateral ligaments, posterolateral, and/or posteromedial corners. Although the current standard of care is reconstruction of the cruciate ligaments via an arthroscopic approach, some surgeons choose to utilize a more traditional technique, namely, an open approach [47]. Furthermore, certain clinical situations necessitate an open cruciate reconstruction. An irreducible knee dislocation requires an open approach to remove the incarcerated knee joint capsule or fibers of vastus medialis obliquus [3, 4]. Other situations where an open extensile incision may be considered as a primary approach include the presence of open wounds anteriorly or concomitant disruption of the extensor mechanism. The latter is a rare situation whereby the extensor injury may be exploited to allow for a “trap door” approach to the anterior aspect of the knee.

There are several advantages to an open approach to cruciate reconstruction. An open approach gives excellent visualization of the anatomic locations of the origins and insertions of both the ACL and PCL. This allows for accurate tunnel placement during reconstruction. In addition, an open approach decreases the risk for compartment syndrome associated with prolonged arthroscopic surgery in the setting of a potentially compromised knee joint capsule [48]. Despite these advantages, there are drawbacks to an open approach to cruciate reconstruction. The use of a large arthrotomy necessitates a greater degree of soft tissue dissection and damage, particularly to the extensor mechanism. This may increase the risk for postoperative arthrofibrosis. In addition, the location of a relatively large midline incision may complicate reconstruction of the collateral ligaments since additional large incisions, to avoid undermining soft tissues and creating dysvascular tissue flaps, are necessary. These multiple large incisions around the knee may complicate anticipated future procedures, such as total knee arthroplasty. Conversely, arthroscopic cruciate ligament surgery minimizes the incisional load around the knee, allowing for placement of single accessory incisions utilized for collateral ligament reconstruction.

Few studies are available regarding the outcome of open multiligament knee reconstruction. Owens et al. described their findings on the treatment of 30 knee dislocations utilizing an open approach [47]. The mean Lysholm score was 89 and the mean arc of motion was 119°. Hirschmann et al. reported their functional outcome findings on the open treatment of 56 patients with multiligament knee injuries treated with a single-stage open reconstruction [49]. The mean Lysholm score was 83. The results of these studies compare well with the aggregate average of Lysholm scores (84.3) and range of motion (117°) from all reported arthroscopic multiligament knee reconstructions performed over the past 10 years [50].

Overall, the functional outcome and range of motion of open cruciate reconstruction in the setting of multiligament knee injury is comparable to arthroscopic cruciate reconstruction.

## 4.6 Transtibial Tunnel or Tibial Inlay Surgery

Injuries to the PCL can occur in isolation or as a component of a multiligament knee injury. When in isolation, PCL injuries, even up to grade II, can often be managed successfully with conservative measures consisting of physiotherapy with quadriceps strengthening and brace wear, especially when patients are competing in athletic activities [51, 52]. Grade III injuries likely indicate concomitant injury to the posterolateral or posteromedial corners [53]. Occasionally, isolated PCL injuries that remain symptomatically unstable benefit from reconstruction, although the absolute and relative operative indications remain poorly defined. Most dedicated reconstructive knee surgeons would agree that in the scenario of a combined cruciate injury or multiligament knee injury, the PCL should be routinely reconstructed as a priority. Once a decision has been made to reconstruct the PCL, the choice for operative technique must be made. There are two common approaches to reconstruction, namely, a transtibial technique and a tibial inlay technique [54].

The transtibial technique for PCL reconstruction is commonly used in the scenario of multiligament knee injury. This technique necessitates the patient to be positioned supine, allowing for concomitant reconstruction of the ACL without changing the position of the patient. Furthermore, the transtibial technique can be performed arthroscopically without the need for a formal open approach; however, a small posteromedial safety incision is commonly used to insure accurate placement of the tibial guidewire [55]. The transtibial technique does have several potential drawbacks. Due to the intra-articular anatomy of the knee and the disparity between tibial and femoral tunnel orientation, the graft must curve tightly around the posterior aspect of the proximal tibial. This is known as the “killer turn” and can contribute to numerous difficulties (Fig. 4.7) [56, 57]. The acute angle formed by the killer turn frequently causes difficulty with direct tensioning of the graft as the line of pull is almost 90° to the intra-articular graft direction. Moreover, this sharp turn can lead to graft attenuation and ultimately graft failure [58, 59]. The “killer turn” phenomenon is thought to be the major contributor to postoperative graft laxity. Due to the biomechanical challenges of the arthroscopic transtibial technique, many surgeons have looked for an alternative for PCL reconstruction.

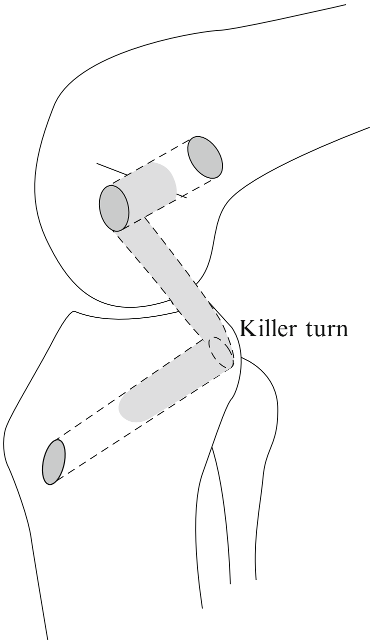

**Fig. 4.7** Killer turn phenomenon. Courtesy of Sports Medicine Clinic, Carleton University. Reprinted with permission

The tibial inlay technique for PCL reconstruction is an attractive alternative to the transtibial technique. This technique utilizes a bone block placed in the tibial sulcus, at the attachment site of the native PCL [60]. This anatomic attachment site avoids the geometric problems associated with the transtibial technique and its killer turn. The technique may be ideally indicated in the scenario of a revision procedure when an inappropriately placed tibial tunnel, and potentially compromised available bone stock, already exists [61]. Alternatively, the tibial inlay technique may also be beneficial in the setting of a previous fracture or osteotomy of the proximal tibial. In these cases, the normal anatomy required for safe tibial tunnel drilling is often lost. A previous tibial shaft fracture treated with an intramedullary nail will also preclude use of a transtibial technique.

Several studies have reported a lower incidence of residual posterior laxity following tibial inlay technique [62–64]. In addition, there is a lower risk of graft abrasion with this technique when compared to a transtibial technique. The tibial inlay technique does however have several drawbacks. For placement of the distal bone block, an open approach to the posterior aspect of the knee must be performed. This approach is rarely performed in routine orthopedics and requires an intimate knowledge of the neurovascular anatomy of the posterior aspect of the knee [65, 66]. For these reasons, the tibial inlay technique frequently has prolonged operative times. The posterior approach necessitates prone patient positioning, making concomitant ligament reconstruction difficult in the absence of a change in patient position. Moreover, the tibial inlay technique requires a capsulotomy which can compromise arthroscopic distention and subsequent visualization intra-articularly. This consideration is especially pertinent in the setting of a multiligament knee injury where reconstruction of both the PCL and ACL is routine. Finally, the tibial inlay technique necessitates femoral-sided tensioning, precluding the use of a tensioning boot apparatus.

There have been no published studies comparing the transtibial versus tibial inlay techniques for PCL reconstruction in the setting of multiligament knee injuries. However, the general principles for isolated PCL reconstruction can reasonably be extrapolated. A recent systematic review was unable to draw any firm conclusions with respect to differences between the tibial inlay and transtibial tunnel techniques [67]. They cited poor methodological quality and inconsistent reporting of findings as major drawbacks and areas for future improvement. Surgeons involved in the care of patients with multiligament knee injuries should use all available patient information and their best clinical judgment when deciding between the transtibial and tibial inlay techniques for PCL reconstruction.

## 4.7 Single- or Double-Bundle Cruciate Reconstructions

The vast majority of ACL reconstructions that are performed utilize a single-bundle technique [68]. In an attempt to recreate a more anatomic reconstruction, the relative position of the tunnels, particularly on the femoral side, has gone through an evolution [69, 70]. The use of an anteromedial drilling portal was borne out of concern for the theoretical inability of a transtibial reconstruction to anatomically position the graft in the native femoral footprint and subsequently restore transverse

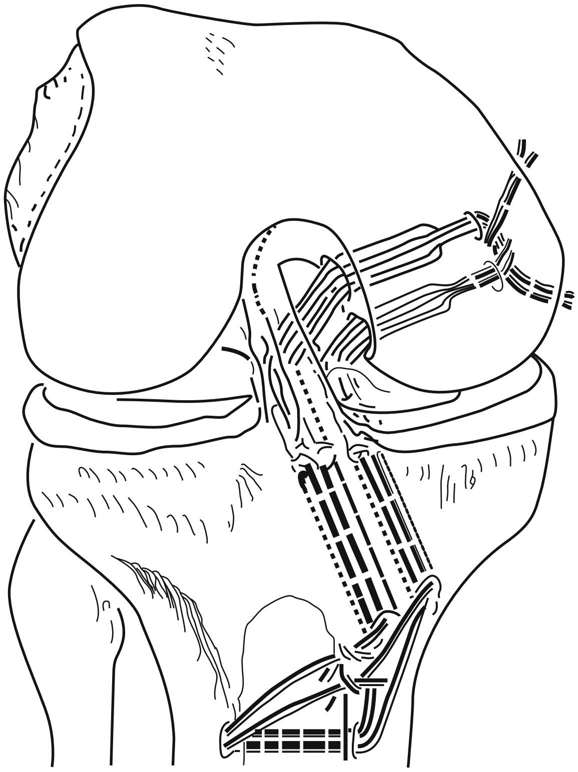

**Fig. 4.8** Double-bundle PCL reconstruction. From Chen B, Gao S. Double-bundle posterior cruciate ligament reconstruction using a non-hardware suspension fixation technique and 8 strands of autogenous hamstring tendons. Arthroscopy: J Arthroscopic Related Surg. 25(7);2009:777–782. Reprinted with kind permission from Elsevier

plane knee rotatory control [71]. However, there continues to be controversy with respect to ideal placement of the femoral tunnel. Moreover, the lack of reliable landmarks on which to base femoral tunnel placement has lead to variability and inconsistency in ACL reconstructions. An analogous situation has developed with respect to PCL reconstruction. The desire to create a truly anatomic repair, and thereby provide maximum stability, has lead many surgeons to look for alternatives to single-bundle cruciate reconstructions.

The ACL and PCL have long been cited to possess two distinct bundles that independently contribute to their stability at various degrees of knee flexion and extension [72, 73]. Over the past 10 years, the interest in double-bundle cruciate ligament repairs has increased due to a desire to create a more stable and overall more anatomic repair [74, 75]. With respect to the ACL, a double-bundle repair attempts to independently recreate the anteromedial bundle, which is tighter in flexion, and the posterolateral bundle, which is tighter in extension [76]. Proponents of the double-bundle ACL reconstruction cite better rotational and sagittal plane stability when compared to single-bundle reconstructions [77, 78]. Despite the convincing biomechanical evidence for the superiority of double-bundle ACL reconstructions, a meta-analysis on the topic suggests no in vivo clinically significant differences with respect to stability and control between single- and double-bundle ACL reconstructions [79]. In addition, the procedure is not without its relative drawbacks. Increased surgical time, the need for additional graft material, and an increased technical challenge have contributed to some surgeons' trepidation for adopting the double-bundle technique. Continued higher-level research on the topic will likely lead to more definitive evidence on which to base treatment decisions.

The same stimulus that propelled the interest in double-bundle ACL reconstructions has also lead to the concept of double-bundle PCL reconstructions (Fig. 4.8). The relative rarity of PCL reconstructions, compared to ACL reconstructions, has contributed to a lower total volume of literature regarding double-bundle PCL reconstructions. The theoretical advantages of a double-bundle PCL reconstruction are less posterior laxity and better rotational control, although there is currently a paucity of research to support these claims [80–82]. Double-bundle PCL reconstructions, like their ACL counterparts, also have the drawbacks of increased operative time, a greater need for graft material, and increased technical challenge [83].

In the setting of a multiligament knee injury, the relative merits of double-bundle ACL and PCL reconstructions must be scrutinized. Recurrent laxity is a frequent complaint following multiligament knee reconstruction. Therefore, the potential increased stability afforded by a double-bundle approach may help obviate this problem. However, the gross instability associated with multiligament knee injuries may not allow for fine adjustments in the tensioning of the double-bundle constructs. In addition, the geometric complexity associated with placement of four tunnels on both the femoral and tibial sides of the joint may outweigh the potential benefits, especially when one considers that proximal tibial and distal femoral bone stock will allow for only a finite number of tunnels and apertures before coalescence and intersection difficulties arise. Finally, increased arthroscopic operative time, in the setting of a potentially compromised knee joint capsule, may not be optimal.

Overall, the decision to utilize a double-bundle ACL or PCL reconstruction must be based on individual patient factors, institutional resource availability, and the technical abilities of the treating surgeon.

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# Chapter 5
# Classification of Knee Dislocations and the Surgical Implications

**Bryon D. Hobby, Daniel C. Wascher, and Robert C. Schenck Jr.**

## 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]. While still rare occurrences with an incidence of 0.02–0.2% of all orthopedic injuries, knee dislocations are now being seen with increased frequency, for a variety of reasons [2]. Possible causes are increasing rates of trauma, newer safety measures that have decreased mortality from trauma, and an increase in extreme activities. 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 [3]. The recognition of the spontaneously reduced knee dislocation has led to a greater awareness by physicians that multiligament knee injuries must be treated as knee dislocations. A classification system for knee dislocations was necessary in order to help orthopedic surgeons with the diagnosis and treatment of these complex knee injuries.

Classification systems serve many purposes and there are many factors that make them useful. A classification system must be simple and reproducible and will aid in both communication between providers and overall acceptance of its use. A system must also aid in the decision-making process, especially in 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, 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 exam 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, and range of motion. The ligament examination must include a Lachman's exam 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. A careful neurovascular assessment must be performed and is critical in the management of KDs. A delayed diagnosis of a vascular injury can result in a compartment syndrome or amputation. At a minimum, vascular assessment should include palpation of the posterior tibial and dorsalis pedis pulses and assessment of capillary refill time. Depending on the initial examination, further investigation should be directed by an evidence-based protocol which can include measurement of the ankle brachial index (ABI), angiography, CT angiography, or emergent exploration of the popliteal artery [4–7]. Vascular interventions may be necessary depending on

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**Fig. 5.1** Angiogram of a patient who suffered a popliteal artery injury as a result of a knee dislocation. Reprinted with permission from Wascher DC. High-energy knee dislocations. In: Drez D, Jr, DeLee JC, editors. Operative techniques in sports medicine vol. 11. Philadelphia: W. B. Saunders; 2003

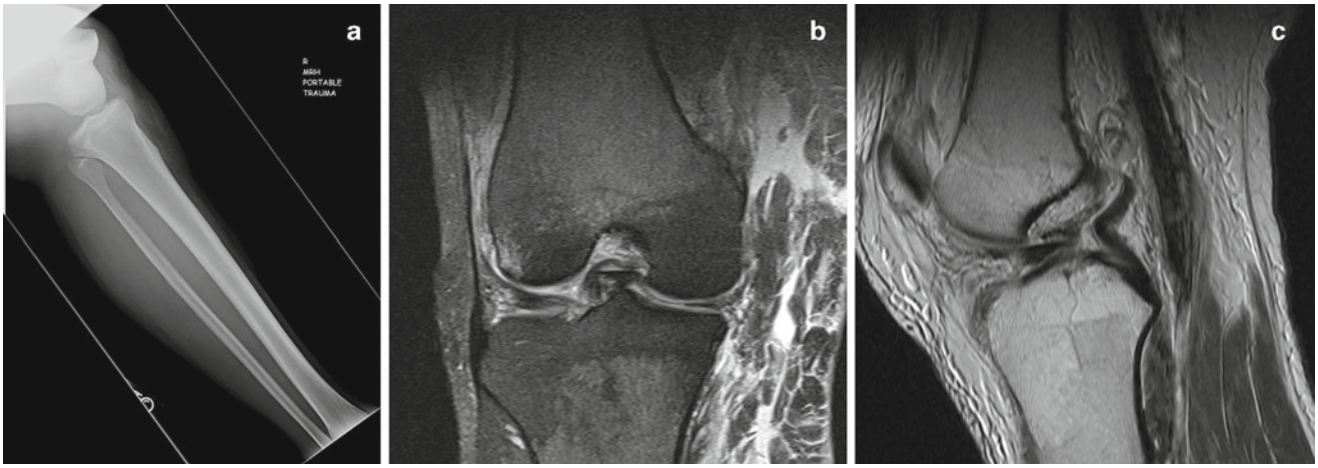

**Fig. 5.2** (**a**) Spot radiograph of a knee dislocation. (**b**) Coronal and (**c**) sagittal intermediate-weight MRI images, of the same patient, showing torn ACL, PCL, and bucket handle meniscal tear. Coronal section shows injury to MCL as well

the results of these investigations (Fig. 5.1). While nerve 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 can help in planning treatment and predicting outcomes [8, 9].

Following a thorough physical examination, AP and lateral radiographs should be obtained to identify fractures and assess tibiofemoral displacement. Repeat radiographs should be performed following reduction to ensure satisfactory alignment of the joint. Magnetic resonance imaging (MRI) is extremely useful in identifying the structures injured, the degree of injury, and the location of the injury [10–12]. While MRI is helpful in surgical decision making and planning, it does not replace a thorough physical examination (Fig. 5.2).

The final and most critical step in assessing the injured knee is an examination under anesthesia (EUA). A thorough EUA gives the clinician an idea of the functionality of the injured structures. In many cases, structures identified on MRI as injured

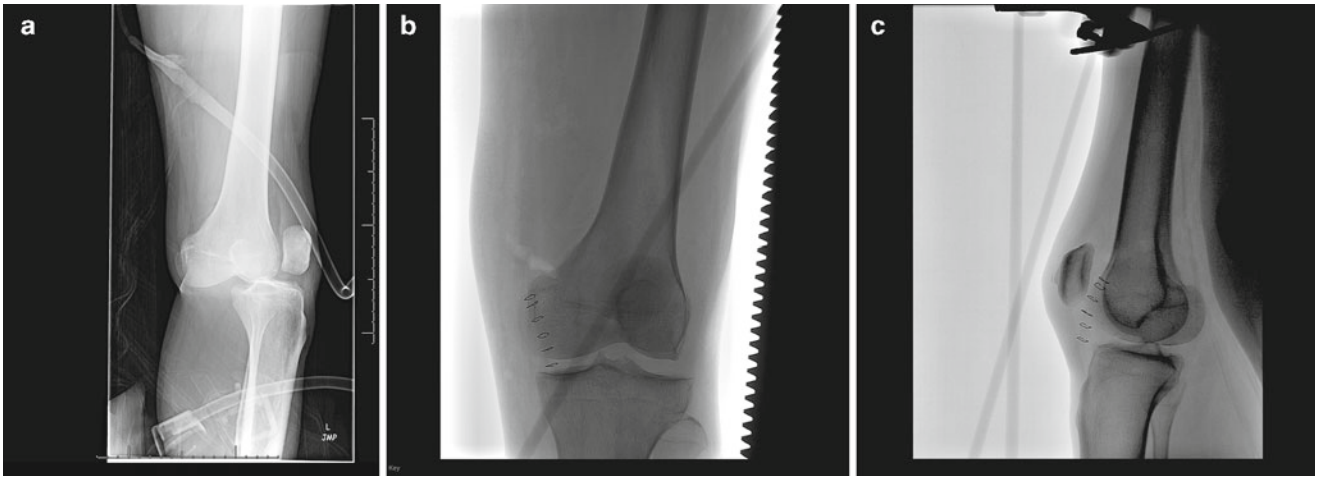

**Fig. 5.3** (**a**) Radiograph of a posterolateral dislocation. This KD was irreducible and required an open reduction where the MCL was interposed into the joint. Postreduction radiographs, (**b**) AP, and (**c**) Lateral. Once the interposed structures were reduced, the knee is concentrically reduced

may remain functional 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 [13, 14].

## 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 [15]. 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, with the posterolateral dislocation being the most common presentation of rotatory injuries.

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 injury. The anterior and posterior dislocations have been associated with a higher likelihood of coexisting popliteal artery injury [1, 15, 16]. However, since 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. The position system can also help with planning of a reduction maneuver, but most dislocations reduce easily with longitudinal traction. The position system is very useful when the physician identifies a posterolateral knee dislocation (Fig. 5.3). These dislocations are often irreducible with closed means as the medial femoral condyle button holes through the medial joint capsule, forcing the medial collateral ligament or other medial structures to invaginate into the joint [13, 14, 17–20]. The hallmark sign of the posterolateral KD is “medial skin 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. Prompt reduction is necessary because if left unreduced the pressure from the medial femoral condyle can lead to necrosis of the skin and/or medial collateral ligament. Identifying a posterolateral knee dislocation alerts the orthopedic surgeon about the high likelihood of requiring an open reduction. Peroneal nerve injuries are also frequently associated with posterolateral dislocations [13].

The major limitation of the position system is that it is unable to classify the approximately 50% of knee dislocations that are reduced at presentation. Since 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 the careful assessment and monitoring of the vascular status. If a neurovascular injury in a reduced knee dislocation is not recognized, this would have devastating consequences.

There are other deficiencies in the position classification system which we have found. The position system does not help with surgical treatment. No information is conveyed which would assist in the planning of surgical incision placement, 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. 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.

## 5.4 Energy of Injury Classification System

Knee dislocations have also been classified by the energy (or velocity) of injury. Dislocations are either categorized as high energy or low energy based on mechanism of injury (Table 5.1) [21–23]. 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 thought of those sustained during sporting activities, minor falls, or in the obese patient.

**Table 5.1** Energy of injury classification

| Classification | |
|---|---|
| High-energy KD | MVC, falls from height, polytraumatized patients |
| Low-energy KD | Sporting activities, falls, often isolated injury |

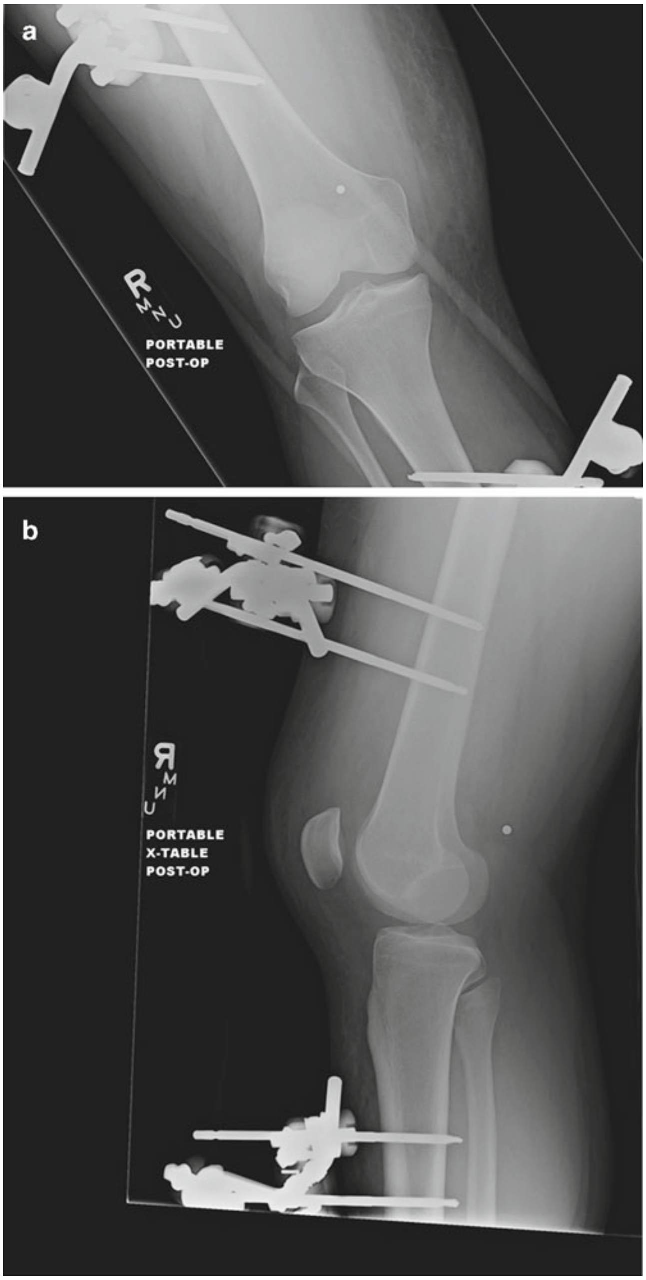

**Fig. 5.4** (**a**) AP and (**b**) lateral radiographs of a spanning external fixator placed for an unstable knee dislocation

Most KDs are high energy and are the result of major trauma. The patients that sustain a high-energy KD often have associated traumatic injuries to multiple systems including head, chest, abdominal, and other extremity injuries. These injuries can be life threatening and should often take precedence over the ligamentous aspects of the KD. KDs occurring in multitrauma patients require a coordinated team approach with emergency physicians, trauma surgeons, and orthopedic surgeons to assure 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 six to eight hours has a high likelihood of limb loss [16, 24].

The level of energy, does to some extent, dictates the course of treatment of a KD. High-energy KDs most often have other associated injuries, which may lead to delay in definitive treatment. We have found that high-energy KDs are best stabilized with an external fixator to allow for mobilization of the patient until surgical repair can be undertaken (Fig. 5.4). In some patients with severe associated injuries, immobilization in the fixator for 6–8 weeks can occasionally serve as definitive treatment. Conversely, patients who sustain low-energy KDs often are suitable for early reconstruction and repair or reconstruction of collateral structures, once motion is restored. Low-energy knee dislocations have also been seen to have a lower incidence of vascular injury, although complete popliteal artery injury can occur in any patient with a knee dislocation [5, 22].

Classifying KDs by energy of injury does have significant limitations. First, 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 racer who fell at high speed, colliding with barriers along the way. The initial and definitive management could be different for each of these individuals. Secondly, the energy of injury classification system does not accurately predict the risk of associated neurovascular injury. Thirdly, this classification does not identify the injured structures nor help in surgical planning. Finally, 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 Anatomic Classification

The anatomic classification is based on the ligamentous anatomy of the knee and what structures have been torn [25]. 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 posteromedial capsule, or posterior oblique ligament (POL). The posterolateral structures consist of the lateral collateral ligament (LCL), popliteal fibular ligament, popliteus tendon, and the posterolateral capsule.

The anatomic classification system is relatively simple and reproducible as it is based on what structures have been torn. In order to classify a knee dislocation (KD) 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 5.2). Injuries are classified by Roman numerals which 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 [26]. A KD II is a bicruciate injury with functional integrity of the collateral structures, also relatively rare. 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. 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 [3]. A KD V is a knee dislocation with an associated periarticular fracture and can be subclassified by other systems such as Moore and Stannard [6, 27]. Stannard further classified KD Vs based on the injured ligamentous structures [6]. 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 [28]. An example of using this system would be a knee dislocation with ACL, PCL, and MCL 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-M-N." 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 KD III-M with a torn ACL, PCL, and MCL but increased signal in PLC. This would still be classified as a KD III-M as the PLC is functionally intact and does not require treatment.

**Table 5.2** 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, M = medial involvement |
| KDIV | All four ligaments torn |
| KDV | Fracture dislocation |

C = arterial injury, N = nerve injury

The anatomic classification has several significant advantages over older classification systems. First, all KDs can be classified using this system, including multiligament 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 the worse the prognosis. KD IVs have been shown to have a higher incidence of vascular injuries as the tibiofemoral joint has lost all ligamentous structures functionality [4, 6]. Third, the anatomic classification helps guide treatment as the injured structures which will need reconstruction/repair are identified. Finally, the anatomic classification allows for easy communication between providers and allows accurate comparison of outcomes.

## 5.6 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 and energy 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 also 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.

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# Chapter 6
# Instrumented Measurement of the Multiple-Ligament-Injured Knee: Arthrometry, Stress Radiography, Rotationometry, and Computer Navigation

**Sasha Carsen and Donald Johnson**

## 6.1 Introduction

The multiple-ligament-injured knee presents a variety of unique challenges. Among the many significant challenges are the accurate clinical diagnosis and classification of the ligamentous and soft-tissue injuries. The history (i.e., mechanism) and clinical exam are the most important elements of assessment of the knee. Instrumented measurement is an important adjunctive tool available, along with imaging, to assist.

The most important element of instrumented examination in the dislocated knee is, of course, the safe medical management of the patient. Any application of physical stress to the knee joint should take place only after the patient has been deemed to be in stable condition and a vascular lesion has been ruled out. In addition, appropriate analgesia is of paramount importance, as many of the instrumented measurements require some level of stress on the joint and therefore can lead to significant pain. In addition to discomfort for the patient, pain can interfere with accurate measurements.

## 6.2 Indications and Reasons for Instrumented Measurement

While not every patient nor every clinician requires instrumented measurement, there are many ways the various techniques can be of benefit. Having objective measurements can be of benefit for the academic or community clinician, as well as for researchers. They can also be helpful to the extended care team in certain cases, including the primary care sports medicine physician, physiatrist, physiotherapist, or athletic trainer.

### *6.2.1 Diagnosis*

Accurate diagnosis in multiligament knee injury is imperative, as it ultimately defines the type and extent of surgical intervention required. Modern imaging is impressive and forms an indispensable part of the diagnostic picture but does not always tell the whole clinical story. The difference between a partial and complete ligamentous rupture may be difficult to impossible to gauge on imaging, but the difference could have a profound effect on surgical planning.

Instrumented testing can provide a more objective measure of laxity and therefore assist with differentiation of complete versus partial ligament injuries, essentially allowing for the definition of clinical laxity requiring surgical intervention. Although advanced soft-tissue imaging is now relatively standard, there are cases and situations where they are not available. Some patients will have a contraindication for MR imaging. Others may have significant artifact secondary to previous injury or surgery. Another growing problem is imaging for patients who are morbidly obese, a patient group that happens to also be at greater risk for multiligament knee injury.

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### *6.2.2 Post-Op*

By comparing instrumented measures pre- and postoperatively, one can quantify the clinical effect of the surgical intervention. A direct comparison with the same measurement tool using the same technique can allow immediate postoperative information to the surgeon on the effect of the repair or reconstruction.

### *6.2.3 Follow-up/Rehab*

In follow-up, postinjury or postoperatively, repeated instrumented measurement can provide insight into the integrity of the repair or reconstruction or show remaining clinical instability. This can be especially beneficial after a reinjury, as postoperative changes may make imaging-based diagnosis more challenging. Having a clear objective measurement to compare against can clear the picture significantly.

## 6.3 Methods of Measurement

### *6.3.1 Stress Radiography*

#### 6.3.1.1 Posterior Stress

Stress radiographs are most indicated and most helpful in defining the posterior displacement of the tibia relative to the femur [1]. There are numerous described techniques for stressing the posterior structures, and the four most common are presented below.

## 6.4 Hamstring Contraction

The active resisted hamstring contraction radiograph is performed by having the patient lay their leg and knee laterally over an XR cassette with the knee flexed to 90° and then having them actively contract their hamstrings against pressure with the knee staying at 90° (Fig. 6.1). The resultant lateral radiograph of the knee can then be measured, assessing the posterior tibial displacement. In one comparative study, the hamstring contraction stress view showed similar results to the Telos stress device and far greater accuracy than the axial stress view [2].

**Fig. 6.1** The active resisted hamstring contraction stress X-ray. The patient is performing an active maximal hamstring contraction against resistance in the lateral position. The X-ray is done during the maximal contraction

## 6.5 Axial View

A modified axial patellofemoral radiograph has been described as a quick and easy form of stress view of the posterior structures of the knee. The patient is laid supine, with knees flexed to 70° and feet flat on the table in moderate plantar flexion, and the tibia in neutral rotation. The X-ray beam is then directed from distal to proximal and parallel to the longitudinal axis of the patella, at an angle of 10° to the table. Early results of the technique were promising [3]. However, more recent multitechnique comparisons have shown it to be a less reliable technique compared to the alternative stress views [2, 4].

## 6.6 Posterior Sag/Gravity View

The patient is laid supine on the X-ray table, and both the hip and knee are flexed to 90°. The tibia is held in place in neutral rotation. A lateral radiograph of the knee is then taken. The method is quick and easy but has not compared favorably to other stress views [4].

## 6.7 Kneeling Stress View

The stress view with the best and most reliable results thus far is the kneeling stress view. The patient kneels on a bench or similar structure with the edge of the knee over the edge of the bench (i.e., the femoral condyles are past the bench, while the tibial tubercle is supported by it). The knee is maintained at 90° flexion. A true lateral radiograph of the knee is then taken. Measurement of displacement is then performed using the posterior cortex of the tibia and posterior cortex of the distal femur. The kneeling stress view was found to have very high inter- and intraobserver reliability [5] and reliable evaluation of posterior laxity [6].

Of note, however, a recent study comparing Telos stress views to kneeling stress views showed significantly different displacement measurements—both pre- and postreconstructive surgery [7]. This has been hypothesized to likely be due to the difference in force placed on the anterior tibia with the two techniques. Essentially, this means that further study will be required to better define normative displacement measurements for the kneeling exam, as well as a larger comparative study.

## 6.8 Valgus Stress

A valgus stress of the knee will put stress on the MCL and allow for grading of MCL injury. The patient is laid supine on a radiolucent table and their knees bound together. The examiner is then able to apply valgus stress to both knees by attempting to separate the patient's feet from the foot of the bed. The knees should be maintained in approximately 10–15° of flexion, and the feet slightly externally rotated while performing the stress. An AP radiograph is then taken of the knee at the endpoint of displacement. Displacement is measured from the medial plateau to the femoral condylar line (Fig. 6.2) [8].

### *6.8.1 Advantages*

- Cost effective
- Some protocols have very good reliability and effectiveness

### *6.8.2 Disadvantages*

- Training for clinicians and radiation technologists
- Standardization of protocols is necessary for comparable data

**Fig. 6.2** The opening of the medial joint space is measured in mm

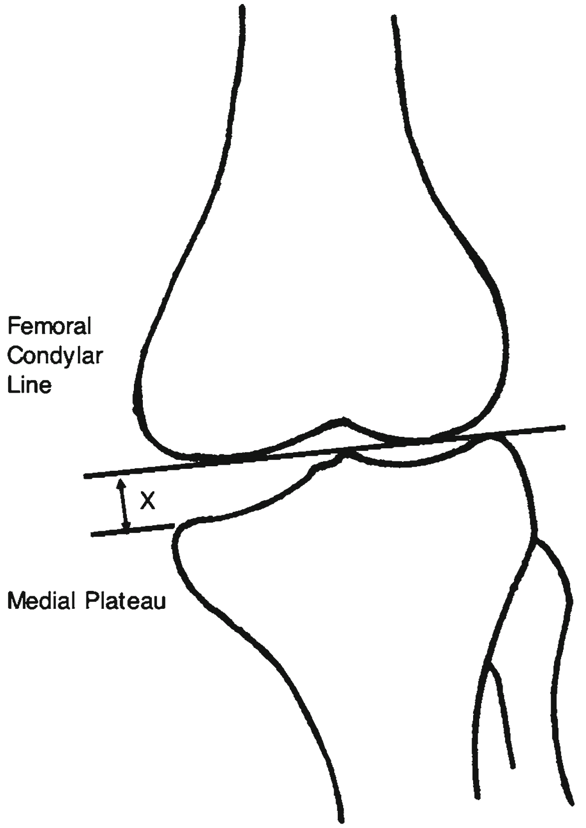

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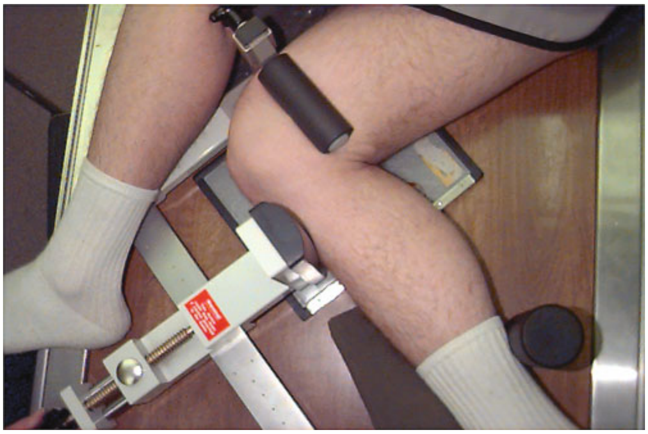
**Fig. 6.3** The stress X-ray examination of the PCL-deficient knee with the Telos device



#### 6.8.2.1 Instrumented Stress Radiography

Telos Stress Radiography

The Telos stress device (Austin and Associates Inc. Fallson MD) is a commercially available system that allows for reproducible and consistent stress forces through the knee while a radiograph is taken (Fig. 6.3). Measurement of displacement on the radiograph can then be performed. Depending on the patient's position and device's orientation, it can be used to stress the tibiofemoral joint anteriorly, posteriorly, medially, or laterally.

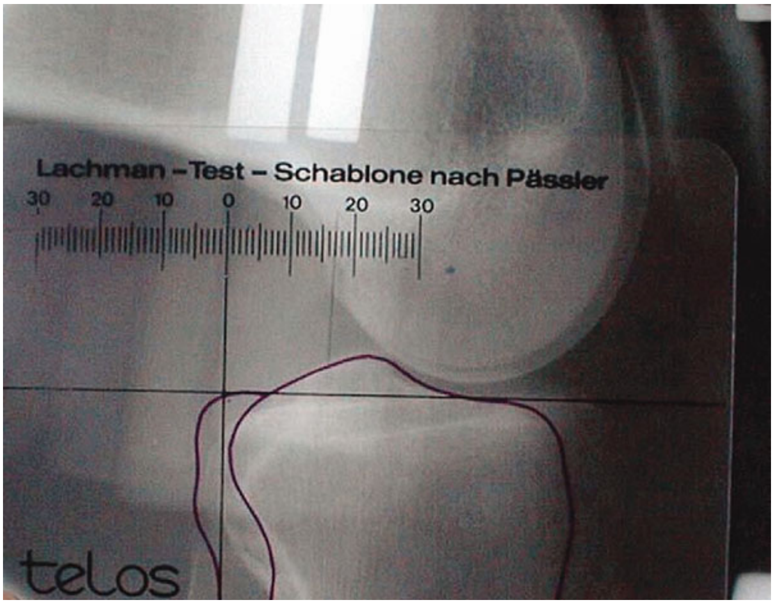


**Fig. 6.4** The Telos stress X-ray with the measuring template

## 6.9 Posterior Stress

The method of measurement with the Telos device to perform a posterior stress X-ray. The patient is laid on the radiolucent table in the lateral decubitus position, and the knee is positioned at 90° of flexion inside the Telos device (see Fig. 6.3). The knee must be in neutral rotation. A 15-kPa force is exerted on the anterior tibial tubercle, and an X-ray is taken. The knee must be positioned in a true lateral position, which should be reflected in the radiograph.

Measurement of displacement is performed by using the template, aligning the inferior horizontal line along the tibial plateau. The perpendicular "zero" line is then lined up with the posterior border of the plateau. The measurement of displacement is then made in mm between the posterior border of the tibial plateau and the posterior border of femoral condyles.

The degree of posterior displacement is measured with a template on the lateral stress X-ray (Fig. 6.4). In this example the posterior displacement is 17 mm.

The difficulties with this method are:

- It is essential to have a true lateral X-ray with the femoral condyles overlapping as in the above picture.
- The template must be accurately positioned to reproduce the same measurement each time.

One of the most significant challenges with the Telos system is ensuring standardized measurement. It has been shown, though, that using a strict standardized protocol does produce reliable and reproducible measurements [9].

A recent study examing the Telos device in more than 1,000 patients over 12 years found it to be very reliable and effective at diagnosing posterior laxity [10]. They found that a measurement of greater than 8 mm of posterior displacement was very sensitive for complete PCL rupture, while a measurement of greater than 12 mm was indicative of injury to secondary supporting structures as well.

### 6.9.1 Anterior Stress

The Telos system has not been shown to be as helpful in testing for anterior laxity. An anterior displacement of more than 7 mm has been shown to be abnormal, with a false-negative rate of 12% [11]. The patient and device positioning for anterior stress are essentially identical to the posterior stress, with the position reversed.

### 6.9.2 Advantages

- Accurate measurement of the posterior displacement with a template.

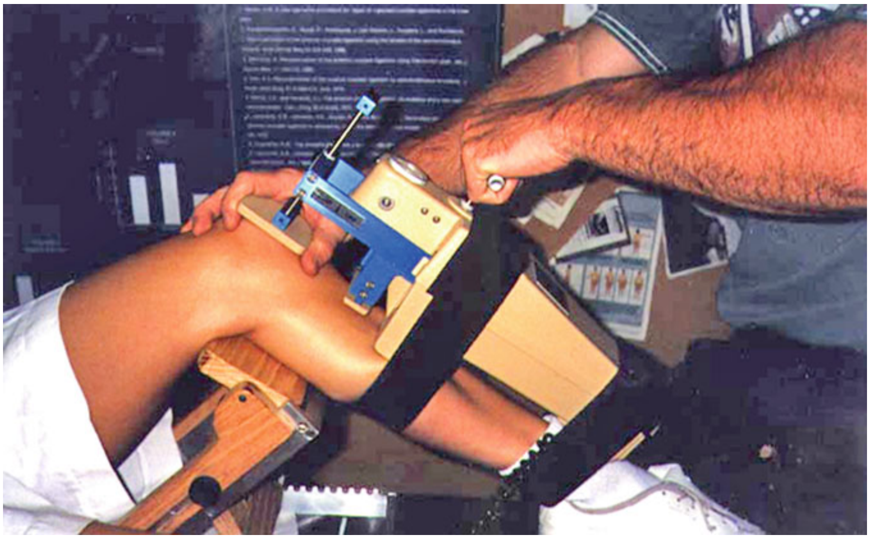


**Fig. 6.5** This photo shows the KT-1000 device to measure the posterior displacement

### *6.9.3 Disadvantages*

- The use of X-rays/radiation.
- The radiological technician must be trained in the correct use of the device.
- The Telos device is expensive.

#### 6.9.3.1 Arthrometer

KT-1000/2000

The KT-1000 and KT-2000 (the KT-2000 is essentially the same arthrometer but with an added graphic plotting interface) are arthrometers that measure anterior-posterior tibiofemoral translation (i.e., translation in the sagittal plane).

## 6.10 Anterior

The KT-1000 (MEDMetric Corp., San Diego, CA) has become the standard for the measurement of anterior cruciate ligament laxity. Starting from its introduction in the early 1980s, it has continued to be found to accurately and reliably measure the anterior translation of the tibia on the femur [12]. It has proven to have strong reliability, with good inter- and intrarater performance [13]. It has recently performed equally compared with intraoperative computer-assisted surgery/navigation [14]. The device is used with the patient supine and a thigh support platform placed under the thighs and foot support platform under the feet. This puts the knees at approximately 25–35° flexion, appropriate for an instrumented Lachman test for the ACL. The arthrometer is placed securely on the knee and lower leg, and the patella is stabilized while the force handle is pulled to achieve translation readings (Fig. 6.5). The maximum manual test has been found to have the highest diagnostic value for the ACL [15].

The best results with the KT-1000 are still clearly had when comparing within the same patient and when the same examiner performs the exam. Though the arthrometer is simple to use, there is still a learning curve associated.

## 6.11 Posterior

The KT-1000 has not, however, achieved the same level of acceptance for the posterior cruciate ligament. Daniel [16] first described the method of measuring the posterior laxity by determining the quadriceps neutral point (see Fig. 6.5).

The principle of the measurement as described by Daniel is to determine the 4 levels of anterior to posterior motion:

- Anterior
- Quadriceps neutral
- Posterior sag
- Posterior displacement

In the photo above, the patient is contracting the quadriceps to bring the tibial forward to the "quadriceps neutral" position.

The posterior motion from this point to the posterior sag and then the posterior displacement with 20 pounds of posterior force are measured. The total amount of posterior motion is determined when these 2 are added.

In my experience, it is difficult to get the patient to contract his quadriceps to bring the tibia fully forward to the neutral position. This amount of forward displacement is often underestimated. We presented a study to the PCL study group in 1995, comparing the *KT* value against the stress X-ray. The results were:

When the mm of displacement of the *KT* is expressed as a percentage of the Telos:
>10 mm of posterior displacement—the *KT* is 65% of the Telos
<10 mm of posterior displacement—The *KT* is 72% of the Telos

The message is that the KT measurement is less than that which is measured with the stress X-ray and that this difference is more marked when the displacement is greater than 10 mm. The PCL-deficient knee should be measured with the stress X-ray.

This underestimation of displacement by the KT-1000 was also confirmed by Dr. Frank Noyes et al. [17], who found that stress radiography was superior to both arthrometer and clinical posterior drawer testing and that eight millimeters of posterior displacement was the cutoff indicating complete PCL rupture.

This study confirms that the measurement of the posterior displacement is more accurate with the stress X-ray, especially in those cases that are greater than 10 mm.

Another study by Harner et al. [18] compared a novice and an experienced user of the KT-1000 device and found that the device was a moderately reliable tool to evaluate PCL laxity. This was a small group of patients, most who had less than 10 mm of laxity.

### 6.11.1 Advantages

- Widely used and accepted method of measurement of anterior displacement in the ACL-deficient knee
- Widely available

### 6.11.2 Disadvantages

- Underestimates posterior displacement, especially when measuring more than 10 mm

### 6.11.3 Knee Laxity Tester

The use of the Knee Laxity Tester (KLT) arthrometer (Orthopedic Systems Inc., Hayward CA) or Stryker Knee Laxity Tester (Stryker, Inc., Kalamazoo, MI) likely hits its peak in the 1990s, and though the arthrometer is no longer available, it is still used by some and was highly tested. Like the KT-1000, the KLT measures tibiofemoral translation in the sagittal plane.

## 6.12 Anterior

The technique is similar to the KT-1000 and has produced similar results [19].

## 6.13 Posterior

The measurement of posterior laxity has been described by Cannon [20]. The patient is positioned sitting with the knee flexed to 90° over the end of a table. The patient actively contracts the quadriceps. At this quads neutral point, the instrument is set to 0. The tibia is then displaced posteriorly with a 20- and 40-pound force. The displacements are recorded. The authors [21] found that the arthrometric measurements correlated well with the clinical examination. The arthrometer was also able to detect subtle grade 1 injuries.

### *6.13.1 Advantages*

- The knee is held in the 90° position and it may be easier for the patient to perform the quads active test.

### *6.13.2 Disadvantages*

- The instrument is not widely available.
- The 71° position was determined by Daniel to be the optimum position to measure the quads active position.

#### 6.13.2.1 Rotationometer/Laxiometer

The Lars Rotational Laxiometer (LARS, Dijon France) was developed specifically to measure the degree of rotation of the tibia relative to the femur. It is a simple device which can be strapped externally to the subjects' tibia and measures rotation in a noninvasive manner (Fig. 6.6). Objective measurement of external rotation of the tibia at 30 and 90° of knee flexion provides an indication of clinical posterolateral corner (PLC) laxity.

This device has been validated to measure the normal variation of tibial rotation [22], and baseline measurements of the degree of normal external rotation of the tibia at 30° and 90° were established.

Three authors each examined 30 asymptomatic patients to determine the side-to-side difference. At 90°, the side-to-side difference was 4.4° (range 3.7–5.1) and at 30°, the difference was 5.5° (range 4.7–6.3).

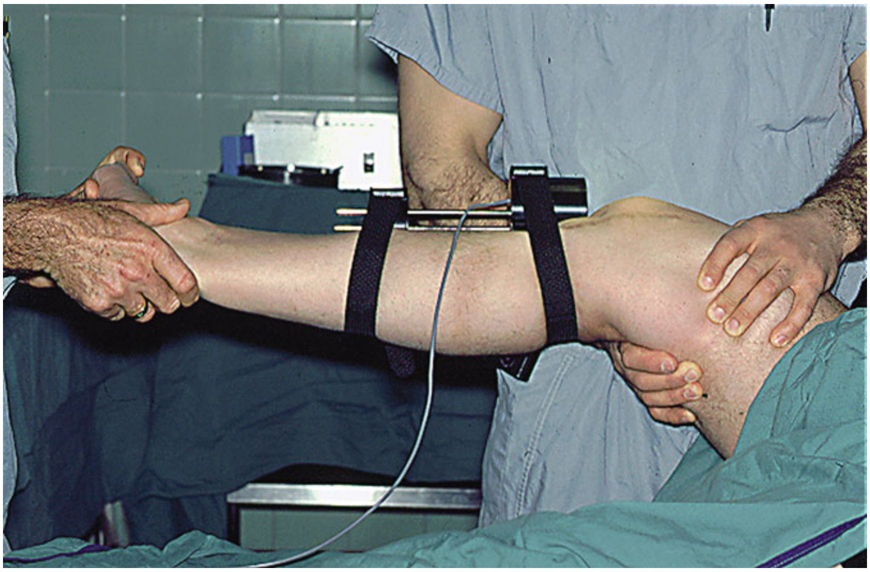


**Fig. 6.6** The rotational laxiometer used to measure the external rotation of the tibia at 30–90° of knee flexion

This means that any measurement above this number is abnormal. This gives us a baseline to determine who needs to have a posterolateral reconstruction. It also gives us a measurement device to assess reconstructed knees postoperatively. One caveat to the use of the rotational laxiometer, as pointed out by the validating authors [22], is that the device is not able to measure the moment applied by the observer during testing or to cancel out the coupled motion of the femur.

### *6.13.3 Advantages*

- Measures external/internal tibial rotation

### *6.13.4 Disadvantages*

- The device requires two people to operate.
- The device is expensive and not widely available.

#### 6.13.4.1 Computer-Assisted Navigation

There has been great progress made in recent years in the area of computer-assisted surgery (CAS). The role of computer navigation in soft-tissue knee reconstruction surgery has been largely focused on accurate tunnel and fixation positioning. However, with increasingly accurate mapping and navigation technology, many of the CAS systems, such as the OrthoPilot system (Aesculap Implant Systems, Center Valley, PA), are now able to intraoperatively measure knee kinematics in multiple planes.

With growing interest in CAS, there have been a number of groups studying various systems' accuracy in mapping and plotting the kinematics of the knee. Results thus far have been very promising, with accuracy measured in most to be within 1 mm or 1–2° [23–25]. A recent study comparing computer navigation to the KT-1000 in the ACL-deficient knee found them to have comparable results [14]. The keys to accurate measurement with CAS are fluency with program (each system has its own learning curve associated), accurate bony markers placed for navigation, and a properly calibrated system.

The future of CAS is quite promising, and it will allow for improved accuracy and reproducibility in the measurement of laxity in the knee in all planes. This has especially great promise in measuring immediate pre- and postreconstruction kinematic changes in complex multiligament reconstructions. However, there are still a number hurdles for computer navigation to overcome. The systems are still very costly, and most centers will still be unlikely to have access to them. They require appropriate training and support. Also, computer navigation is an important tool for instrumented measurement but will not negate the need for other instrumented measures, as it can only be used in the operative setting. At this point, computer navigation does not have a significant role to play in preoperative diagnosis or in follow-up.

### *6.13.5 Advantages*

- Accuracy
- Immediate postreconstruction measurement

### *6.13.6 Disadvantages*

- Costly
- Facility availability
- Only able to use in OR setting

## 6.14 Future Directions

The instrumented measurement of knees is currently in the midst of undergoing somewhat of a renaissance. The development of arthrometers and measurement tools first became a hot topic in the early 1980s, and a number of tools (both successful and unsuccessful) were designed and produced. The KT-1000 arthrometer alone has now been used in well over 500 published peer-reviewed studies. As our soft-tissue surgeries and tools have progressed over recent years, so too has our interest in accurate and objective measurements. A better understanding of the soft-tissue anatomy and kinematics of the knee, the advent of anatomic ligament reconstruction as well as double-bundle reconstructions, and the wider introduction and adoption of computer navigation have all led to an increased interest and need for objective and reproducible measures. A number of recent "Current Concepts" reviews have highlighted the current state of instrumented measurement, the most recent outcomes and evidence, and also some of the new tools [26, 27].

One of the key areas of growth in measurement is in the area rotational laxity. Rotation has proven itself to be more difficult to reliably assess than linear translation and displacement, and its clinical importance over the long term is still being investigated. There are several recent tools that have been developed by respected research groups attempting to better characterize and define ligamentous laxity [27–30]. Most of these systems incorporate electromagnetic markers which are placed on surface landmarks on the lower extremity as well as some form of standardized force and vectors in rotation and translation. While these systems will be unlikely to play a role in the average clinician's practice, they will help to continue to shed light on the complex kinematics of the knee and help us to better understand the various soft-tissue deficiencies that must be addressed in the multiligament-injured knee and their relative importance.

## 6.15 Conclusion

The cornerstone of assessment of the multiple-ligament-injured knee is the clinical exam. The clinical exam along with advanced soft-tissue imaging provides much of the information necessary for initial assessment and management. Instrumented measurement can provide a useful adjunct and allows for more objective clinical testing and more reliable comparators that can be used to compare within a patient or allow for standardized presentation of clinical findings and results. Familiarity and practice with the instrumented measure being used are integral to gathering reproducible measurements.

The choice instrumented measurement systems should be based on both the ligaments being tested and the resources available. In the setting of CAS, very accurate measurements can be taken intraoperatively both pre- and postreconstruction. Unfortunately, these systems are still not widely available, are expensive to purchase, and do not create measurements that are interchangeable with other instrumented means. The use of computer navigation for the purpose of instrumented measurement is still in its infancy.

The KT-1000 arthrometer is widely available and has proven reliable and accurate in measurement of the ACL but is not nearly as effective at gauging posterior laxity. The KT-1000 is the tool of choice for objectively assessing the ACL. The posterior structures, the PCL and PLC, are best assessed using the Telos stress radiography system. However, the system's cost and limited clinical adoption make it an unlikely option for many clinicians. The Lars Rotational Laxiometer can be an objective adjunct to a clinical exam of tibiofemoral rotation and is of benefit in assessing and following posterolateral corner injuries. Recent renewed interest in stress radiography has produced a number of comparison trials of stress radiography, and thus far, it appears that kneeling stress radiographs show great promise as a reliable measure of posterior laxity.

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# Chapter 7
# MRI Imaging in the Multiple-Ligament-Injured Knee

**W. James Malone, Faiz I. Syed, and Peter R. Bolos**

## 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.

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## 7.2 Central Stabilizers: Normal Anatomy and Injury

The ACL must be evaluated in terms of its signal intensity and morphology. The sagittal plane of imaging is often utilized as the sequence, which lays out 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. 7.1a, b). 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 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 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 7.2a, b 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. 7.3a, b). This femoral avulsion type of tear may not be well depicted in the sagittal plane and is increasingly 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. 7.4a, b). 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. 7.8a, b). 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. 7.9a, b). 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].

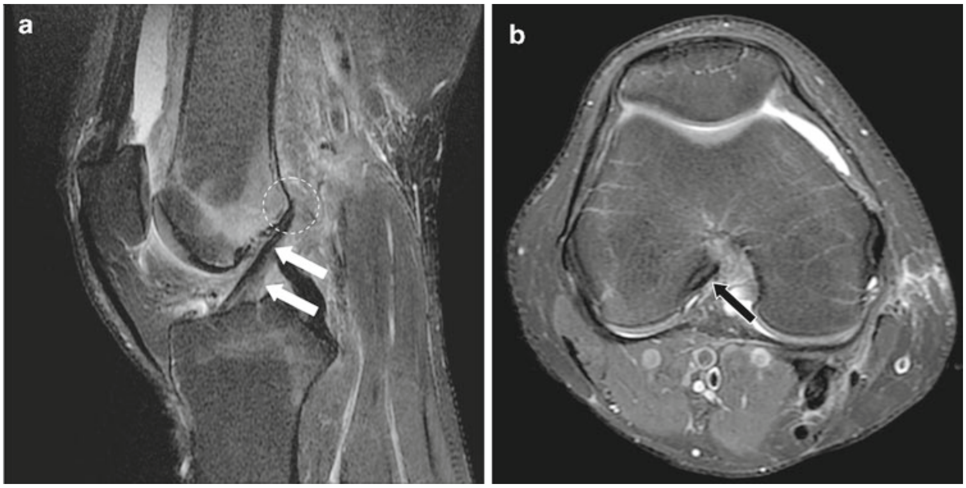


**Fig. 7.1** (**a**) and (**b**) Demonstrate the normal ACL on sagittal and axial T2 images, respectively. (**a**) Shows the taut, predominantly hypointense ACL (*white arrows*). Also in (**a**), note the normal appearance of the tibial attachment (*circle*). (**b**) Shows the normal appearance of the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

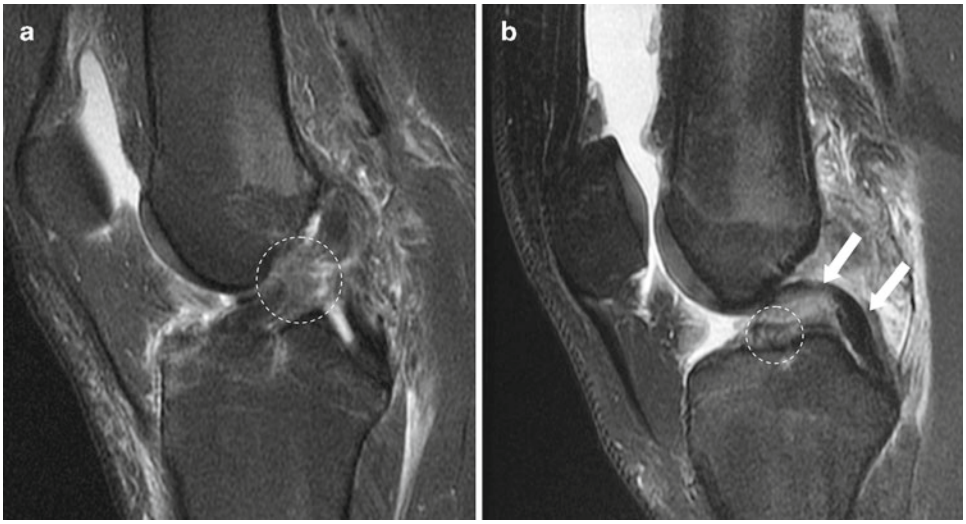


**Fig. 7.2** (**a**) and (**b**) Demonstrate ACL tears in two different patients. (**a**) Demonstrates a wavy ligament with midsubstance discontinuity (*circle*). In (**b**), only the remnant tibial stump of the ACL is visualized (*circle*). Note the normal PCL (*white arrows*)

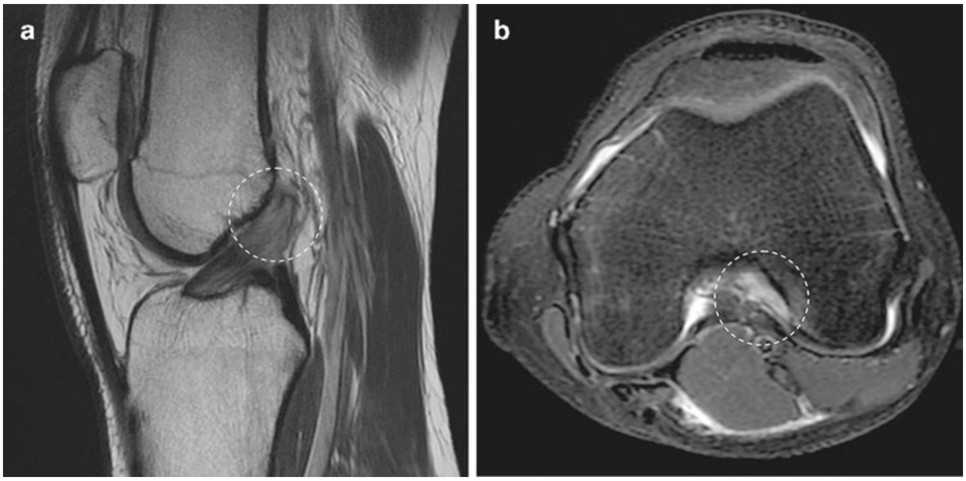


**Fig. 7.3** (**a**) and (**b**) are coronal PD and axial T2 images in a patient with arthroscopically proven femoral avulsion of the ACL. In (**a**), there is increased signal at the femoral attachment of the ACL and the attachment itself is nonvisualized (circle). In (**b**), the femoral attachment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

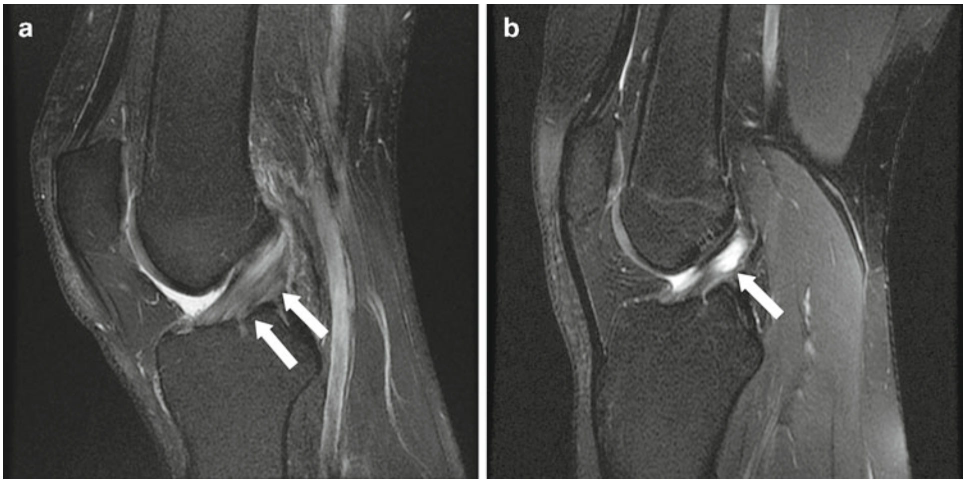


**Fig. 7.4** (**a**) and (**b**) Demonstrate ACL tear mimics. (**a**) Demonstrates an intact ACL with mild diffuse mucoid degeneration (*arrows*). In (**a**), ACL is thickened with T2 bright striations, but the slope is normal, there is no focal discontinuity, and the femoral attachment is intact. (**b**)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

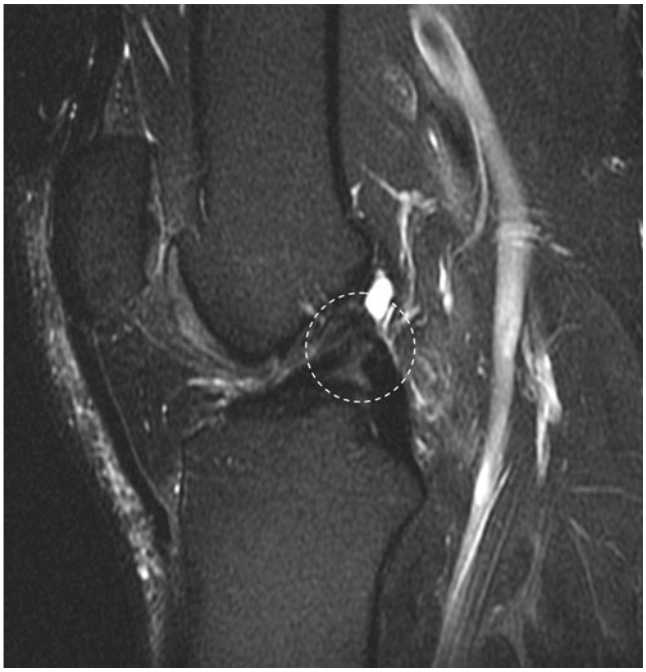


**Fig. 7.5** Demonstrates a previously torn ACL, which has subsequently scarred down to the PCL (*circle*). Findings were confirmed arthroscopically

**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*)

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

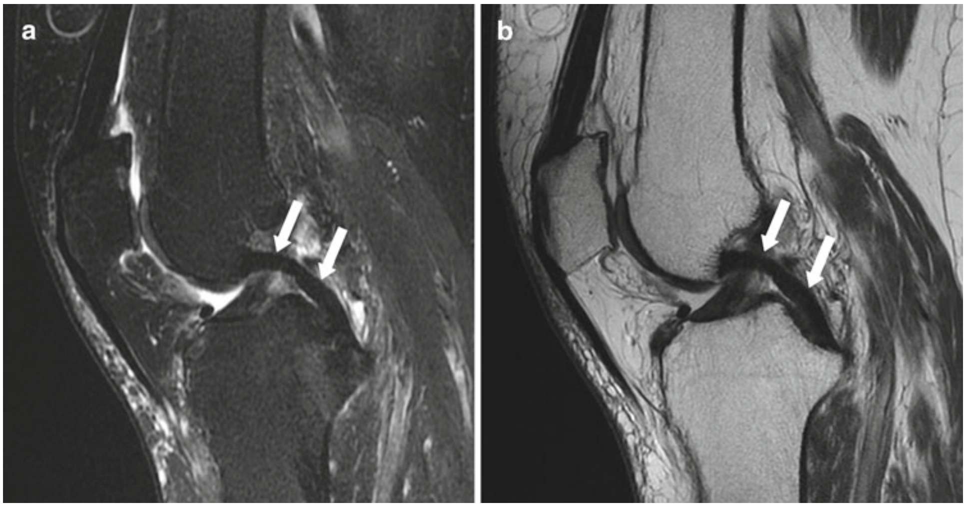


**Fig. 7.8** (**a**) and (**b**) Demonstrate the normal appearance of the PCL (*arrows*) on T2 and PD images, respectively. Note the normal curved appearance and the homogeneously low signal on both sequences

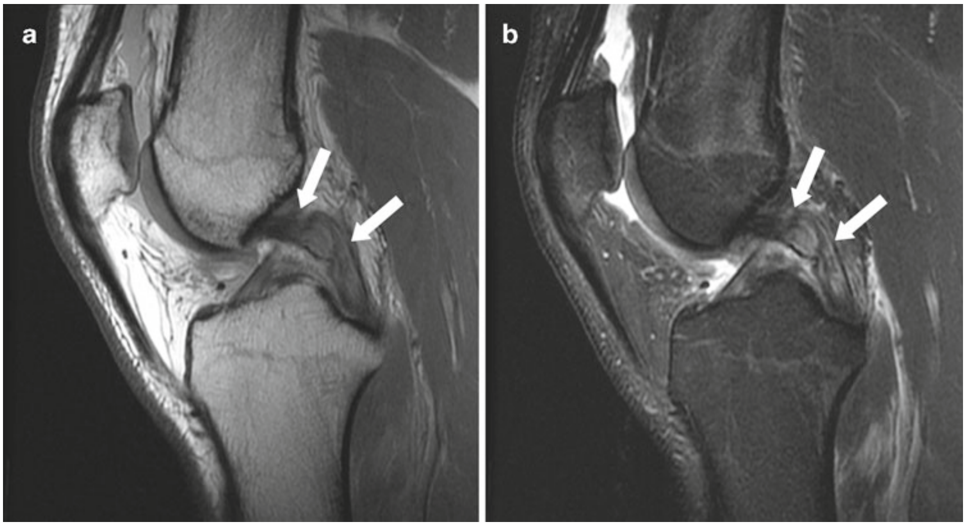


**Fig. 7.9** (**a**) and (**b**) are sagittal PD and T2 images demonstrating a torn PCL (*arrows*). The PCL is thickened and edematous but is not completely disrupted

## 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. 7.10a, b). This allows one to utilize the same signal, morphology, and orientation changes seen with native cruciate to diagnose ACL and PCL graft tears (Figs. 7.11a, b–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 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].

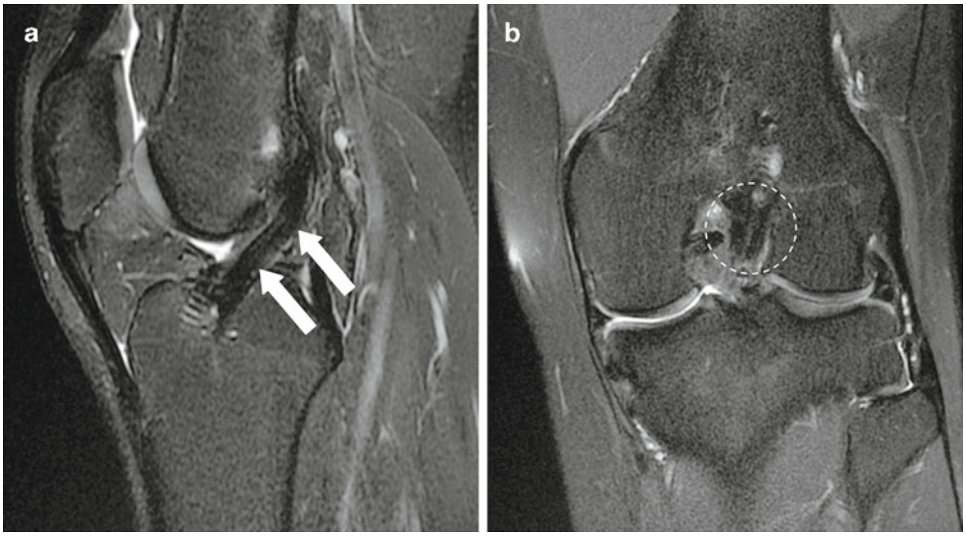


**Fig. 7.10** (**a**) and (**b**) are sagittal and coronal images showing an intact ACL graft. (**a**) shows the normal low intensity graft (*arrows*) with slope following Blumensaat's line. (**b**) demonstrates the two distinct bundles of the double-bundle graft (*circle*)

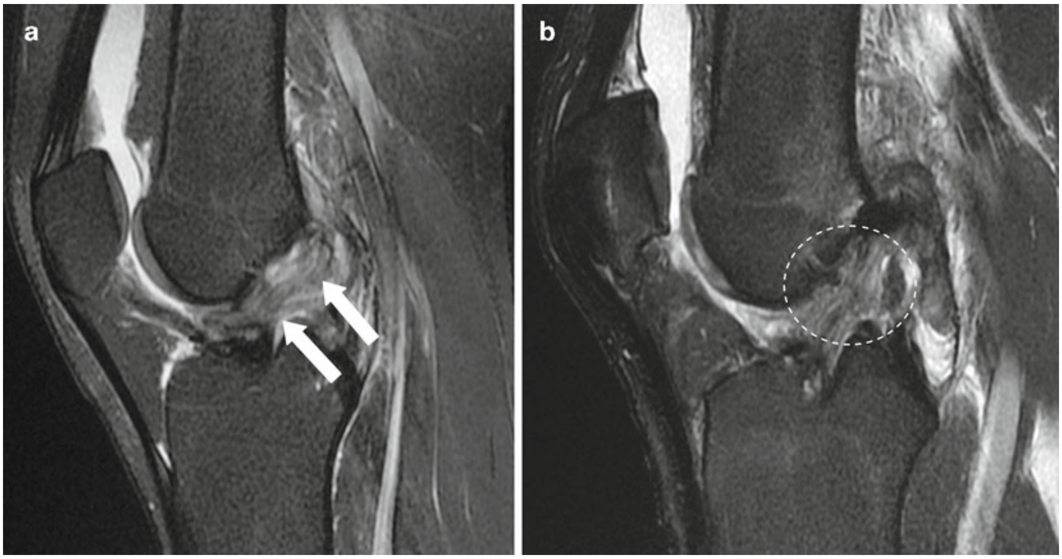


**Fig. 7.11** (**a**) and (**b**) Demonstrate two different patients with midsubstance ACL graft tears, as denoted by *arrows* and *circle*, respectively. Compare to normal graft in Fig. 7.10a

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

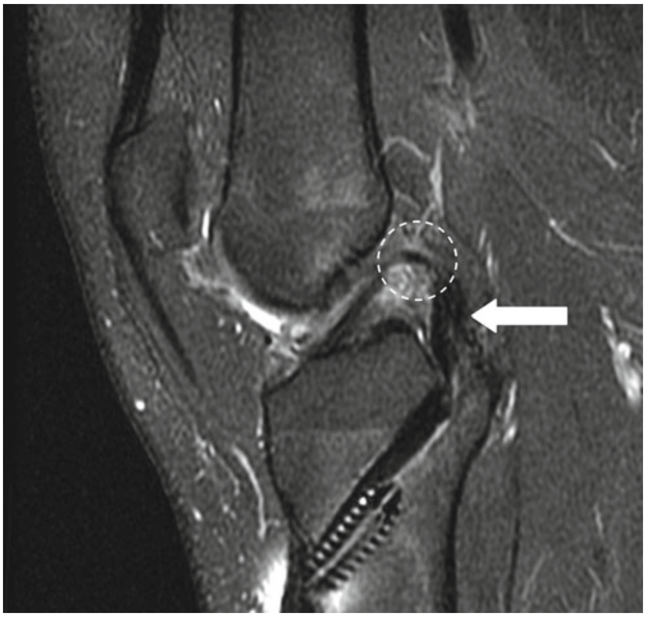


**Fig. 7.13** Shows a double-bundle PCL graft with single-bundle tear. The tear involves the more anterior bundle near the femoral attachment with an intact posterior bundle (*circle*). Compare the attenuated PCL graft proximally at site of tear (*circle*) to the normal graft thickness distally where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

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].

## 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 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), respectively. However, this antiquated terminology undermines the complexity and importance of the individual structures. Recent improved understanding of the intricate anatomy and function of these 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 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

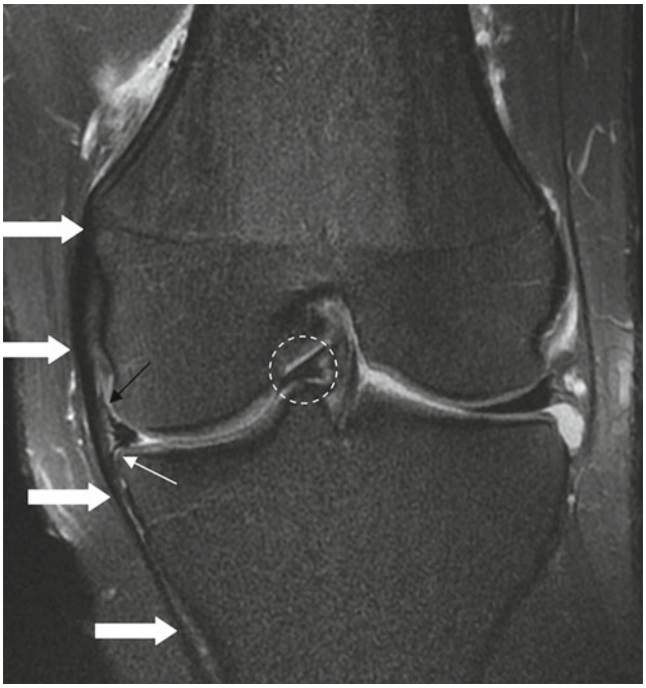


**Fig. 7.14** Shows the normal medial stabilizer anatomy in the middle third of the knee. Note the thick low signal superficial MCL (*thick white arrows*). The underlying deep MCL ligament has meniscofemoral (*thin black arrow*) and meniscotibial components (*thin white arrow*), which tether the meniscus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

**Fig. 7.15** Demonstrates 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

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].

## 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 7.16–7.21 show varying degrees of injuries to the medial and posteromedial corner stabilizers.

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.

**Fig. 7.16** Demonstrates 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

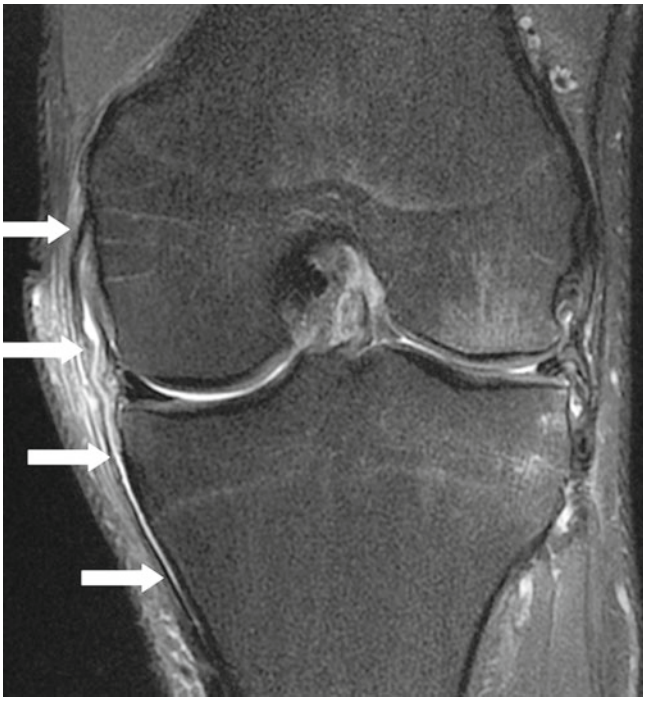


**Fig. 7.17** Demonstrates a grade 2 injury to the medial stabilizers. The superficial MCL (*white arrows*) is mildly wavy and demonstrates signal within and surrounding the superficial and deep components. No focal disruption is seen

**Fig. 7.18** Demonstrates 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)

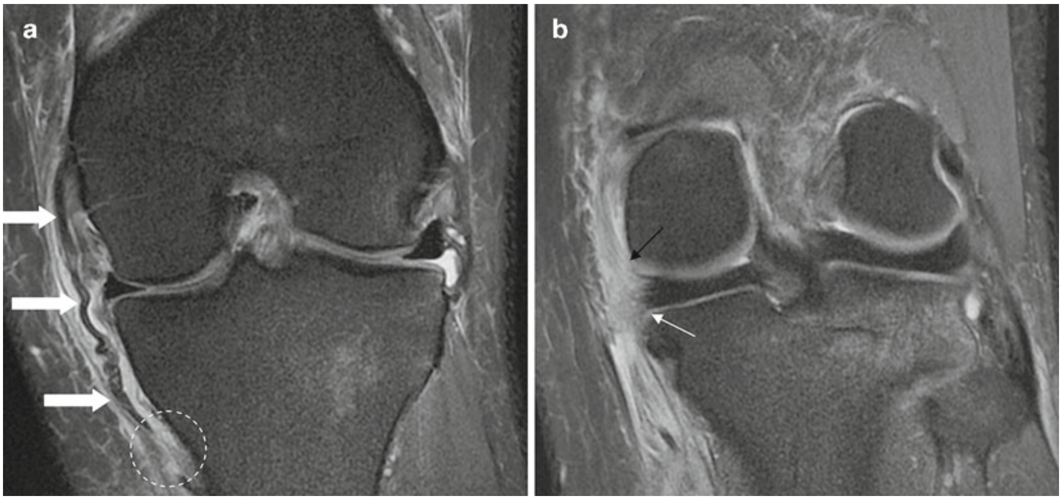


**Fig. 7.19** (**a**) and (**b**) Demonstrate a grade 3 injury to the medial stabilizers and posteromedial stabilizers (POL). (**a**) Shows a wavy proximal superficial MCL (*large white arrows*) with focal discontinuity at the tibial attachment (*white circle*). The deep MCL is nonvisualized and was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

**Fig. 7.20** Demonstrates 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*)

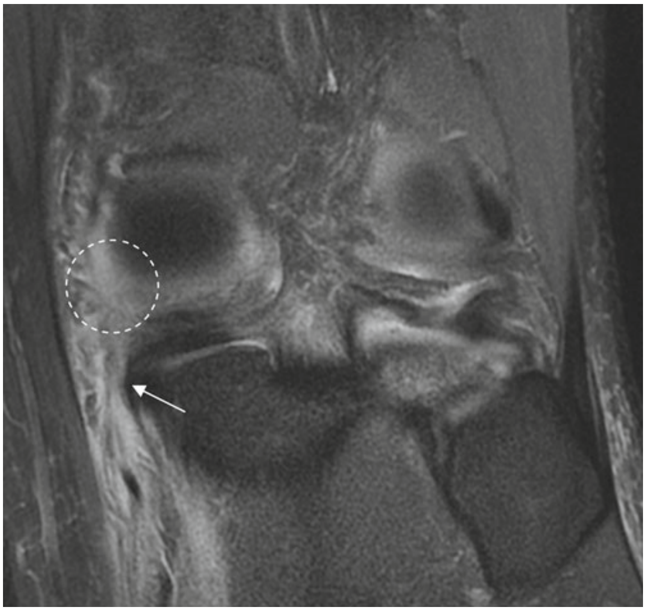


**Fig. 7.21** Demonstrates a high grade injury to the meniscofemoral portion of the POL (*circle*). The meniscotibial portion of the POL is intact (*white arrow*)

## 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. Prior to discussing MRI findings, two important X-ray signs of PLC injury should

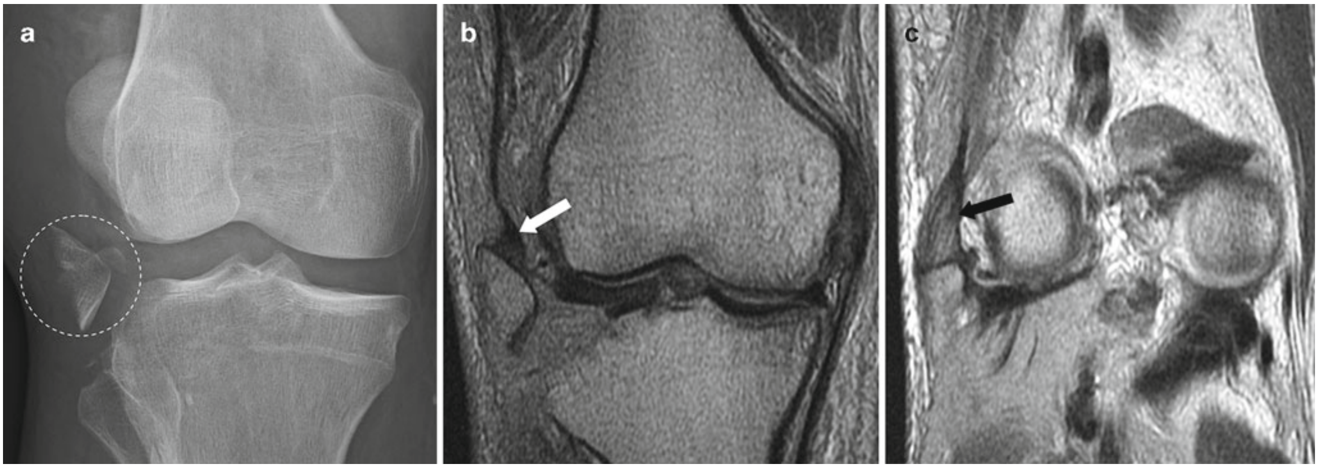


**Fig. 7.22** (**a**)–(**c**) is an X-ray with MRI correlation demonstrating a lateral/posterolateral corner injury. (**a**) is an AP radiograph, which shows two superimposed avulsed bone fragments from the fibular head (*circle*). The smaller and more posterior and medial of the two fragments is the 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*)

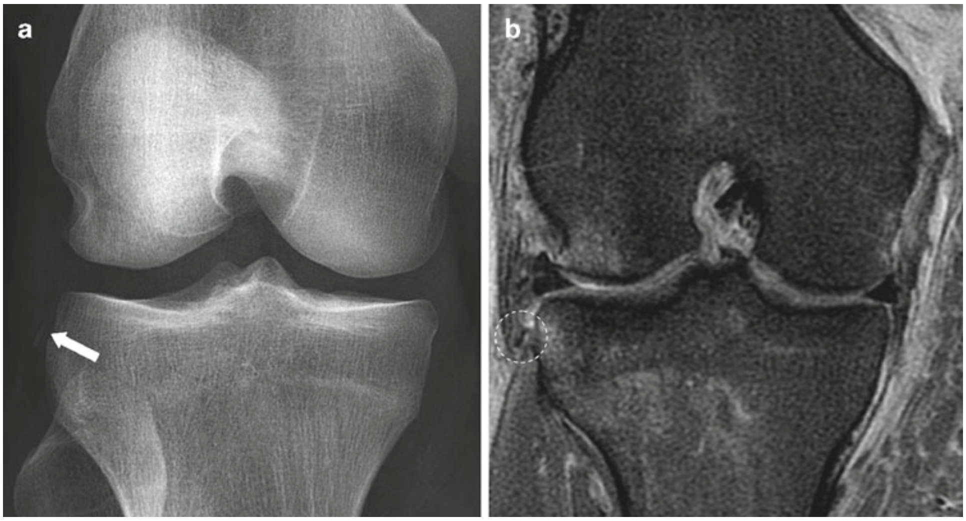


**Fig. 7.23** (**a**) and (**b**) are X-ray with corresponding MRI demonstrating the Segond fracture. (**a**) demonstrates the lateral capsular avulsion fracture (*white arrow*). (**b**) Demonstrates how easily one could miss this small linear low signal sliver of cortical bone on MRI (*white circle*)

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. 7.22a–c). 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 avulsed cortex is even more inconspicuous on MRI (Fig. 7.23a, b).

### 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 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 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

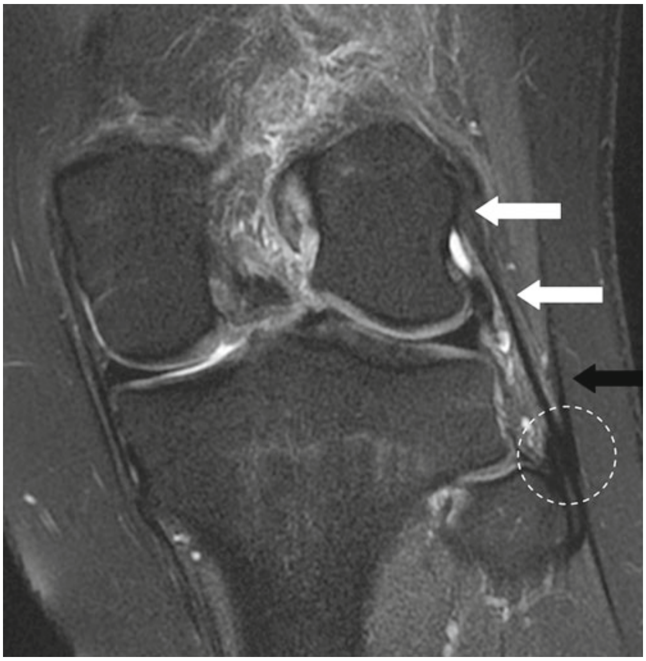


**Fig. 7.24** Is a coronal MRI demonstrating normal posterolateral corner anatomy. The white arrow demonstrates the normal appearance of the fibular collateral ligament (FCL) (*white arrows*) from its femoral attachment to its fibular attachment. The conjoined attachment (*circle*) with the partially 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** Demonstrates 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** Demonstrates 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*)

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. 7.30–7.34). Like the pivot shift contusion pattern with ACL tear, fibular head edema is highly suggestive of PLC

**Fig. 7.27** Demonstrates 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*)

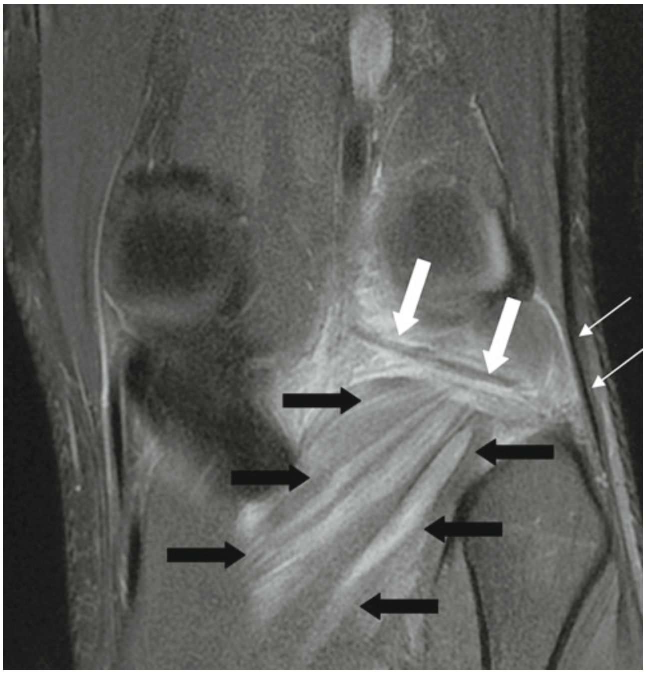


**Fig. 7.28** Demonstrates the normal extra-articular portion of the popliteus tendon (*black arrows*) and the intact and nearly horizontally oriented popliteofibular ligament (*white arrows*)

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 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

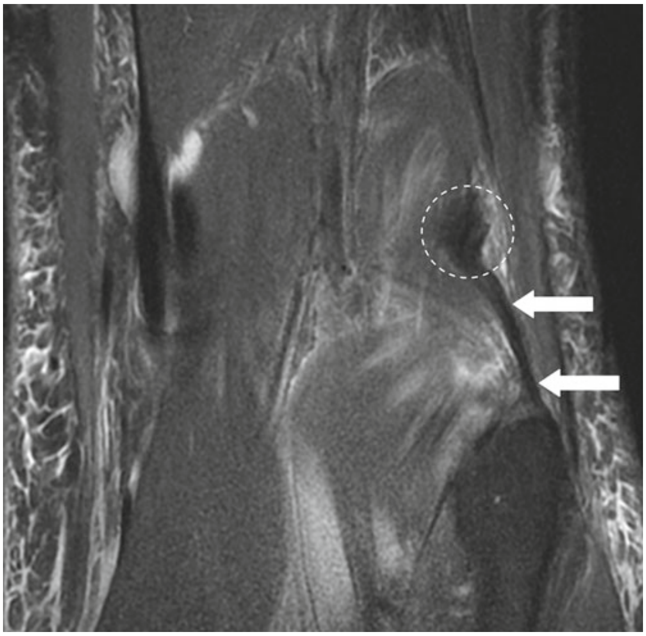


**Fig. 7.29** Demonstrates the normal fabellofibular ligament (*white arrows*) and nonossified fabella (*circle*)

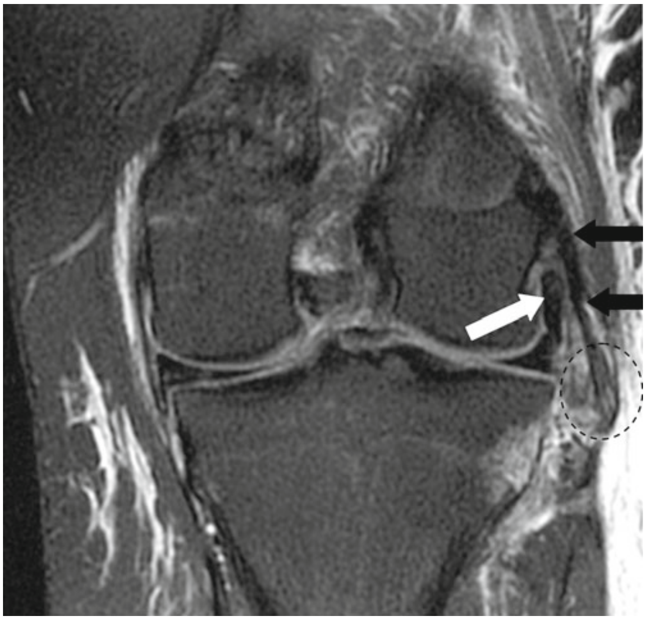
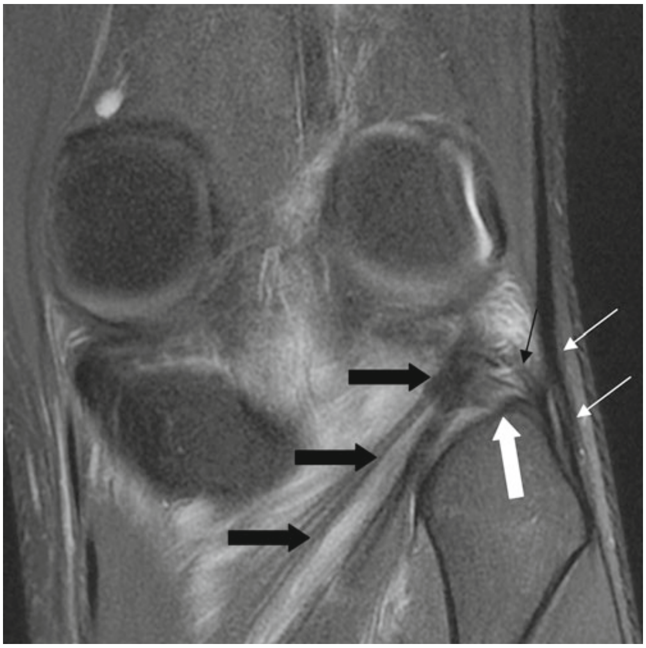


**Fig. 7.30** Demonstrates an intact proximal FCL (*black arrows*). The distal FCL attachment is completely torn and retracted proximally (*black circle*). Note adjacent popliteus tendon (*white arrow*), which was intact on the study

from injury versus absence due to 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.

**Fig. 7.31** Demonstrates 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** Demonstrates 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



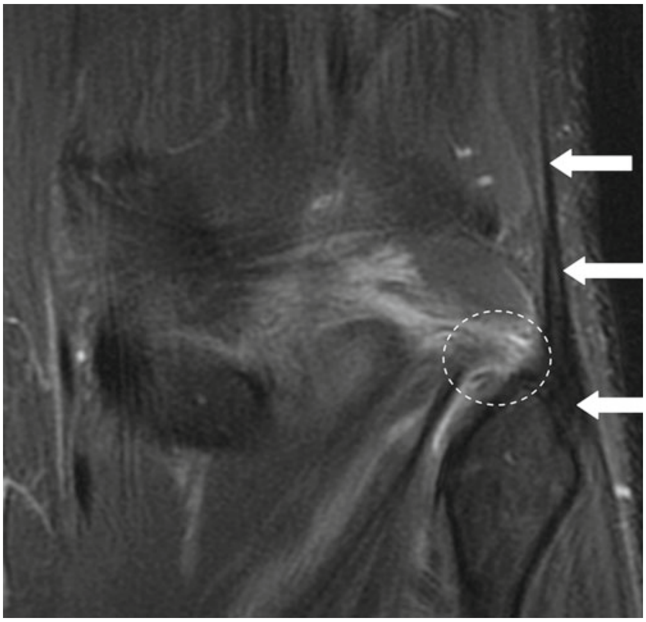


**Fig. 7.33** Demonstrates a grade 2–3 injury to the popliteofibular ligament (*circled*). The conjoined tendon insertion is intact (*white arrows*)

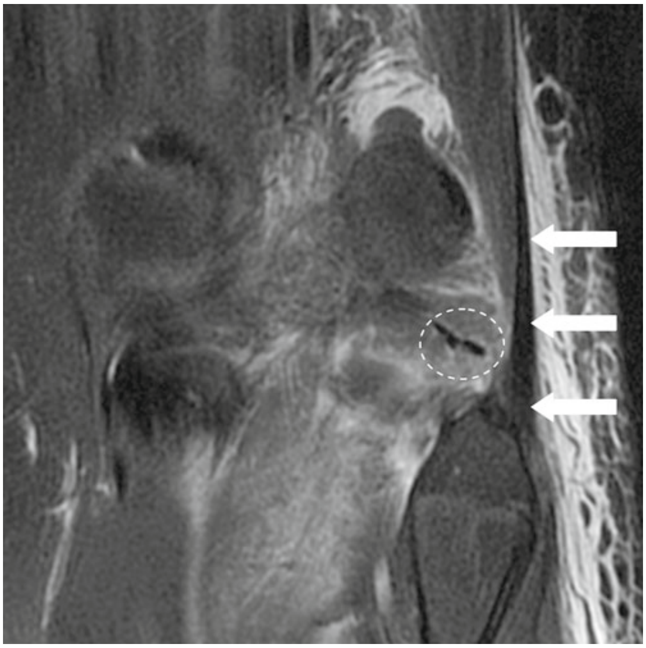


**Fig. 7.34** Demonstrates a torn and proximally retracted popliteofibular ligament (*circle*) and intact conjoined tendon insertion (*white arrows*)

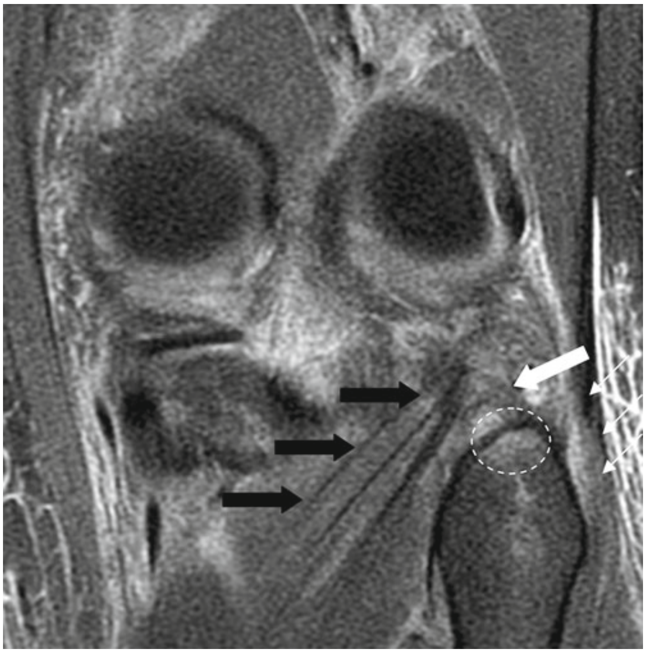


**Fig. 7.35** Demonstrates fibular head edema at the popliteofibular ligament attachment (*circle*). There is a grade 2 injury to the popliteofibular ligament (*white arrow*) and a grade 3 injury to the conjoined tendon insertion (*thin white arrows*). The extra-articular popliteus at the myotendinous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

## 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

# Chapter 8
# Nonoperative Treatment of the Dislocated Knee

**John David Beck, Kaan Irgit, and John T. Riehl**

## 8.1 Introduction

The term knee dislocation is used in an attempt to group a vast array of injuries to the knee involving two or more collateral or cruciate ligaments [1]. By definition a dislocation is a complete separation or disruption of two articulating bony surfaces. In joints other than the knee, the above definition is sufficient to define an injury pattern. However, many patients with knee dislocations do not present with a frankly dislocated knee, instead they present with knee pain after trauma. Consequently, any patient with knee pain with at least two ligament instabilities should be treated as an occult dislocation, as the knee may have spontaneously reduced prior to presentation. Therefore, the definition of knee dislocation must be more inclusive than other joints. For the purposes of this chapter a knee dislocation will encompass both multi-ligament knee injury and radiographic dislocation.

Historically, knee dislocations have been rare but serious traumatic injuries that require prompt diagnosis and treatment. This injury makes up roughly 1 in 100,000 hospital admissions [2]. Studies have reported incidence ranging from 0.001 to 0.013 % [3, 4] although the true incidence is higher as many dislocations spontaneously reduce in the field. Over the last century both the incidence of knee dislocation and the mechanism of injury have changed. From 1911 to 1960 only 14 knee dislocations were found in a review of two million admissions at the Mayo Clinic [5]. Over the last 60 years the number of people surviving high-speed motor vehicle accidents, secondary to improved automotive safety features, has led to an enlarged population of multi-trauma patients with knee dislocations. In addition, a new mechanism for knee dislocations has become prevalent with the obesity epidemic in America. Hangio et al. reported on 7 cases of spontaneous knee dislocations while standing in patients with morbid obesity [6]. Body mass index of greater than 35 was found to be a specific risk factor for spontaneous knee dislocation with associated popliteal artery injury [7]. Even with the improvements in trauma care and the rise in morbid obesity, knee dislocations continue to be rare injuries. As such, research populations are composed of mixed pathology and varied treatment protocols. With modern technology, including MRI and arthroscopy, outcome studies have favored operative intervention for patients with knee dislocations. To follow are the historic treatment and outcomes of knee dislocations that drove the treatment pendulum from primarily closed treatment or amputation to present day reconstruction.

## 8.2 Associated Injuries

In order to fully understand the progression of the standard of care from nonoperative treatment to modern reconstruction, one must understand that a knee dislocation is not an isolated injury. A true understanding of the associated pathology in knee dislocations is essential to proper treatment and improved outcomes in this mixed patient population.

A dislocation of the knee can present with varying combinations of ligamentous involvement. Disruption of both the anterior cruciate ligament (ACL) and the posterior cruciate ligament (PCL) is common with or without associated injury to

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the collateral ligaments and the posterolateral or posteromedial corners. Many authors report that frank dislocations require disruption of at least three of the four major ligaments [8, 9], although numerous papers present reports of knee dislocations with less than three of the major ligaments disrupted [10–12]. In a study by Fanelli et al. 19 of 20 patients had disruption of both the ACL and the PCL with associated posterolateral corner (PLC) or MCL injury [9]. The variation possibly places an emphasis on a detailed, meticulous ligamentous examination to ensure an accurate diagnosis is made. As MRI resolution continues to improve, it has become the gold standard for imaging in the setting of acute knee dislocation. A study by Bui et al. compared operative findings with preoperative MRI in 20 patients with knee dislocation to assess the accuracy of MRI. They found four false-positive interpretations in which the ligament was reported as a complete tear and was found to be partially torn or healed at the time of surgery. They also found two false negatives; both had meniscus tears not present on MRI [13]. A similar study by Twaddle et al. reports that following knee dislocation MRI could predict soft tissue injury with 85–100 % accuracy [14].

The most devastating condition associated with knee dislocations is injury to the popliteal artery. At the time of knee dislocation, the popliteal artery is susceptible to injury because it is tethered proximally by the adductor hiatus and distally by the fascial arch over the proximal soleus [15]. The incidence of vascular injury in the literature varies from 16 to 64 % with pathology ranging from contusion to intimal tear to complete transection [3, 5]. This injury must be identified and treated emergently as history has shown that the collateral circulation provided by the genicular arteries is insufficient to support a viable limb. In 1946, DeBakey and Simone reviewed 2,471 popliteal artery injuries during WWII and found that 72.5 % of soldiers that were not treated with revascularization eventually required amputation [16]. In later wars, Korea and Vietnam, when vascular repair was a more common practice, amputation rate following popliteal artery injury decreased to 32.5 % [17]. Further studies delineated that not only was repair paramount but the time to repair was important to limb salvage. In 1977, Green and Allen reported an 11 % amputation rate if vascular repair was performed within 6–8 h after popliteal artery injury and an 86 % amputation rate if repair was delayed for greater than 8 h [18]. Lower Extremity Assessment Project (LEAP) demonstrated that an average warm ischemia time for patients with amputation following knee dislocation was 7.25 h, while those not requiring amputation averaged 4.7 h, confirming the results of Green and Allen. The study concluded that prolonged warm ischemic time was the major factor in determining the need for amputation [19]. This reinforces the need for accurate and prompt diagnosis and treatment of vascular injuries for successful outcomes following knee dislocation. As presented above, poor results can be expected when popliteal artery injury is treated nonoperatively.

Nerve injuries are also common following acute knee dislocation. Both the tibial and the peroneal nerves are not as firmly fixed as the popliteal artery, but their anatomy still contributes to their propensity for injury. The peroneal nerve has a thin epineural tissue making it more susceptible to stretch injury; this compounded with its limited excursion (0.5 cm) place the peroneal nerve at risk for injury [20, 21]. The incidence of tibial or peroneal nerve palsies ranges from 10 to 50 % while peroneal nerve injury alone is reported in 5–50 % of cases [2, 3, 22–24]. Peroneal nerve palsies are most common when disruption of the PCL and PLC is present. In a study by Niall et al. 55 patients with peroneal nerve palsy were followed for nerve recovery. Twenty-one percent of patients had complete motor recovery, 29 % had partial motor recovery, and 50 % of patients had no useful motor or sensory function return [25]. Consequently, a detailed clinical examination is of utmost importance at the time of initial presentation. Patients with persistent nerve dysfunction can be treated with ankle-foot orthoses (AFO), nerve procedures (neurolysis, neurorrhaphy or nerve grafting), posterior tibial tendon transfer, or hindfoot fusion although results are varied. With or without surgical intervention prognosis for full recovery is poor, and this should be discussed with the patient during the early course of their evaluation and treatment.

As the ability to recognize and accurately diagnose specific ligament, nerve, and vascular injuries has evolved, so have the treatment modalities. Decades of patients treated prior to advances in arthroscopic techniques of ligament reconstruction provide evidence from which we can draw conclusions on the effectiveness of nonoperative treatment in the active population. What follows is a historical review of where the treatment of knee dislocations began, the results of nonsurgical treatment, and evidence that has driven current knee surgeons to advance the field of knee ligament reconstruction in the setting of multi-ligament knee injuries.

## 8.3 Nonoperative Treatment

In 1743 Lorenz Heister wrote about knee dislocations in his book *A General System of Surgery* stating “it is as difficult to make a perfect cure thereof without letting the bones join together, or leaving some stiffness in the knee” [26]. This statement embodies the assumption at that time that stability could be attained by nonoperative treatment at the expense of motion. This thinking leads to the initial treatment of knee dislocations with cast immobilization. In 1825, Sir Astley Cooper published his experience with knee dislocations in a chapter titled *A Treatise on Dislocations and Fractures of the Joints*. He found that in the majority of knee dislocations he was able to perform a closed reduction and treat the patient with cast immobilization. But in cases of irreducible dislocation or open dislocation he advocated immediate amputation [27]. This treatment algorithm was common among authors in the nineteenth century.

The mainstay of treatment in the twentieth century was cast immobilization for 4–6 weeks [28]. As the century progressed surgeons were beginning to recognize that patient's range of motion was limited following prolonged immobilization. In 1967, Myles evaluated 7 knee dislocations and found that the patient's final range of motion was inversely proportional to their duration of immobilization [29]. The limitation in motion drove surgeons to attempt open treatment. In 1963 Kennedy reported his results with 22 knee dislocations. In his series 12 patients were treated with immobilization, 5 with selected ligament reconstruction, and 5 with acute amputation. Using evaluation standards of the time, he reported good functional results in both the reconstructed and nonreconstructed groups [2].

## 8.4 Old Results

In 1969, Shields et al. presented 26 knee dislocations treated at Massachusetts General Hospital as the largest series of knee dislocations at that time. Nine patients (35 %) were treated nonoperatively with closed reduction and cast immobilization, and 12 (36 %) were treated with closed reduction and open ligament repair. Five patients required above-knee amputations. They found patients treated without repair needed longer hospital stays and longer-term physiotherapy and had worse functional results. They concluded that due to the severity of ligament disruption present during knee dislocation, healing would be impaired by closed means; thus, early open repair would be more beneficial [4].

In a study of 18 traumatic knee dislocations reported by Meyers and Harvey, results after treatment were classified according to patients' daily function. Results were classified as excellent if the patients returned to work or their previous level of activity, good if the patients had slight complaints during daily activities, fair when patients had difficulty with walking up stairs or running, and poor when patients were severely handicapped during daily activities. Their subjective scoring method, although difficult to clearly interpret, found that all patients treated nonoperatively had at least fair results. In fact, only 3 of 18 (16 %) patients with good or excellent results were all treated with early ligament repair [3].

Taylor and colleagues retrospectively reviewed 42 knee dislocations treated between 1954 and 1970. Twenty-six knees were treated conservatively by closed reduction and immobilization followed by various periods of physiotherapy. Taylor et al. evaluated knee function using the following outcome scale: good was a stable, painless knee with 90° of flexion or more; fair had slight instability on straining, no pain, and range of flexion from 60° to 90°; and poor was any knees that were unstable, painful, or with less than 60° of flexion [30]. After comparing the functional outcomes of their surgical and nonsurgical patients for stability, range of motion, and pain, they proposed conservative treatment was a favorable option in the absence of neurovascular complications [30]. They stressed the importance of shortening the immobilization period to reduce the risk of stiffness. Thomsen et al. used the same evaluation system in their small series of knee dislocations and found equal results between operated and nonoperated groups. However, they chose only the stable knees after the index reduction for the nonoperative treatment [23].

In the mid-1980s Sisto and Warren as well as Roman et al. each published their results on 20 knee dislocations. Sisto and Warren treated 5 patients nonoperatively, while 4 patients were treated nonoperatively in the latter study [8, 31]. In both studies details of conservative treatment and physiotherapy were not clear, but both recommended early surgical treatment of knee dislocations in the young active population.

## 8.5 Definition of Good

After the mid-1980s clinical and functional evaluation of ligament injuries changed and included more sophisticated and objective scoring systems such as the Lysholm scale, International Knee Documentation Committee (IKDC), Hospital for Special Surgery (HSS), and Tegner scoring scales as a standard in studies [32–35]. The Lysholm knee scoring scale evaluates limp, support, stair climbing, squatting, instability, catching and locking, pain, swelling, and bracing. The maximum attainable score is 100. A score of 95–100 denotes an excellent result, 84–94 a good result, 65–83 a fair result, and below 64 a poor result. In addition objective tests have also become more standardized and reproducible. Knee laxity, previously based on manual stressing alone, is now being measured by KT-1000 or KT-2000 arthrometer (MEDmetric, San Diego, CA). Thus, the definition of a "good result" has become more stringent over the last two decades.

Several changes in classification and treatment make it difficult to compare early knee dislocation data with current results. First, in many early studies fracture dislocations were included in study population [4]. Fracture dislocations are associated with significant joint instability and require extensive ligamentous reconstruction and stable fracture fixation. These injuries are a different entity than pure ligamentous dislocation, and combining their results confounds outcomes [36]. Secondly, early operative treatment included direct repair or reconstruction with primarily open techniques. In addition, reconstruction was limited to the ACL in most early studies. Current advancement in arthroscopic technique allows surgeons to reconstruct both the ACL and PCL with less soft tissue damage leading to less edema, hematoma, and stiffness. Also, the role of the PLC in knee stability and the importance of its repair have become well understood over time [37]. Another difference is in the approach to rehabilitation and the duration of immobilization. In 1743 Heister's stated that some loss of motion should be sacrificed for stability. This led many surgeons for years to use prolonged immobilization in the hope that scaring would lead to a more stable knee [26, 30, 38]. Current improvements in arthroscopic techniques and more secure ligament fixation methods have made it possible for more aggressive physical therapy programs. This has contributed to improved surgical results [39].

## 8.6 New Studies

Few studies compare the surgical and nonsurgical outcomes of knee dislocation in the last decade [33, 34, 38, 40, 41]. In 2002, in a series of 89 patients, Richter et al. retrospectively evaluated their surgical and nonsurgical treatment outcomes with traumatic knee dislocation [33]. Surgical repair or reconstruction of the cruciate ligaments was performed on 63 of 89 patients, and 26 patients were treated nonsurgically. The average follow-up was 8.2 years. They assessed the patients clinically with examination including KT-1000 arthrometer, radiographically with the Jager and Wirth osteoarthritis radiologic rating scale, and functionally with Lysholm Score, Tegner Score, and IKDC. The outcomes in the surgical group were better than the nonsurgical group. Best outcomes were seen in patients younger than 40 years old, with low energy injuries, who underwent reconstruction followed by functional rehabilitation. In this study functional rehabilitation was the most important prognostic factor for a good result. They concluded that surgery was requisite to gain sufficient stability for functional rehabilitation.

In a study by Rios et al. 26 patients were diagnosed with traumatic knee dislocations and 5 out of the 26 were treated nonoperatively. One patient refused to undergo operation, one developed infection overlying the surgical area, and three could not be operated on due to serious chest and head injuries. The follow-up assessment included the Lysholm, Marshall, and Meyers scoring systems; subjective questionnaire based on the IKDC evaluation; ROM; limping; and instability. They concluded that all patients treated nonoperatively had unsatisfactory results and all required secondary surgery to address treatment sequelae [41].

During a 6-year period, Wong et al. treated 29 knee dislocations of which 26 were available for follow-up [42]. Eleven of 26 patients (42.3 %) were treated with closed reduction and immobilization, casting, or external fixation, while 15 patients (57.7 %) were treated surgically. They compared the two groups in regard to range of motion, flexion contracture, stability, and functional outcomes assessed by IKDC. Flexion contracture was greater and range of motion was lower in the operative group compared to the nonoperative group, although only the latter was statistically significant. However, IKDC scores were higher in the operative group. They stated that although operative patients had increased stiffness these changes did not affect the overall functional outcome or final knee stability.

Plancher and Siliski retrospectively evaluated 48 knee dislocations with an average follow-up of 8.3 years [34]. Nineteen knees underwent nonsurgical treatment. The nonsurgical group was treated with cast immobilization ($n=10$), brace/splint immobilization ($n=5$), or external fixation ($n=5$). Thirty-two percent of patients in the nonsurgical group had treatment failures (four amputations, two arthrodeses) in this study. They used Lysholm and modified HSS scores to compare the functional outcomes. Patients treated nonoperatively had statistically significant decrease in knee flexion and increased pain at rest compared to the operative group. Anterior and medial stability was better in the operative group. Nonoperative patients experienced symptoms with activities of daily living two times more often than operative patients. Overall the operative group had better results on both Lysholm and modified HSS scoring scales [34].

## 8.7 Natural Course

Patients with high grade III PCL tears are known to develop medial compartment and patellofemoral chondrosis [43]. Torg et al. stated "specifically, those knees with PCL disruption without associated ligamentous laxity will probably remain symptom-free. However, when PCL disruption is associated with combined instabilities, a less than desirable functional result will probably occur" [44, 45]. Animal studies have shown that an ACL-deficient knee leads to arthritic changes in the knee [46]. In patients with chronic ACL tears, increased incidence of meniscal injury and chondral surface damage is well documented [47, 48].

Although Almekinders and Logan's study showed no difference on roentgenographic examinations of surgically and nonsurgically operated knee dislocations, their surgical method consisted of ligament repair which is inferior to ligament reconstruction [39]. Recent studies demonstrate that knee dislocations treated nonoperatively tend to develop more severe degenerative changes than operative patients [33, 34]. Plancher demonstrated that 88 % of nonoperative patients had grade II or greater chondromalacia, compared with 47.4 % of operative patients at an average 8.3-year follow-up [34]. This decreased risk of degeneration is attributed to early and improved surgical treatment creating better stability and allowing for more rapid mobilization [31, 37].

## 8.8 Who Should Be Operated on: What Is New?

There is a debate in the literature between 1960 and 1995 whether nonsurgical or surgical treatment yields superior results. Despite that debate, it is clear that certain injuries associated with multi-ligament knee trauma necessitate immediate surgical intervention: (1) open dislocations, (2) irreducible dislocations, (3) vascular damage, and (4) compartment syndrome [30, 40]. These associated injuries have a great effect on the short- and long-term outcomes in patients with knee dislocations. In fact, most arterial injuries and open dislocations necessitate immediate surgical intervention because they have the potential to be limb or life threatening. Some surgeons prefer to explore the common peroneal nerve and perform an early neurolysis when associated posterolateral knee injury is present [49]. Availability of allograft tissues, better sterilization and storage technique of allografts, better graft fixation methods, improvement in arthroscopic surgical instrumentation, improved understanding of knee anatomy and kinematics, and improvement in surgical techniques allow surgeons to perform less invasive arthroscopically assisted ACL and/or PCL reconstructions. These innovations and more aggressive physical therapy methods have helped surgeons change the treatment standard from a more conservative treatment protocol to a more interventional course in the last two decades [41, 50].

## 8.9 Conclusion

The low incidence of multi-ligament knee injuries and a lack of prospective randomized studies in the literature have made it difficult to determine the best choice of treatment for many years. Immobilization in a long-leg cast was the initial treatment standard. Poor functional results, stiffness, and decreased range of motion as a result of prolonged immobilization combined with the improved surgical techniques have moved the treatment standard to arthroscopic-assisted reconstruction/repair. Although some well-organized studies have shown that return to sports or preinjury work levels may not vary between operative and nonoperative patients, there is strong evidence that nonoperative patients have increased instability, more pain with activities of daily living, worse functional outcomes, and develop increased rates of degenerative arthritis. When all evidence is considered, nonoperative treatment in the earlier studies seems to be related to surgeon preference, lack of experience, and lack of technology available at that time. Currently, in our opinion, all knee dislocations except the patients who have comorbidities preventing operative intervention should be treated surgically.

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# Part V

# Surgical Treatment of the Multiple Ligament Injured Knee

# Chapter 9
# Graft Selection in Multiple Ligament Injured Knee Surgery

**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 possible 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 different from what the surgeon would normally use 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; however, most authors prefer to delay ligament

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reconstruction for a few days to weeks in an attempt to decrease swelling of the soft tissue envelope. 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 [2–5]. Others have advocated different timing of surgical intervention based on which constellation of ligamentous injuries exist with 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 [6, 7]. 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 [8, 9].

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 [10–12]. Despite the controversy, the efficacy of both graft options has been demonstrated, and thus, both appear to be good options [6, 13–21].

## 9.4 Availability of Graft

There is a limited supply of both autograft and allograft tendons available for clinical use. Autograft tendons 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 sight 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 of America (USA), 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 [22–32]. 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 USA.

Bioengineered ligament grafts are also not currently approved for implantation in the USA; 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 [33–39].

## 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 bone–patellar tendon–bone (B–PT–B), hamstrings (semitendinosus and/or gracilis), and quadriceps tendon–patellar bone (QTB). With regard to ACL reconstructions specifically, B–PT–B autograft has historically been one of the most commonly utilized grafts and is the gold standard to which all other grafts are compared [14, 40]. 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 [41, 42]. 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 B–PT–B autografts 3 months after the index surgery [43]. For a variety of reasons, QTB is less popular than other graft options and is thus utilized much less frequently [44, 45]. However, good short- and long-term results have been reported for primary ACL reconstruction with QTB [46, 47]. More recently, two independent series of QTB autograft ACL reconstructions demonstrated no significant difference in functional outcomes when retrospectively compared to autograft B–PT–B 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 [48, 49]. 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 [50–55]. Autograft B–PT–B 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 [21, 45, 51, 56–64]. QTP has a similar constellation of associated complications to B–PT–B, albeit to a lesser degree, consisting of a low incidence of decreased range of motion, anterior knee numbness, anterior knee pain, and residual laxity [48, 49]. 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 B–PT–B 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 [65–67]. 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

The American Orthopaedic Society for Sports Medicine (AOSSM) has estimated that approximately 60,000 allografts were used in knee reconstruction procedures alone in 2005 [68]. 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. 9.10), and QTB (Fig. 9.9) 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 [15, 19, 69, 70]. 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, 14, 26, 40, 71–76].

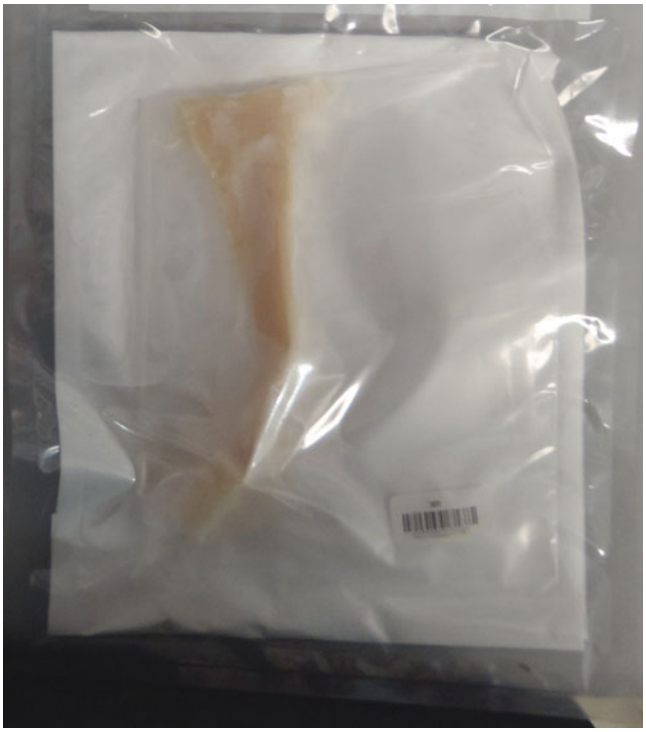

**Fig. 9.1** Achilles allograft in tissue bank packaging. (Image kindly provided by Musculoskeletal Transplant Foundation (MTF))

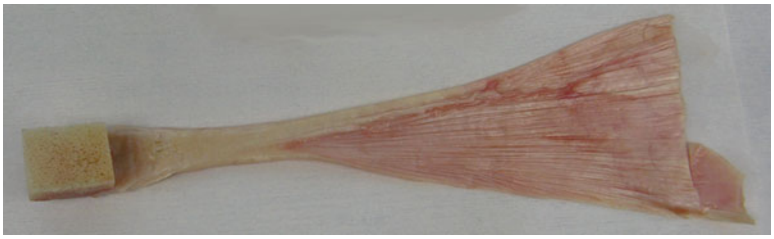

**Fig. 9.2** Achilles tendon–bone allograft removed from package. (Image kindly provided by Musculoskeletal Transplant Foundation (MTF))

**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))

**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))

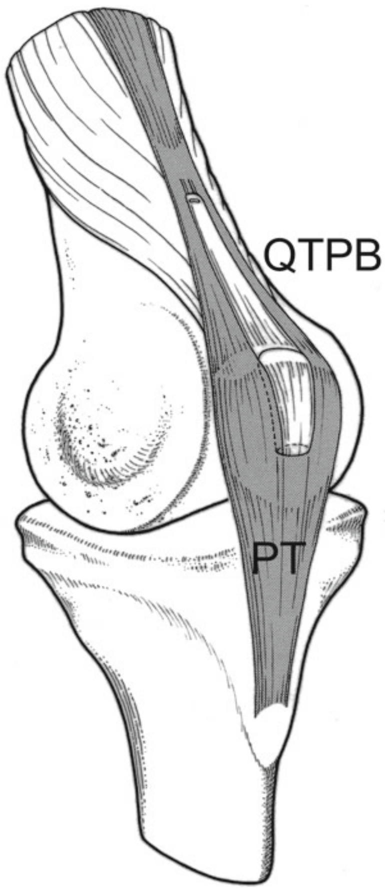

**Fig. 9.9** Diagram of QTB harvesting. (From Dargel J et al, Arch Ortho Trauma Surg 2006;126:265–70. Reprinted with permission from Springer)

**Fig. 9.10** Hamstrings allograft tensioned on graft station

## 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 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 B–PT–B 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 [71]. Three weeks following surgery the recipient was treated with supportive therapy for flu-like illness and lymphopenia was noted. The patient was not 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 [71]. 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 [77, 78]. 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 [77]. 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 [71, 79, 80].

In addition to viral transmissions several bacterial infections have resulted from musculoskeletal allograft implantation [1, 81]. 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 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, 81]. 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, 82].

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 [83]. 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 cause of the permanent strength loss observed in reconstructed ligaments, when compared to their biomechanical strength at the time of implantation [72]. 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 [72–76]. It may take up to one and a half times longer for allograft to completely remodel and gain comparable strength to autograft [84]. ACL retrieval studies at autopsy suggest that allograft incorporation continues for more than 2 years [75]. Despite the slower rate of incorporation, the eventual healing is almost identical to the healing of autograft [85, 86]. 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 [87, 88].

## 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, 81, 82].

## 9.10 Sterilization of Allografts

In 2006 a survey of 365 members of the AOSSM indicated that 86 % of them utilized allografts, yet 21 % were not aware of whether their allograft source was accredited by the AATB [1]. Furthermore, the vast majority of surgeons surveyed believed that the sterilization process had deleterious effects on the biomechanical strength of these allograft tissues. 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 [80]. 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 [82, 89]. 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 [90].

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 [91, 92].

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 [81]. Some tissue banks with proprietary sterilization techniques claim that tissue integrity is not damaged by the sterilization process [93]. However, sterilized grafts have been associated with poor clinical outcomes in several investigations [94–96].

## 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 posttransplantation indicates that there was minimal cell survival among these cryopreserved allografts [96].

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 [73]. 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 [79, 97, 98].

## 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, 99].

## 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 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 [72]. 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 [100]. 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

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

| | Tensile load (*N*) | Stiffness (*N*/mm) |
|---|---|---|
| Native ACL | 2,160 [104] | 242 |
| Bone–patellar tendon–bone | 2,977 [105] | 620 |
| Tibialis anterior (double stranded) | 4,122 [106] | 460 |
| Tibialis posterior (double stranded) | 3,594 [106] | 379 |
| Gracilis 1st strand | 837 [107] | 160 |
| Gracilis 2nd strand | 1,550 [107] | 336 |
| Semitendinosus 1st strand | 1,060 [107] | 213 |
| Semitendinosus 2nd strand | 2,330 [107] | 469 |
| Quadruple hamstrings | 4,090 [107] | 776 |
| Quadriceps tendon | 2,352 [108] | 463 |

6–8 weeks, much like the typical time frame for primary bone healing of a fracture [101], whereas the duration required for significant tendon-to-bone healing of an autograft ligament reconstruction is approximately 8–12 weeks in an animal model [102]. Clinically, Noyes et al. concluded that B–PT–B allografts more effectively restored anterior–posterior translation in their report comparing allograft B–PT–B to fascia lata soft tissue allograft ACL reconstructions [103]. More recently, meta-analysis comparing soft tissue hamstring autografts to B–PT–B autografts has also demonstrated significant benefits with regard to less residual laxity and a lower graft failure among B–PT–B grafted patients [51]. 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, isolate and preserve the prepatellar retinaculum. The quadriceps tendon and its junction with the vastus medialis obliquus and vastus lateralis obliquus are identified proximally (see Fig. 9.9). 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 [46, 111].

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# Part VI

# Surgical Treatment of the ACL-Based Multiple Ligament Injured Knee

# Chapter 10
# Surgical Treatment of Combined ACL and Medial-Sided Knee Injuries: Acute and Chronic

**Michael J. Medvecky**

## 10.1 Introduction

This chapter will review the evaluation and treatment of combined anterior cruciate ligament (ACL) and medial collateral ligament (MCL) injuries. Although the MCL injuries are 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 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 (POL), 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. 10.1a, b) [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].

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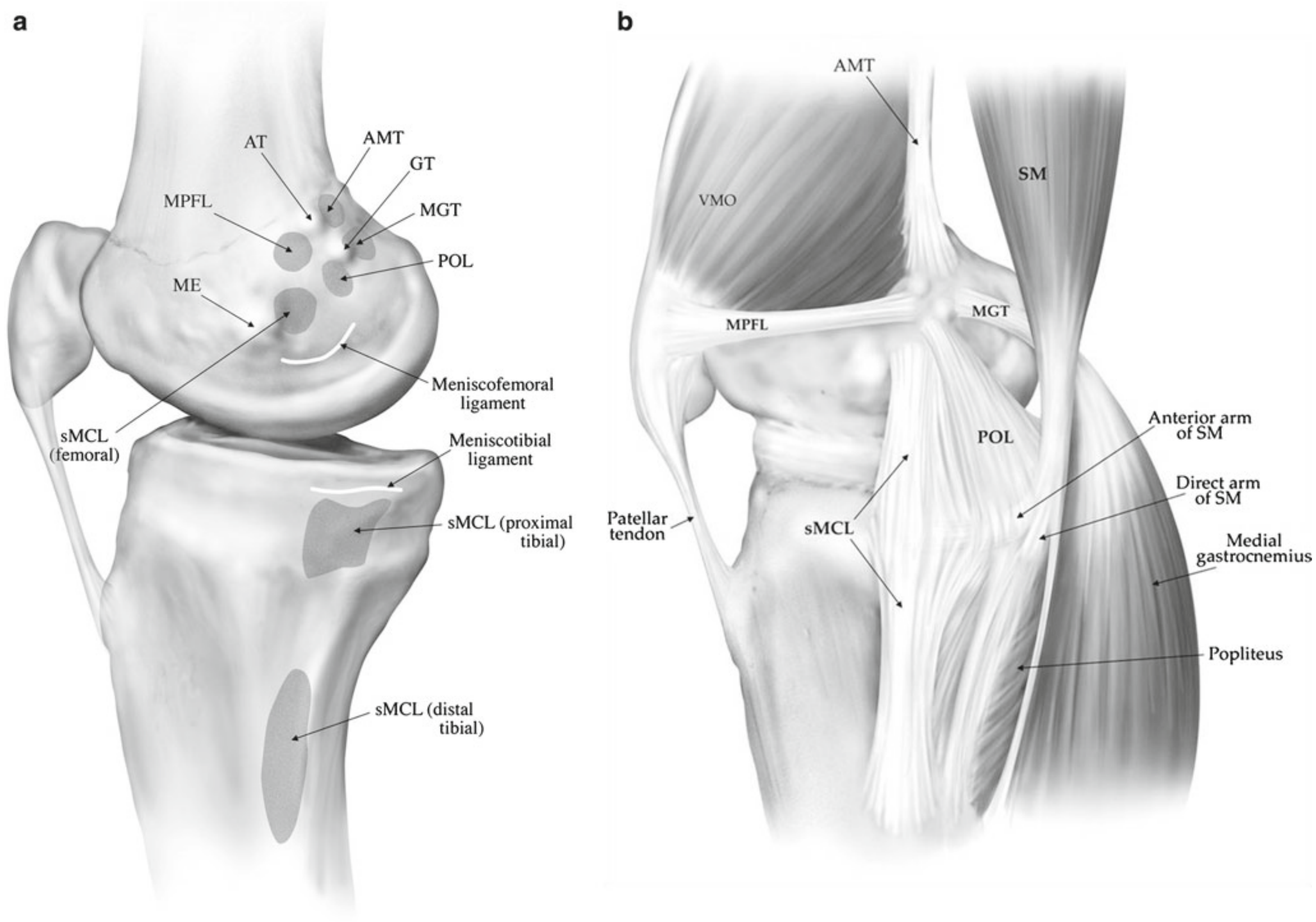


**Fig. 10.1** Anatomy of the medial aspect of the knee. From [1]. Reprinted with permission. (**a**) ligamentous attachment sites. (**b**) medial ligament anatomy

## 10.4 Posterior Oblique Ligament

The 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, 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 muscle 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 consist attachments: a direct arm, an anterior arm, and the 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 off the

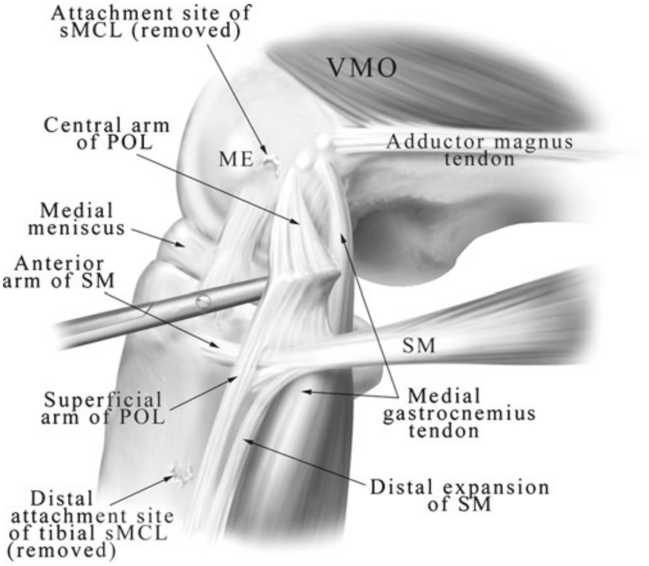


**Fig. 10.2** Semimembranosus tendon tibial attachments. From [1]. Reprinted with permission

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 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, 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 with comparison to contralateral knee [8].

## 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

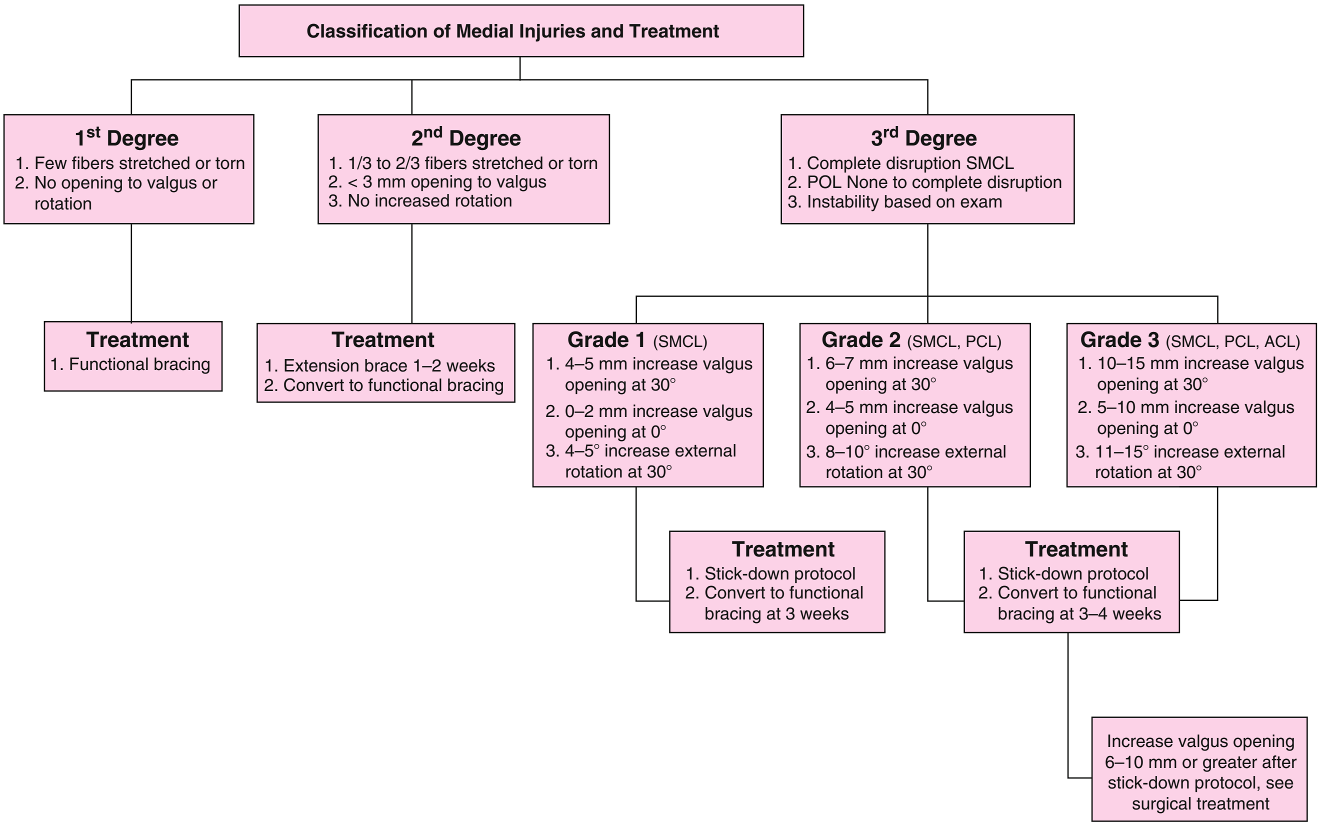


**Fig. 10.3** Classification of medial-sided knee injuries. From [10]. Reprinted with kind permission from Elsevier

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 = Δ0–5 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. (Fig. 10.3) [2].

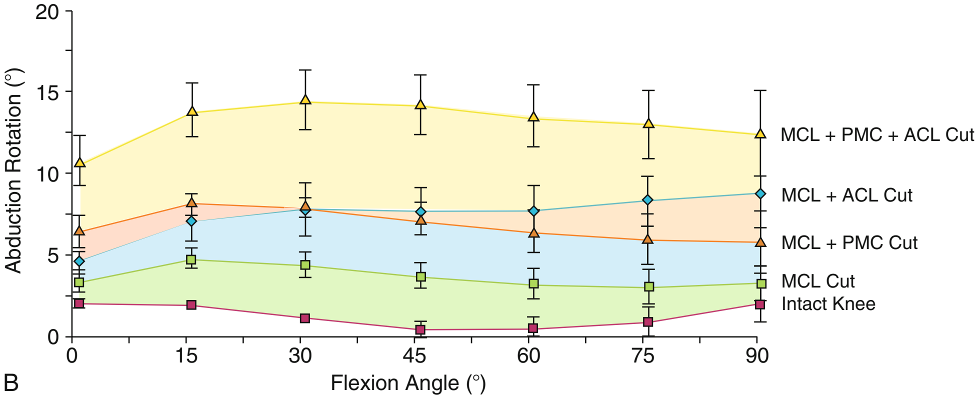
## 10.9 Clinical Biomechanics

### *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. 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 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



*(From Haimes, J.L.; Wroble, R.R.; Grood, E.S.; Noyes, F.R.: Role of the medial structures in the intact and anterior cruciate ligament–deficient* knee, *Limites of motion in the human knee.* Am J Sports Med *22: 402–409, 1994.)*

**Fig. 10.4** Valgus opening with selective ligament sectioning. From [10]. Reprinted with kind permission from Elsevier

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).

### 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°) [15]. This demonstrates the utility of the Lachman test versus the anterior drawer test. In the ACL-*deficient* knee, section 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 [16].

### 10.9.3 External Rotation Limits

The rationale of performing the dial test in the assessment of ACL–MCL injuries is shown below Fig. 10.5 [16]. 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. 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 of 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 [16]. 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°. Additional sectioning of the ACL did not result in significant increase in internal rotation in the range of either the 30° or 90° position.

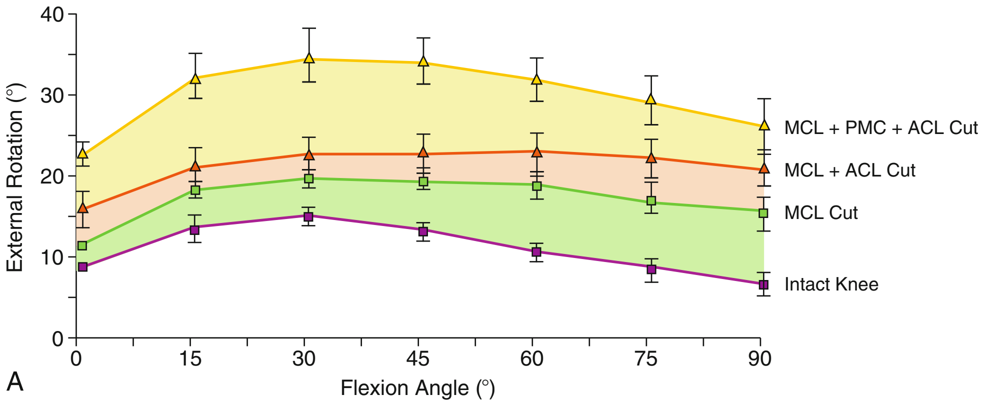


**Fig. 10.5** External rotation limits with selective ligament sectioning. From [10]. Reprinted with kind permission from Elsevier

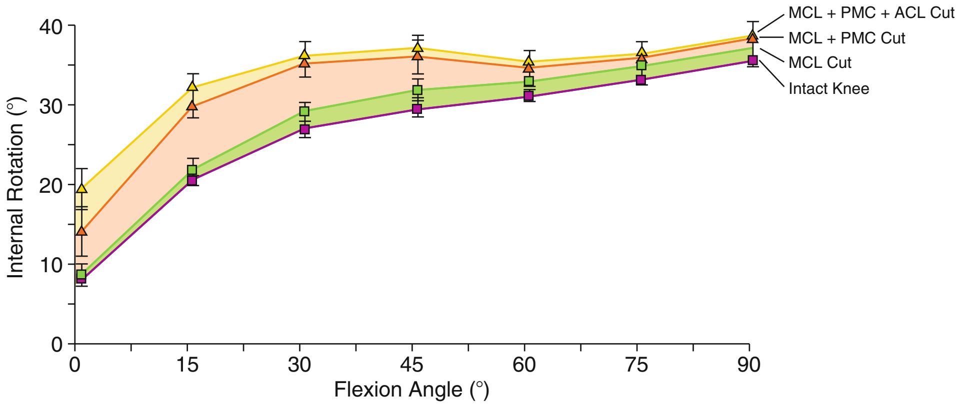


**Fig. 10.6** Internal rotation limits with selective ligament sectioning. From [10]. Reprinted with kind permission from Elsevier

## 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. 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. [17] 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 misaligned knee where corrective osteotomy may need to be considered before ligamentous reconstruction.

MRI is considered 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) [18–20].

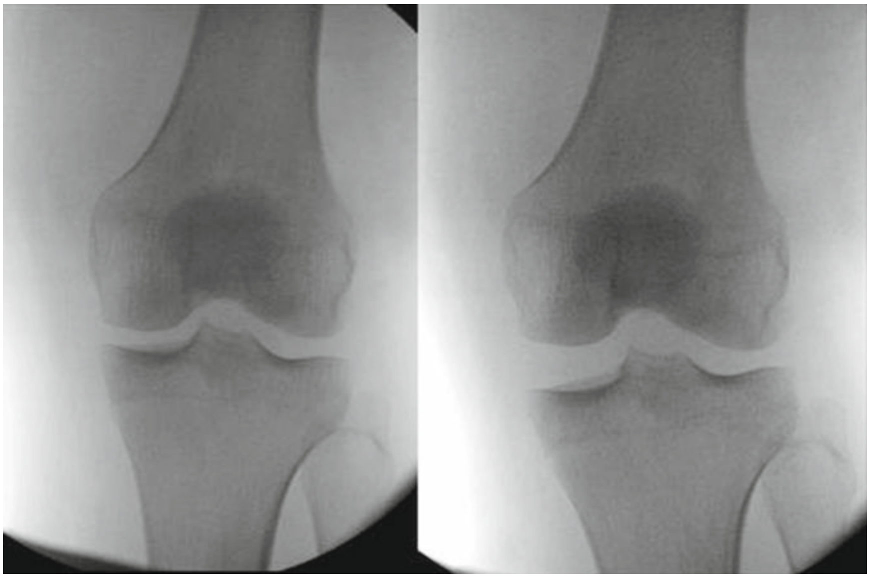


**Fig. 10.7** Fluoroscopic images obtained during examination under anesthesia demonstrating excessive medial compartment gaping at 30° of flexion, consistent with 3° injury of sMCL

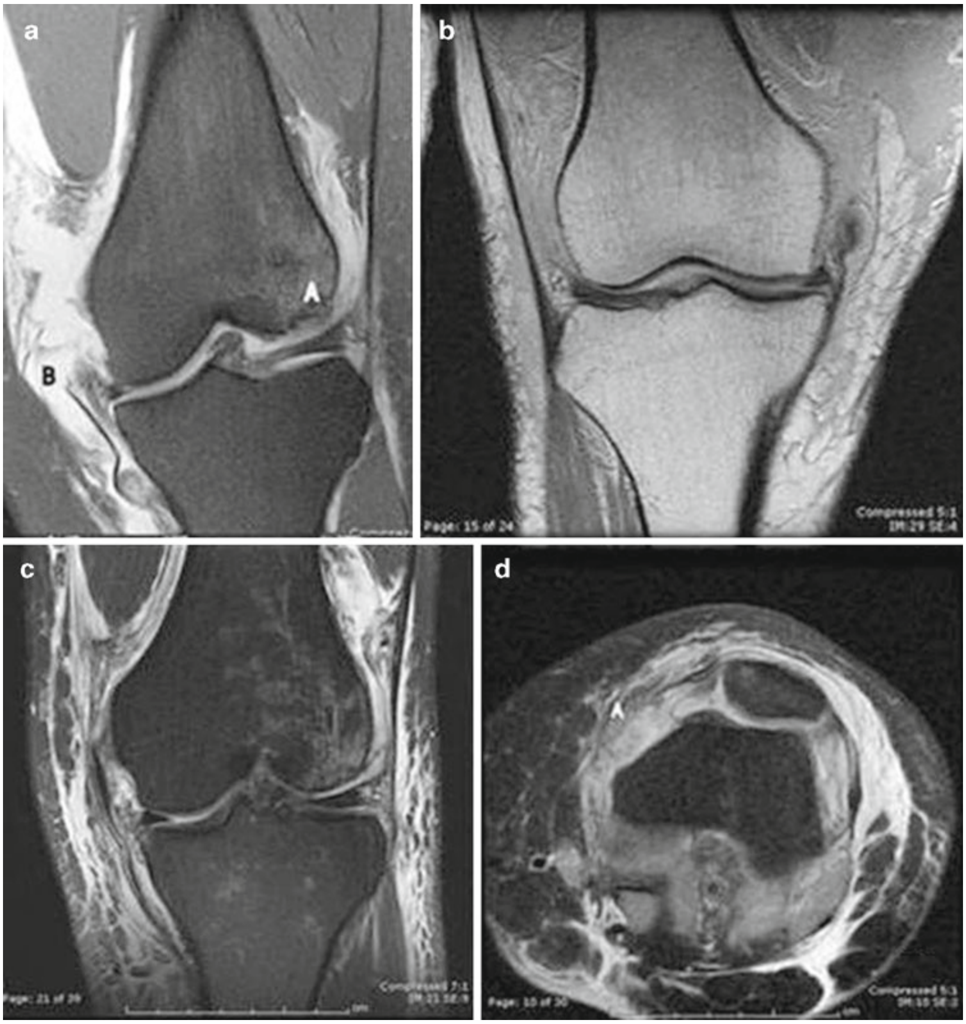


**Fig. 10.8** MRI images demonstrating femoral sMCL avulsions and MPFL avulsion. (**a**,**b**,**c**) femoral sMCL avulsions seen on coronal MRI image. (**d**) MPFL avulsion seen on axial MRI image

## 10.11 Treatment Algorithm

There is a fairly uniform consensus in the literature that nonoperative management of first- and second-degree MCL injuries is appropriate [21–25]. With regard to acute third-degree medial-sided injuries, some controversy does exist regarding nonoperative versus operative intervention [25–27]. However, most studies advocate nonoperative 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, the author advocates the use of nonoperative management, however, utilizes the 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 of injury, any associated injuries, and to exclude the need for operative repair (see Fig. 10.3) [18, 28, 29].

A long-leg cylinder cast is placed with the knee in full extension, and the patient is instructed on foot-flat touchdown 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 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 author feels 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 [28], associated patella dislocation with concomitant MPFL avulsion, 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 [25]. At this point, no clinical data supports this versus acute repair of these structures [30].

In cases of acute sMCL, POL, and ACL injury, 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 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. 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 the valuable information to localize the zone of injury and develop a surgical preoperative plan [18].

## 10.13 Operative Strategy for Acute Medial Ligamentous Repair

Operative strategy and sequence of repair or reconstruction is similar for acute and chronic injuries. Progression of anatomical restoration will proceed from deeper structures to superficial [1, 31]. Deepest layers consist of the meniscofemoral and meniscotibial ligaments and the associated attachment to the medial meniscus, which is repaired if disrupted.

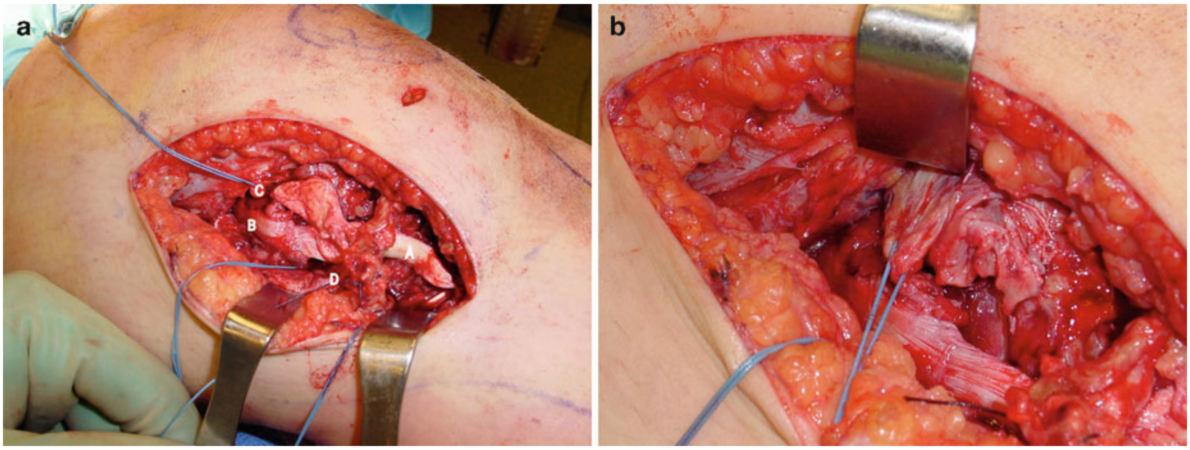
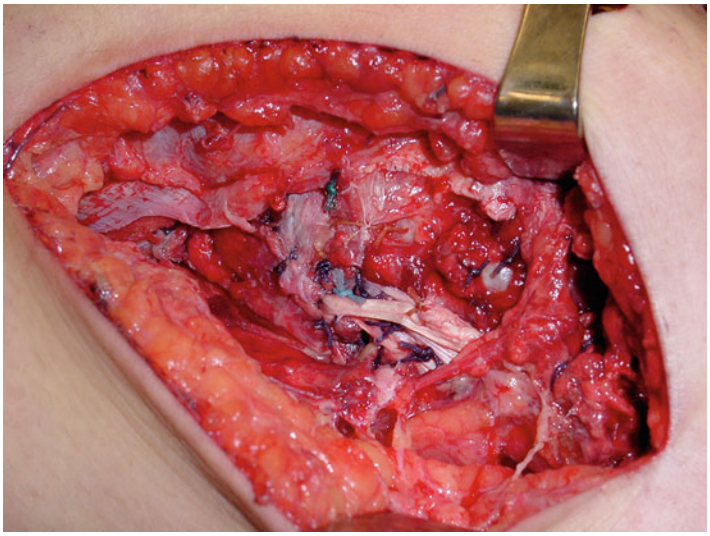


**Fig. 10.9** (A) sMCL tibial attachment, (B) sMCL femoral attachment, (C) MPFL, (D) infrapatellar branch of saphenous nerve, (**a**) surgical exploration of medial-sided knee injury. (**b**) traction suture placed in MPFL in preparation for pull-through repair

**Fig. 10.10** Medial structures after direct repair of sMCL, MPFL, POL, and medial retinaculum



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 [32, 33]. 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 as well as disruption of the femoral or tibial attachment sites. Repair is performed from deep progressing towards superficial layers. This is performed using both absorbable and nonabsorbable suture material. 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. 10.9, 10.10, 10.11, and 10.12).

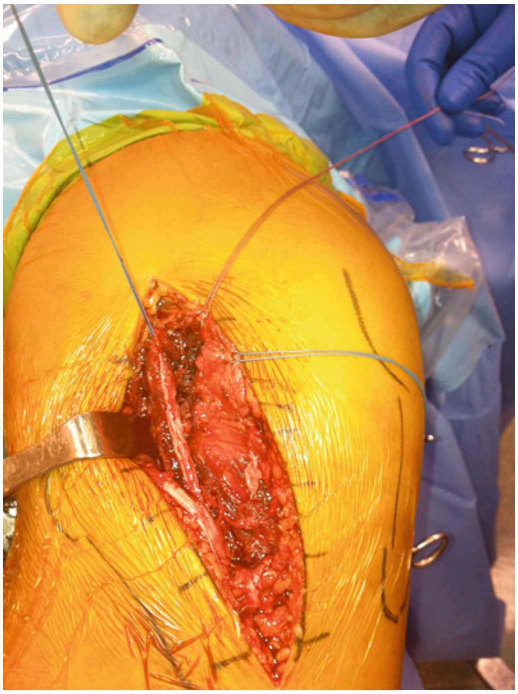


**Fig. 10.11** Intraoperative image of left knee demonstrating avulsion of the sMCL off femoral attachment site, medial retinaculum tear, MPFL avulsion, and avulsion of meniscofemoral ligament

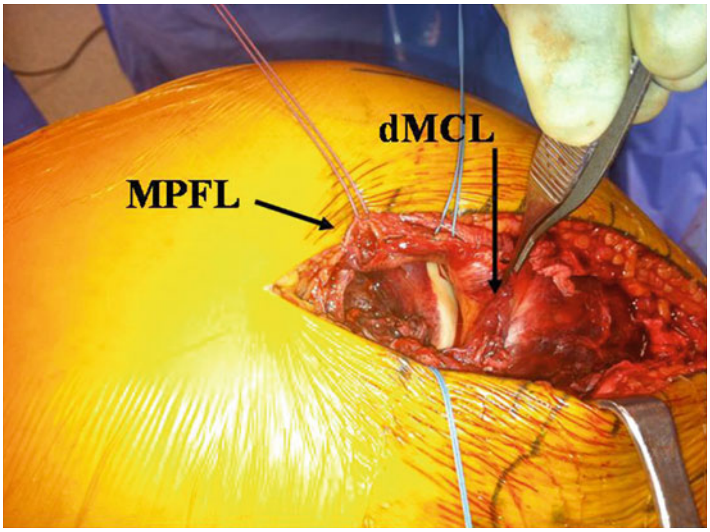


**Fig. 10.12** Intraoperative photograph of a left knee demonstrating the disruption of the medial retinaculum including the MPFL and the dMCL

Avulsion of the direct semimembranosus attachment site can be repaired by 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 technique (Fig. 10.13) 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 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 towards superficial. The sMCL is tensioned at approximately 25° of flexion. The POL is tensioned at approximately 10–20° of knee flexion, to avoid overconstraining the knee and result in loss of terminal extension. Plication of the POL is also typically needed with direct suture repair of the

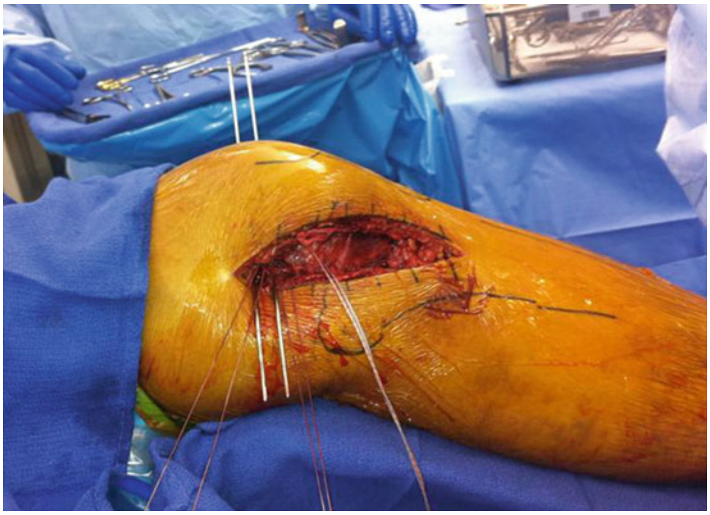


**Fig. 10.13** Beath pins placed into MPFL and sMCL femoral attachment sites on femur in preparation for direct repair via pull-through technique, with sutures tied over button on lateral condyle

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, 31]. The knee is taken through a full range of motion on the table prior to closure to verify joint motion is not overconstrained. If there is MPFL or medial retinacular disruption, this is repaired at approximately 20° of flexion to also avoid overconstraining of the patellofemoral joint.

The patient is also consented for 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.

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.

## 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 for 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, I 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 nonoperatively, and ACL reconstruction is treated in isolation.

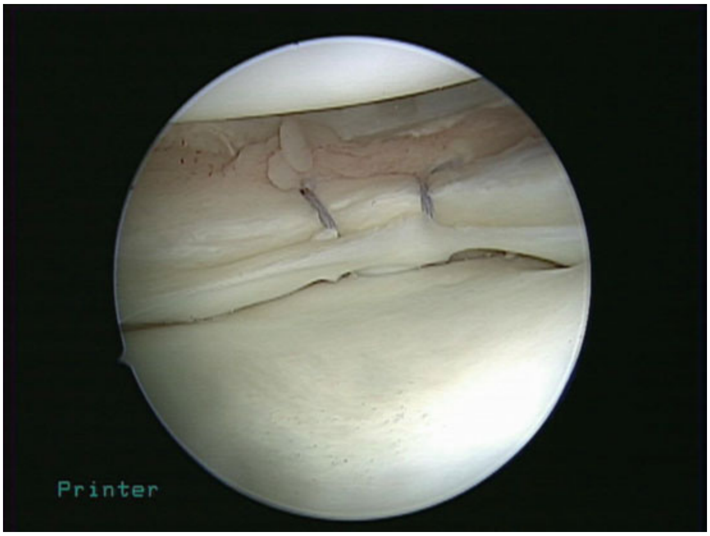


**Fig. 10.14** Obvious medial compartment gapping consistent with medial collateral ligament deficiency. Note no lift-off of medial meniscus from tibial plateau and therefore intact meniscotibial ligament. Medial meniscus repaired prior to sMCL and ACL reconstruction

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 [34, 35]. Recent in vitro testing of an anatomical medial knee reconstruction restored knee stability in a simulated sMCL and POL injury [30]. 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 [36]. Prior studies have investigated the biomechanical changes that occur with various advancement procedures of either the proximal or distal insertions sites of the sMCL [37, 38]. 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 [39]. These biomechanical findings are useful to help guide our treatment of these combined chronic medial-sided knee injuries.

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 (Fig. 10.14).

The remaining tissue of the sMCL is utilized and advanced either proximally or distally, based upon the site of the prior injury. Potentially repairing the meniscotibial ligament with bioabsorbable suture anchors is based upon the initial diagnostic arthroscopy and MRI findings. If the initial zone of injury was proximal, the femoral sMCL origin is osteotomized and advanced proximally in line with the fibers, with the knee placed in 30° of flexion. The osteotomized piece is secured with a four-prong staple or small-fragment screws and a one-third tubular plate, to include point of fixation at the native sMCL femoral attachment site, so as to minimize the functional lengthening of the sMCL [10, 39].

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

The sMCL advancement may be augmented utilizing double-bundle reconstruction of the sMCL (Figs. 10.15 and 10.16) [28, 30]. 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 [36].

If distal advancement and augmentation is performed, 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 [30]. 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

**Fig. 10.15** Anatomical medial knee ligament reconstruction. From [30]. Reprinted with permission

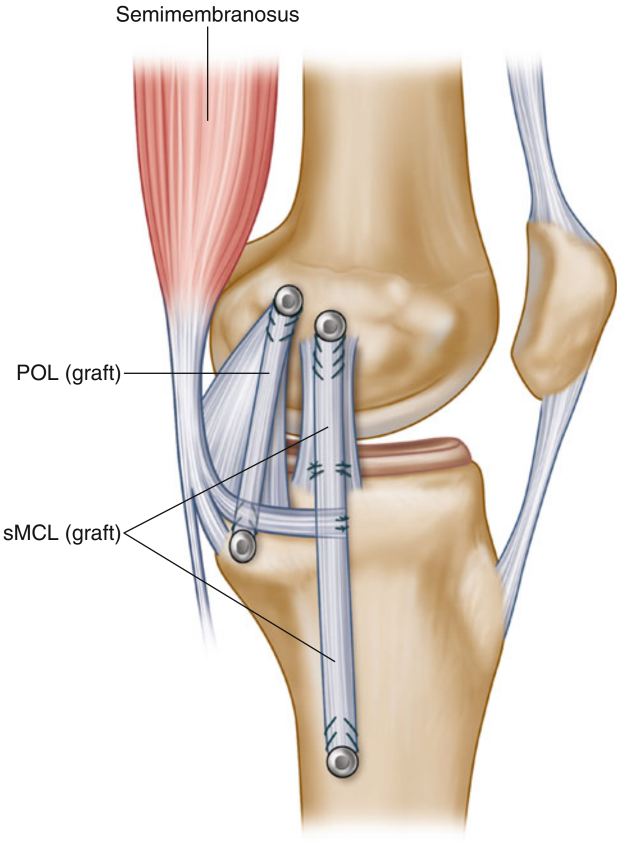
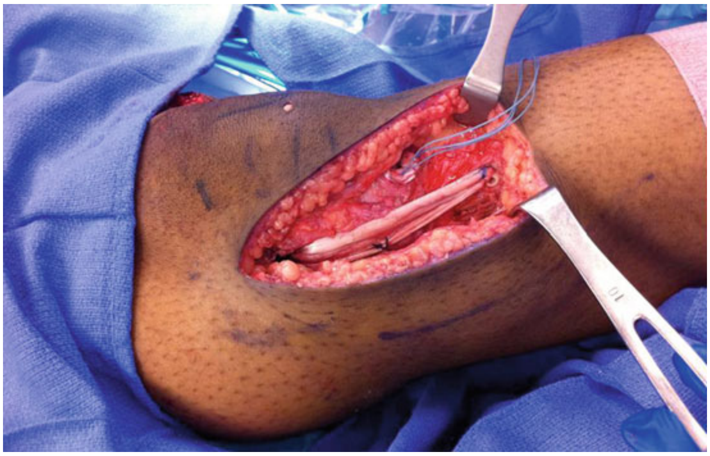


**Fig. 10.16** Left knee s/p ACL quadriceps tendon autograft and MCL allograft reconstruction



sMCL [10, 30]. The POL component of the described technique is reserved for severe loss of medial-sided tissue where there is insufficient POL tissue to imbricate and restore full-extension stability [10, 31]. The closure and postoperative dressing and immobilization are similar to as described earlier.

## 10.15 Conclusion

sMCL sprains are common knee injuries but less commonly seen in combination with ACL tear. Accurate diagnosis of both sMCL and POL injury is critical to determine the optimal treatment plan. Typically, this injury is able to be effectively treated with nonoperative 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 towards 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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# Chapter 11
# Surgical Treatment of Combined ACL and Lateral Side Injuries: Acute and Chronic

**Julienne Lippe and Robert A. Arciero**

## 11.1 Introduction

Management of the patient with combined ligamentous knee instability can be a challenging problem. Several studies have suggested that lateral/posterolateral knee instability accompanies anterior cruciate injury in 11–12.5% of patients [1–3]. As approximately 100,000 anterior cruciate ligament (ACL) reconstructions are performed in the United States each year, this combined injury pattern is an entity that the orthopedic surgeon must be able to recognize and appropriately address [4].

The purpose of this chapter is to discuss the current state of combined anterior and lateral knee instability. It will begin with a review of the pertinent pathophysiology and biomechanics of the ACL and lateral knee ligaments to provide a framework for further discussion. A discussion of the clinical exam will follow and include the key features of the history, physical exam, imaging studies, and diagnostic arthroscopy that will enable the surgeon to appropriately evaluate these injuries and successfully move forward. Finally, the surgical options for combined anterior cruciate and lateral knee ligament injuries will be reviewed, with suggested treatment strategies and approaches for both the acutely and chronically injured patient.

## 11.2 Pathophysiology/Biomechanics

Overall knee stability is dependent on the balanced interactions of the cruciate ligaments and the medial and lateral ligament complexes. The ACL is the primary restraint to anterior tibial translation and at 30° is responsible for 82–89% of the restraint of an anterior applied load [5]. Others have shown that in the setting of ACL deficiency, there is a “coupled” increase in internal tibial rotation [6–9]. This “coupled” function of the ligament as a secondary restraint against rotatory loads occurs since the axis of rotation of the tibial plateau is close to the ACL [6, 10, 11]. The primary restraints to rotational control appear to be the more peripheral ligamentous structures of the knee, predominantly the posterolateral complex [6]. This concept is further supported by Gollehon’s cadaveric sectioning studies where he found an increase in tibial internal rotation in specimens that had both the ACL and posterolateral structures sectioned, but no increase with isolated sectioning of the ACL [12].

Anatomical descriptions of the lateral and posterolateral knee, originally reported by Seebacher et al., discuss three complex layers [13]. The most important structures, from a clinical perspective with regard to stability, are the lateral collateral ligament and the popliteus complex, which consists of the popliteus muscle-tendon unit and the popliteofibular ligament [14, 15]. Biomechanical studies, in which these structures are selectively cut, have demonstrated that they are important in resisting posterior translation, primary varus and external rotation, and coupled external rotation [16, 17].

The majority of cadaveric studies that examine the biomechanical properties of the knee ligamentous structures focus on isolated ACL, isolated PLC, or combined ACL/PLC injuries. Within these studies though, some authors do address the combined ACL/PLC injury pattern [12, 16, 18, 19]. Veltri et al. found that sectioning of the posterolateral structures increased primary varus, primary external rotation, posterior translation, and coupled external rotation, yet in a subsequent study the

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authors reported that combined sectioning of the ACL and PLC did not lead to an increase in tibial external rotation [16, 18]. This is in contrast to the findings of Wroble et al., who noted in their cadaveric study of similar experimental design that there was an increase in external rotation with sectioning of both the ACL and PLC [19]. Despite these conflicting findings, it would appear that the combined ACL/PLC injury increases primary anterior/posterior translation, primary varus, coupled ER, and likely primary IR [12, 14, 18, 19].

LaPrade et al. demonstrated the significance of the combined anterior and lateral knee injury pattern in a cadaveric study that examined the forces upon the ACL graft in the setting of posterolateral structure deficiency [20]. In this study, they reconstructed eight fresh-frozen cadaveric knees with central one-third bone-patellar tendon-bone autograft and then assessed the forces upon the ACL graft prior to and after sequentially sectioning the posterolateral structures. They found that the graft force was significantly higher after LCL transection with varus loading at both 0° and 30° of knee flexion and that coupled loading of varus and internal rotation moments further increased the forces seen by the ACL graft. This increase in graft force was continued with further sequential sectioning of the popliteofibular ligament and popliteus tendon, and the authors concluded that untreated grade III posterolateral knee injuries contribute to clinical ACL graft failure by allowing higher forces to stress the graft [20].

## 11.3 Clinical Evaluation

A proper diagnosis is the foundation for developing an appropriate and successful treatment plan in the patient with a ligamentous knee injury. It is essential to do a complete clinical workup that should consist of obtaining a careful history, performing a thorough physical exam, and obtaining appropriate imaging studies. After all these steps have been accomplished, the surgeon must develop a comprehensive preoperative plan with the patient prior to entering the operating room. At our institution, this is commonly achieved during the preoperative visit.

It is important to note that the clinical findings associated with the combined ACL/PLC injury have a direct correlation to the mechanism of injury. Several authors have reported that the application of a varus force in the hyperextended knee is the most common injury mechanism to the posterolateral knee structures [21, 22]. This knee position stresses not only the lateral and posterolateral knee structures but also the ACL. Ross et al. reported that in their cohort of 13 patients who sustained ACL/PLC combined injuries from sports-related trauma, all occurred via a hyperextension and varus mechanism [23].

### *11.3.1 History and Physical Examination*

The importance of performing a thorough history and physical exam in the evaluation of the patient with the multiple-ligament-injured knee cannot be understated. Although ACL injury is often readily identified through the mechanism, history, and exam, it is not uncommon for concomitant injury to the lateral and posterolateral knee to be initially missed, with some authors reporting a mean delay in diagnosis of 30 months [1, 14, 24–26]. As the failure to recognize and treat PLC instability can have a negative effect on the success of ACL reconstruction, it is imperative that these injuries be identified early [1, 2]. In fact, many authors have suggested that a primary cause of ACL graft failure can be attributable to undiagnosed PLC injury [1, 18, 20, 24, 27].

The clinical diagnosis of an anterior and lateral combined knee injury begins with obtaining a good history of the injury. Patient-directed questions should assess the mechanism of injury (with higher suspicion with a varus-hyperextension force), whether or not there was the sensation of a “pop,” presence and timing of associated swelling, and any subsequent feelings of instability or loss of motion (typically full extension).

The physical exam should begin with a thorough neurovascular exam. Documentation of distal pulses and function is crucial, especially in the setting of a grossly unstable knee. The incidence of peroneal nerve injury in the setting of a posterolateral corner injury has been reported to be 12–16% [21, 22]. Serial examinations should be done to ensure an occlusive vascular lesion is not developing on a delayed basis, and the utilization of the ankle-brachial index (ABI) may be useful in determining a need for further evaluation and intervention [28]. Key points with regard to the ABI are to take the blood pressures supine, use the ipsilateral upper extremity as the denominator, and realize that it may be unreliable in patients with peripheral arterial disease or vessel calcifications. An ABI <0.9 should alert the physician to an increased likelihood of significant arterial injury [29].

The physical examination should continue with an assessment of the patient’s standing alignment. Any varus malalignment, which cannot be attributable to lateral structural injury, should be identified and further worked up with a standing

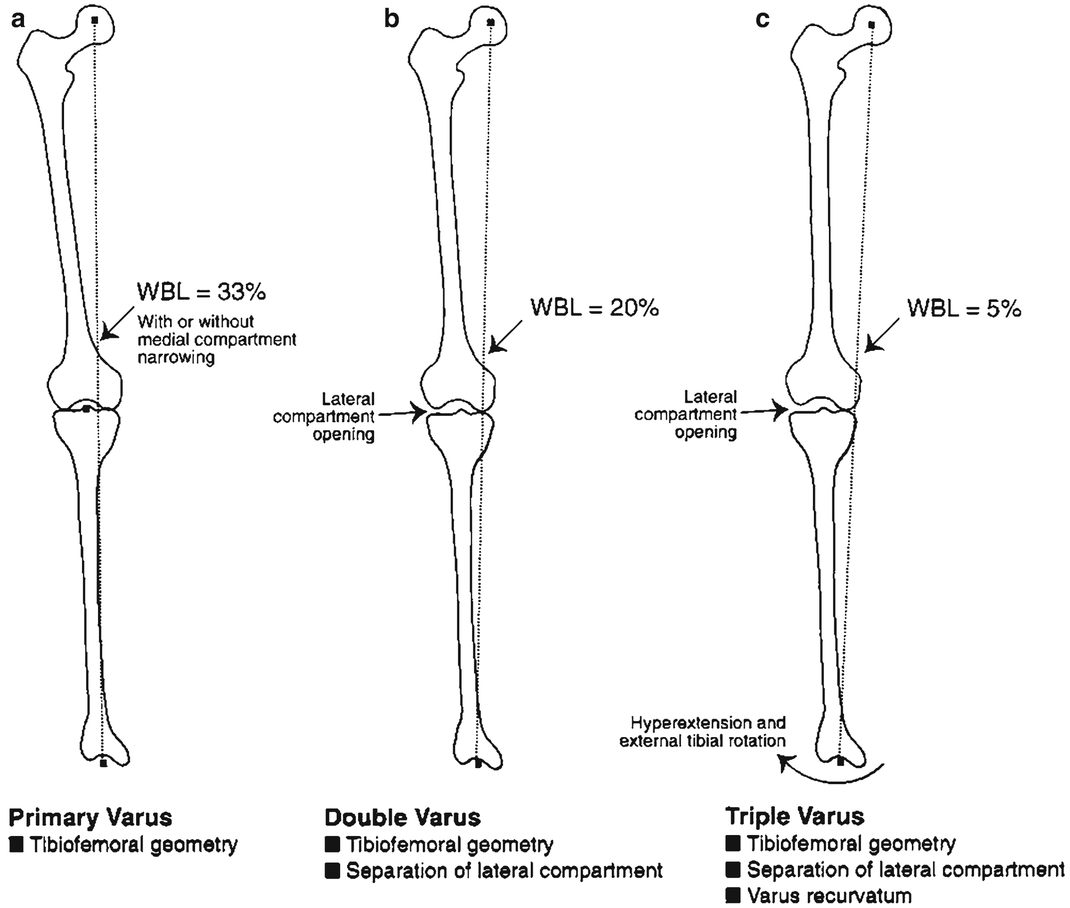


**Fig. 11.1** Categories of varus angulation based on clinical findings. (**a**) Tibiofemoral geometry causes include loss of medial meniscus or articular cartilage. (**b**) Separation of the lateral compartment is due to lateral soft tissue deficiency. (**c**) Varus recurvatum includes chronic stretching or traumatic injury to the posterolateral ligament structures. From [30], reprinted by permission of SAGE Publications

hip-to-ankle radiograph. The surgeon should also evaluate the patient's gait pattern, specifically checking for a varus thrust. These findings are both clinically important as they may be indicators of concomitant lateral and posterolateral structural injury as described by Noyes et al. in the "double and triple varus" knees (Fig. 11.1) [30]. As ligamentous reconstruction in the setting of baseline varus malalignment has an increased risk of failure due to increased graft forces, some of these patients may benefit from a high tibial osteotomy in addition to ligament reconstruction [20, 27, 30].

Important tests to assess the integrity of the ACL include the Lachman test and the pivot shift test. The Lachman test is the most sensitive physical exam maneuver for the ACL and should be performed with the knee in 20–30° of knee flexion [31, 32]. A technical point when doing this exam is to ensure that the proximal hand simply stabilizes the thigh and does not inadvertently push posteriorly, as this can dampen the anterior tibial translation noted by the distal hand. The pivot shift maneuver is performed by applying a valgus and internal rotation force to the tibia while flexing the knee [33]. A palpable clunk may be appreciated as the subluxed tibia reduces with increasing knee flexion. While this exam is the most specific test for the ACL, it has relatively poor sensitivity (32% reported by some authors) due to the discomfort it can elicit in the awake patient who thus guards against it [31].

It cannot be emphasized enough that the posterolateral complex of the knee should be examined in every patient with a suspected ACL injury. Varus and valgus stability should be tested with the knee both in 0° and in 20–30°. Instability at 30° suggests a collateral ligament injury, while continued instability at 0° is indicative of an additional cruciate ligament injury. Maneuvers such as the posterolateral drawer test and the external rotation recurvatum test can be useful in establishing a diagnosis of posterolateral corner injury (Fig. 11.2) [34]. The posterolateral drawer test is performed with the hip flexed 45°, the knee flexed 80°, and at 10–15° of external rotation [8, 35]. In the setting of PLC deficiency, the lateral tibial plateau externally rotates around the PCL, and there is relative posterior translation with a posteriorly directed force. The external rotation recurvatum test assesses the PLC in extension and is performed by grasping the great toes of both feet and elevating the legs off the bed [8, 35]. Careful observation will reveal a relative tibia vara and hyperextension of the lateral knee in the

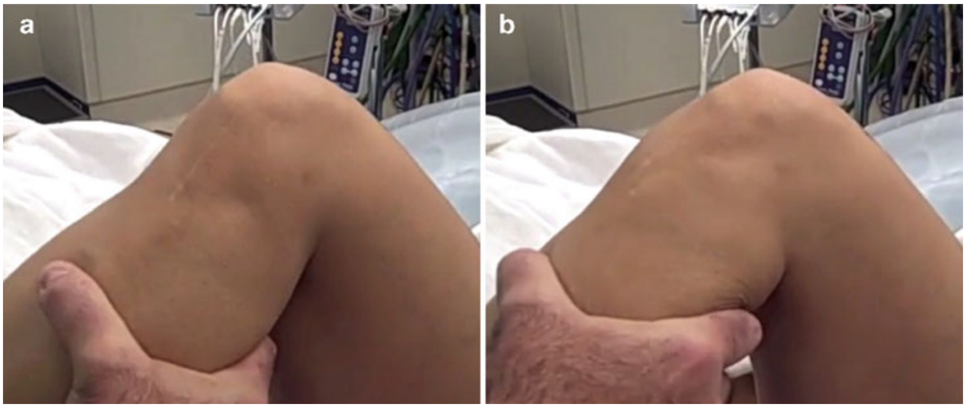


**Fig. 11.2** Clinical photographs demonstrating the posterolateral drawer test for the assessment of posterolateral corner insufficiency. (**a**) Note the relative posterior translation upon application of a posterior force with the knee at 80° and slight external rotation. (**b**) Reduced knee state

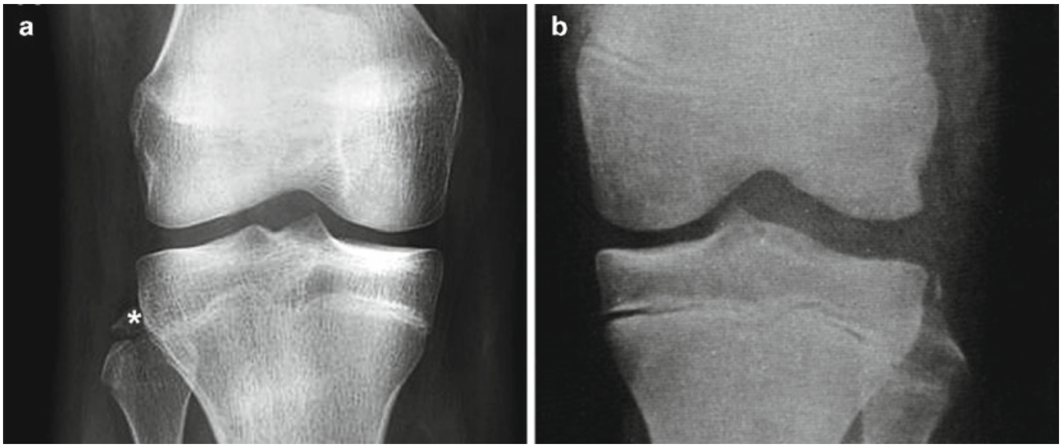


**Fig. 11.3** Radiographs portraying secondary signs of knee ligamentous injury. (**a**) Arcuate sign, suggestive of a posterolateral corner injury (*asterisk*). From Malone WJ, Verde F, Weiss D, Fanelli GC. MR imaging of knee instability. Magn Reson Imaging Clin N Am. © 2009;17:697–724, vi–vii. Reprinted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

patient with PLC injury. Finally, the dial test, which has been described in either the prone position or supine with the leg hanging off the bed, may also be beneficial in differentiating a PLC injury from a combined PCL/PLC injury [36, 37]. If there is asymmetric tibial external rotation of 10° or more in 30° of knee flexion, then it is suggestive of a posterolateral corner injury. If this asymmetric rotation also occurs in 90° of knee flexion, then there is likely a combined PCL/PLC injury present.

Besides the aforementioned specific exam maneuvers, careful palpation of the soft tissue and bony structures may provide clues as to the nature of the injury. A biceps femoris tear may be present, and a defect is often palpable just proximal to the fibular head [23]. While most intra-articular knee injuries are accompanied by a large intra-articular effusion, the absence of a contained knee effusion can be suggestive of a complete posterolateral corner injury with concomitant capsular disruption [23].

### *11.3.2 Imaging*

Plain radiographs of the knee should be obtained not only to assess for the presence of any periarticular or intra-articular fractures but also to evaluate for certain secondary findings which may be seen in the setting of a ligamentous knee injury (Fig. 11.3). A small avulsion fragment off of the fibular head, termed the arcuate sign, may be noted and is indicative of injury to the posterolateral knee structures, particularly the LCL and/or biceps femoris [38]. In a study by Juhng et al., 89%

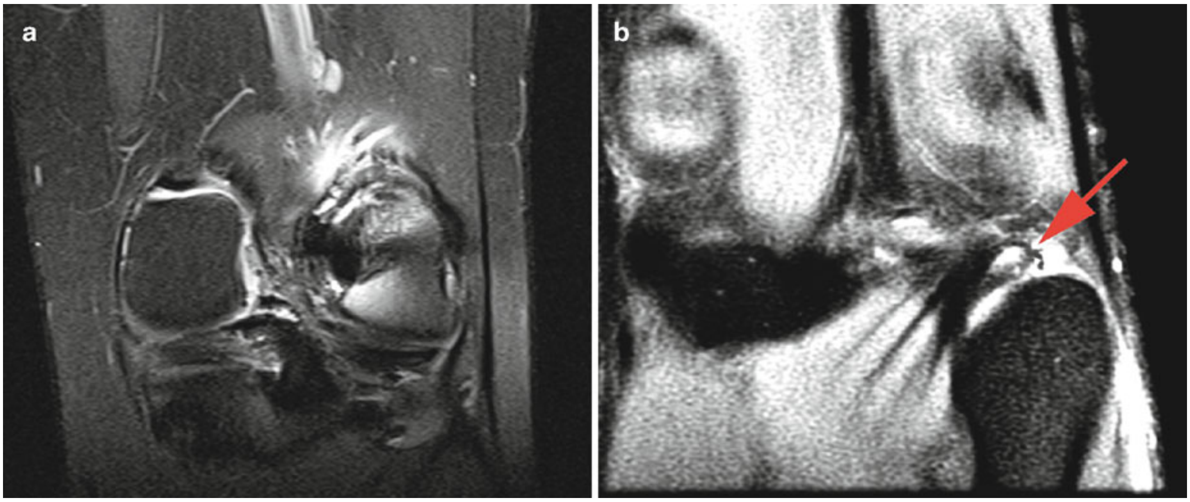


**Fig. 11.4** T2-weighted coronal oblique MR images depicting (**a**) intact popliteofibular ligament and (**b**) disrupted ligament (*arrow*)

of patients with this finding had a concomitant cruciate ligament injury, and 25% of these were isolated injuries to the ACL [38]. There may also be an avulsion fracture of the lateral tibial plateau, termed a Segond fracture, which is due to the pull of the lateral capsule and seen with an ACL injury [39].

As discussed earlier, a standing hip-to-ankle AP radiograph is warranted if there is any clinical suggestion of varus malalignment or a varus thrust gait pattern. In the normally aligned knee, a line drawn from the center of the femoral head to the center of the ankle (mechanical axis) should pass through the 62% point of the knee, where 0% is medial and 100% is lateral [30, 40].

MRI is useful to assess the extent of injury and facilitate preoperative planning. It has been reported to be 92.3% sensitive in identifying acute grade III tears of the ACL in the multiple-ligament-injured knee [41]. While it is excellent at identifying injuries on the lateral side of the knee as well, especially to the LCL or popliteus, it is reported to be less accurate (53–68%) in assessing the popliteofibular ligament [42, 43]. LaPrade et al. have recommended obtaining T2-weighted coronal oblique views to assist in identifying injuries to the PLC (Fig. 11.4) [42].

Bone bruises are also another MRI finding which not only help the surgeon understand the mechanism of injury but can also facilitate the prediction of injured structures. They can be identified in 71–88.6% of patients with an ACL injury and are commonly located on the anterolateral femoral condyle near the sulcus terminalis and the posterolateral tibial plateau [41, 44]. In patients with a combined posterolateral complex and cruciate ligament injury, there is also often a bony contusion of the anteromedial femoral condyle, which should increase the surgeon's suspicion for such an injury pattern [45, 46]. Geeslin et al. recently published a case series of 102 patients with acute PLC injuries [46]. In the 38 patients that had a concomitant ACL tear, 50% (19 patients) had evidence of an anteromedial femoral condyle bone bruise on MRI, and 29% (11 patients) had a posteromedial tibial plateau bone bruise (Fig. 11.5). They advised that in the setting of an ACL tear, the surgeon should have an increased suspicion for a secondary PLC injury if the MRI portrays these additional bone bruises.

Oftentimes the lateral knee injury is distal, where the LCL and popliteofibular ligaments are avulsed from the fibula, and the capsule is torn from the proximal lateral tibia [23]. It is also imperative to evaluate the biceps femoris insertion as it may be injured in up to 46% of patients with combined ACL/lateral knee injuries [23]. These findings are crucial to note preoperatively, as they are associated with anterior displacement of the common peroneal nerve 89% of the time, and the surgeon should approach the lateral knee with this expectation to avoid iatrogenic nerve injury [47].

### *11.3.3 Diagnostic Arthroscopy*

There are certain findings that can be noted at the time of arthroscopy in the patient with an ACL/lateral knee injury. Again, these become increasingly important to investigate for in the patient undergoing the routine ACL reconstruction with no clear preoperative suspicion of posterolateral knee injury so that a concomitant lateral knee injury is not missed. The popliteus tendon can be easily visualized from the lateral compartment, but the surgeon should also investigate the lateral gutter where the popliteofibular ligament can be assessed as the vertical fibers descending from the inferior surface of the

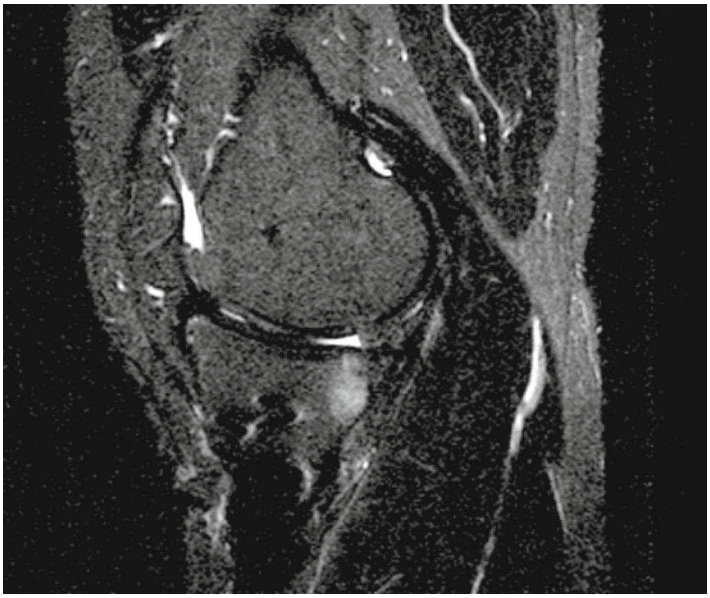


**Fig. 11.5** T2-weighted MR image depicting a posteromedial tibial plateau bone bruise that should raise the surgeon's suspicion for the existence of a PLC injury

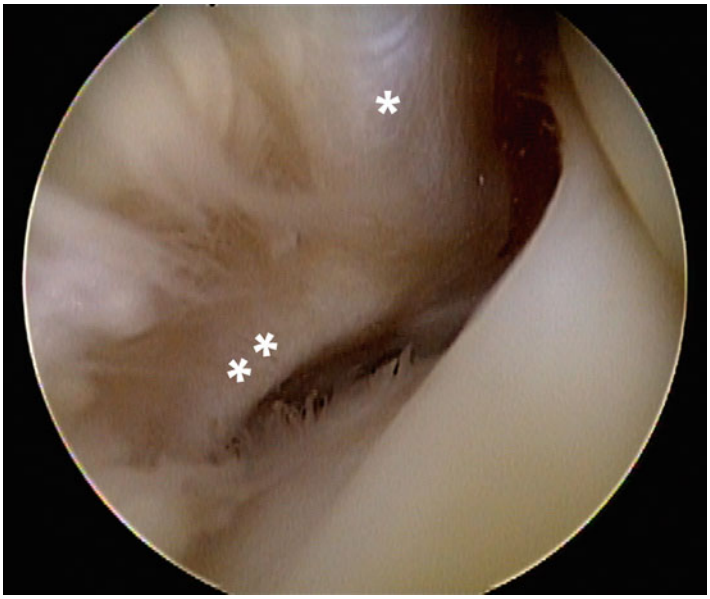


**Fig. 11.6** Arthroscopic visualization of the popliteus and popliteofibular ligament from the lateral gutter in a right knee. Popliteus (*asterisk*); popliteofibular ligament (*double asterisks*)

popliteus tendon (Fig. 11.6) [48]. LaPrade et al. described an arthroscopic "drive-thru" sign of the knee where opening of the lateral compartment greater than 1 cm with varus stress at 30° was indicative of a grade III injury to the lateral knee [49]. A "lateral gutter drive thru" sign has also been described, where the arthroscope may be placed deep into the posterolateral compartment via the lateral gutter due to an increased interval between the lateral femoral condyle and the popliteus tendon seen with injury [50].

## 11.4 Nonoperative Management

The decision to pursue an operative or nonoperative course is one that the patient and surgeon must make together. Important factors to consider include the patient's activity level, comorbidities, and the overall nature of the injury. Nonoperative management may be appropriate for the older, sedentary patient with a milder injury pattern who wishes to "cope" via brace use and physical therapy. While the literature is sparse regarding outcomes in nonoperative management of combined

**Table 11.1** Surgical indications

| |
|---|
| Active patient involved in pivoting, cutting, deceleration activities |
| Young patients |
| Concomitant meniscal/cartilage pathology |
| Mechanical symptoms |
| Loss of motion |
| Failed nonoperative management (continued pain/instability) |

anterior and lateral knee injuries, most studies show that reasonable functional and subjective outcomes can be achieved in appropriate patients with isolated ACL or isolated mild to moderate PLC injuries treated without surgery [51–54].

However, recent evidence does suggest that conservative management of ACL ruptures may lead to an increased risk of osteoarthritis [55]. Mihelic et al. published a long-term follow-up study of 17–20 years and demonstrated that their cohort of 33 patients who underwent reconstruction of their ACL had a significantly lower percentage of osteoarthritis compared to 18 patients who were managed nonoperatively [55]. This becomes important to discuss with the patient considering nonoperative management.

Kannus et al. evaluated patients with grade II and III lateral knee instability at 8 years postinjury [54]. All patients were treated nonoperatively, and 6 patients with grade III instability were also noted to have partial-thickness ACL tears. Immobilization was between 2 and 7 weeks dependent on the extent of injury, and all patients initiated a rehabilitation program early and continued it for 6 months. All 11 patients with grade II instability had good or excellent functional outcomes and 82% returned to full activities. Patients with grade III injuries had much poorer results with only fair outcomes, and 75% needed to decrease their activity level due to pain and/or instability. They concluded that nonoperative management should be reserved for patients with grade II or less lateral instability [54].

Many patients will choose surgical reconstruction of their ACL so that they may maintain an active lifestyle. Mihelic et al. reported 94% stability at 17–20 years post-ACL reconstruction, whereas 84% of nonreconstructed knees had abnormal or severe laxity [55]. Correlating with this, they also noted significantly higher subjective-IKDC scores in the operative group (83 versus 64). In the setting of a combined anterior and lateral knee injury, if operative management is elected for the ACL, then the patient should have the lateral/posterolateral knee injuries addressed as well. Cadaveric studies by LaPrade et al. have shown significantly increased forces on the reconstructed ACL graft in the setting of lateral ligament deficiency [20]. As discussed earlier, if an associated posterolateral corner injury or a varus malalignment is not addressed in conjunction with an ACL reconstruction, then the graft is at an increased risk for early failure [27].

## 11.5 Surgical Indications

In our practice, we tend to favor surgical intervention in patients who sustain a combined anterior and lateral knee injury. While these injuries in isolation may be treated successfully nonoperatively, together they often produce significant instability that remains symptomatic for the patient. Indications for surgery include any active patient involved in pivoting, cutting, or deceleration activities (Table 11.1). We advocate surgery in young patients and patients with concomitant meniscal and/or cartilage pathology, mechanical symptoms, or loss of motion. Any patient that fails nonoperative management and has continued instability and/or pain should undergo surgical stabilization. Relative contraindications to surgery include morbid obesity, advanced age, limited preinjury function, or patients with significant medical contraindications to surgery. These patients should be managed with initial immobilization, aggressive rehabilitation, and functional bracing.

## 11.6 Surgical Management

There is not an overwhelming agreement by surgeons on the surgical management of combined ACL and lateral knee injuries. Algorithms are often based on whether the injury is acute (<3 weeks) or chronic (>3 weeks) [56–58]. While there is general consensus from the literature that surgical treatment of the PLC should be performed if the ACL is reconstructed to reduce the risk of early graft failure, some surgeons advocate repair whereas others prefer reconstruction by a variety of techniques, which will be discussed below.

### *11.6.1 Acute Combined Injuries to the ACL and Lateral Knee*

Initial treatment of the acute ACL/PLC injured knee should consist of immobilization, modalities to reduce soft tissue swelling and intra-articular effusions, and therapy to maximize preoperative range of motion. It is the author's preference to reconstruct the knee within the first 2 weeks. During this time, a complete preoperative workup, as described above, should be performed and an operative plan should be made. This timing also allows for the confirmation of allograft availability, which should be done prior to the surgical date. Finally, when formulating a plan, it is important to consider patient expectations, compliance and motivation, and postoperative resources.

Ross et al. reported on 30-month follow-up on nine patients who underwent early repair (within 2 weeks) of the posterolateral corner with concomitant ACL reconstruction [23]. They recommended early, aggressive treatment after noting favorable outcomes with three normal and six nearly normal knees via the International Knee Documentation Committee (IKDC), 100% satisfaction, and seven patients being able to return to their prior activity level. While the literature is sparse with respect to studies evaluating combined ACL/lateral knee injuries, there is recent evidence that suggests a higher failure rate with repair of the posterolateral corner compared to reconstruction [56, 58, 59]. Stannard et al. prospectively studied 57 patients with a posterolateral corner injury who had either a primary repair or a PLC reconstruction using a modified two-tailed technique and found a 37% failure rate of the primary repair group versus only 9% for the reconstructed [58]. Levy et al. also noted a 40% failure of PLC repairs versus a 6% failure of their PLC reconstructions using a dual femoral and fibular tunnel technique [56].

Thus, in the setting of an acute injury (<3 weeks), many surgeons now advocate augmenting repair of the PLC tissues with a graft reconstruction [27, 56, 58, 59]. We agree with this recommendation, as even in the acute setting the tissues are often inadequate, especially with midsubstance ruptures. Reconstruction of the PLC can follow either anatomic or nonanatomic principles, and there are proponents of both methods.

The biceps tendon transfer procedure, first described by Clancy et al., involved tenodesis of the full biceps tendon onto the lateral epicondyle to re-create the lateral collateral ligament and negate the deforming force of the biceps femoris muscle [60]. As this technique does not address the posterolateral structures and effectively adds to their destabilization by removing the dynamic effect of the biceps femoris, Fanelli et al. modified it to a split biceps tendon transfer procedure [61–63]. In their study of 41 patients treated with combined PCL/PLC reconstructions with this technique and a posterolateral capsular shift, posterolateral stability was restored and the knee was actually tighter than the normal knee in 71% of patients [62]. This phenomenon of overcorrection of abnormal external rotation and varus rotation via a biceps tenodesis procedure is consistent with what Wascher et al. showed in vitro [64]. Although the patients had good functional outcome scores, it is not known whether the apparent overconstraint of the joint with this nonanatomic procedure will normalize or even attenuate into laxity over time, nor do we know the effect it has on the stress seen by the other intra-articular structures.

As it has been shown that the popliteofibular ligament plays an important role in the posterolateral stability of the knee, current techniques emphasize its reconstruction in addition to the LCL [16]. Veltri and Warren described reconstructing the popliteus and popliteofibular ligament with a split patellar tendon or Achilles tendon graft, in which the bone plug was fixed in the common femoral tunnel and the two limbs were passed through tunnels in the proximal tibia and fibula (Fig. 11.7) [65]. They then addressed the LCL independently. Stannard et al. described what they termed a "modified two-tailed" technique, where a tibialis allograft tendon was tensioned through transtibial and transfibular tunnels and fixed on a single isometric point on the lateral femoral condyle with a spiked washer and screw (Fig. 11.8) [66]. Unlike Veltri's technique, this reconstructs the popliteus, popliteofibular ligament, and the LCL, by drilling the fibular tunnel in an anterolateral to posteromedial direction. In a cohort of 22 patients, including 7 combined ACL/PLC reconstructions, they reported excellent functional outcomes and a 9% overall failure rate at a 2-year follow-up [66].

Many surgeons advocate eliminating the tibial tunnel and utilizing only a transfibular tunnel. This is supported by a recently published biomechanical study by Rauh et al., which showed that the transfibular tunnel was equally effective as the dual tibial/fibular tunnels at restoring external rotation and varus stability [67]. Not only is this technically easier, but also it reduces the overall volume of tibial tunnels, which is especially pertinent in the reconstruction of the multiligamentous knee where there may already be multiple tibial tunnels for ACL and/or PCL grafts. Others have shown that reconstruction of the PLC with a single sling through a fibular tunnel has been shown to have better rotational stability, less morbidity, and less operative time when compared to a tibial tunnel [68].

Lee et al. recently published a retrospective review of 44 patients who underwent combined ACL/PLC reconstruction with hamstring autograft using a modified posterolateral corner sling, which involved an oblique fibular tunnel from anteroinferior to posterosuperior (Fig. 11.9) [1]. At a minimum 2-year follow-up, they reported 89% normal or nearly normal IKDC scores, and 91% had similar or improved rotational stability when compared to the contralateral side. While this technique was nonanatomic, with only one femoral tunnel at the isometric point, they suggested that their oblique fibular tunnel was able to restore rotational stability in this combined ACL/PLC injury pattern.

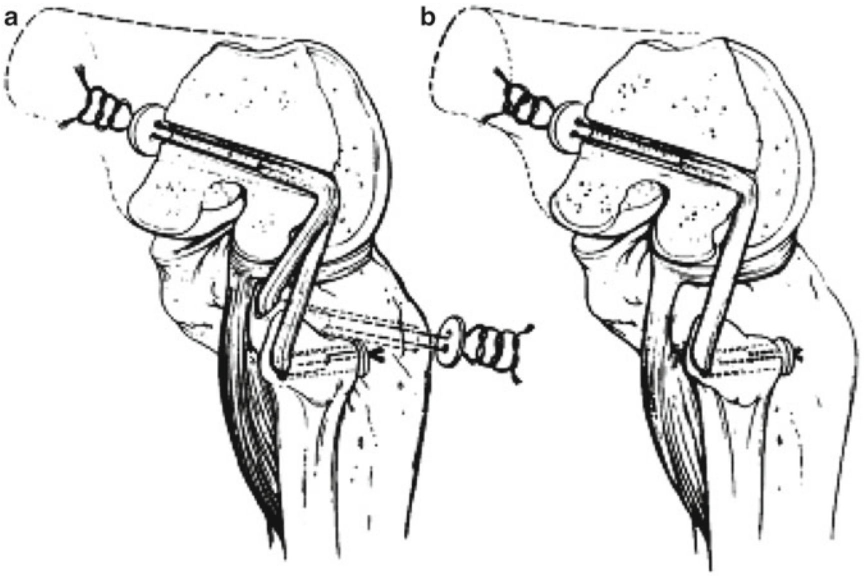
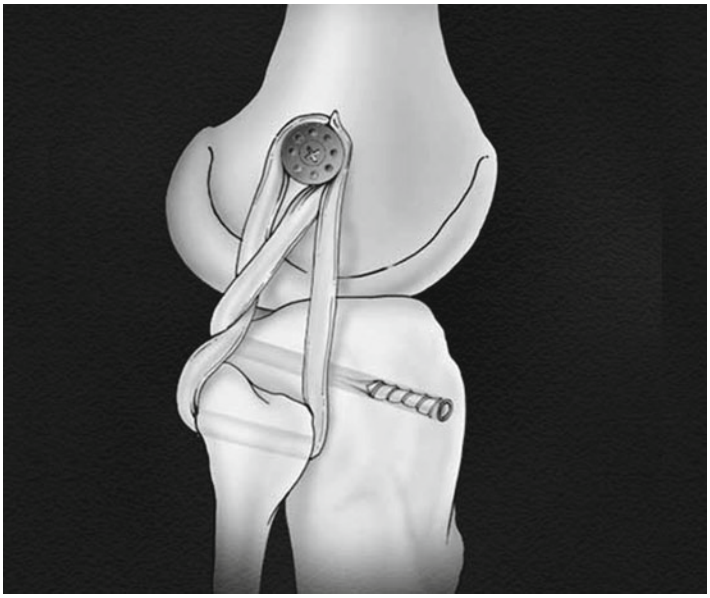


**Fig. 11.7** Reconstruction of the popliteus. (**a**) Reconstruction of the tibial attachment of the popliteus and the popliteofibular ligament with a split patellar tendon graft. (Achilles tendon allograft can also be used.) The graft is fixed in the lateral femoral condyle, and its bifid distal ends are secured in the tibial and fibular tunnels. (**b**) Isolated reconstruction of the popliteofibular ligament with a graft. From [65], reprinted with kind permission from Elsevier

**Fig. 11.8** Diagram depicting the modified two-tailed reconstruction of the posterolateral corner, which addresses the popliteus, popliteofibular ligament, and the LCL. From [48], reprinted by permission of SAGE Publications



Anatomic reconstruction of the posterolateral corner, which involves the placement of two femoral tunnels to replicate both the insertion point of the LCL on the lateral epicondyle and the popliteus tendon 18.5 mm anterior and distal to it, has been shown by several authors to yield excellent results [69–72]. Ho et al. showed improved knee kinematics with better rotational stability and resistance to posterior translation in anatomic PLC reconstructions with two femoral tunnels, compared to a nonanatomic single femoral tunnel technique [73]. We recently published on 24 patients who underwent combined anatomic PLC and cruciate ligament reconstruction at 39 months' follow-up [72]. Good to excellent outcomes were noted in 70% of patients, including 7 patients that had combined ACL and PLC reconstruction.

*Senior Author's Preferred Technique*. In the acute injury, it is preferable to surgically intervene within 2–3 weeks. 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 [74, 75].

**Fig. 11.9** Modified posterolateral sling technique with oblique fibular tunnel and single isometric femoral tunnel. With kind permission from Springer Science+Business Media [1]

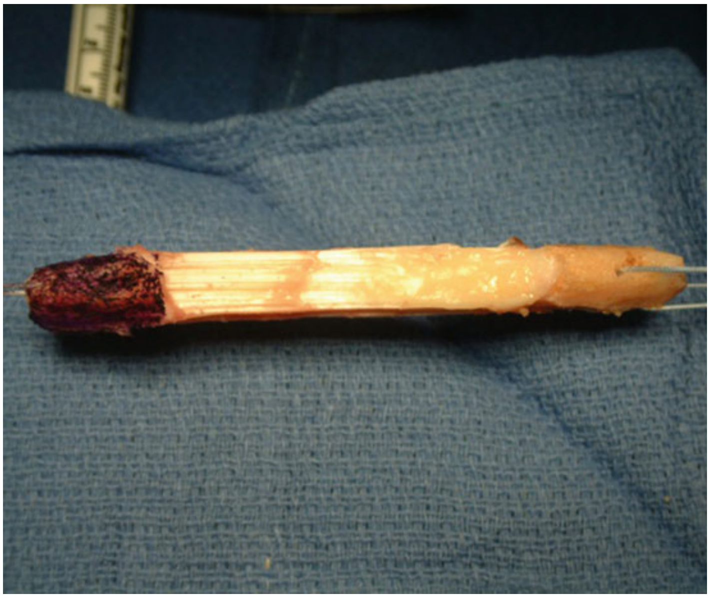


**Fig. 11.10** Prepared bone-patellar tendon-bone autograft. Note the shelf of bone on the left side of the graft (*darkened with marker*) that has been maintained to protect the graft from injury during screw insertion

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 [76]. 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 used to compress and round the edges (Fig. 11.10). 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 allots a level of protection in case 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

**Table 11.2** Key steps for anatomic reconstruction of combined anterior cruciate and lateral knee ligamentous injuries

| |
|---|
| Prepare graft (if harvesting bone-patellar tendon-bone, preserve tibial "shelf" of bone to protect ACL graft when fixing with interference screw in femur) |
| If possible, repair any meniscal injury rather than resect |
| Prepare notch (leave some ACL tissue at footprints, so they are clearly delineated) |
| Drill femoral tunnel with low-profile reamer from low anteromedial portal (hyperflex knee to avoid neurovascular injury) |
| Drill tibial ACL tunnel |
| Pass ACL graft and fix in femur |
| Approach posterolateral corner and perform peroneal neurolysis |
| Drill fibular head tunnel (anterolateral to posteromedial) |
| Drill femoral socket for LCL (to medial cortex) |
| Drill femoral socket for popliteus (maximal 30 mm deep) |
| Pass PLC graft through fibular head and secure in popliteus socket with biotenodesis screw |
| Secure tibial end of ACL graft with the knee in 20° flexion |
| Secure PLC graft into LCL socket with bio-interference screw and the knee in 30° flexion, neutral rotation and slight valgus |

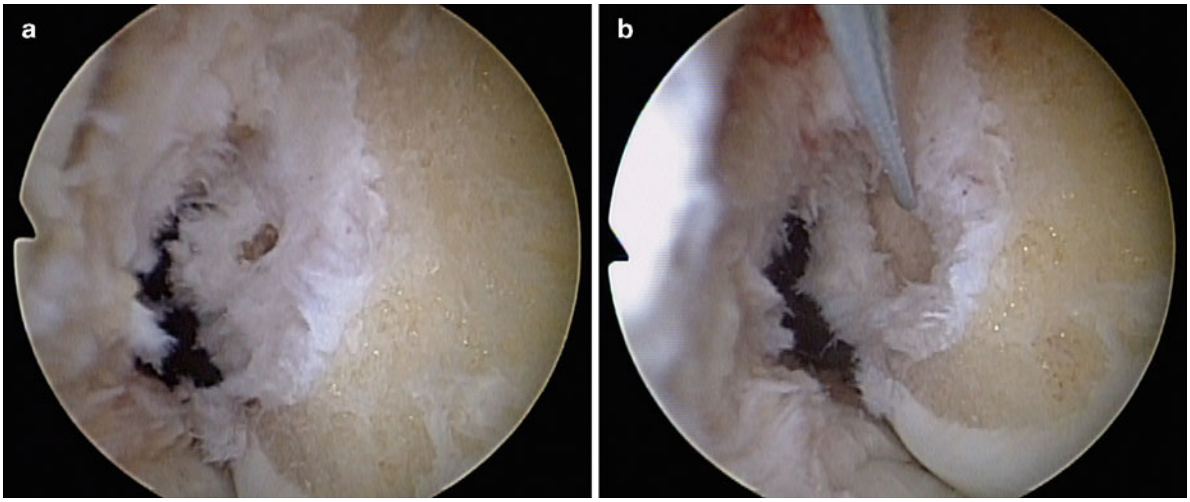


**Fig. 11.11** Femoral ACL tunnel. (**a**) An awl is used to mark the center of the anatomic footprint. This is facilitated by not removing all of the footprint soft tissues. (**b**) Drilled femoral tunnel with passing suture in place

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. Autologous hamstrings are doubled and prepared with a whipstitch of #2 Fiberwire in each end. They are then 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 pretensioned on a tensioning board at 10# for 10 min.

The patient is positioned supine with a well-leg support using a padded boot or stirrup. A nonsterile 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 [77]. The operative extremity is placed into a knee holder if there is preoperative suspicion for a meniscal tear as this enables the surgeon to apply adequate stress to open up the compartments; otherwise a lateral post is used.

Any autograft tissue is harvested initially so that an assistant may prepare the grafts while the surgeon is continuing with the diagnostic arthroscopy (Table 11.2). 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 tissue 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 [78].

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. 11.11). 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. 11.12). The tibial tunnel is

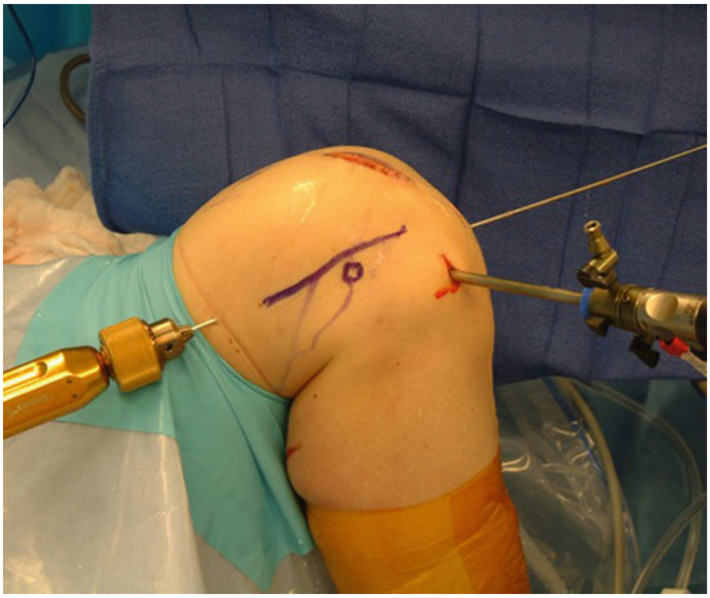


**Fig. 11.12** Appropriate trajectory of guide pin during the drilling of the femoral tunnel is achieved by hyperflexing the knee

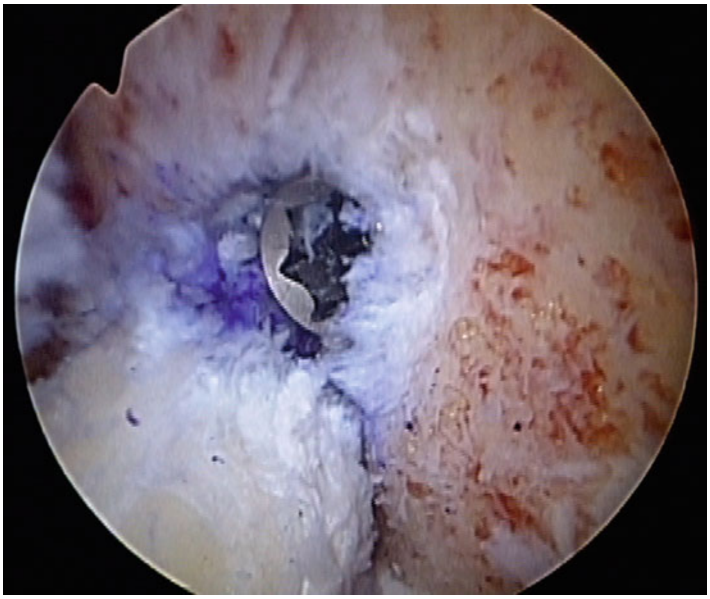


**Fig. 11.13** Metal interference screw fixation in femur of bone-patellar tendon-bone ACL graft. Note the shelf of bone is anterior against the screw and the collagen of the tendon is protected posteriorly

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. 11.13).

The posterolateral corner is then approached via a curvilinear incision, and three fascial incisions are made, as described by Terry and LaPrade [79]. The first incision is made over the posterior aspect of the biceps femoris, exposing the peroneal nerve for a neurolyis 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 posteromedial) fibular tunnel (Fig. 11.14). 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. 11.15).

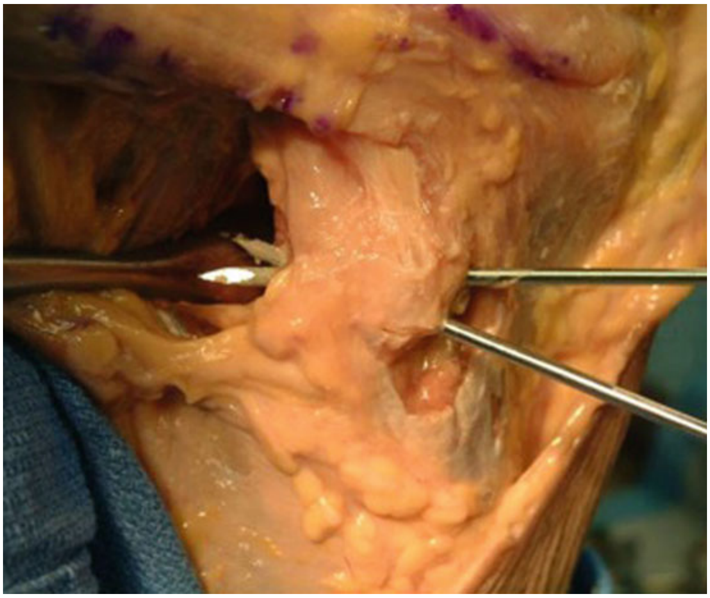


**Fig. 11.14** Photograph demonstrating the oblique fibular tunnel. (Note the difference compared with traditional direct anterior-posterior guide-wire placement.)

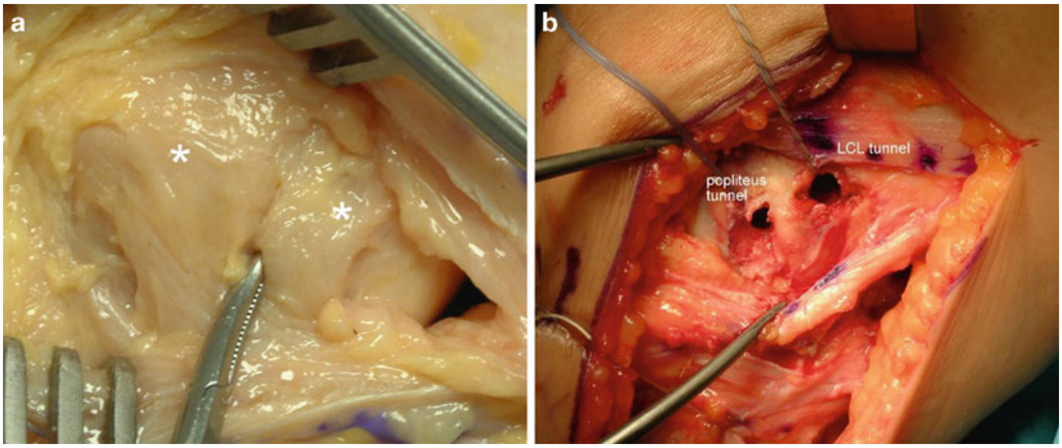


**Fig. 11.15** Anatomic posterolateral corner reconstruction. (**a**) Photograph of the anatomic femoral attachments of LCL and popliteus tendon (*asterisks*). Note the popliteus is 18.5 mm distal and anterior to the LCL origin. (**b**) Intraoperative photograph showing the dual femoral tunnels. From [27], reprinted with kind permission from Elsevier

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 biotenodesis screw (which is a type of biointerference 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. 11.16). Finally with the knee in 30° 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. 11.17).

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 [80]. 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° [80]. 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 points allow our trajectories for the PLC tunnels to be distinct from the ACL tunnel.

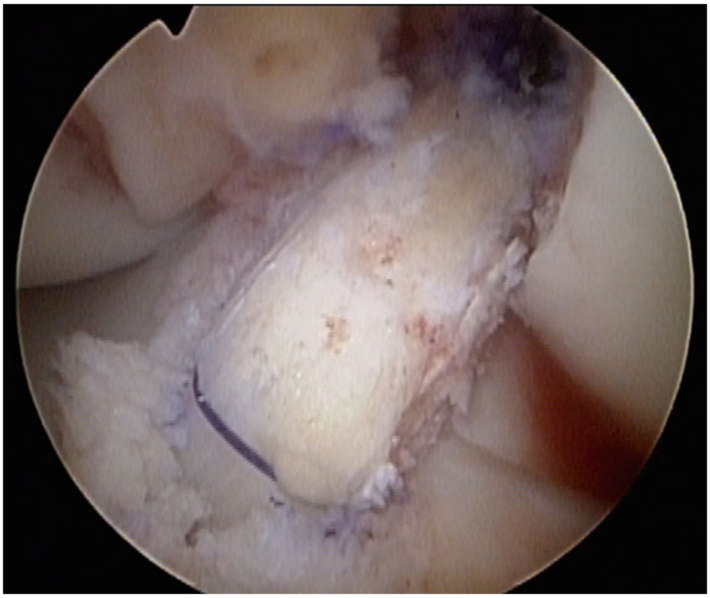


**Fig. 11.16** Arthroscopic view of completed ACL reconstruction

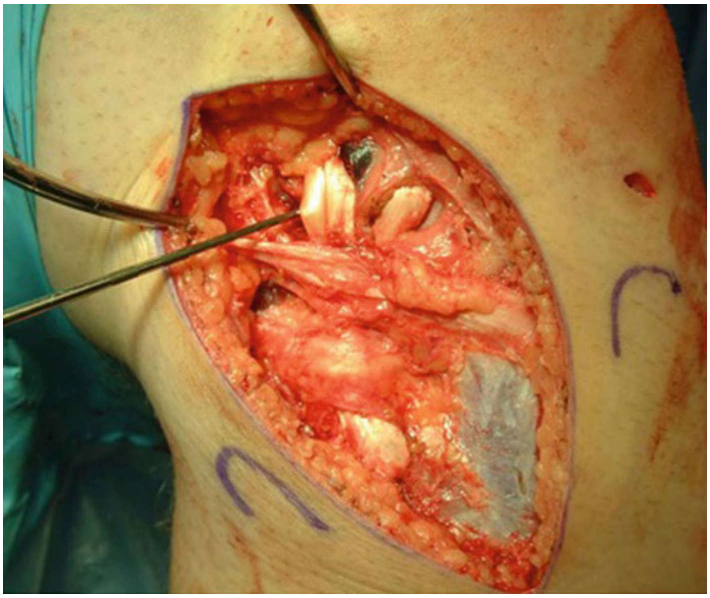


**Fig. 11.17** Completed anatomic posterolateral corner reconstruction. From [27], reprinted with kind permission from Elsevier

### 11.6.2 *Chronic Combined Injuries to the ACL and Lateral Knee*

It is not uncommon for patients to present to the surgeon's office with a combined ACL/PLC injury in a delayed manner. They may be chronic injuries (>6 weeks) that were either initially unrecognized or those that failed a trial of nonoperative management. Or they may be subacute in nature (>3 weeks, but less than 6 weeks). In this setting, the patient may present with significant swelling and reduced motion and require crutches for ambulation. As with the acutely injured knee, any patient that has any loss of extension >5° or loss of flexion beyond 100° should undergo a vigorous course of therapy to regain range of motion and resume a fairly normal gait prior to considering surgical stabilization. Reconstruction of the stiff, swollen knee predisposes the patient to the postoperative complication of significant motion loss.

Chronic injuries are associated with poor tissue quality, and thus reconstruction of the PLC is indicated, and there is no role for a primary repair. In the chronically unstable knee, surgical intervention is warranted, and the authors follow the same technical guidelines as those described above for the acute injury. It must be emphasized that it is extremely important in the chronic multiligament knee to thoroughly evaluate alignment of the extremity, as it is not uncommon for the patient to have a triple varus knee from long-standing instability [30]. These patients may benefit from an opening wedge high tibial osteotomy to complement the reconstruction. In a study of 41 chronic-ACL reconstructed knees with HTO, in which 18 were triple varus knees that required posterolateral reconstruction, Noyes et al. noted 71% good or very good results and elimination of instability in 85% of patients [30]. As their patients had an average of 4 procedures prior to the reconstruction, which was eventually performed at an average of 4 years after injury, they recommended osteotomy in addition to ligament reconstruction in these complex chronic combined anterior and lateral knee injuries [30].

## 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 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 the surgical management of combined anterior and lateral knee injuries include wound infection, hematoma, loss of postoperative knee range of motion, failure of the reconstruction with recurrent pain and/or instability, and hardware irritation [14]. 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 [47].

Lee et al. reported a complication rate of 11.4% (5/44 patients) in patients undergoing combined ACL/lateral knee reconstructions at a median of 5 months from injury [1]. In his cohort, complications included arthrofibrosis in two patients, recurrent injury in one patient, and a septic arthritis in two patients. In an evaluation of 15 multiligament knee reconstructions, where 7 were combined ACL/PLC, Stannard et al. reported a wound complication rate of 20% (to include a hematoma, infection, and a fistula) and a 27% incidence of postoperative arthrofibrosis requiring an arthroscopic lysis of adhesions [66].

## 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 left unaddressed these entities can lead to early graft failure of the reconstructed ACL. 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 both varus and external rotation.

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# Chapter 12
# Surgical Treatment of Combined ACL Medial and Lateral Side Injuries: Acute and Chronic

**Bradley R. Wasserman and Robin V. West**

## 12.1 Introduction

The initial treatment of a knee with multiple ligament injuries begins with a thorough history and detailed physical examination. Vascular and nervous injuries are not uncommon in the multiple-ligament-injured knee and must be recognized and treated accordingly. If a reduction is performed in the setting of a knee dislocation, a thorough neurovascular examination must be performed both pre- and post-reduction. Once all limb-threatening injuries have been addressed, a repeat physical examination is necessary to ensure that all associated injuries are recognized. The purpose of this chapter is to describe the management of combined anterior cruciate ligament (ACL) and medial-sided injuries as well as combined ACL and lateral-sided injuries. One of the more common reasons for failure after anterior ACL reconstruction is failure to recognize concomitant ligament injuries including the posterior cruciate ligament (PCL) as well as the posterolateral corner (PLC). Additionally, operating on a knee with an unrecognized combined ACL and medial collateral ligament (MCL) injury can lead to stiffness or recurrent valgus instability, depending on the location and severity of the MCL tear.

## 12.2 Combined ACL/MCL/Posteromedial Corner Injuries

Combined ACL and MCL/posteromedial corner injuries have an estimated frequency of 6.7% of all knee ligament injuries [1]. These injuries can be associated with both high and low energy mechanisms.

The superficial MCL is the primary restraint to valgus stress at 30° of flexion. To evaluate the MCL, a valgus stress is applied to the knee at both 30° of flexion and full extension. Medial joint opening less than 5 mm with the knee in 30° of flexion is characteristic of a grade I isolated MCL injury; medial joint opening between 5 and 10 mm is indicative of a grade II MCL tear, whereas opening greater than 10 mm is consistent with a grade III MCL rupture. Opening between 5 and 10 mm with the knee in full extension is characteristic of a combined ACL and medial-sided injury. Medial joint opening more than 10 mm in full extension is consistent with a combined bi-cruciate ligament and medial-sided injury. In addition to cruciate injury, patellar instability and tearing of the vastus medialis obliquus (VMO) are associated with laxity in full extension.

## 12.3 Imaging

Plain radiographs are required to evaluate for the presence of fractures and to assess for tibiofemoral subluxation or dislocation. Initial views in the acute setting should include anteroposterior (AP) and lateral radiographs. When presentation is more delayed and the patient can bear weight, a forty-five degree posteroanterior (PA) flexion view should be obtained to allow for more

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accurate assessment of the tibiofemoral joint space [2] as well as a patellar axial view to evaluate the patellofemoral joint. Magnetic resonance imaging (MRI) is a sensitive tool for identifying soft tissue structures in a patient whose physical examination is difficult to assess secondary to guarding. It provides detail for injuries of the menisci, cruciate ligaments, the superficial MCL, POL, posteromedial complex, and semimembranosus tendon. It is also useful for identifying osteochondral injuries and can be helpful in preoperative planning to identify the location of the MCL tear and therefore limit the exposure needed intraoperatively.

## 12.4 Nonoperative Treatment

Numerous factors, including the severity, location, time from injury, as well as associated injuries, must be considered when formulating a treatment plan. There is no specific algorithm that can be generalized to the entire population; it needs to be individualized based on the patient's clinical exam, comorbid diseases (if present), occupation, and physical demands. The MCL is an extra-articular ligament with an intrinsic ability to heal. While the ACL is composed of cells that resemble fibrocartilage, the MCL has cells characteristic of fibroblasts, which may be another reason that the MCL has a superior intrinsic healing ability. Combined injury to the MCL and ACL represents a completely different entity than an isolated MCL injury. Even though the general consensus is that isolated MCL ruptures can be treated nonoperatively, the optimal treatment for a concurrent ACL and MCL injury remains controversial. Nonoperative treatment of the MCL in the setting of an ACL tear is indicated for midsubstance MCL tears, grade I MCL tears, grade II femoral-sided MCL tears in patients who are not professional or competitive athletes, and grade III femoral-sided MCL tears in non-active individuals. In these scenarios, management of active individuals consists of delayed surgical reconstruction of the ACL, typically 6 weeks post-injury, to allow the MCL to heal.

Initial treatment of these injuries involves placing the extremity in a hinged knee brace locked in full extension and protected weight-bearing with crutches. We encourage rest, ice, and elevation to help decrease swelling. After a brief period of immobilization (the authors prefer 1 week for femoral-sided injuries and 2–3 weeks for tibial injuries), the knee should be reexamined by applying a gentle valgus stress. Once the swelling has subsided, and the MCL is stable with a good endpoint, the brace should be unlocked to allow for flexion and extension range-of-motion (ROM) exercises and quadriceps and hamstring strengthening should begin. Once the patient can ambulate without a limp, the crutches can be discontinued; stationary bicycle riding can begin as tolerated. Patients who wish to return to cutting sports (basketball, football, soccer, volleyball) or whose jobs require knee stability (armed services, manual laborers, firefighters, workers on ladders) or wish to maintain an active lifestyle, an ACL reconstruction is indicated. In these patients an ACL reconstruction should be performed once full ROM is achieved. Additionally, if residual laxity to valgus stress is present at the time of ACL reconstruction, the MCL can be addressed surgically at that time.

## 12.5 Operative Management

The indications for operative treatment of an MCL tear/PMC injury in the setting of an ACL tear continue to remain controversial. The three main surgical options include (1) surgical reconstruction/repair of both ligaments, (2) ACL reconstruction and nonoperative treatment of the MCL, and (3) operative management of the MCL with nonoperative treatment of the ACL (Fig. 12.1). An additional area of controversy relates to the timing of the ACL reconstruction, early versus late. Generally speaking, the indications for operative management of an MCL tear/PMC injury in the setting of a concurrent ACL tear include a femoral or tibial-sided MCL avulsion; a Stener lesion, in which the distal MCL is flipped over the pes anserinus tendons; and grade II or III MCL tears in active individuals. A femoral or tibial-sided MCL avulsion is best managed with a single-stage procedure consisting of an ACL reconstruction and repair of the MCL to its anatomic origin (femoral) or insertion (tibial). This is best accomplished with a screw and washer. Tissue augmentation or reconstruction is typically not necessary in avulsion-type injuries. The repair is performed in 30° of flexion. In the setting of gross clinical instability, treatment options consist of MCL reconstruction, distalizing the tibial attachment of the MCL, and/or recessing the femoral attachment.

Knowledge of the clinically relevant anatomy of the medial aspect of the knee is critical to optimize functional results after an MCL reconstruction. The medial side of the knee is arranged into three layers (Fig. 12.2) [3]: layer 1 consists of the sartorius and the sartorius fascia; layer 2 is defined by the parallel fibers of the superficial MCL, posterior oblique ligament (POL), and semimembranosus; and layer 3 consists of the deep MCL and the posteromedial aspect of the capsule. The gracilis and semitendinosus are located between layers 1 and 2, while the posterior aspect of layer II merges with layer III to

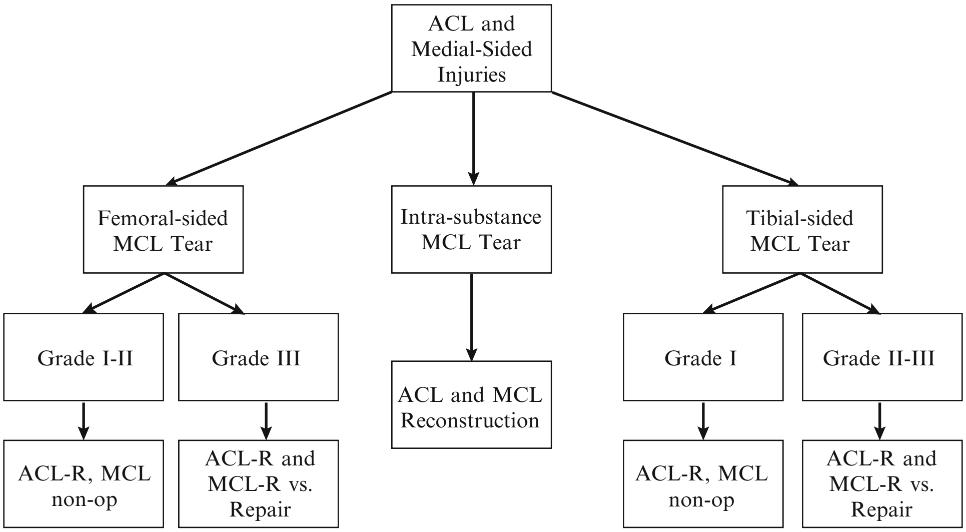

**Fig. 12.1** Treatment algorithm for combined ACL and medial-sided knee injuries

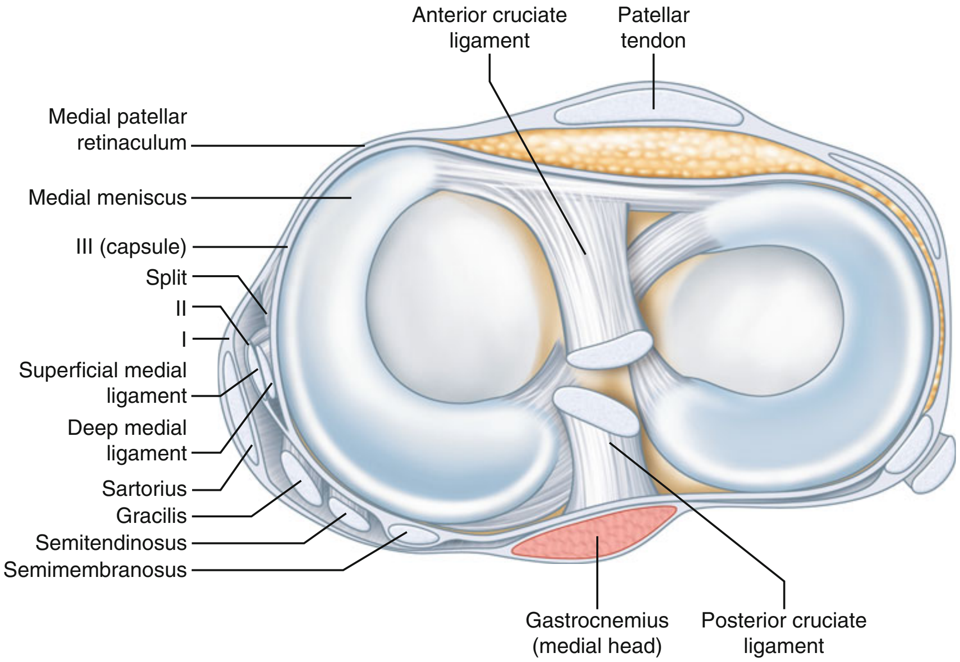

**Fig. 12.2** Cross section demonstrating the three layers of the medial side of the knee. Reprinted with permission from Warren LF, Marshall JL. The supporting structures and layers on the medial side of the knee: an anatomical analysis. J Bone Joint Surg Am. 1979;61:56–62

form the posteromedial corner. LaPrade et al. [4] performed a cadaveric study evaluating the anatomy of the medial aspect of the knee. They noted three osseous prominences on the medial aspect of the distal femur: the medial epicondyle, the adductor tubercle, and the gastrocnemius tubercle. The superficial MCL is the largest structure on the medial knee. The femoral attachment is an average of 3.2 mm proximal and 4.8 mm posterior to the medial epicondyle and has an average length of 10–12 cm. The majority of the distal attachment is located within the pes anserine bursa, with the posterior aspect blending with the distal aspect of the semimembranosus tendon, an average of 61.2 cm distal to the joint line. The POL is a thickening of the capsular ligament. Its origin lies approximately 8 mm distal and 6 mm posterior to the adductor tubercle [4]; distally it fans out into three different arms: (1) the tibial arm inserts close to the posterior edge of the tibial articular surface, (2) superior (or capsular) arm which is continuous with the posterior capsule and is confluent with the oblique popliteal ligament, and (3) a poorly defined superficial (distal) arm that inserts onto the semimembranosus tendon and the tibia [5]. The deep MCL extends from the femoral condyle to the meniscus (meniscofemoral) and from the meniscus to the tibia (meniscotibial ligament).

## 12.6 Authors' Preferred Technique

### *12.6.1 ACL Reconstruction*

We perform an anatomic single-bundle ACL reconstruction using a three-portal technique. We routinely do not use a tourniquet for an ACL reconstruction. The anterolateral portal is used for visualization: for the diagnostic arthroscopy, meniscal repair/meniscectomy, and visualization of the tibial tunnel during the ACL reconstruction. An anteromedial portal serves dual purposes: a working portal for meniscal surgery, as well as for visualization of the intercondylar notch during identification of the anatomic ACL footprint, and drilling of the femoral tunnel. In our experience this portal provides the optimal view of the medial aspect of the lateral femoral condyle. We utilize an accessory anteromedial (AAM) portal for drilling of the femoral tunnel. It is important to hyperflex the knee when drilling from the AAM portal to obtain a longer femoral tunnel. Graft choice is surgeon dependent; in the setting of an isolated ACL reconstruction, our graft preference is to harvest quadrupled hamstring autografts (gracilis and semitendinosus doubled over) in young patients; however, we alternatively utilize a bone-patella tendon-bone (BPTB) autograft in patients with grade II or III MCL injuries due to concern for valgus laxity in these patients. If we plan on simultaneously reconstructing the MCL, we prefer allograft tissue for the MCL reconstruction, as described below. In older patients with less physical demands or individuals that participate in activities that involve less cutting and pivoting maneuvers, we prefer to use allograft tissue for the ACL reconstruction, with the same technique described above.

### *12.6.2 MCL/PMC Reconstruction*

With the exception of femoral or tibial-sided avulsions, which we treat with a screw and washer, or suture anchors, we prefer to reconstruct the MCL with a double-bundle technique with the medial epicondyle as the femoral origin for both bundles and separate anterior and posterior insertion sites on the tibia. We proceed with an imbrication of the POL, as needed. We prefer to use a tibialis anterior or semitendinosus allograft. We prepare the allograft by doubling it over and whipstitching 3 cm of the looped-over graft, followed by whipstitching 2 cm of each of the 2 free ends of the tendon in a running baseball fashion. Our reconstruction technique is similar to that described by Borden et al. [6]. We palpate the medial epicondyle and make a 2–3 cm longitudinal incision centered over it and carry the dissection down, exposing the origin of the superficial MCL on the femur. A 2 mm Kirschner wire (K-wire) is drilled into the center of the origin from medial to lateral out the lateral cortex of the femur. Next we identify the insertion of the superficial MCL on the tibia. Using the same incision that we used to drill the ACL tibial tunnel, dissection is carried down to the sartorius fascia. This is split along the superior border of the gracilis tendon to expose layer II of the MCL and the attachment of its anterior fibers on the tibia. A tunnel is made using blunt dissection with either a clamp or a finger from the femoral incision, along layer II of the MCL, so that it can be seen exiting out the tibial wound along the same direction as the MCL fibers.

To ensure isometry of the reconstruction, a suture is looped over the K-wire in the femoral condyle and then passed in the direction of the MCL along the tunneled path made via blunt dissection. Isometry is evaluated by holding the suture at the MCL tibial insertion site and moving the knee through a full ROM. The isometric point on the tibia is the location where there is little or no change in length of the suture. Next we proceed with drilling of the tunnels. The femoral tunnel is drilled over a K-wire with the reamer the same diameter as that of the looped allograft. The tibial tunnels are then drilled, again the same diameter reamer as that of the non-looped free ends of the graft, without penetrating the lateral cortex to minimize damage to the peroneal nerve. If there is a size discrepancy between the 2 free ends, we prefer to use the wider bundle for the anterior tunnel. Using a Beath pin with a passing suture, we pass the tendon through the femoral tunnel and out the lateral aspect of the femur. The graft is fixed with a bioabsorbable interference screw (usually 25 mm in length). The remainder of the graft is passed through the previously created plane over layer II down to the tibial insertions. We use the Arthrex (Naples, FL) biotenodesis screw for tibial tunnel fixation. By using this technique we avoid using a Beath pin, breaching the anterolateral tibial cortex, and injuring the neurovascular bundle. The posterior bundle is passed from medial to lateral and fixed with a bioabsorbable tenodesis screw, with the knee in 60° of flexion with a gentle internal rotation force [6]. The anterior

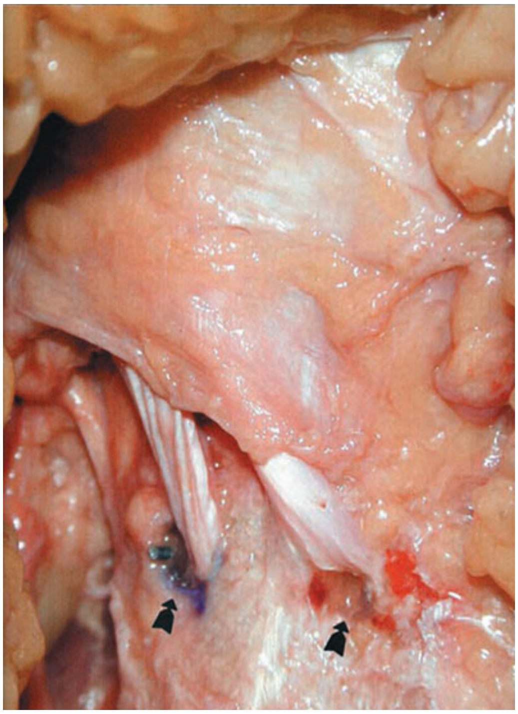

**Fig. 12.3** Figure demonstrating placement of the anterior and posterior bundles in the tibia for an MCL reconstruction with bioabsorbable screws, depicted by the arrows. Reprinted with permission from Borden PS, Kantaras AT, Caborn DNM. Medial collateral ligament reconstruction with allograft using a double-bundle technique. Arthroscopy 2002;18(4):E19

bundle is then passed in a similar fashion and fixed with the knee in 30° of flexion and the leg internally rotated (Fig. 12.3). The knee is taken through a full ROM, ensuring adequate tension of both the anterior and posterior bundles. The POL is inspected. If there is any laxity upon palpation or if laxity persists after a valgus stress is applied to the knee, we proceed with an imbrication of the POL in a pants-over-vest fashion. The wounds are then closed in layered fashion.

When a combined ACL/MCL is performed, we perform our diagnostic arthroscopy and drill the ACL femoral and tibial tunnels prior to drilling the MCL tunnels. We place a tunnel dilator through the ACL tibial tunnel to minimize convergence of the MCL tibial tunnels with the ACL tibial tunnel as the tibial tunnels for the MCL reconstruction are drilled blindly (without penetrating the lateral cortex). If this begins to occur, the dilator will limit further drilling of the MCL tunnel and it can be redirected as needed. In those patients who had an ACL reconstruction after nonoperative management of the MCL and mild valgus laxity is present at the time of the ACL reconstruction, Jari and Shelbourne have reported treating the MCL via multiple sharp longitudinal perforations to stimulate further healing. The authors concluded that this technique can tighten the MCL without compromising knee ROM [1]; however we have no experience with this technique.

## 12.7 Postoperative Management

Postoperative rehabilitation consists of placing the knee in a hinged knee brace locked in full extension for a maximum of 2 weeks, after which time the brace is unlocked to allow for progressive range-of-motion exercises. However others have advocated immobilizing in extension greater than 3 weeks [7]. The authors' preference is to allow the patient to weight-bear as tolerated with the brace locked in extension for 6 weeks. Crutches are discontinued after the patient is able to bear full weight, and closed kinetic chain strengthening is initiated. Once the patient regains full motor strength, and proprioceptive skills, they are permitted to return to sports and/or strenuous labor, typically after 9 months postoperatively. Following complex knee ligament reconstructions, 10–15° loss of flexion can be expected.

Despite the advances in treatment of multi-ligamentous knee injuries, we have only found one prospective randomized trial regarding the treatment of grade III MCL injuries with concurrent ACL tears. In 2006, Halinen et al. evaluated their results of a prospective randomized trial of 47 patients with combined ACL and grade III MCL injuries [8]. All patients underwent early ACL reconstruction (within 3 weeks of injury); 23 patients had their MCL treated operatively, while 24 underwent nonoperative management of the MCL. The authors reported that the patients who underwent nonoperative treatment of the MCL had similar results to those treated surgically in terms of Lysholm score, subjective function, knee stability, and ROM. The authors concluded that when the ACL was reconstructed early, grade III MCL tears can be treated nonoperatively.

To our knowledge, no prospective studies have directly compared MCL repair versus reconstruction in the setting of an ACL tear. Stannard et al. retrospectively reviewed their outcomes in 73 dislocated knees with posteromedial injuries [9]. Twenty-five patients had a repair of the posteromedial corner (PMC); five (20 %) failed requiring revision. Autograft reconstructions were performed on 27 knees with 1 (3.7 %) failure. Allograft reconstructions were performed on 21 knees with only one (4.8 %) failure. There was a significant difference between the failure rate of PMC repairs and reconstructions ($p=0.042$). The authors concluded that PMC repair is inferior to reconstruction in patients who sustain knee dislocations. Studies have also noted differences in ROM after ACL reconstruction combined with MCL repair based on location of the MCL tear. Robins et al. [10] retrospectively analyzed their results in 20 patients, 13 who had MCL tears at or proximal to the joint line and 7 with tears distal to the joint line. They noted a statistically significant faster return of motion (flexion and extension) in patients with MCL lesions distal to the joint line. The authors also demonstrated 8° more flexion (statistically significant) and 3° more extension (did not reach statistical significance). Furthermore, there was a trend toward more subsequent procedures (extension casting, manipulations, surgical releases) in the cohort with proximal MCL disruptions (eight procedures in five patients) versus no additional procedures in the group with distal disruptions, $p=0.053$.

## 12.8 Combined ACL/Lateral-Sided Injuries

Combined ACL and lateral-sided injuries have been reported to comprise 0.4% of all knee ligament injuries, while combined ACL/PCL/lateral-sided injuries occur in 0.3% of knee ligament injuries [1]. Miyasaka et al. reported that the incidence of combined grade III ACL-posterolateral rotatory insufficiency was 1.2% of all knees with pathologic motion [11]. Isolated lateral-sided injuries are extremely uncommon; to this end, physicians should have a high suspicion for additional ligament injuries when evaluating patients. The incidence of peroneal nerve injuries in patients with combined ACL and posterolateral knee injuries has been reported in 27% of patients in one series [12]. Therefore clinicians must have a high index of suspicion of neurovascular injuries in patients with multiple-ligament-injured knees. The lateral side of the knee consists of both static and dynamic stabilizers. The primary static stabilizer to varus stress is the lateral (fibular) collateral ligament (LCL). Additional static stabilizers include the popliteofibular ligament (PFL) and the posterolateral aspect of the capsule. The popliteus muscle and tendon are responsible for both static and dynamic components to posterolateral stabilization of the knee. The PFL acts as the primary restraint to external rotation of the knee at 30° of flexion with additional stability provided by the popliteus. The posterolateral aspect of the capsule provides additional resistance to external rotation, hyperextension, and varus-directed forces on the knee [7]. The long and short heads of the biceps femoris, the iliotibial band (ITB), and the lateral gastrocnemius muscle have also been proven to provide varus stability when the LCL is incompetent.

The most common mechanisms of injury to the LCL and/or PLC, resulting in posterolateral instability, include a direct blow to the anteromedial aspect of the knee, a varus-directed noncontact force, or a hyperextension injury. The common denominator is a stress applied to the structures that comprise the PLC, which resist varus rotation and posterolateral tibial rotation, as described above. Additionally, a hyperextension force which results in posterior tibial translation with the knee in full or near-full extension can damage the structures of the PLC. Therefore a thorough physical examination is essential when evaluating patients with posterolateral injuries, as the majority of injuries to the lateral side of the knee are often multi-ligamentous. When assessing competency of the LCL/PLC, specific physical examination tests are utilized to assess the involvement of specific anatomic structures. A varus stress test is applied at both full extension and 30° of flexion. Opening less than 5 mm compared to the contralateral knee indicates a grade I injury; 6–10 mm of opening is characteristic of a grade II injury, while more than 1 cm opening is described as a grade III injury. Grade I–II injuries at 30° of flexion are indicative of isolated tearing of the LCL, while grade III tears correlate with complete tearing of the LCL as well as the possibility of injury to additional varus stabilizers [13]. Opening at full extension is consistent with a severe LCL injury, as well as possible injury to the lateral capsule and damage to the popliteus, ACL and/or PCL, and/or superficial layer of the ITB. The external rotation recurvatum test evaluates for combined ACL and PLC injury. In a positive test, the knee falls into recurvatum and varus; increased external rotation can be seen by lateral rotation of the tibial tubercle. To test for an isolated PLC injury, the dial test is performed at 30° of flexion. Increased external rotation greater than 10° compared to the contralateral knee is consistent with a PLC injury, whereas a positive dial test at 90° of flexion is indicative of combined PLC/PCL injury [14]. The posterolateral drawer test also evaluates posterolateral stability. This compares external tibial rotation and posterior tibial translation in relation to the lateral femoral condyle. After flexing the knee 80° and the hip 45°, the examiner stabilizes the patient's foot. Increased posterior translation with the knee externally rotated is consistent with a popliteal injury/PLC injury, whereas increased posterior translation with the knee in neutral or internal rotation is characteristic of a PCL injury.

As with medial-sided injuries, knowledge of the attachment sites of the structures of the posterolateral aspect of the knee is important for both repair and/or reconstruction. The LCL originates on the femur an average of 1.4 mm proximal and 3.1 mm posterior to the lateral epicondyle; its distal insertion, on average, lies 28.4 mm distal to the tip of the fibular styloid and a mean of 8.2 mm posterior to the anterior aspect of the fibular head [15]. The popliteus originates on the posteromedial aspect of the proximal tibia. As it courses proximally and laterally, the tendon becomes intra-articular and courses around the posterior aspect of the lateral femoral condyle. It lies medial to the LCL prior to inserting on the popliteal sulcus. The popliteus tendon insertion lies anterior and distal to the origin of the LCL on the femur with an average distance of 18.5 mm between the two structures (see Fig. 3.1b). The PFL consistently has 2 divisions, an anterior and posterior [15]. Both the anterior and posterior divisions of the PFL originate at the proximal-lateral aspect of the musculotendinous junction of the popliteus. The attachment of the anterior division of the PFL is, on average, 2.8 mm distal to the tip of the fibular styloid on the anteromedial downslope, whereas the posterior division attaches a mean of 1.6 mm distal to the tip of the fibular styloid on its posteromedial downslope. After dissecting out the posterolateral structures of the knee in ten cadavers, LaPrade et al. reported that the posterior division of the PFL was larger than the anterior division in all knees studied in their series.

## 12.9 Imaging

As with combined ACL and medial-sided injuries, plain radiographs are required to evaluate for the presence of fractures and to assess for tibiofemoral subluxation or dislocation when concern exists for lateral-sided injuries. The same initial views in the acute setting are performed and include AP and lateral radiographs. We also obtain long-cassette films to assess the mechanical alignment of the extremity and for comparison to the contralateral limb. When presentation is more delayed and the patient can bear weight, a forty-five degree posteroanterior (PA) flexion view and patellar axial views should be obtained. MRI is sensitive for identifying soft tissue injuries if the patient is difficult to examine clinically secondary to guarding. The MRI is essential for preoperative planning as it can provide detailed information about which structures of the PLC are injured [16]. Varus and valgus stress radiographs can be performed to assess the degree of joint opening, but these are not routinely obtained.

## 12.10 Nonoperative Treatment

The role of nonoperative treatment for combined ACL and lateral-sided injuries is limited. Exceptions include patients who are hemodynamically unstable and cannot undergo surgery or in non-ambulators. Krukhaug et al. reported good outcomes in patients with mild (1+) isolated varus instability treated nonoperatively [17]. Six of seven patients with 1+ isolated lateral instability were completely stable to varus stress at a median follow-up of 7.5 years. The one patient with persistent 1+ instability was treated in a plaster cast for 6 weeks; the remaining six that were stable were treated with primary mobilization. They concluded that patients with isolated 1+ varus instability should be treated with primary mobilization and patients with more serious (2+ and 3+) varus instability have a higher percentage of combined ligament injuries and should be treated surgically. In addition, Kannus reported that patients with 2+ and 3+ varus instability with or without only partial cruciate ligament injuries remained unstable or even worsened when treated nonoperatively [18]. Our preference is to treat mild (1+) isolated varus instability nonsurgically (which is beyond the scope of this chapter) and those with grade 2+ or 3+ instability or combined lateral-sided and cruciate ligament injuries surgically (Fig. 12.4).

## 12.11 Operative Management

Many patients with multiple-ligament-injured knees have sustained injuries to other organ systems. Therefore the timing of operative treatment may be dictated by other factors, including hemodynamic instability, open versus closed injury, vascular compromise of the limb, and/or the skin condition of the limb. There are a variety of techniques that have been described for the surgical management of PLC injuries. Operative treatment can be broadly categorized into primary repair, augmentation, and reconstruction. However, the optimal treatment of an unstable PLC remains unclear. Surgical treatment of acute PLC injuries is more successful in restoring function when compared to chronic injuries [17, 19–22]. If addressed in the first 3 weeks after injury, some authors advocate primary repair of posterolateral knee injuries as that has yielded good results [17, 19–21]. For acute injuries where the severity of injury to the soft tissue is not amenable to direct repair, injured structures can

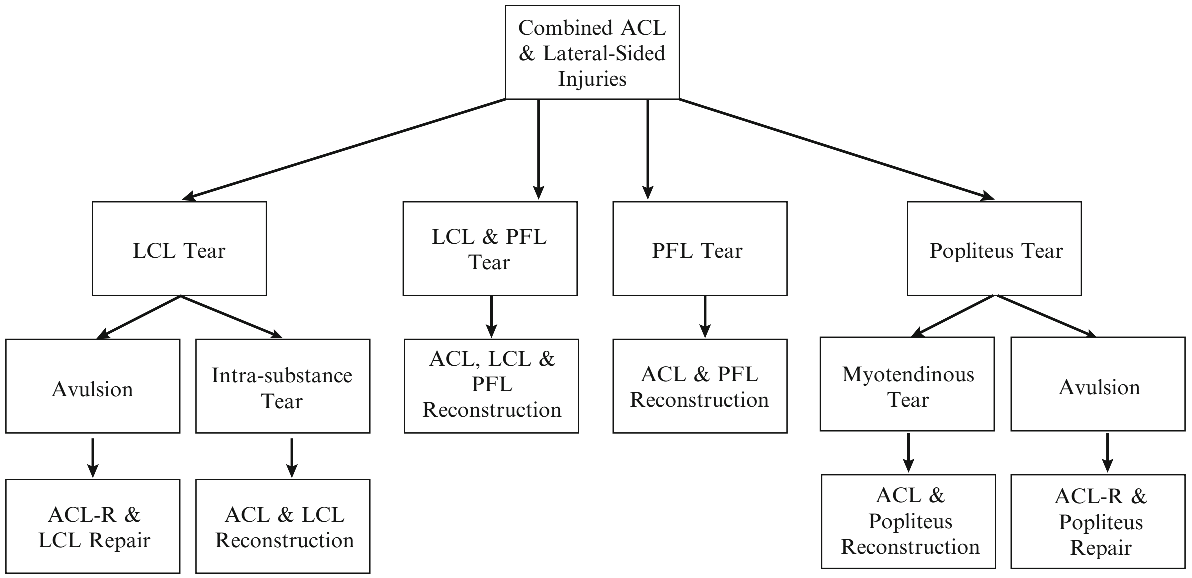

**Fig. 12.4** Treatment algorithm for combined ACL and lateral-sided knee injuries

be augmented with an autograft including the hamstring tendons, biceps femoris tendon, ITB, or an allograft; alternatively, an anatomic reconstruction can be performed (see Fig. 12.4). For chronic PLC injuries, improved outcomes have been reported after anatomic PLC reconstruction as compared with repair [9, 23]. Our preference for combined ACL and posterolateral injuries is to surgically address the damaged structures as early as possible after the soft tissue swelling has subsided. Acutely (within 3 weeks of injury), this includes anatomic ACL reconstruction with allograft as described above, followed by direct repair of the injured posterolateral injuries. These are typically direct avulsions of the LCL, popliteus and/or biceps femoris tendons, or fibular head fractures. We also perform a peroneal nerve neurolysis if there are any neurological deficits. In patients with soft tissues that are not amenable to repair, we proceed with an anatomical PLC reconstruction with allograft tissue. In chronic cases, we prefer to perform an anatomic ACL reconstruction in conjunction with an anatomic PLC reconstruction [24].

## 12.12 Authors' Preferred Technique

### *12.12.1 Acute*

We begin with a diagnostic arthroscopy to identify the soft tissue and chondral injuries. We use low-flow or gravity arthroscopy to avoid compartment syndrome in the setting of an acute lateral-sided injury and an associated capsular injury. Next we proceed with a standard surgical approach to the posterolateral aspect of the knee, as described below, in preparation for the PLC repair. If the LCL or popliteus is avulsed off the femur, the ends are whipstitched with number 2 non absorbable suture. Once the injured structures are tagged, we proceed with an anatomic ACL reconstruction, to include drilling the femoral and tibial tunnels. We fix the graft in the femoral tunnel; however we perform the PLC repair prior to securing the ACL graft in the tibial tunnel. Once inspection has verified that the tissue of the injured structures of the posterolateral knee is of sufficient quality to hold the suture and there is sufficient length of the injured structure, a cruciate ligament guide is used to place a guide pin through the anatomic attachment site of either the LCL or popliteus tendon (or both, depending on the particular injury). The guide pin is drilled from lateral to medial and out the femoral cortex, proximal to both the medial epicondyle and the adductor tubercle. An incision is made along the distal border of the VMO, which is then retracted proximally to allow placement of the passing sutures and polyethylene button to be tied over the medial femoral cortex, deep to the muscle fibers. The guide pin is overdrilled with a 5–6 mm cannulated reamer, 1 cm in depth. A Beath pin with a passing suture is shuttled from lateral to medial, and the passing suture is pulled out medially. The knee is placed in full extension, and care is taken to confirm that the avulsed structure is recessed into the tunnel. Prior to tying the sutures, we proceed with preparation of the tibial tunnel for the ACL reconstruction and fix the ACL graft [12]. After this is performed, and a Lachman exam demonstrates improvement in anterior tibial translation, we complete the PLC repair. With the knee in 30° of flexion

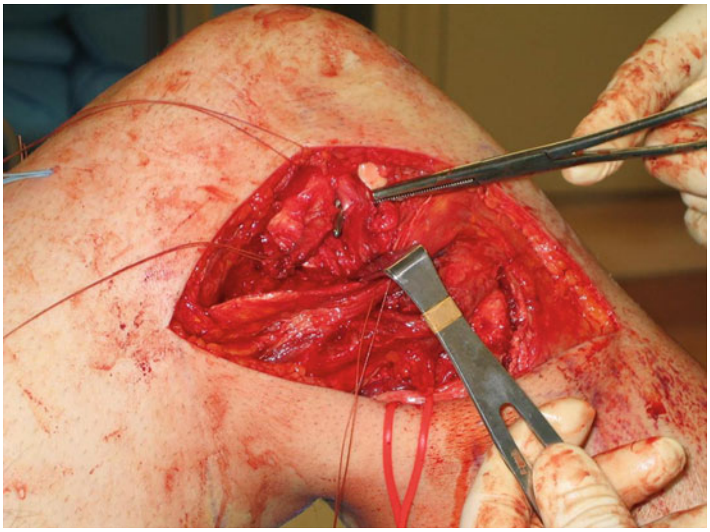

**Fig. 12.5** Diagram demonstrating the first fascial incision. The retractor is immediately anterior to the biceps femoris, reflecting it posteriorly. The clamp is exposing the popliteus tendon. The Penrose drain is around the peroneal nerve

and a valgus load applied, the sutures are tied over the button on the medial femoral cortex pulling the injured LCL or popliteal tendon into the recessed hole and fixed. The wounds are closed in layered fashion. For intrasubstance tears of the LCL or popliteus tendon, we prefer to proceed with a PLC reconstruction.

### *12.12.2 Chronic*

In the setting of a combined ACL-chronic PLC injury, or acute injuries where the injured PLC structures have significant soft tissue compromise that precludes them from holding sutures, we perform an anatomic PLC reconstruction using an allograft (using either a semitendinosus or Achilles) [25] because of the strength of large allografts and the absence of donor site morbidity. We proceed with the ACL reconstruction prior to the PLC reconstruction [24]. Our goal is to reconstruct the LCL, popliteus tendon, and the PFL. Our approach is similar to that described by Terry and LaPrade [26]. Using a lateral hockey-stick incision, dissection is taken down to the iliotibial band (ITB). We perform three fascial incisions. The first incision is through the superficial layer of the ITB to expose the femoral attachments of the LCL and the popliteus tendon (Fig. 12.5). A longitudinal arthrotomy is made anterior to the fibula, exposing the lateral meniscus, popliteomeniscal fascicles, and the popliteus. The second fasciotomy is made parallel to and immediately posterior to the biceps femoris to expose the posterolateral aspect of the tibia and the fibular styloid. Blunt dissection is performed between the lateral gastrocnemius and the soleus muscles. This provides visualization of the PFL insertion onto the fibular styloid and the posterior popliteal sulcus. The third incision is posterior to the long head of the biceps where we identify the common peroneal nerve posterior and medial to the long head of the biceps tendon and proceed with a common peroneal nerve neurolysis. The nerve is tagged with a Penrose drain (see Fig. 12.5) and protected throughout the remainder of the case.

Our reconstruction technique is similar to that described by LaPrade et al. [27]. A guidewire is used to drill one hole in the fibular head for the LCL insertion, aimed towards the posteromedial aspect of the styloid, for reconstruction of the PFL. The LCL attachment site on the fibula is identified by entering the bursa between the long head of the biceps and the LCL. The wire is overdrilled with a 7 mm reamer. Next we use a cruciate ligament aiming guide to drill a tibial tunnel from anterior to posterior starting at Gerdy's tubercle, aimed towards the posterior popliteal sulcus, at the level of the musculotendinous junction of the popliteus for reconstruction of the popliteus tendon (see Fig. 3.11). A 9 mm reamer is passed over the guidewire to prepare the tunnel. This tibial tunnel is made only if there is a myotendinous injury to the popliteus tendon. Otherwise the LCL and PFL are reconstructed through a fibular tunnel only, in a figure-of-eight fashion. Attention is then turned toward drilling the tunnels for the anatomic femoral attachments of the LCL and popliteus. Two Beath pins are drilled from lateral to medial across the femur at the previously identified anatomic attachment sites. We measure the distance between the two sites, ensuring they are correctly placed, approximately 18.5 mm apart. The pins are aimed such that they are exiting proximal and medial to the medial epicondyle and the adductor tubercle. The bone plugs from the two ends of the allograft are passed through each tunnel after they are overdrilled with the same diameter reamer as that of the prepared allograft. Each tunnel is fixed with an interference screw. The free end of the allograft that was placed in the tunnel for the popliteus (in the setting of a myotendinous injury) is passed distally and medially through the popliteal hiatus and passed from posterior to anterior through the tibial tunnel to reconstruct the popliteal tendon. The second graft, from the LCL attachment on the femur is used to reconstruct the LCL and the PFL. It is passed deep to the superficial layer of the ITB and anterior aspect of the long head of the biceps in the same path of the native LCL. The graft is shuttled through the fibular head from lateral to posteromedial. With the knee flexed 30° and a small valgus stress applied (to minimize any gapping of the lateral compartment), the graft is tensioned and fixed to the fibular head with a bioabsorbable interference screw, reconstructing the LCL. The remaining portion of the LCL graft is passed from posterior to anterior through the tibial tunnel, reconstructing the PFL. The knee is internally rotated and flexed to 60°, and the graft is secured with a bioabsorbable screw placed in the anterior tibial tunnel. For added fixation, a staple is placed over the free ends of the grafts on the anterior tibia. An examination under anesthesia is performed to confirm stability with varus, and external rotation and posterolateral rotation. The wound is closed in layered fashion. The anterior aspect of the long head of the biceps is reattached to the fibula; the lateral arthrotomy is closed with absorbable sutures, as is the ITB incision; the subcutaneous tissues are re-approximated, and the skin is closed in subcuticular fashion.

## 12.13 Postoperative Management

Following a combined ACL reconstruction and PLC repair or reconstruction, patients are placed in a hinged knee brace in extension for 1 week. They are kept non-weight-bearing for 6 weeks. Straight leg raises and quadriceps strengthening are encouraged. Gentle passive ROM exercises are initiated after the first week and advanced as tolerated. At 6 weeks postoperatively, patients are allowed to progressively increase their weight-bearing as tolerated. Crutches are weaned when a normal, steady gait is obtained. After 3 months low-impact exercises are introduced and closed chain exercises are initiated; open chain hamstring exercises are avoided for 3–4 months to minimize stress on the setting of a PLC repair. Patients are typically cleared to return to athletics 9 months postoperatively after operative treatment of a combined ACL and lateral-sided injury.

To the best of our knowledge there has only been one outcome study after anatomic posterolateral knee reconstruction. LaPrade et al. reviewed their outcomes in 64 patients following anatomic posterolateral knee reconstruction after a mean follow-up of 4.3 years [28]; 22 patients had a concurrent ACL reconstruction. The total modified Cincinnati score averaged 65.7, the symptom subscore averaged 32 points, and the function subscore averaged 34 points. There was no significant difference between patients who had an isolated PL knee reconstruction and those with multiple ligament reconstructions with regard to the 3 scores. There was a significant improvement in the International Knee Documentation Committee (IKDC) scores for varus opening at 20°, external rotation at 30°, reverse pivot shift, and single-leg hop (all $p<0.001$). The authors concluded that an anatomic posterolateral knee reconstruction can result in significant improvement in patients with chronic posterolateral knee instability, as well as those who underwent multi-ligament reconstructions.

## 12.14 Conclusion

The principles of surgical management of the multiple-ligament-injured knee include identification and treatment of all pathology, including meniscal and articular surface injuries, as well as the collateral, capsular, and cruciate ligaments involved. Anatomic graft insertion, combined with secure graft fixation and an individualized postoperative rehabilitation program, provides for the most stable postoperative function. Preoperative planning, including the timing of surgery, vascular status of the involved limb, soft tissue viability, and injuries to other organ systems must be considered during an individual's treatment algorithm.

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# Chapter 13
# Revision ACL-Based Multiple Ligament Knee Surgery

**Seth A. Cheatham and Darren L. Johnson**

Injuries to the anterior cruciate ligament (ACL) are common in the athletically active population. This population of patients has increased dramatically in the last 30 years. Since the enactment of Title IX, male participation at the high school level has remained constant, while female participation has increased approximately tenfold (from 0.3 to 3.2 million) [1]. High school and collegiate athletics contributes to >50,000 ACL injuries in female athletes each year. Studies have shown that adolescents are participating in competitive sports at a much younger age with constant year-round competitive practice, game sessions, and tournament events which significantly increase the exposure risk of that knee. Our baby boomer population continues to remain quite athletically active into their sixties and seventies. In fact, ACL reconstruction has become one of the most common procedures performed by orthopedic surgeons today. Over the past several decades the number of ACL reconstructions performed every year has steadily increased. It is estimated that over 250,000 ACL injuries occur every year in the USA with a correspondingly high number of reconstructions performed. Data from the American Board of Orthopaedic Surgery part II oral exam seems to suggest that the majority of these surgeries are performed by surgeons who perform <20 per year. Of additional concern is that less than 20% of patients undergoing ACL reconstruction have a meniscus repair performed when we know that the incidence of meniscal pathology approaches 60%. It is clearly possible that menisci are being excised that have the potential to be saved with current meniscal repair techniques.

Primary ACL reconstruction has been shown to be quite successful in restoring knee stability and function in the majority of patients. Although our ability to diagnose, reconstruct, and rehab these patients has led to a better understanding of the natural history and functional consequences of an ACL-deficient knee, there still remains considerable room for improvement if we look critically at our outcomes. While we have greatly improved with our ability for the ACL-injured athlete to return to the field after primary ACL reconstruction in the majority of cases, unfortunately only a minority of them truly return to their previous level of performance. Evidence indicates that normal function of the knee, as defined by the IKDC guidelines, may only be restored in approximately 40% of patients. Of more concern is that, in some studies, up to 90% of individuals undergoing primary ACL reconstruction have radiographic evidence of osteoarthritis within 7 years of primary surgery. The current way we evaluate our results may be outdated and not nearly sensitive enough to determine if a reconstruction is truly a success long term. One must question our short-term versus long-term goals of treatment: early return to the playing field versus long-term development of irreversible osteoarthritis. Our physical exam skills that enable us to objectively evaluate anterolateral rotational laxity in the office are nonsensitive, nonspecific, unreliable, and not validated as an objective measurement tool. While the majority of ACL reconstructions may have a good endpoint on a Lachman or anterior drawer, there is no reliable way to measure rotational stability in the office/laboratory with any reproducible objectivity. If a "success" is determined only by a good endpoint on a Lachman or drawer testing, we are not being honest with ourselves or our patients. The primary reason to reconstruct the ACL is to eliminate the pivot shift or anterolateral patholaxity.

A failed ACL reconstruction needs to be clearly defined. Not all ACL failures present with the same symptoms or complaints to the office. Most would agree that a reconstructed knee that demonstrates recurrent instability or a stable knee with significant loss of motion after surgery limiting functional activity may be considered an objective clinical failure [2].

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Some may also argue that persistent, chronic pain that prevents return to activities following reconstruction may also be classified as a failure. On the other hand, there can also be a subjective sense of surgical failure by the patient. The highly competitive athlete who competes at an elite level that does not return to competitive sports at the same level in terms of intensity, frequency, and performance may be unhappy with their surgical result. Although the physical exam performed in the office may not detect any obvious objective failure signs or symptoms, it is a subjective failure to the patient because their knee does not perform at the level they were at prior to their injury. The absence of a universally accepted definition of ACL reconstruction failure makes it difficult to calculate the true number or incidence of failures. Unsuccessful results from ACL reconstruction have ranged from 3 to 52% in the literature depending on the criteria used to define failure [2–4]. There are numerous reasons why ACL reconstructions fail but are generally placed into one of four categories: (1) recurrent patholaxity or instability, (2) loss of motion or arthrofibrosis, (3) persistent pain, and (4) extensor mechanism dysfunction. We will focus our discussion to ACL failure due to recurrent patholaxity secondary to missed capsular and ligamentous injuries and how to best address these surgically.

ACL injuries frequently occur concurrently with other capsular and ligamentous injuries. A truly isolated ACL injury is extremely uncommon. Failure to recognize and appropriately address associated injuries to the secondary and tertiary restraints to anterior tibial translation as well as pathologic rotatory laxity may subject the primary ACL graft to excessive tensile forces and result in early failure. This usually occurs relatively early after primary ACL reconstruction because of the large nonphysiologic forces the graft must absorb. The pathologic forces that the graft experiences early in the incorporation phase have a detrimental effect on collagen incorporation and ultimate strength of the graft. Posterolateral instability is the most commonly unrecognized concurrent deficiency and has been reported to be present in 10% to 15% of chronically ACL-deficient knees [5]. The medial collateral ligament (MCL), posterior horn of the medial meniscus, and posterior capsule/posterior oblique ligament (POL) also provide secondary stability in the ACL-deficient knee and must be carefully assessed for injury [6]. This only emphasizes the importance of a thorough exam under anesthesia. One must correct these concurrent instability patterns at the time of revision surgery for another failure not to occur.

## 13.1 Posterolateral Corner Injuries

The importance of the posterolateral corner (PLC) structures in maintaining knee stability and the fact that they interact functionally with the cruciate ligaments have become better understood in recent years [7]. Injuries to the PLC can result in posterolateral rotatory instability of the knee, which is a pathological instability that is caused by posterolateral tibial subluxation when an external rotational force is applied to the knee [8]. These injuries do not usually occur in isolation but are often associated with injury to the cruciate ligament in 29–89% of patients [9]. However, the diagnosis of a PLC injury can be elusive unless there is a high degree of suspicion for possible injury to this region. To illustrate this point, a recent study found that there was a mean delay to the diagnosis of a PLC injury of 30 months from the time of injury [10]. In all, 72% of PLC injuries were not identified at the time of initial presentation. The correct diagnosis, including injury to the PLC, had only been made in 50% at the time of referral to a specialist. Failure to diagnose the injury to the PLC has been found to increase the forces experienced by the ACL grafts and can lead to its subsequent failure.

Recent anatomic and biomechanical studies have more clearly defined the various anatomic structures composing the PLC. These structures include the iliotibial band (ITB), lateral collateral ligament (LCL), popliteus tendon complex, popliteofibular ligament (PFL), and the posterolateral capsule [11]. The femoral insertion is located proximal and posterior to the lateral epicondyle in a small depression between the lateral epicondyle and the supracondylar process. Distally, the LCL attaches to the fibular head a mean of 8.2 mm posterior to the most anterior aspect of the fibular head [12, 13]. The popliteus tendon complex consists of the popliteus muscle-tendon unit and the ligamentous connections from the tendon to the proximal fibula, tibia, and meniscus. The popliteus muscle originates from the posteromedial aspect of the proximal tibia and gives rise to its tendon, which courses intra-articularly through the popliteus hiatus of the coronary ligament to insert on the popliteal saddle on the lateral femoral condyle. The femoral insertion of the popliteus is consistently anterior and distal to the femoral insertion site of the LCL, according to LaPrade et al. [13]. In addition, the ITB is composed of multiple layers and blends with a confluence of the short head of the biceps to form an anterolateral sling around the knee. The long and short heads of the biceps femoris muscle provide dynamic stability, with the fabellofibular ligament being a thickening of the distal capsular edge of the short head of the biceps [11]. The common peroneal nerve is located on the posterior border of the long head of the biceps [13].

The primary function of the PLC is to resist varus rotation, external tibial rotation, and posterior tibial translation [7]. Biomechanical studies involving selective sectioning and joint loading have helped to define the interrelationships between the PLC and the primary functions of the LCL, popliteus tendon, and the PFL [14]. The LCL is the primary static restraint to varus stress. In a cadaveric study by LaPrade et al. [14], it was found that the mean load responses to external rotation in the LCL were significantly higher than those of the popliteus tendon and PFL at 0 and 30° of flexion. The popliteus tendon and PFL, on the other hand, demonstrated higher loads at higher knee flexion angles, peaking at 60°. It was concluded that the LCL, popliteus tendon, and PFL performed complimentary roles as stabilizers to external rotation with the LCL assuming the primary role at lower knee flexion angles and the popliteus complex assuming a primary role with higher knee flexion.

Load sharing patterns of intact ACL and PCL in knees with uninjured and combined injury to the PLC were investigated in a cadaver model under various external loading conditions. This study demonstrated that sectioning of the PLC increases the forces in the ACL under both varus and internal tibial torques. Further, LaPrade et al. [15] studied the effect of grade III injuries to the PLC (sequential sectioning of LCL, PFL, and popliteus tendon (PT)) on the force experienced by the ACL grafts. They found that sectioning the LCL increased the forces in the ACL graft both under varus and combined varus and internal torques. Additional sectioning of the PFL and PT further elevated the ACL graft forces under the two loading conditions.

## 13.2 Posteromedial Corner Injuries

An injury to the posteromedial corner (PMC) of the knee is significantly different, both anatomically and biomechanically, from an isolated injury to the MCL. The PMC encompasses medial-sided structures posterior to the MCL, including the POL, semimembranosus tendon, posterior horn of the medial meniscus, and the associated joint capsule. In comparison with a PLC injury, a PMC injury is studied less often, perhaps because it is equated or coexistent with MCL injuries. Newer anatomic and biomechanical studies are refining our understanding of static and dynamic stabilizers of the medial side of the knee, as well as their role in multiple ligament injuries. In particular, persistent valgus instability places additional strain on a reconstructed ACL which can contribute to graft failure. It is often assumed that medial-sided injuries will heal with non-operative management, even with a concomitant ACL injury. Although the defining work addressing isolated MCL injuries was prepared by Indelicato [16], his patient population was restricted to those who had no valgus instability in full extension and no evidence of injury to the meniscus, ACL, or PCL. By definition, this was a limited patient population, absent of injury to the PMC or other ligaments. Therefore, injuries to the PMC may not heal without surgical repair or reconstruction, particularly when they occur as part of a multiple ligament injury. It is important to identify these injuries before ACL reconstruction so that appropriate repair or reconstruction of the PMC and MCL can be undertaken at the same time.

The MCL complex has been described with several different names by several different authors. The PMC can be defined as structures between the posterior border of the longitudinal fibers of the superficial MCL, extending around to the medial border of the PCL [17, 18]. Important structures in this area include the POL, expansions off the semimembranosus, oblique popliteal ligament, and posterior horn of the medial meniscus [17, 18].

The POL consists of fascial attachments extending off the semimembranosus tendon immediately posterior to the superficial MCL, and it may act as a secondary stabilizer to posterior tibial translation. It attaches to the femur slightly anterior and inferior to the medial head of the gastrocnemius. Three arms of the POL have been described: the superficial, the central or tibial, and the capsular [18, 19]. The origins of the superficial arm fibers blend in with the posterior border of the superficial MCL anteriorly and course into the other arms of the POL inferiorly and posteriorly. The central arm is considered to be the main component of the POL, arising from the main semimembranosus tendon, reinforcing the deep MCL, directly attaching to the posterior joint capsule and posterior meniscus, and blending with the semimembranosus attachment on the tibia [19]. The capsular arm comes off the distal aspect of the semimembranosus tendon, attaching to the meniscofemoral portion of the joint capsule and medial head of the gastrocnemius and over the adductor magnus [19].

The semimembranosus tendon has multiple attachments to the tibia and acts as a dynamic stabilizer providing motor function to the PMC [17, 18]. It may also help to prevent impingement of the posteromedial meniscus in flexion [18]. The anterior arm of the semimembranosus attaches to the tibia deep to the proximal attachment of the superficial MCL, whereas the direct arm attaches posterior to the medial tibial crest [18, 19].

In Warren and Marshall's 3-layer description of the medial side of the knee, the POL makes up the posterior aspect of layer II [20]. Further posteriorly, layers II and III merge and encompass the semimembranosus. In another dissection, the POL was inseparable from the capsule and was obvious only when tension was placed across the PMC [17].

The PMC and POL in particular are biomechanically separate structures from the superficial MCL. The PMC is a primary stabilizer of the extended knee. It provides approximately one-third of the restraint to valgus stress with the knee in extension [21]. With flexion, the PMC slackens, causing the superficial MCL to become the primary stabilizer to valgus stress across the remainder of the flexion-extension arc. Several recent biomechanical studies have further elucidated the function of the POL, which is primarily a stabilizer for internal rotation at all knee flexion angles [22], although the most load occurs in full extension [23]. In full extension, the POL helps to prevent posterior tibial translation and valgus abduction, even with an intact PCL. The effect of the posterior tibial translation increases when the tibia is internally rotated because of the orientation of the POL and capsule fibers [21].

Injury to multiple structures on the medial side of the knee helps to explain the phenomenon of anteromedial rotatory instability (AMRI), which is defined as anterior subluxation and external rotation of the medial tibial plateau with respect to the femur. In Hughston's series describing patients with AMRI, patients had an injury to the midportion of the superficial and deep MCLs or to the POL, often (but not always) with an associated ACL injury [24]. In biomechanical studies, combined sectioning of the PMC, superficial MCL, and deep MCL had the most significant effect on tibial external rotation, as compared with sectioning of only 1 or 2 structures [21]. For patients with symptomatic AMRI, the medial-sided structures involved most almost always included the POL, with a few basic patterns becoming apparent. In one cohort of patients with POL injuries, the semimembranosus was injured 70% of the time, and there was a peripheral meniscal detachment 30% of the time. Of these patients, 19% had combination patterns, with injury to the semimembranosus, as well as peripheral meniscal detachment [18]. Grade III MCL injuries frequently occur in combination with ACL tears as part of the "unhappy triad." These patients may be likely to have an associated PMC injury as well. Almost all the patients (22 of 23) in one series of surgically treated MCL and ACL injuries had POL ruptures, with 8 of 23 having rupture of the entire PMC [25].

## 13.3 Revision ACL Reconstruction

It is our belief that anatomic restoration of ACL anatomy in the revision setting is best accomplished using the double-bundle technique in those cases where native footprint anatomy dictates. It has been shown to be superior to single-bundle reconstruction in the restoration of normal kinematics of the knee [26]. Additionally, it provides a greater volume of tissue and collagen to counteract the effects of laxity due to deficiencies of secondary restraints (i.e., menisci, collateral ligaments, capsule) that are often encountered in the revision setting that may need to be addressed concomitantly. There are, however, certain situations where double-bundle reconstruction is not possible or not indicated. These include instances where the intercondylar notch is small and will not allow enough bony surface area to safely perform a double-bundle reconstruction. Those patients with small ACL footprint anatomy and skeletally immature patients should undergo SB revision surgery. In these cases, we prefer to perform anatomic matched single-bundle reconstruction. It should also be noted that double-bundle ACL reconstruction is technically demanding surgery with a steep learning curve.

## 13.4 Preoperative Planning

The primary cause of failure of the index ACL reconstruction must be determined in order to devise a successful plan for revision surgery. In this case, the cause of failure is due to failure to recognize injury to the PLC/PMC that leads to early failure of the ACL graft. Furthermore, evaluation of the patient's current or, more importantly, desired level of activity as well as realistic goals and expectations must be addressed. Recent data from the Multicenter ACL Revision Study (MARS) group has shown that only approximately 10% of patients have normal menisci/articular cartilage at the time of revision surgery [27]. Detailed knowledge of the primary injury and surgery, including operative notes and intraoperative photos, is important in determining a plan of action. It is also helpful to understand what the patient's postoperative course was like including complications and rehabilitation protocol. The patient's subjective complaints may vary widely along a spectrum from pain to instability. This is important because if the patient's only complaint is pain, revision ACL surgery may not be indicated. Taking into consideration all these factors will allow the surgeon to adequately plan for the expected course of events in the revision surgery, the equipment needed to perform the surgery, and the expected pitfalls that may be encountered. These include bone loss, hardware and fixation issues, as well as additional sources of instability that may need to be addressed.

## 13.5 Physical Examination

Physical examination of the extremity should be comprehensive. It must include all objective and subjective tests to qualify and quantify the amount of patholaxity present as well as concomitant pathology that will affect the revision surgery. These include evaluation of the ACL, menisci, PLC, and PMC. It is, however, our experience that the in-office examination often does not correlate well with the examination under anesthesia (EUA). This is especially true in regards to performing an accurate pivot shift examination and determining the amount of pathologic rotatory laxity that is present. Another advantage of the anatomic double-bundle reconstruction is its ability to eliminate the rotatory laxity that is often missed or underappreciated with the in-office examination. The location of previous incisions should also be noted and planned for to avoid any soft tissue compromise.

## 13.6 Radiographic Evaluation

Preoperative radiographs should always be obtained before going to the operating room in a revision setting as they provide invaluable information. We obtain standard anteroposterior (AP) and lateral views of the knee, as well as a weight-bearing 45° flexion posteroanterior (PA) view. Mechanical axis full-length standing films are also obtained which is critical in determining the overall mechanical alignment of the limb. This is important to make sure there is not a significant amount of varus/valgus present that may compromise the ACL graft and may need to be addressed. Development of degenerative changes should be documented, and the patient should be counseled on how these findings may alter the approach and expectations with revision reconstruction.

Radiographs should be assessed for the presence of metal hardware that will interfere with the revision procedure, tunnel position, and tunnel expansion. Previously placed metallic fixation devices do not necessarily require removal. If subsequent tunnels will not be affected by their location, removal is not advised as this may create residual bony defects that require further attention. If hardware removal is necessary, a complete set of implant drivers and screw-removal instruments must be available at the time of revision surgery. Special equipment such as trephines, end-cutting reamers, picks, curettes, and a universal screwdriver system are also needed frequently.

Although small errors in tunnel placement may not be clearly visualized, gross tunnel malposition can usually be seen on standard radiographs (Fig. 13.1). The tibial tunnel should penetrate the articular surface at midpoint of the tibial plateau on the AP view. On the lateral view, the tibial plateau can be divided into 4 quadrants as described by Harner et al. [28]. The tibial tunnel should enter the joint in the posterior third of quadrant 2. For the femoral tunnel, assessment based on the lateral radiograph is less useful. Assessment of appropriate graft obliquity can best be determined on an AP radiograph.

Lastly, tunnels should be assessed for expansion and bone loss. Excessively posterior femoral tunnels at the original procedure may result in posterior wall blowout, which will limit options for fixation at the revision procedure. Furthermore,

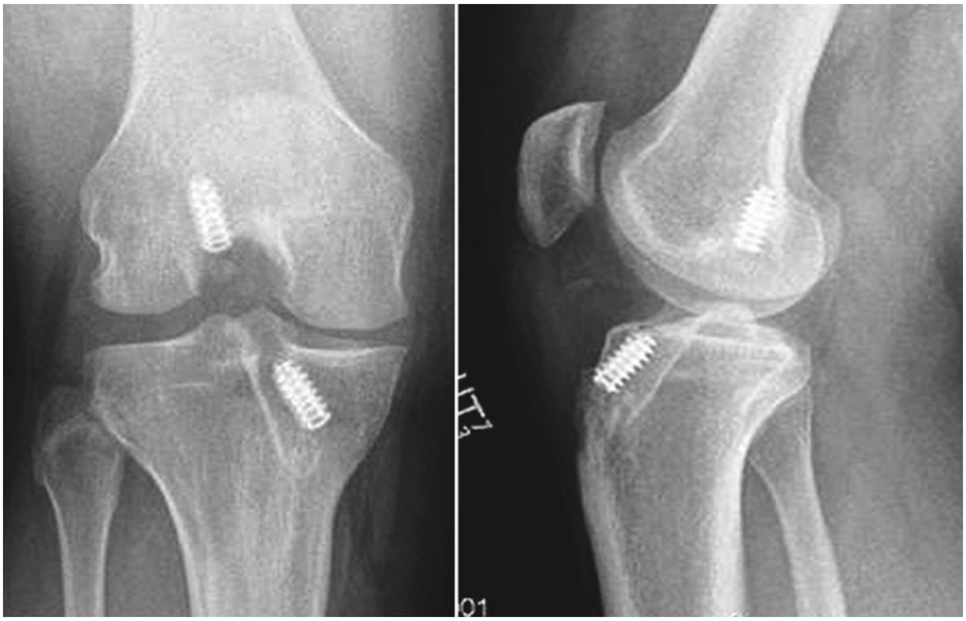

**Fig. 13.1** AP and lateral radiographs of a “vertical” primary ACL reconstruction

if adequate expansion of the tunnels cannot be made from plain radiographs alone, CT images (with or without 3-dimensional reconstructions) can provide detailed information regarding tunnel positions and residual bony defects. MRI can also be a useful adjunctive tool, although its use can sometimes be compromised by the presence of metal hardware. Important information, however, may be obtained regarding graft integrity as well as concomitant meniscal, chondral, and injury to secondary stabilizers such as the PMC/PLC that will need to be addressed at the time of surgery.

## 13.7 Staging

On occasion, revision of the failed primary ACL is not feasible or recommended in one stage. If it is determined either pre- or intraoperatively that the reconstruction cannot be performed anatomically, that stable fixation cannot be achieved, that motion is not full, or that significant limb malalignment is present, the procedure must and should be staged. Examples of this include massive tunnel osteolysis (>15 mm) that will not allow stable fixation in an anatomic position and arthrofibrosis that will not allow full range of motion, or if significant limb malalignment has been the cause of ACL failure, then in these situations the pathology must be addressed first so that at the time of revision the knee's environment is in an optimal state for successful revision. The surgeon and patient must be willing to accept staging to ensure a successful outcome. If staging is required, return to ACL-dependent activities may be delayed up to 1 year.

## 13.8 Examination Under Anesthesia

After placement of a regional femoral nerve block and induction of general anesthesia, a complete examination of the operative and nonoperative knee is performed. Special attention is paid to the degree of laxity present on the Lachman and pivot shift examinations. The importance of the EUA is demonstrated by the presence of isolated rotatory instability seen on the pivot shift examination with a normal Lachman exam and a firm endpoint. In these circumstances, the surgeon may elect to perform an augmentation of the primary graft, often the AM bundle, by reconstructing just the PL bundle versus a complete revision. As mentioned previously, other ligamentous structures are also evaluated at this time. The lateral and MCLs are tested in full extension and at 30° of knee flexion. Posterolateral and posteromedial instability should be determined with the dial test in both 30° and 90° of flexion. If additional laxity is identified, we prefer to address the additional patholaxity simultaneously. Failure to identify and address coexistent laxity will result in repeat failure of the ACL graft.

## 13.9 Patient Setup

It is the author's preference to use an arthroscopic leg holder on the operative extremity with moderate hip flexion, allowing full clearance for deep flexion of the knee during the case. Once the leg is placed in the arthroscopic leg holder, the surgeon must verify that the knee can be maximally flexed to at least 130° if drilling and fixation of the femoral tunnels are to be done through an accessory medial portal, which we recommend for anatomic primary and revision surgery. The nonoperative leg is placed in a well-padded leg holder in the lithotomy position in maximal abduction and external rotation so it is out of the way of the surgical team. This assures adequate room to address the concomitant medial or lateral pathology.

## 13.10 Graft Selection

Graft choice is tailored to the patient and affected by the graft used in the primary reconstruction. If possible, in the high school or collegiate athlete who desires to continue to participate in high-demand activities and has failed a prior allograft reconstruction, the use of autogenous tissue is preferred. In these cases, we prefer to use 8–9 mm central bone-patellar tendon-bone autograft for the AM bundle and 5–6 mm gracilis or semitendinosus autograft for the PL bundle. In situation involving the recreational athlete, the low-demand patient older than 25 years of age, or the patient who has failed prior autograft use, the use of a calcaneus-Achilles allograft is preferred for revision surgery. Due to this allograft's large size and flexibility, it may be split and used for reconstruction of both bundles which may also result in a significant cost savings to the patient, hospital, or surgery center. To address the posterolateral or posteromedial pathology we often use a semitendinosus allograft.

## 13.11 Portal Placement and Arthroscopy

The primary ACL arthroscopic portals may not be ideal, and new portals should be established. Poor portal placement will increase the difficulty of the case and lead to poor visualization and easy access anatomic bony insertion sites. A very high and tight anterolateral portal adjacent to the inferior pole of the patella and patellar tendon is established first. This allows the surgeon to later get an optimal view of the ACL footprint on the tibia when looking down from the high lateral portal. A low and tight anteromedial portal is then made under spinal needle localization that is also adjacent to the patellar tendon and just above the intermeniscal ligament, directly in-line with the ACL tibial footprint. A diagnostic arthroscopy is then performed with special attention to the articular cartilage, menisci, primary ACL graft, and indirect signs of secondary restraint laxity such as a positive “drive-through” or “gap” sign. The anterior fat pad is often debrided at this time in order to increase visualization.

In the case of complete failure of the primary graft, the previous graft is removed from the medial wall of the lateral femoral condyle. Adequate notchplasty/wallplasty may be performed at this time to allow adequate visualization of important anatomic landmarks such as the lateral intercondylar and bifurcate ridges. Care is taken to ensure that no additional bone is removed from the anatomic insertion site as this changes the normal length of the ACL. If required, removal of previous hardware may be performed at this time, taking care to minimize any bone loss. Once the hardware is removed, the defect can be filled with excess bone from the calcaneus-Achilles allograft. If the hardware does not interfere with drilling of the new revision femoral tunnels, the hardware is often left in place. Retaining hardware eliminates the need for bone grafting any defects and will not weaken the integrity of the lateral femoral condyle. At this time, a far accessory medial portal is made with the knee flexed to 90° using a spinal needle to ensure adequate room around the medial femoral condyle with proper placement/direction to the native ACL insertion site on the wall of the lateral femoral condyle. We prefer to make this accessory medial portal in a horizontal fashion because the instruments introduced through this portal are directed in a medial-to-lateral direction.

## 13.12 Tunnel Placement

At this time, the arthroscope is placed in the anteromedial portal in order to get a direct view of the medial wall of the lateral femoral condyle. Using an awl placed in the accessory medial portal, and with the knee again flexed to 90°, the anatomic positions of the AM and PL bundles are marked. Use of the accessory portal and marking of the sites at 90° of flexion are vital to ensure anatomic placement and drilling of the femoral tunnels. Without the use of this visualization portal, we have found it very difficult or impossible to recreate the native anatomy of the femoral insertion site of the ACL.

Standard guide pins are placed through the accessory medial portal, and tunnels are reamed in 110° of flexion to create the 5–6 mm PL tunnel first and then at 130° of flexion for the 7–9 mm AM tunnel. By hyperflexing the knee, this greatly reduces the risk of posterior wall blowout and maximizes tunnel length. We have found that using this technique the PL tunnel often measures 24–28 mm and the AM tunnel 34–40 mm in nearly all cases with anatomic placement. By drilling the two tunnels in different degrees of flexion, this causes tunnel divergence which is optimal for biologic graft fixation. Half-fluted reamers are used to decrease the risk of articular injury to the medial femoral condyle. The integrity and position of these tunnels can be verified by placing the arthroscope through the accessory medial portal if needed. A shaver is then used, again through the accessory medial portal, to clear out remaining bone debris and smooth the edges of the tunnels to decrease any fraying the graft may have. In cases of interference or overlap from previous tunnels, usually closest to the position of the AM tunnel, it is our preference to divergently ream or overream this tunnel and use it for the new AM bundle. One may also use a two-incision outside-in technique to drill the new AM tunnel when overlap may be a concern. The revision ACL surgeon must be comfortable and proficient in different ACL reconstruction techniques including tibial tunnel drilling, two-incision techniques, outside-in retrograde drilling, and far accessory medial portal drilling.

The tibial tunnels are created after preparation of the femoral tunnels. If necessary, hardware is removed with care to maintain bony integrity, and the tunnel is debrided of soft tissue. The ACL tibial guide is first placed through the anteromedial portal and set at 55–60° for creation of the AM bundle. As is commonly the case on the tibial side, the primary ACL tunnel may be used for creation of the AM tunnel. Creating the ideal tunnel can be achieved by placing a guide pin by hand through the primary ACL tibial tunnel and securing the tip of the pin in the roof of the femoral notch. A cannulated drill/reamer or dilator can then be used for directed expansion of the tunnel. Expansion in the anterior direction is often required due to the original graft being placed in a too posterior position. For the PL bundle, the guide can be placed through the far accessory medial portal which allows the surgeon to get medial enough without difficulty. For the PL tunnel, the guide is set to 45° and the tunnel is started medial to the AM tunnel and just anterior to the MCL on the tibial metaphysis using the downslope of the medial tibial spine as a reference. These tunnels may converge into the previous tunnel opening visualized arthroscopically at the level of the joint line which essentially results in one tunnel at this level. In our experience, this has not affected the placement of the grafts, fixation, or tensioning patterns.

## 13.13 Graft Passage and Fixation

The grafts are passed using a passing pin and sutures in a standard fashion. The passing pin is first placed through the accessory medial portal and up the femoral tunnels with the knee flexed to the same angle used to drill each femoral tunnel. At this time, the exit point of the passing pins may be used to ensure anatomic placement of the tunnels. They should exit the skin parallel to the lateral distal femur along the iliotibial band and approximately one inch apart. The loop of suture is then retrieved intra-articularly through the respective tibial tunnels with a pituitary and is brought to the outside of the tibial metaphysis. For anatomic double-bundle reconstructions, the PL graft is generally passed first and fixed on the femoral side before passing the larger AM bundle. Fixation is generally accomplished with the use of a 15 mm Endobutton (Smith & Nephew) for the PL bundle and often variable fixation for the AM bundle (Endobutton, cannulated interference screw) on the femoral side depending on the type of graft that is used. The grafts are then cycled individually to evaluate isometry as well as pretension each graft.

We recommend tensioning and fixing the PL bundle on the tibial side in full extension, while the AM bundle is tensioned and fixed in 30–60° of flexion. Fixation is usually achieved with cannulated bioabsorbable soft tissue interference screws and backup fixation using either staples or a screw and washer construct. Final arthroscopic visualization is then performed to ensure no impingement of the graft on the roof of the notch in full extension, as well as proper tensioning of the two bundles at varying degrees of flexion (Fig. 13.2).

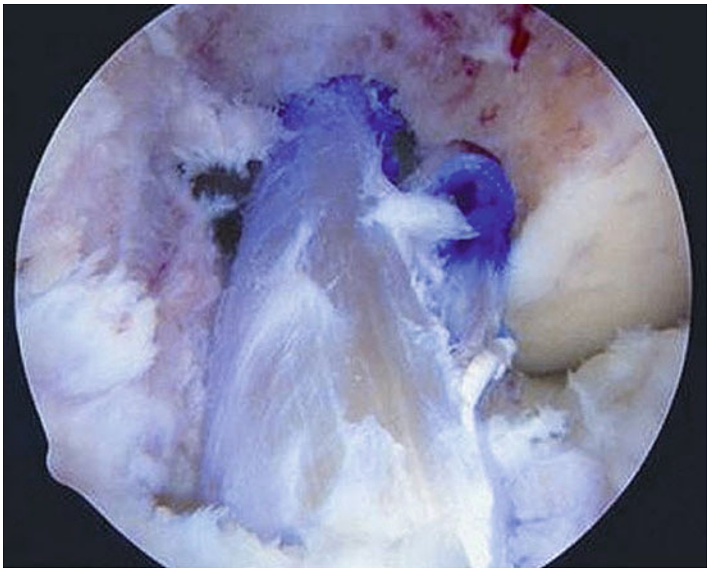

**Fig. 13.2** View of a double-bundle reconstruction from the anteromedial portal with the knee in 90° of flexion

## 13.14 Addressing Posterolateral Corner Injuries

Once the revision ACL reconstruction has been performed and the graft has been fixed, attention can then be turned to the posterolateral corner laxity. Often at the time of arthroscopy a “drive-through” sign is present when looking at the lateral compartment with a varus stress on the knee. Furthermore, depending on the extent of the injury, the popliteus tendon may or may not be visualized. Acute hemorrhage is unlikely to be seen in this setting as these injuries will be chronic.

A lateral hockey stick incision is made, paralleling the posterior edge of the IT band. Exposure is carried out through three fascial incisions to provide adequate visualization of both the femoral and the fibular attachment points of the LCL, popliteus, and PFL: (1) along the posterior aspect of the biceps to expose the peroneal nerve, (2) between the IT and the biceps for access to the fibular head, and (3) a longitudinal incision in the midaspect of the IT band over the lateral epicondyle. The incision originates distally just proximal to Gerdy’s tubercle and extends proximally to the distal termination of the lateral intermuscular septum. A small horizontal incision is made through the anterior arm of the long head of the biceps femoris, 1 cm proximal to the lateral aspect of the fibular head, which opens the fibular collateral ligament/biceps bursa. The attachment site of the LCL can be identified through this bursa. The common peroneal nerve is identified so it can be protected throughout the reconstructive procedure.

A critical point to consider is graft isometry. Attachment sites must be chosen that have minimum length change through the range of motion, a basic principle of any ligament reconstruction. The attachment sites for the popliteus tendon and PFL are highly nonisometric. This is due to the fact that the popliteus is a muscle-tendon unit and thus has the ability to adjust length/tension with changes in muscle length. A graft reconstruction of these structures uses a static graft with a single fiber length. Sigward et al. [29] reported that the mean relative length changes of popliteus tendon and PFL grafts with the attachment sites centered over the popliteus tendon femoral footprint were 3.7 and 5.0 mm, respectively. This data argues against simply reproducing anatomy with a static graft for the popliteus tendon and PFL. In contrast, the same study found that use of the native attachment sites for the LCL resulted in a satisfactory isometry profile.

A fibular-based reconstruction is a popular choice among many orthopedic surgeons for its simplicity and results. A single, large graft placed into the fibula is the preferred technique, similar to that described by Noyes and Barber-Westin [30]. The value of this technique is the ability to use a relatively large graft. The graft reproduces the LCL. It is placed into a drill tunnel at the LCL femoral insertion site and then into a tunnel in the tip of the fibular head (Fig. 13.3). Various techniques in the fibula can be used, such as the use of an interference screw or the “docking” technique. Femoral fixation can be performed with an interference screw, over a screw and washer, or sutures pulled through to the medial side through a drill hole (Fig. 13.4).

**Fig. 13.3** View of a fibular-based PLC reconstruction after passing the graft through the fibular tunnel

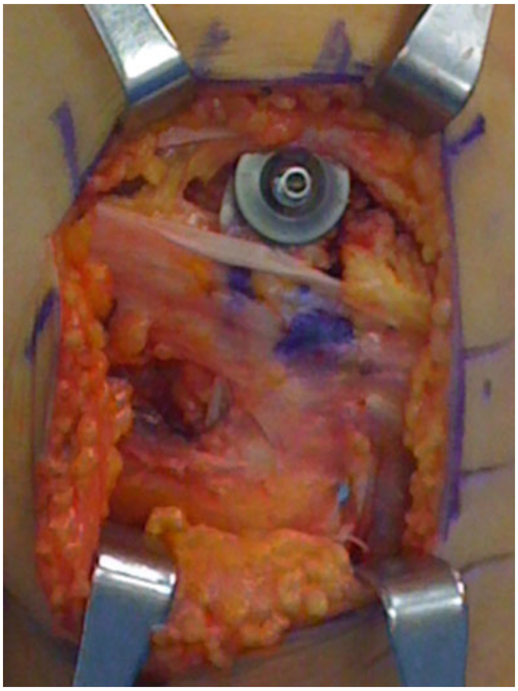

**Fig. 13.4** Final view of fibular-based PLC reconstruction with femoral fixation over screw and washer

In the chronic setting, there may be increased laxity, with increases in both varus and external rotation. In this situation, an additional graft limb may be passed into the posterior tibia to replace the popliteotibial arm. One option to do this is to use an Achilles allograft tendon with a bone block placed into the lateral femoral condyle at the LCL insertion site. The soft tissue portion of the allograft is fashioned into two tails. One limb is placed into a drill tunnel in the posterolateral tibia, entering posteriorly at the approximate site of attachment of the popliteus muscle-tendon unit to the posterior tibia. Sutures are placed into the top of the fibular head to reproduce the LCL. An alternative technique that has been used in the chronic setting is to place the two-limbed graft at the femoral popliteus insertion point. One limb can be passed through a fibular drill tunnel as described above to reproduce the PFL and then brought back to the femur to reproduce the LCL. The second limb is placed into the tibial tunnel to reproduce the attachment of the popliteus to the posterior tibia. However, these attachment points for the popliteus and PFL are nonisometric.

## 13.15 Addressing Posteromedial Corner Injuries

EUA and diagnostic arthroscopy are again helpful tools to evaluate chronic PMC injuries. Depending on the location of the injury, there may be complete peripheral detachment of the meniscus or gross elevation of the meniscus off the tibia with valgus stress often referred to as a positive drive-through sign. Others refer to a "spin sign" that is sometimes seen when the tibial plateau moves independently of the meniscus and femur because of a tear in the meniscotibial attachment or when the femur moves independently of the meniscus and tibia, indicating a tear in the meniscofemoral attachment [31, 32].

Many authors recommend soft tissue autograft or allograft reconstruction of the superficial MCL, with readvancement of the POL to the superficial or deep MCL [32, 33]. The native POL is intimately opposed to the superficial and deep MCL; thus, both techniques restore the native anatomy. Bone tunnels are drilled at the femoral and tibial insertions, and the graft can be secured with interference screw fixation or with sutures passed through a bone tunnel. Importantly, the graft should be tensioned and the bony fixation applied with the knee in 30° of flexion and with a gentle varus stress. The POL can then be sewn to the superficial or deep MCL with nonabsorbable suture, using a pants-over-vest technique, which will restore tension in the PMC [32, 33].

Three techniques for reconstructing the MCL and the POL have been described [34–36]. Two use semitendinosus autografts with the pes anserinus insertion of the tendon left intact [35, 36]. The graft is subsequently secured at the femoral insertion of the superficial MCL, and the free end of the remaining tendon recreates the POL. This is either looped around the direct head of the semimembranosus [35] or pulled through a tibial tunnel 10 mm below the joint line, posterior and

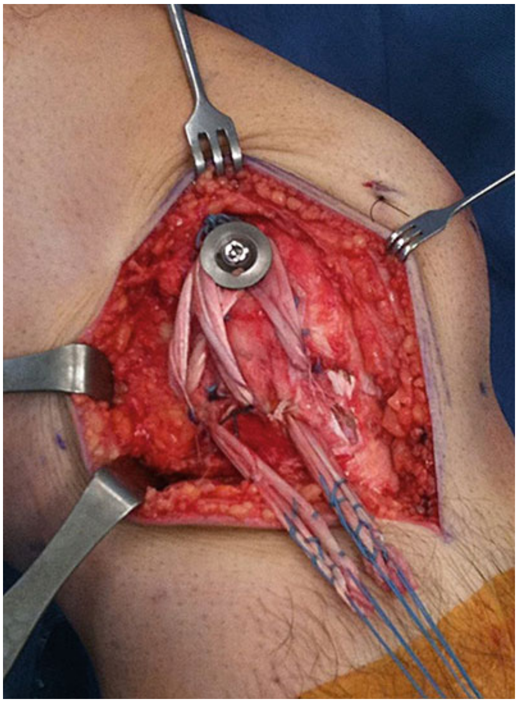

**Fig. 13.5** Reconstruction of a chronic PMC injury with the use of two allografts to recreate the POL and MCL

lateral to the semimembranosus insertion [36]. The third technique for MCL and POL reconstruction differs from the previously described techniques in that separate soft tissue grafts are used to reconstruct the superficial MCL and POL (Fig. 13.5) [34]. All the grafts are secured with bone tunnel/interference screw constructs at the anatomic femoral and tibial insertion sites. The femoral insertion sites are fixed first. The distal tibial insertion of the superficial MCL is secured next with the knee in 30° of flexion and neutral rotation. The POL is secured last, with the knee in full extension. Although clinical follow-up is not available for this technique, biomechanical data showing restoration of valgus, rotational, and anterior/posterior stability after reconstruction has been published [34].

## 13.16 Postoperative Rehab

In the operating room, the patient is placed in a hinged knee brace locked in extension. Non-weight-bearing status is maintained for the first 6 weeks. The authors emphasize early protected range of motion and aggressive rehabilitation to decrease the incidence of postoperative stiffness. The brace is typically unlocked after 6 weeks once the patient has regained adequate neuromuscular control of the major muscle groups of the hip, thigh, and lower leg. Progressive weight bearing is achieved during postoperative weeks 7–10. Progressive closed kinetic chain exercises are performed in a supervised physical therapy environment. The brace and crutches are typically discontinued somewhere between 8 and 12 weeks. Patients should be aware that the rehabilitation process is long, with return to sports and activity after 9–12 months. In regards to VTE prophylaxis, we currently do not use or recommend routine prophylaxis as we feel the risks outweigh the benefits with this procedure.

## 13.17 Summary

As the number of primary ACL reconstructions continue to increase, so too does the number of failures. Failure of an ACL reconstruction may be attributed to a multitude of factors. Recurrent patholaxity, loss of motion, graft failures, persistent pain, and extensor mechanism dysfunction are all reasons why patients return to the office unsatisfied with their reconstruction. Understanding the exact etiology of failure is the first and most important step if a successful revision surgery is to be attempted.

The current literature suggests that only approximately 60% of patients are able to return to sports following single-bundle ACL revision surgery [37]. Many of these patients that do return are not able to perform at the same level, frequency, or duration they were at before their injury. Of even greater concern is that >50% of patients have early radiographic signs of degenerative arthritis as early as 5 years after primary ACL surgery. We believe that use of nonanatomic principles combined with unrecognized laxity of secondary restraints is the primary reason that this occurs. Not all medial-sided knee injuries heal with nonoperative management. Furthermore, unrecognized PLC injuries remain one of the more common reasons why ACL reconstructions fail. Failure to address the PMC or a missed PLC injury may be a cause of residual laxity or failure of an associated ACL reconstruction.

While addressing missed injuries to secondary restraints, it is our contention that use of the anatomic double-bundle ACL techniques and principles in revision surgery will improve knee kinematics and therefore improve overall outcome. It is also possible that by restoring native ACL anatomy the incidence of post-ACL reconstruction degenerative changes may decrease although long-term data is needed to support this claim. During the past 3 years, the senior author has revised over 100 ACLs in the manner described here, with no functional failures due to stiffness, no episodes of fracture or fixation loss, and only two requiring a staged procedure. Our short-term functional results using anatomic double-bundle techniques in revision situations have been encouraging in terms of patient satisfaction and ability to return to preinjury level of activity while formal evaluation is in progress.

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# Part VII

# Surgical Treatment of the PCL-Based Multiple Ligament Injured Knee

# Chapter 14
# Arthroscopic Primary Cruciate Repair in the Multiligament Injured Knee

**Micah Lissy, Christopher J. Dy, Anil S. Ranawat, and Gregory S. DiFelice**

## 14.1 Introduction

Multiligamentous injuries of the knee (MLIK) are rare, with a reported prevalence of 0.2–2% of all orthopaedic injuries [1–4]. Because of the difficulty associated with studying a rare clinical condition, the scientific literature is largely limited to Level III and IV evidence. Furthermore, many of these retrospective comparisons and case series evaluate a heterogeneous group of patients with a wide spectrum of traumatic knee pathology, including various degrees of posterolateral and posteromedial corner, neurovascular, and chondro-osseous injuries [1, 5–8]. The relative paucity of high-quality evidence has left a lack of consensus on how to best manage these difficult and complex injuries [9].

There are numerous controversies regarding ideal management of the MLIK. These include, but are not limited to, the role of nonoperative management [10–15], timing of surgery [5], staging surgery [2], role of acute repair [3], graft choice [16–18], and arthroscopic versus open management [19–22]. Although historically acute repair was the mainstay of surgical treatment [23–27], recent literature does not support primary repair of the ACL, PCL, or collaterals [19, 20, 27]. While the recommendations against primary repair of the collaterals are evidence-based [28], the argument against primary repair of the cruciates is expert opinion derived from inconclusive evidence [2, 8, 29]. We feel primary repair of the cruciate ligaments has a role in the armamentarium of the surgeon managing the MLIK patient.

Historically, primary repair of the cruciate ligaments was done using an open approach [6, 23, 24, 30]. The benefits of primary open repair include the use of native tissue, which can potentially preserve the proprioceptive and native function of the cruciate ligaments [6, 31]. Additionally, the cost and potential morbidity associated with reconstructions, such as infection from allografts or host-site morbidity from autograft, can be avoided by performing primary cruciate repair. The results by Owens and colleagues are particularly encouraging for primary repair, as 23 of the 25 patients treated with open primary repair were able to return to their previous activity with little or no disturbance in function [32].

Modern arthroscopic techniques can be utilized to perform primary cruciate repair with limited incisions, helping to minimize surgical time and avoiding the morbidity of an open arthrotomy [33]. Furthermore, the entirety of the knee joint can be inspected easily, and arthroscopic tools can be used to accurately and precisely replicate ligament insertion angles. Lastly, if primary repair is not successful in achieving stability, this procedure usually does not interfere with delayed reconstruction.

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For the purposes of this chapter, we define primary repair of the ACL and PCL as the apposition of the avulsed end of the cruciate ligament to its anatomic footprint with intrasubstance locking sutures passed through drill holes or engaged into bone anchors. The senior author (GD) performs primary repair of the ACL and PCL in selected patients. This technique is usually done arthroscopically but can also be done open if traumatic wounds dictate. This chapter will review our strategies to maximize outcomes after arthroscopic primary cruciate repair of the MLIK. We will discuss the appropriate patient indications, necessary surgical equipment and techniques, and our postoperative rehabilitation philosophy. Lastly, we will review outcome literature and some case examples.

## 14.2 Indications and Imaging

Appropriate and refined indications are critical in identifying patients who are most likely to benefit from primary repair of the ACL and/or PCL. A thorough history and physical examination are necessary. An understanding of associated neurovascular and soft tissue injuries will guide the technique and timing of surgery. Open injuries often lend themselves to acute repair. In addition, large capsular injuries may necessitate some delay in surgery to prevent fluid extravasation. Most importantly, the treating surgeon should be aware of the difficulty of attempting arthroscopic primary repair after 3 weeks from the injury. With such delayed intervention, scar tissue formation and deterioration in soft tissue quality can limit the likelihood of accomplishing the repair or adversely affect outcomes if the repair is accomplished [3, 5, 6]. Our ideal time frame is 10–21 days.

Advanced imaging is mandatory. This includes standard orthogonal plain radiographs of the knee. Post-reduction radiographs, when necessary, as well as occasionally oblique X-rays may be obtained as well. Bony injuries, such as articular fractures or avulsion fractures, should be further evaluated using computed tomography (CT). When considering acute primary repair versus delayed reconstruction, the surgeon should consider whether articular fracture patterns would interfere with potential reconstructive tunnel placement or create undue risk of fracture propagation into the reconstructive tunnels. Besides radiographs, magnetic resonance imaging (MRI) is particularly useful in defining which cruciate injuries are amenable to acute repair.

MRI has been shown to accurately characterize the injury to the cruciate ligaments [34–36]. Patients with avulsion or soft tissue peel injuries of the cruciate ligaments, either from the tibial (Figs. 14.1 and 14.2) or femoral (Figs. 14.3 and 14.4) insertions, are identified when one end of the ligament insertion and a majority of the ligament substance are relatively intact,

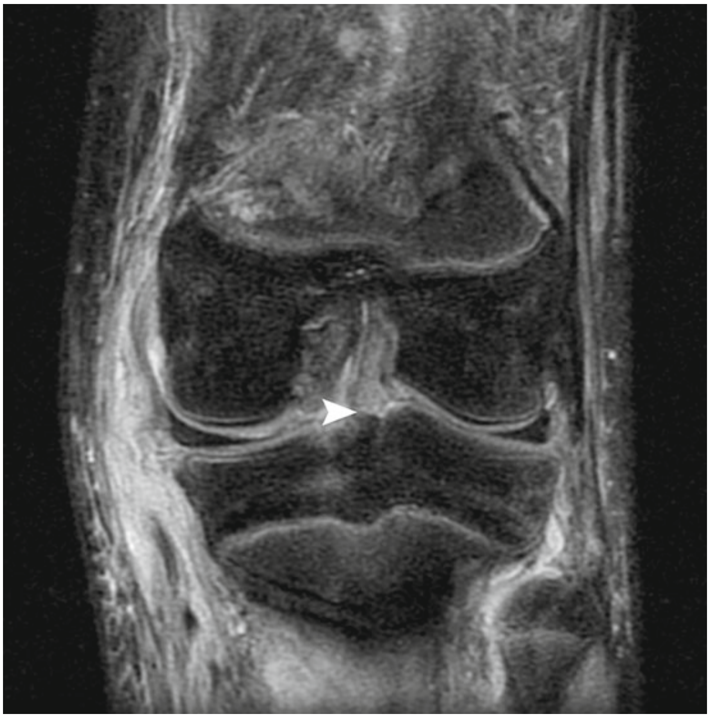

**Fig. 14.1** A fat-saturated proton density-weighted coronal MRI image of an ACL avulsion from the tibia. The *white arrowhead* shows the discontinuity of the tendon at its tibial insertion

**Fig. 14.2** A short TI inversion recovery (STIR) with fat suppression sagittal MRI image of a PCL avulsion from the tibia. The *white arrowhead* is pointing to the avulsed end of the ligament. Note the wavy nature of the PCL, the relatively intact femoral origin, and that the ligament does not insert into the tibia

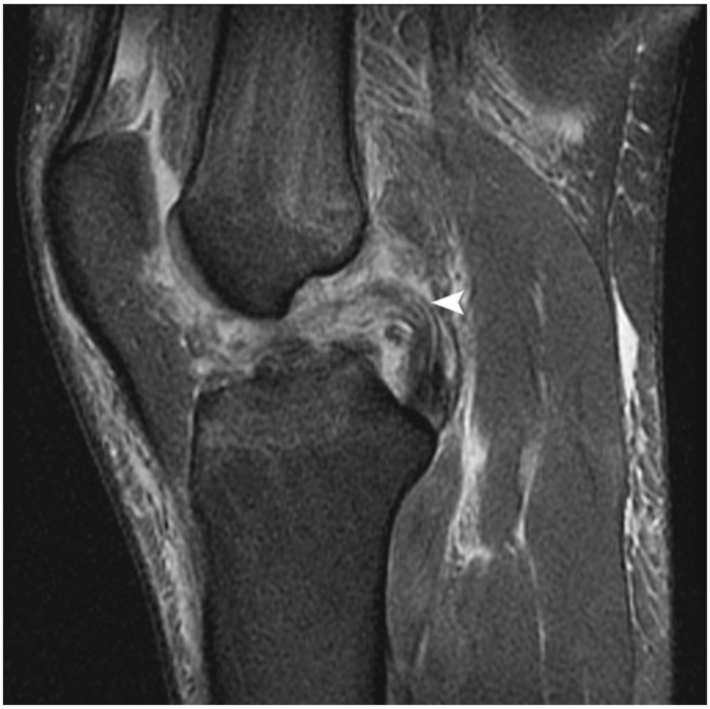

**Fig. 14.3** A STIR with fat suppression sagittal MRI image of a PCL avulsion from the femur. The *white arrowhead* is pointing to the avulsed end of the ligament. Note the wavy nature of the PCL, the relatively intact tibial insertion, and that the ligament does not reach the femoral origin

whereas the other end does not reach to bone. These types of tears are the most likely to benefit from acute primary repair. Conversely, patients with midsubstance tears of the ACL (Fig. 14.5) and PCL, when the majority of the ligament is amorphous or absent, are least likely to benefit from end-to-end primary repair. MRI can also be used to evaluate signal changes within the midsubstance of the ligament that suggests intrasubstance injury. Success with this procedure is critically dependent on tissue quality as this relates to the ligament's ability to hold sutures. However, it is our experience that while the MRI finding of a ligament avulsion with relative length is predictive of the possibility of repair, the MRI finding of intrasubstance injury is not predictive of the ability of the tissue to hold sutures. MRI is also valuable in defining concomitant soft tissue

**Fig. 14.4** A T1 weighted sagittal MRI image of an ACL avulsion from the femur. The *white arrowhead* points to the avulsed femoral end of the ACL. Note the relatively intact tibial insertion and that the ligament does not reach the femoral origin

**Fig. 14.5** A STIR with fat suppression-weighted sagittal MRI image of a midsubstance ACL rupture. Note that the majority of the ligament is absent or amorphous (*white arrowhead*)

pathology about the knee joint, such as injuries to the structures of the posterolateral and posteromedial corners. Recognition of concomitant pathology and appreciation of the overall injury pattern are critical in determining the optimal candidates for primary repair of the MLIK.

Lastly, one must have a thorough understanding of the patient and their demands from their knee. Patients who are poor at coping, those with low pain thresholds, or those who are low demand and are not willing to proceed with a rigorous rehabilitation program may benefit from a less invasive, all-arthroscopic repair when injury patterns are favorable. Table 14.1 outlines our indications for attempting arthroscopic cruciate repair.

**Table 14.1** Surgical indications for attempting arthroscopic cruciate repair

| |
|---|
| Imaging evidence of either soft tissue peel off or bony avulsions of one side of the cruciate insertions |
| 10–21 days post injury |
| Capsular integrity to maintain arthroscopic fluid |

## 14.3 Surgical Technique

The goal of arthroscopic primary repair of the cruciate ligaments is to recreate their anatomic insertions in order to maximize biomechanical function while minimizing joint stiffness and instability. Repair can be performed to both cruciate ligaments if the injury pattern is amenable, but it is more common to repair either the ACL or PCL and perform either simultaneous acute or delayed reconstruction of the other cruciate ligament. Arthroscopic primary repair of the cruciate ligaments is ideally performed 2 weeks after the initial injury. The timing of surgery may be affected by factors beyond the surgeon's control. Concomitant articular fractures or injuries to other soft tissue structures about the knee may delay surgical repair, as will systemic injury from the traumatic incident.

The ability of the surgeon to accurately and expeditiously perform an arthroscopic cruciate ligament repair is critically dependent on modern arthroscopic instrumentation. The surgeon must ensure the availability of the appropriate arthroscopy equipment and implants. Standard knee arthroscopy equipment is used, but oftentimes instrumentation traditionally used for shoulder arthroscopy can facilitate the repair technique. These include a large-bore cannula (such as the PassPort Cannula—Arthrex, Naples, FL), reloadable suture-passing device (such as the Scorpion—Arthrex, Naples, FL), polyester sutures (such as #2 FiberWire—Arthrex, Naples, FL), ligament buttons (such as the RetroButton—Arthrex, Naples, FL), knotted/knotless anchors (such as PEEK FT Corkscrews or BC Vented SwiveLocks—Arthrex, Naples, FL), and a cannulated drill (such as RetroDrill—Arthrex, Naples, FL) to be helpful in performing arthroscopic primary repair of the ACL and PCL.

Standard anteromedial and anterolateral working portals are used to complete a diagnostic knee arthroscopy. The cruciate ligament to be repaired is carefully inspected, mobilized, and gently debrided of any scar tissue. The free end of the ligament is assessed using an arthroscopic grasper to ensure adequate tissue quality and length for primary repair. If the tissue is deemed suitable, then the native insertion site is evacuated of any scar or hematoma and the surrounding area is burred arthroscopically to create a nice healing bed for the repair (Fig. 14.6). When assessing the ligament length, it is particularly important for the surgeon to ensure that the knee is appropriately reduced and that no sagittal plane deformity or sag from ACL or PCL insufficiency is present. For the most part, the anterior tibia should be positioned 1 cm anterior to the femoral condyles when the knee is flexed at 90°.

Accessory portals can be made as needed to facilitate the repair technique. For PCL tibial avulsions, posterior medial and/or lateral portals are commonly made. For femoral-side PCL, or for ACL from either side, an accessory medial portal is often utilized. A malleable large-bore cannula can be particularly helpful in the anteromedial working portal. Once all portals are positioned, the next step depends on fixation method. If a knotted anchor is being used, then the anchor is placed now. If a knotless anchor or drill-hole technique is being used, then sutures are passed through the ligament. If using suture anchors, it is our preference to use knotless anchors so as to avoid issues if the suture integrity is compromised prior to tensioning.

Passing the suture through the ligament is the most technically demanding and difficult aspect of the procedure. A reloadable suture-passing device is used to pass high-tensile suture through the ligament substance as close to the intact insertion as possible. Each limb of the suture is then sequentially reloaded into the device and passed across the ligament substance in the opposite direction while advancing towards the free end of the ligament. This creates a Bunnell-type stitch pattern, with the limbs of the sutures interlocking over three passes to increase strength to pull out and tissue purchase. Great care should be taken to avoid cutting previously passed sutures with each additional pass. Tissue resistance is monitored to ensure that the suture from a previous stitch is not penetrated. If the individual bundles of the ACL and/or PCL are indentifiable, then each bundle is addressed separately; otherwise, the sutures are passed irrespective of bundles. In general, two sutures are passed per repair, resulting in four free suture limbs in a single-bundle repair (Fig. 14.7) and up to eight free suture limbs in a double-bundle repair (Fig. 14.8). Meticulous suture management is critical. Once all of the sutures are passed, they are then "parked" out an accessory portal or tucked behind the large malleable cannula in the anteromedial portal to protect them and the ligament. At this point, an arthroscopic burr can be used again since there is now tension on the ligament, and it can be safely retracted away from the native insertion site to create a nice host bed of bleeding bone.

The next step is placing cannulated drills into the anatomic footprint sites of the ACL and/or PCL, with or without guidewires depending on the type of drill bit used. An exact understanding of the cruciate insertional anatomy is critical. The reader is referred to earlier chapters that cover the anatomic details of the cruciates. Once the drill is passed, a nitinol passing

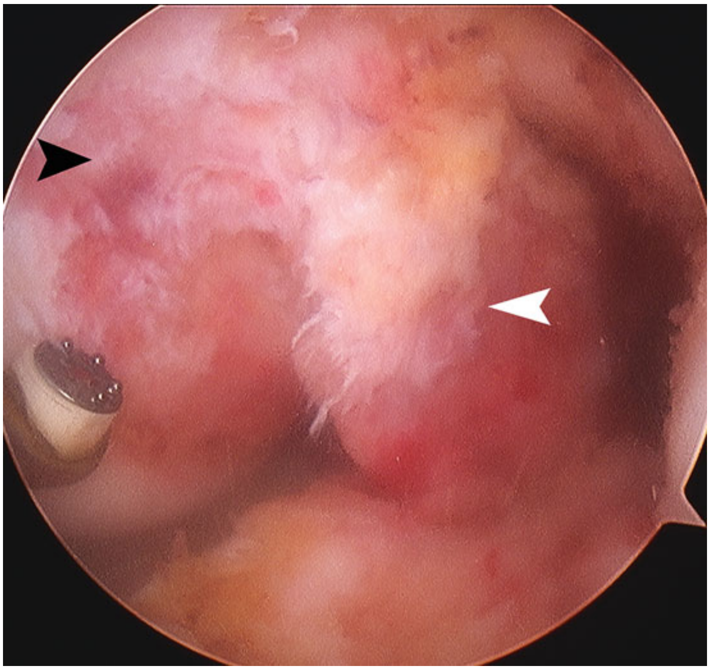

**Fig. 14.6** The *white arrowhead* is pointing to the debrided PCL stump. The *black arrowhead* indicates the PCL footprint on the medial femoral condyle. The PCL appears to be of adequate length for repair

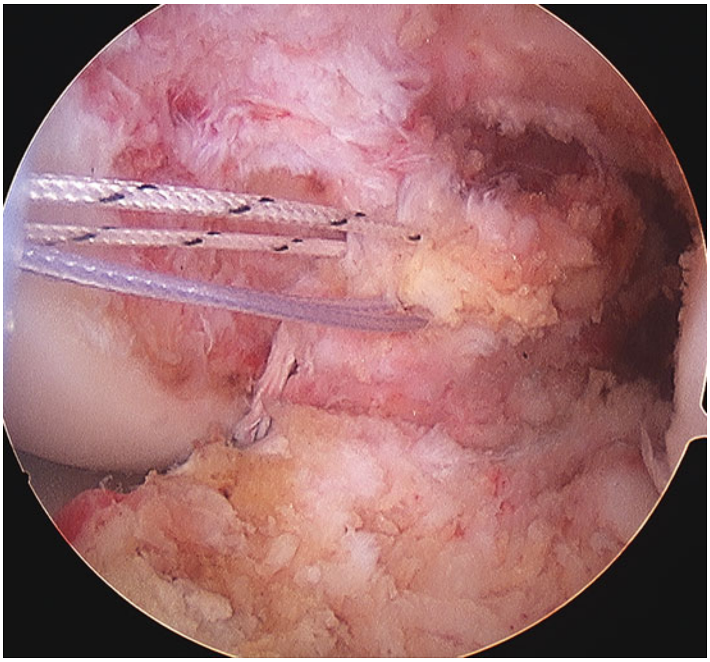

**Fig. 14.7** The PCL stump is visualized in the notch with the four limbs of two newer-generation polyester sutures exiting out the end of the stump. Typically three passes are made with each suture, starting as close to the intact insertion as possible and passing in opposite directions while advancing towards the free end of the ligament to achieve a Bunnell-type stitch pattern

wire is then shuttled down the cannulation of the drill to retrieve the repair sutures (Fig. 14.9). A small incision where the drill enters is made to facilitate fixation. If cannulated instrumentation is not available, a standard 2.4-mm hole can be drilled and spinal needles used to pass the nitinol wire. It is recommended that all drill holes be made prior to any suture retrieval so as to avoid damage to the intraosseous sutures from subsequent passage of the drill.

An alternative technique is to use a RetroDrill or FlipCutter device (Arthrex, Naples, FL) to create a small socket for the ligament to be drawn into. This has the theoretical advantages of increasing the surface area for ligament healing and allowing for additional tensioning. However, it has been our experience that such countersinking is not necessary to achieve ligament healing back to bone. In addition, there is generally not enough length to countersink the avulsed ligament.

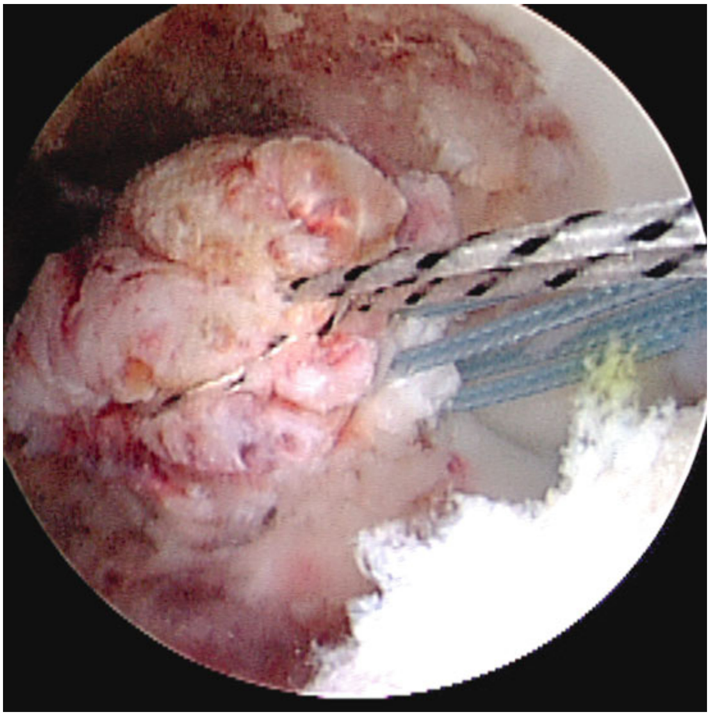

**Fig. 14.8** An arthroscopic view of a double-bundle repair of the PCL demonstrating two sutures in each bundle, creating four limbs per bundle and eight limbs total

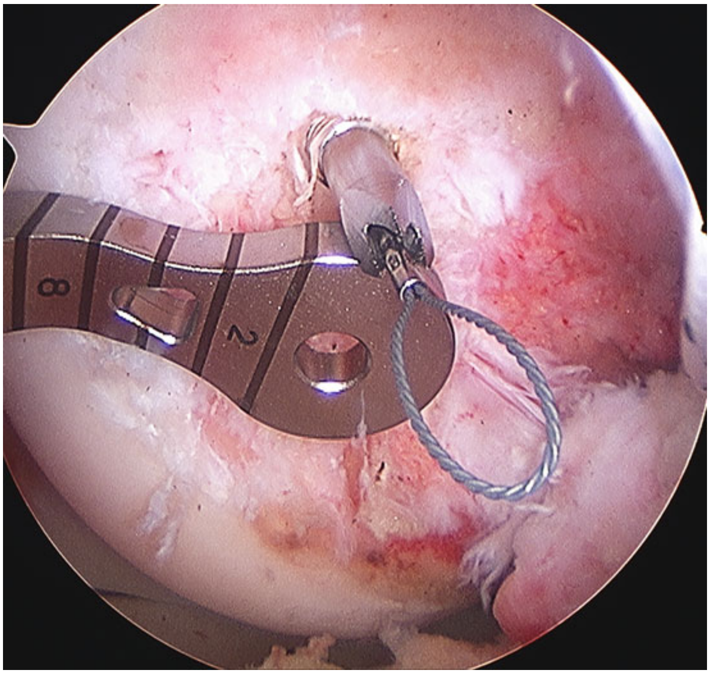

**Fig. 14.9** The PCL footprint on the medial femoral condyle is visualized. The PCL femoral guide is seen, as well as the cannulated drill bit with a nitinol passing wire passed through its cannulation

Since these repairs are usually performed at the same time as other procedures (i.e., collateral surgery), at this point the repair sutures are passed and parked out of an accessory cannula while the rest of the intervention is performed. When appropriate for the particular surgery at hand, then ligament tensioning is performed. For PCL repairs, an anterior drawer force is applied to the knee at 90° of flexion, reducing the tibia anatomically. For ACL repairs, the knee is placed at 30° of flexion. Suture limbs are tensioned in pairs and tied together over the bone bridge between the drill holes. The authors prefer to use a ligament button to minimize compression of the soft tissues at the bone bridge and decrease the chance of future laxity from creep, but screws and washers can also be used as posts. Reduction of the ligament to its insertion while tensioning should

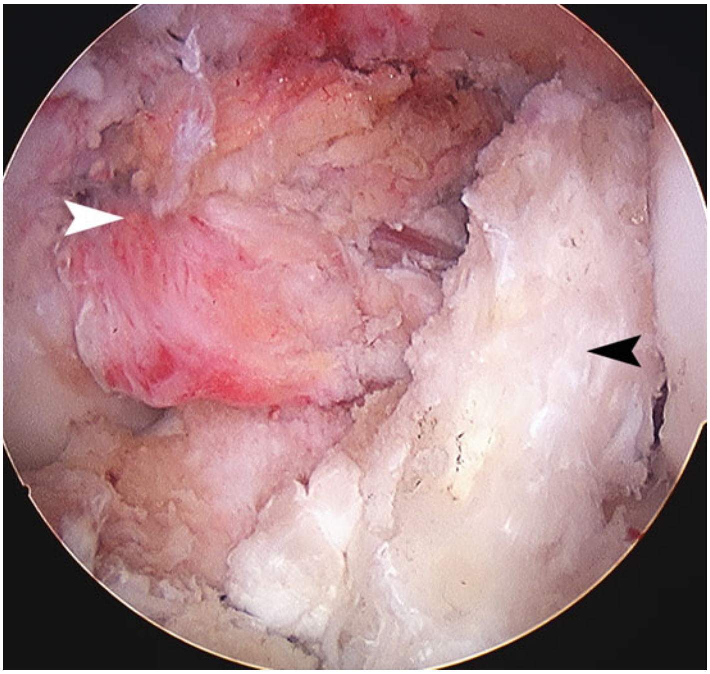

**Fig. 14.10** A completed repair as visualized arthroscopically. The *white arrowhead* is pointing to the repaired PCL that has been tensioned back to the footprint and tied over a ligament button. The *black arrowhead* is pointing to an ACL reconstruction that was completed after the PCL repair

**Table 14.2** Surgical technique pearls

| |
|---|
| Assess the length and quality of tissue first |
| Accessory portals are useful for suture management and to obtain ideal angle for suture, anchor, and/or guide pin insertion |
| Modern arthroscopic instruments are very useful, such as: suture passers, cannulas, and a variety of knotted and knotless anchors |
| Check strength of suture purchase in ligament only after passing several bites of each suture limb to maximize purchase and minimize tissue trauma from pullout |
| Protect suture limbs from instrumentation to avoid having to remove and repass sutures by “parking” them in accessory portals or stab incisions |
| Be sure the knee is in the reduced position when determining if appropriate length and when tensioning the repair |

be visualized using the arthroscope (Fig. 14.10). After the cruciates are fixed and tensioned, then the collaterals and corners are tensioned with the knee in approximately 30° with the appropriate varus or valgus force and foot rotation if necessary. At the conclusion, a gentle anterior and/or posterior drawer examination and Lachman examination to evaluate the integrity of the repaired ligament should be performed. Table 14.2 highlights surgical technique pearls.

Another alternative technique that can be used for repair is to avoid creating the transosseous tunnels altogether by using knotless suture anchors (such as BC Vented SwiveLock — Arthrex, Naples, FL). With this technique the sutures are passed as previously described; however, the fixation to bone is provided by the knotless suture anchors that are placed into the ligament footprint using the standard technique for these devices. This is currently the preferred technique of the senior author (GD).

It should be noted that the initial use of these repair techniques by the senior author (GD) was reserved for patients who had concomitant injuries, either articular fractures or an increased risk of arthrofibrosis (see PCL case), that precluded standard reconstruction. However, with experience and continued success with these repair procedures, the indications were broadened to include those patients who merely had the appropriate injury pattern on MRI. Currently, if the appropriate injury pattern is present on preoperative MRI in the setting of MLIK, then the surgical plan is to attempt arthroscopic cruciate repair where possible and reconstruction where not. If the particular variables of the case do not instill confidence in the repair (i.e., poor tissue hold of the sutures), then a change in surgical plan will proceed with reconstruction.

## 14.4 Postoperative Management

Standard postoperative analgesics and perioperative antibiotics are administered. Regional nerve blocks are performed on a case-by-case basis. Ambulation with a hinged knee brace locked in extension should begin the first day after surgery, with weight-bearing status determined by any other concomitant injuries and reconstructions. It is difficult to generalize a rehabilitation protocol for cruciate ligament repair because other ligamentous and even bony reconstructions/repairs are concomitantly performed in a majority of patients. However, in general, patients are allowed partial weight bearing and gradually advanced over the first few weeks. Routine wound examination is performed at 1 week after surgery. Isometric quadriceps exercises are started immediately after surgery with the knee locked in full extension in a hinged knee brace. Strength of straight leg raise is evaluated at 3 weeks after surgery. Gentle range of motion exercises are generally begun between 2 and 4 weeks postoperatively and progressed as tolerated. We are usually aggressive with ROM since postoperative stiffness is always a risk when operating on the acutely injured knee. Open-chain muscular activity that would put the repair in jeopardy is avoided entirely. Closed-chain exercises are begun at 6–8 weeks postoperatively, again depending on concomitant surgical work or injury patterns. Range of motion and muscle strength are tested at 3 and 6 months after surgery. Gradual return to sport is allowed if assessment at 6–9 months shows 4+/5 quadriceps and hamstring strength, full active extension, and active flexion within 15° of the well knee.

## 14.5 Outcomes

The literature evaluating outcomes after treatment of patients with MLIK largely consists of Level III and IV evidence. The outcomes data following acute primary repair of the cruciate ligaments is even more limited. There is a lack of consensus on how to best manage patients with MLIK because of the relative rarity of the injury and the heterogeneity of injuries in patients included in the existing studies [2, 7, 9].

Recent systematic review [3] and expert opinion [29] regarding decision-making and management of patients with MLIK must be interpreted carefully. Like much of the preceding literature, the portions of these publications [3, 29] that concern repair versus reconstruction are focused on treatment of posterolateral corner (PLC) injuries primarily and cruciate ligament treatment secondarily. The work by Stannard and colleagues [28] is often mentioned in the discussion of evidence-based management of patients with MLIK largely because it is one of the rare prospective cohort studies of this patient population. Stannard and colleagues reported that primary repair of PLC structures was significantly inferior to reconstructions of the PLC. In their study, choice of repair or reconstruction was made by the treating surgeon based on the injury pattern, with injuries judged as less severe generally treated with repair of the PLC. Closer evaluation of the data presented in the study reveals that 25 of the 67 patients treated for PLC injuries also had both ACL and PCL injuries requiring surgical treatment. Of these 25 patients, none were treated with acute primary repair of both the ACL and PCL. Two of the 25 patients were treated with repair of the PCL and reconstruction of the ACL, while the remaining 23 were treated with reconstruction of both cruciate ligaments. The two patients treated with PCL repair, ACL reconstruction, and PLC reconstruction had clinical success as determined by the investigators. In our interpretation, the results from Stannard's work support PLC reconstruction over PLC repair but do not provide conclusive evidence against primary repair of the cruciate ligaments. In a recent systematic review of the literature, Levy et al. [3] looked at surgery versus nonoperative treatment, reconstruction versus repair, and early versus late surgery. They concluded that early operative intervention yields improved functional outcomes. Furthermore, reconstruction of the PLC yields lower revision rates than repair. In a later expert opinion paper by Levy et al. [29], among many other recommendations, arthroscopic reconstruction of the ACL and PCL was advised.

The evidence regarding management of the ACL and PCL in the context of the MLIK is largely based on retrospectively evaluated data. In a Level IV retrospective review of 23 knees, Mariani compared patients with combined ACL/PCL injuries who underwent direct ACL/PCL repair, ACL reconstruction with PCL repair, or ACL/PCL reconstruction. The results of this series showed higher rates of flexion loss and posterior sag, as well as lower rates of return to preinjury activity level, in the ACL/PCL repair cohort. Although 13 of the 20 ACL injuries and 8 of the 23 PCL injuries were midsubstance tears, the type (midsubstance tears or bony avulsion injuries) of ligamentous injury was not specified for each treatment group. The authors did not specify how the treatment protocols for each patient were chosen, but the presumed heterogeneity of ligament injury patterns implies that patient selection may have influenced the outcomes seen in the ACL/PCL repair cohort. Furthermore, the flexion loss described by Mariani and colleagues may be attributed to soft tissue scarring from the wounds created during open arthrotomy and a substantially less aggressive rehabilitation protocol in the ACL/PCL repair cohort. Mariani raises the concern of residual ligament laxity after repair, but attempted repairs of midsubstance tears would predispose to laxity, especially since absorbable sutures were used. Alternatively, Owens and colleagues have reported results in a Level IV series of 25 consecutive patients who had sustained knee dislocations and were treated with open primary cruciate repair [32]. Twenty-three of the 25 patients were able to return to their previous jobs with little or no activity modification with an average Lysholm score of 89. Wheatley et al. in 2002 described an arthroscopic repair of PCL soft tissue avulsions. The authors used a Caspari suture punch to pass multiple nonabsorbable monofilament sutures through the PCL stump in different planes. They reported on 13 patients with International Knee Documentation Committee (IKDC) scores of normal or near normal and an average Lysholm of 95.4 in the 11 repairs available for follow-up at an average of 51 months. To put these numbers into perspective, a recent systematic review of arthroscopic single-bundle PCL reconstructions by Kim et al. in 2010 reported an average Lysholm of 89.6 in 10 studies. When considered together, and in context of the remainder of the literature, we feel that evidence exists showing the potential success of acute primary repair of ACL and PCL and that there is no conclusive evidence recommending against its use. Furthermore, a repair does not preclude later reconstruction should it fail.

One commonly considered disadvantage to primary ligament repair is the potential for occult intrasubstance ligament damage during the original injury. It is hypothesized that if unrecognized or underappreciated, the plastic deformity of the ligament could compromise the outcome of a ligament repair by rendering the ligament functionally incompetent [37]. Inoue and colleagues evaluated the effect of intrasubstance injury on PCL repair with a prospective cohort study in 2004 [38]. There was no significant difference in posterior knee instability and clinical outcomes between patients who did and did not have intrasubstance injury detected on MRI, leading the authors to state that orthopaedic surgeons should not be "overly apprehensive" of occult midsubstance injuries [38].

## 14.6 Case Examples

### 14.6.1 Case #1: Repair of PCL Avulsion from Femur

A 17-year-old male sustained a closed knee dislocation without neurovascular injury after jumping off a trampoline. The patient's knee was reduced at another institution and transferred for definitive management. MRI revealed a soft tissue avulsion of the PCL from the femur (Fig. 14.11) and a midsubstance ACL rupture. The initial treatment plan was for ACL and PCL reconstruction at 2 weeks after injury, but this plan was altered after the preoperative examination under anesthesia revealed less than 90° of flexion, and diagnostic arthroscopy showed substantial hemorrhagic synovitis (Fig. 14.12). Heightened concern for postoperative arthrofibrosis led to the surgical plan being changed to arthroscopic double-bundle repair of the PCL (Figs. 14.13, 14.14, 14.15, and 14.16).

The patient was placed in a hinged knee brace locked in extension, which was unlocked for ROM 0–90° at 2 weeks. Isometric quadriceps exercises in extension were started immediately postoperatively. The patient progressed rapidly with physical therapy, and the initial plan for delayed ACL reconstruction was ultimately deferred because the patient

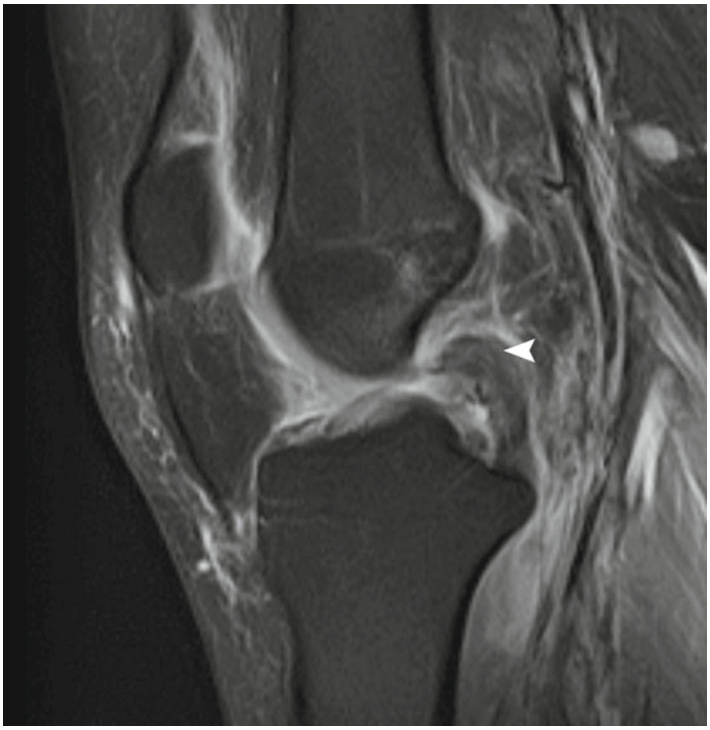

**Fig. 14.11** A fat-saturated proton density-weighted sagittal MRI showing the PCL soft tissue avulsion from case #1. The *white arrowhead* is pointing to the long remnant of PCL contiguous with the tibia

**Fig. 14.12** Initial notch view of the knee in case #1. Significant hemorrhagic synovitis is noted

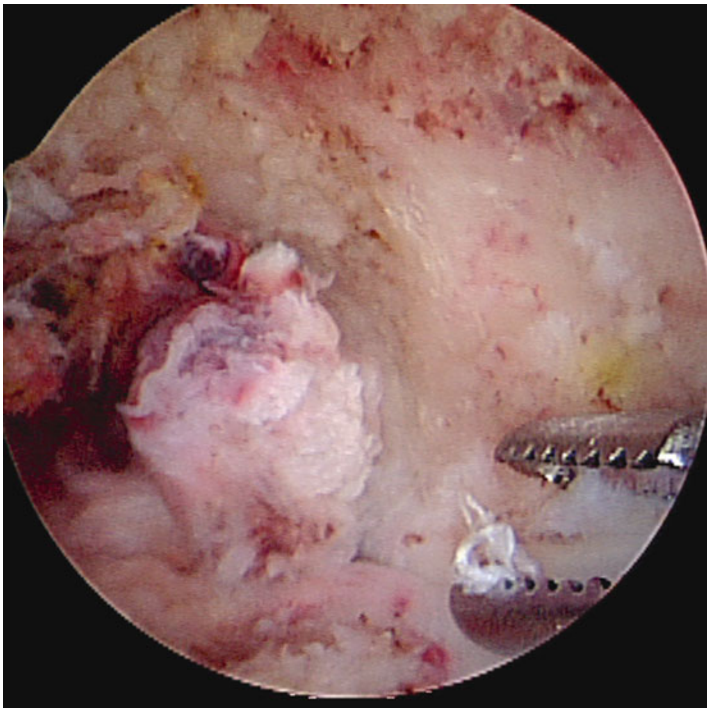

**Fig. 14.13** Arthroscopic view from case #1, showing the PCL stump sitting next to its footprint on the medial femoral condyle

**Fig. 14.14** Arthroscopic view of the medial femoral condyle and the PCL footprint. Three drill bits are seen, of the eventual four, that will be used for a double-bundle repair of the PCL. As these are not cannulated drill bits, they will be removed and spinal needles placed in order to aid in the passage of the nitinol suture passing wires

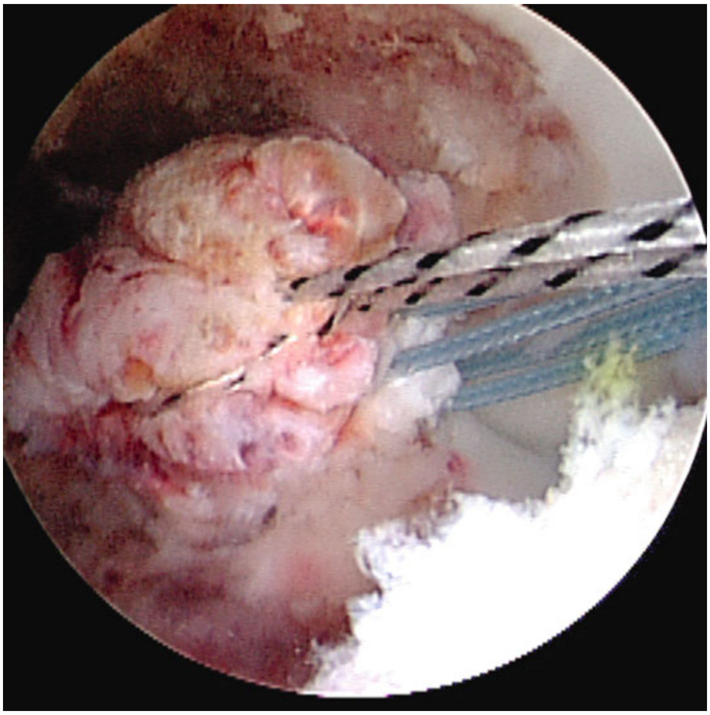

**Fig. 14.15** The PCL with two sutures in each bundle, creating four limbs per bundle and eight limbs total

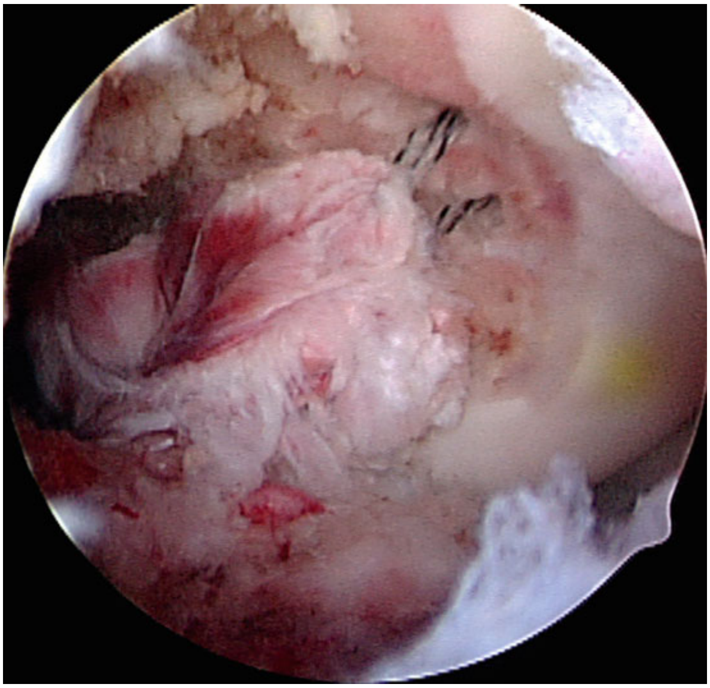

**Fig. 14.16** The double-bundle repair just prior to fixation. The sutures have been shuttled up through the drill holes but have not yet been tensioned or tied down over a ligament button

achieved excellent stability and functional recovery. Follow-up after 5 years showed symmetric full-knee ROM, a negative posterior drawer examination, and a grade 1A Lachman examination. The Lysholm knee score was 95, and modified Cincinnati knee score was 96. The patient resumed competition in recreational sport without limitation. An MRI has confirmed anatomic ligamentous healing of the PCL to its femoral origin.

### *14.6.2 Case #2: ACL Repair to the Tibia*

A 15-year-old bicyclist was struck by a motor vehicle and sustained a traumatic brain injury, a closed clavicle fracture that was treated nonoperatively, and a closed medial knee dislocation without neurovascular compromise. Post-reduction examination revealed gross laxity to anterior and posterior stress, as well as to valgus stress with the knee extended. MRI showed a mid-substance PCL injury, an ACL avulsion from the tibia (Figs. 14.17 and 14.18), an MCL avulsion from the tibia, and medial and lateral meniscal root avulsions. Surgical treatment was delayed until 3 weeks after injury due to the traumatic brain injury.

The preoperative plan was for an arthroscopic ACL repair and PCL reconstruction, with possible meniscal root and MCL repairs. Initial arthroscopic evaluation of the ACL revealed detachment from its tibial insertion with excellent tissue quality and length (Fig. 14.19). Two locking sutures were passed into the ACL substance and parked in a separate stab incision for protection while the rest of the pathology was addressed (Figs. 14.20 and 14.21). An all-inside allograft PCL RetroConstruction (Arthrex, Naples, FL) was then performed and the meniscal root injuries and MCL were both repaired using suture anchors. After this, the sutures were passed through separate transphyseal drill holes at the original ACL insertion (Fig. 14.22) and secured distally over the bone bridge using a ligament button. After the PCL, MCL, and roots were tensioned, the ACL was tensioned (Fig. 14.23).

The patient was placed in a hinged knee brace and made non-weight bearing to avoid compromise to the meniscal root repairs. Isometric quadriceps exercises in extension were begun immediately. Passive ROM exercises were started at 2 weeks after surgery. His weight-bearing status, active ROM, closed-chain strengthening, and resisted exercises were advanced after the first 6 weeks postoperatively. At nearly 3 years after surgery, he has full-knee ROM symmetric to the well knee, a negative posterior drawer examination, and a negative Lachman examination. The Lysholm knee score was 95, and modified Cincinnati knee score was 92. The patient resumed competition in recreational sport without limitation. An MRI has confirmed anatomic ligamentous healing of the ACL to its tibial origin.

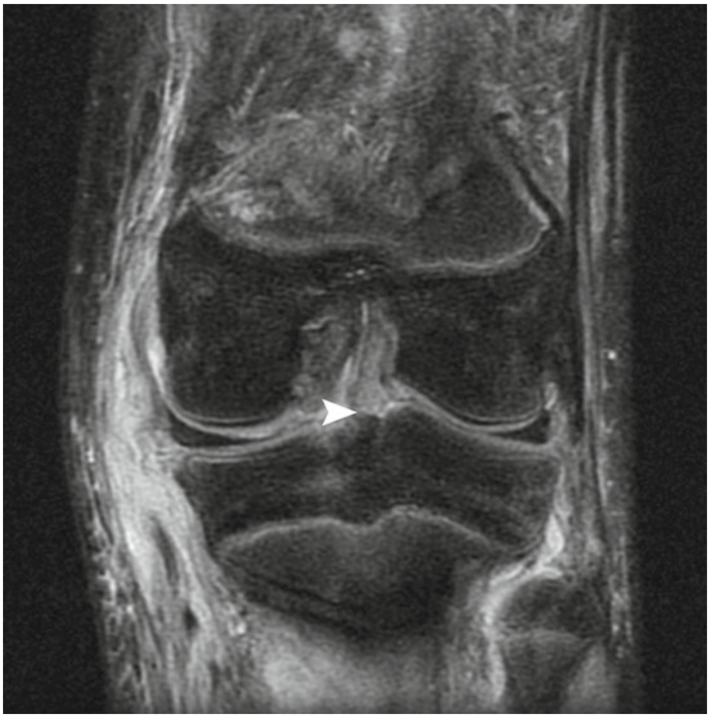

**Fig. 14.17** A fat-saturated proton density-weighted coronal MRI image of an ACL avulsion from the tibia in case #2. The *white arrowhead* shows the discontinuity of the tendon with its tibial insertion

**Fig. 14.18** A fat-saturated proton density-weighted sagittal cut MRI again displaying an ACL avulsion from the tibia. The *white arrowhead* is highlighting the relatively intact proximal segment of ligament

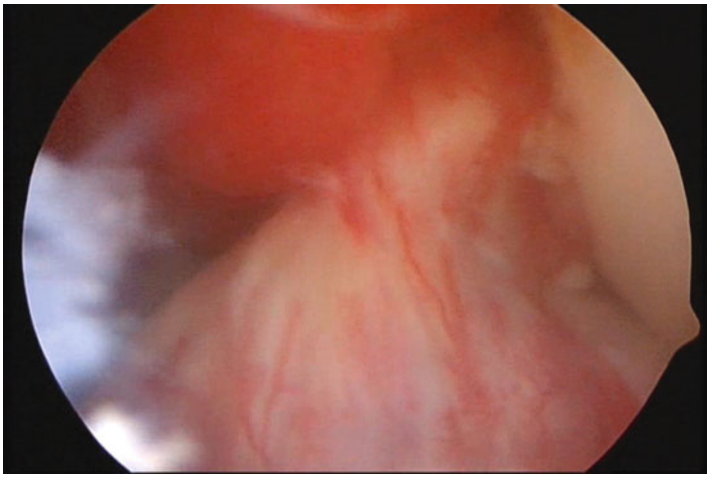

**Fig. 14.19** Initial view of the ACL tibial avulsion from case #2, displaying adequate tissue quality and length. Upon probing of the insertion, it was obvious that the soft tissue avulsion was real

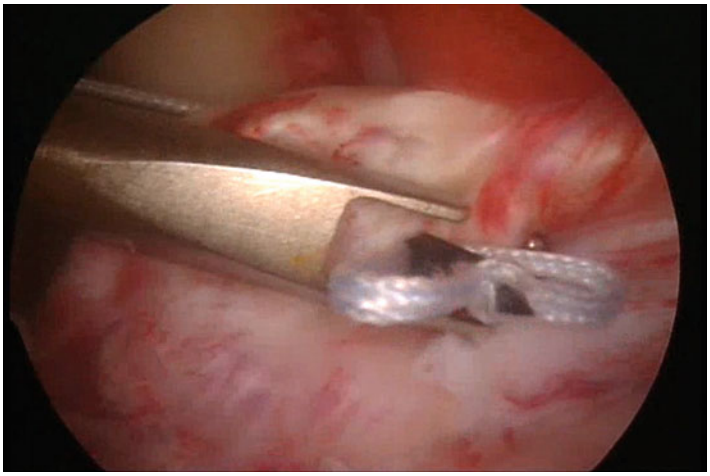

**Fig. 14.20** A reloadable suture passer (Scorpion—Arthrex, Naples, FL) is used to pass polyester suture through the base of the ACL stump

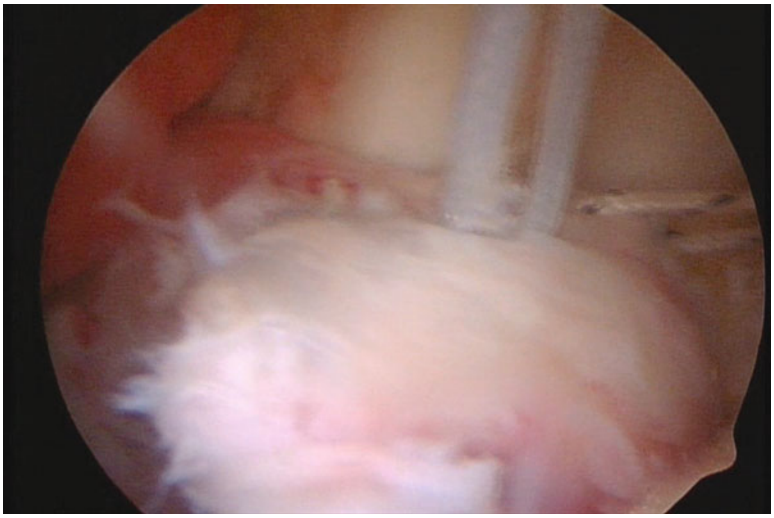

**Fig. 14.21** The completed, Bunnell-type stitch pattern displays the four limbs of the two sutures in the stump of the ACL

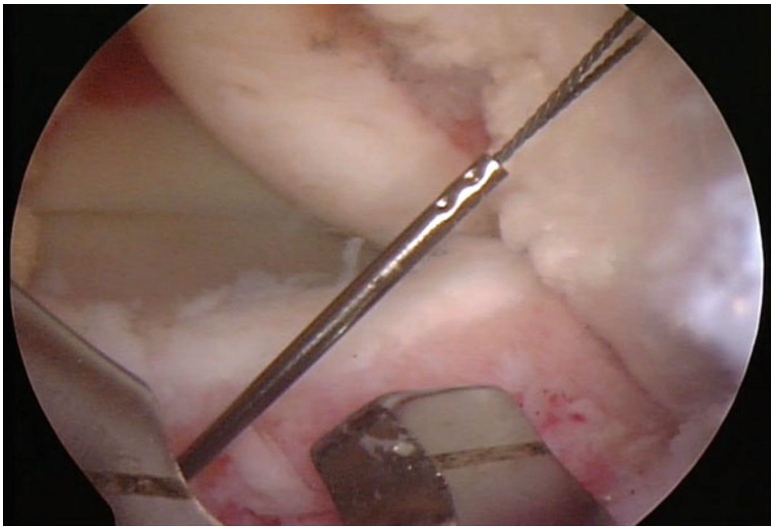

**Fig. 14.22** An ACL tibial drill guide is in place at the ACL tibial footprint. A nitinol passing wire has been passed through the drill hole and into the joint in order to shuttle two suture limbs out of the joint

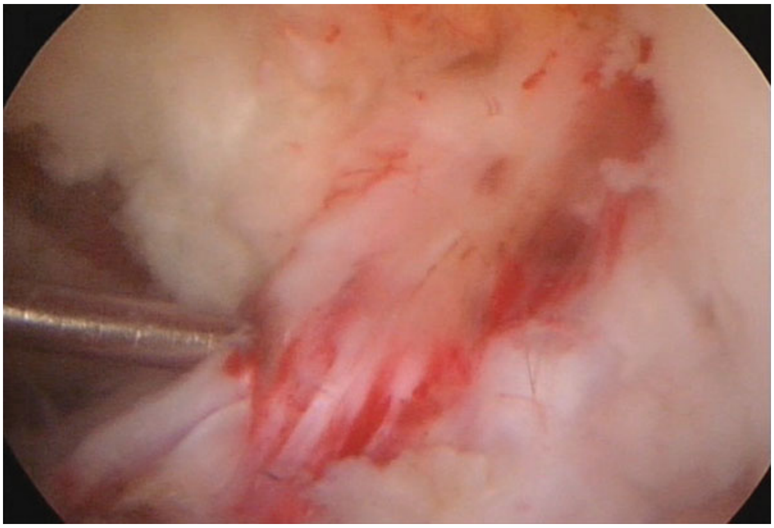

**Fig. 14.23** The suture limbs have been tied down over a ligament button, and the completed ACL repair is seen. The hook evaluates for appropriate fixation and tension

## 14.7 Conclusions

Patients with multiligamentous injuries to the knee present a challenge to the orthopaedic surgeon. The heterogeneity of patients studied within the limited literature has led to a dearth of conclusive guidelines as to how to best manage patients with MLIK. Because the majority of cruciate ligaments are ruptured midsubstance, allograft reconstruction remains the treatment of choice for those injuries. However, advances in diagnostic imaging and arthroscopic technology have increased the chances of identifying when a soft tissue avulsion injury is present and performing a successful primary arthroscopic repair when these situations present themselves. Performing an arthroscopic primary repair avoids the morbidity associated with open approaches, donor site morbidity, potential allograft reactions, and infections and does not create any technical barriers to future revision surgery if the need arises. Arthroscopic primary repair of the ACL and/or PCL should be a tool in the armamentarium of the surgeon treating patients with MLIK. This technique can be applied by trained surgeons if soft tissue avulsion injuries are present in the appropriately selected patient population.

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# Chapter 15
# Surgical Treatment of Combined PCL/Lateral-Sided Injuries: Acute and Chronic

**M. Mustafa Gomberawalla and Jon K. Sekiya**

## 15.1 Introduction

Posterior cruciate ligament (PCL) injuries frequently occur in combination with other ligamentous disruptions. Often, the structures of the posterolateral corner (PLC) will be injured in conjunction with the PCL. Appropriate and timely identification of these combined injuries is crucial when formulating a treatment plan, as mismanagement of these injuries may lead to continued instability and premature posttraumatic osteoarthritis. Specifically, early identification of an acute PCL insufficiency and PLC injury allows for prompt surgical treatment, while chronic injuries are candidates for reconstruction. Although surgical reconstruction remains the mainstay of treatment for the multiple-ligament injured knee, the consequence of surgical treatment of a PCL injury with an unrecognized concomitant PLC injury is early failure of the surgical repair or reconstruction if one is undertaken. As our clinical knowledge of this unique but challenging combined injury continues to grow, a number of reconstructive techniques have been described in the literature. Although controversy remains regarding the various treatment options for these difficult injuries, we present the rationale behind our preferred surgical techniques and management of combined PCL/PLC injuries.

## 15.2 Anatomy

A thorough understanding of the complex anatomy of the PCL, PLC, and lateral-sided structures of the knee facilitates the treatment of these injured structures. The PCL takes its origin from the lateral aspect of the medial femoral condyle and courses posterolaterally behind the anterior cruciate ligament (ACL), to insert onto the posterior aspect of the proximal tibia. The PCL is intra-articular but surrounded by a synovial reflection from the posterior capsule [1]. The PCL consists of two distinct bundles referred to as the anterolateral (AL) and posteromedial (PM) bundles. These bundles experience varying degrees of tension based on the flexion angle of the knee [2]. The PCL is narrowest at the mid-substance of the ligament and fans out closer to its insertion sites on the femur and tibia. The femoral attachment is oriented in a semicircular fashion, with the attachments of both bundles organized in an anteroposterior fashion. The tibial attachment is oriented in a trapezoidal fashion on the posterior aspect of the tibia, between the medial and lateral tibial plateaus at the posterior intercondylar fossa.

The PLC of the knee is composed of several structures that contribute to knee stability, including the popliteus tendon (PT), popliteofibular ligament (PFL), and fibular collateral ligament (FCL). The FCL (also known as the lateral collateral ligament) takes its femoral origin just posterior to the lateral epicondyle. It attaches to the lateral aspect of the fibular head,

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approximately 28 mm distal to the fibular styloid. The PT arises from the popliteus muscle belly on the posteromedial tibia. The tendon travels intra-articularly into the popliteal fossa. It then runs medial to the FCL and attaches in the popliteal sulcus on the femur, anterior and distal to the FCL attachment. The PFL arises off the musculotendinous junction of the popliteus muscle and attaches to the fibular styloid process. It consists of an anterior and posterior division [3]. Other structures that contribute to the PLC include the posterolateral joint capsule, the fabellofibular ligament, the long head of the biceps femoris, the iliotibial (IT) band, and the lateral gastrocnemius tendon.

## 15.3 Biomechanics

The PCL and lateral-sided structures play a unique but integrated role in the biomechanics of the knee, that is, highlighted in cases of combined ligamentous injuries. The intact PCL serves as the primary restraint to posterior translation of the tibia on the femur. Other secondary restraints to tibial translation include the posterior joint capsule and the medial collateral ligament (MCL). The two bundles of the PCL (anterolateral and posteromedial) have shown a codominant role in preventing posterior tibial translation [4]. In addition, the PLC has two main biomechanical functions. The FCL primarily resists varus stress across the knee joint, while the popliteal tendon and PFL primarily resist external rotation of the tibia on the femur.

Several studies of cadaveric models have shown a synergistic relationship between the PCL and PLC in controlling posterior and rotational forces about the knee. Noyes et al. showed that sectioning of the PLC in a PCL-deficient knee leads to an increase in posterior tibial translation when compared to knees with an isolated PCL deficiency [5]. Conversely, Grood et al. sectioned the PCL in a PLC-deficient knee and noted increased tibial external rotation, most significantly at 90° of flexion [6]. However, isolated sectioning of the PCL did not show a measurable difference in external rotation when the PLC is intact.

The importance of this biomechanical association between the PCL and PLC is further illustrated when isolated repairs or reconstructions have been attempted in cases of combined injuries. Surgical treatment with isolated PCL reconstruction in a PCL and PLC-deficient knee results in premature failure of the PCL graft [7]. Furthermore, cadaveric studies have shown that forces on the reconstructed PCL graft can be up to 150% higher in cases of PLC deficiency, specifically on the anterolateral bundle [8]. The results of these studies stress the importance of restoring proper anatomy in order to reestablish functional knee biomechanics and prevent graft failure in individuals with a combined PCL and PLC injury.

## 15.4 Initial Evaluation and Management

The clinical evaluation of a patient with suspected PCL and PLC injury should begin with a focused history, including the date and mechanism of injury, in addition to any prior surgical treatment and the duration of immobilization if initially treated nonoperatively. The patient's functional demand, including previous and anticipated activity level such as participation in sports, is important to guide treatment and patient expectations. Many patients will report a sports-related or high-energy injury to the knee.

The physical exam should begin with inspection to document the presence of an effusion or visible swelling, trauma, or skin compromise. Next, the range of motion and strength are documented. The presence of a posterior sag sign may alert the examiner to the presence of a PCL injury. Ligamentous stability is assessed through a variety of tests. These include the Lachman test, the pivot shift test, the posterior drawer test, the reverse pivot shift test, and the dial test. Each parameter should be compared to the contralateral side. The extent of injury can be graded based on increased posterior tibial translation (for the PCL) and varus laxity (for the LCL/PLC). During the dial test, increased rotational laxity at 30° that does not correct at 90° is indicative of a combined injury to the PCL and PLC. Additionally, a Grade III posterior drawer has been shown in cadaver models to be highly suggestive of a combined PCL and PLC injury [9]. In cases of known or suspected dislocation to the knee, a thorough neurovascular examination should be included as part of the evaluation.

Initial imaging should include standard X-rays of the knee (bilateral flexion weight-bearing PA, lateral, and sunrise views). Stress radiographs are utilized to evaluate posterior tibial translation, whereby greater than 10 mm of posterior tibial translation should increase the examiner's suspicion of a combined PCL and PLC injury (Fig. 15.1) [9]. In cases of chronic multiligamentous knee injury, long leg films should be ordered to evaluate limb alignment. In addition, MRI is often used to confirm the diagnosis of an injury and to evaluate for other intra-articular pathology such as meniscal or chondral damage (Figs. 15.2 and 15.3).

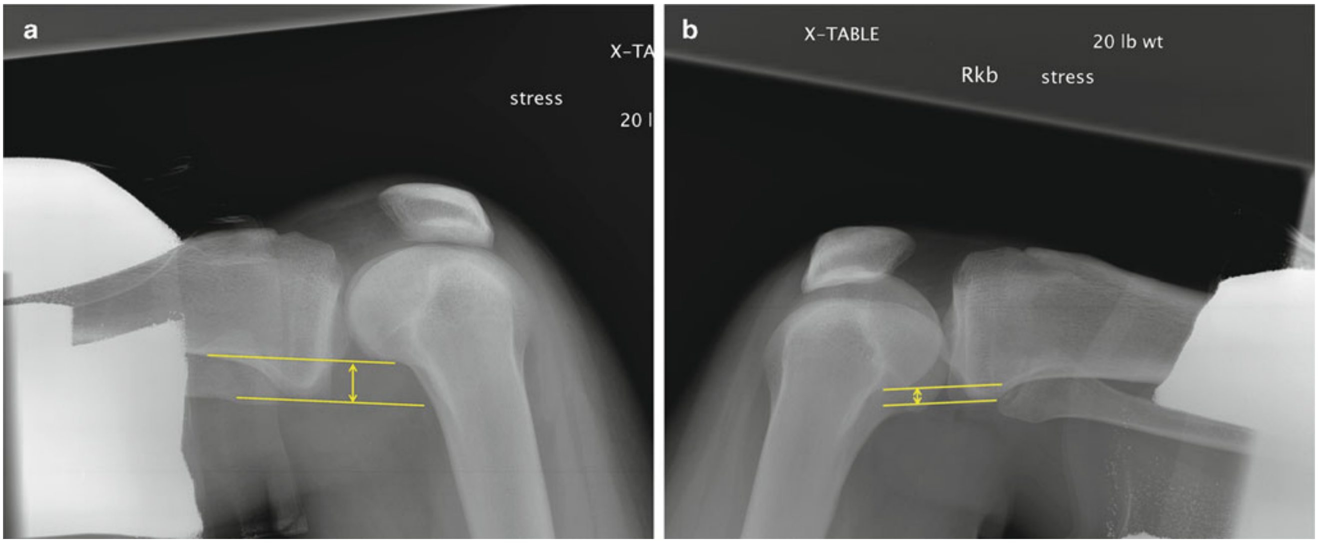


**Fig. 15.1** Stress radiographs demonstrating 15 mm of posterior subluxation of the tibia in the PCL-deficient knee (*left*, **a**), when compared to the normal knee (*right*, **b**)

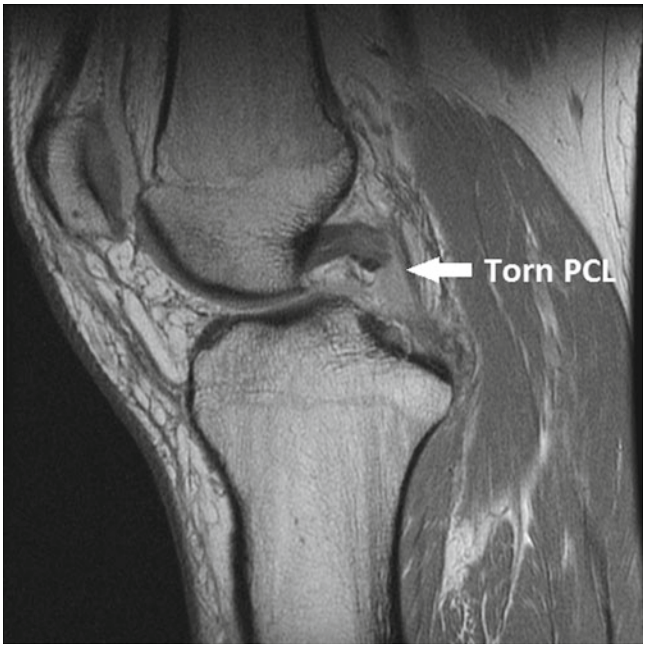


**Fig. 15.2** MRI (T1 weighted, sagittal view) of the knee demonstrating a complete tear of the PCL

If the patient is seen in the acute period immediately after an injury, the initiation of a rehabilitation program may improve range of motion and decrease swelling. Participation in physically demanding activities should be discouraged to prevent further episodes of instability.

The timing of surgical intervention has a significant impact on the available treatment options. If the patient is evaluated in the acute phase (less than 3 weeks from the date of injury), prompt surgical intervention can be performed. The healing potential of the PCL allows for augmentation of remaining fibers or reconstruction in the acute phase. Additionally, early treatment of the PLC has shown better outcomes, although the decision to acutely repair or reconstruct lateral-sided structures remains controversial. In the acute setting, we recommend a combined PCL reconstruction/augmentation and PLC repair/reconstruction. However, there are many factors to consider prior to proceeding with an acute intervention, such as the presence of skin necrosis, arterial injury, or if the patient has other traumatic injuries precluding prompt surgical intervention to the knee.

**Fig. 15.3** MRI (T2 weighted, coronal view) of the knee showing a complete tear of the LCL

If greater than 3 weeks have passed since the time of injury, significant scarring and contraction generally make primary repair of the PLC more difficult, which would outweigh the benefits of a repair. Similarly, the healing potential of the PCL is lost in chronic cases. In this situation, we recommend continued knee rehabilitation to restore range of motion and decrease swelling, and plan for a delayed combined reconstruction of the PCL and PLC.

## 15.5 Surgical Technique: Posterior Cruciate Ligament Reconstruction

As our understanding of the role of the PCL has improved, so have our methods for surgical treatment. Reconstruction has been shown to improve knee stability, while repair has not been a reliable option. As our reconstructive methods evolved, single-bundle reconstructions were undertaken, with the specific aim of restoring the AL bundle. To ultimately recreate the anatomy and biomechanics of the knee, double-bundle reconstruction has been biomechanically favored over single-bundle techniques [10–12]. Two commonly discussed methods of double-bundle reconstruction are the open tibial inlay and arthroscopic trans-tibial techniques. The open inlay technique involves placing a grafted bone plug over the tibial footprint site with direct screw fixation. This offers the advantages of better biomechanical stability because of the stronger fixation and a decreased risk of neurovascular injury secondary to the improved exposure. However, accessing the posterior knee can make positioning and exposure difficult, and carries an increased morbidity because of the posterior capsulotomy. The trans-tibial approach involves graft insertion directly at the tibial footprint and allows for interference screw fixation in the tibia, which can be performed arthroscopically. There are several benefits to an arthroscopic technique, including less morbidity to the patient, avoidance of a capsulotomy, and improved patient positioning during the surgical procedure. However, with a trans-tibial approach, the graft forms a sharp angle as it traverses from the tibial to the femoral tunnel, commonly referred to as the "killer corner," which can result in graft failure from fraying and cyclic loading. Currently, no definite clinical advantage has been shown in one double-bundle technique over the other [13].

We have developed an all arthroscopic technique with tibial inlay fixation for double-bundle PCL reconstructions [14]. This draws from the advantages of both of the aforementioned fixation constructs by utilizing the biomechanical stability from the tibial inlay technique while avoiding the morbidity and complications of an open posterior capsulotomy by performing the reconstruction arthroscopically. This arthroscopic inlay method offers biomechanically similar strength to the open inlay technique [15, 16].

First, the patient is placed supine on the operating table. A sandbag is taped onto the bed under the foot to help support the knee at 80° of flexion (Fig. 15.4). An examination under anesthesia of both knees is routinely performed. The PCL is evaluated by looking for a posterior tibial sag sign, performing a posterior drawer test and the dial test. If the injured knee exhibits increased varus instability, increased external rotation at 90°, or a Grade III posterior drawer, a combined

**Fig. 15.4** Patient positioning for a double-bundle PCL reconstruction. Note the sandbag taped to the operative table, which helps hold the knee flexed at 80°

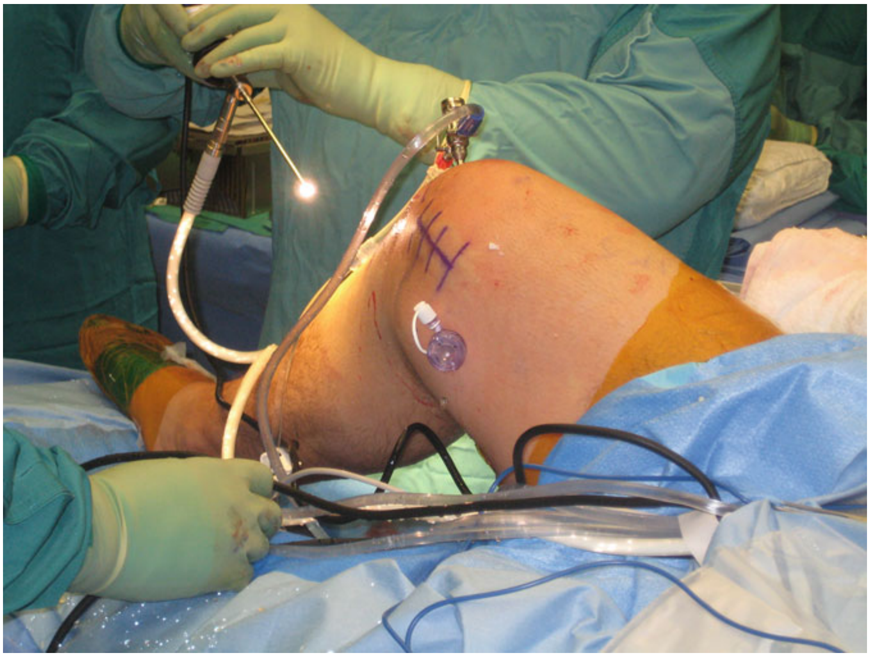


**Fig. 15.5** Photograph showing placement of the posterolateral portal during an arthroscopic inlay PCL reconstruction

PCL–lateral-sided injury is very likely. After the examination, a nonsterile, well-padded tourniquet is placed high on the involved thigh, although it is usually not inflated during the procedure.

A diagnostic arthroscopy is performed utilizing a standard anterolateral portal. The anteromedial portal is created as close to the patellar tendon as possible, to facilitate access to the posteromedial joint space. If any meniscal or chondral pathology is present, this should be addressed first. An 8-mm posteromedial portal is then created to facilitate arthroscopic access to the posterior tibia (Fig. 15.5). The injured PCL ligament is resected with an arthroscopic shaver. The anterior aspect of the tibial

**Fig. 15.6** Photograph of a prepared split Achilles tendon allograft for a double-bundle arthroscopic inlay PCL reconstruction

PCL footprint should be preserved to serve as a reference point for the tibial inlay. Both the 30° and 70° scopes are used to maximize visualization.

Our preferred graft is a bifid Achilles tendon allograft. The tendon should have a minimum length of 7–8 cm. Two bundles are fashioned from the graft by splitting the superficial and deep fibers of the Achilles tendon. The graft is separated into a wider and narrower arm, which will serve as the anterolateral and posteromedial bundles, respectively. This split is developed to within 1 cm of the calcaneal bone plug. Each limb is whipstitched with no. 2 strong, braided, nonabsorbable suture. Next, the bone plug is fashioned by creating a 12-mm cylinder utilizing a coring reamer, which will be press-fit into a 13-mm socket created in the tibia. A 3.5-mm tunnel is created in the center of the cylinder with a cannulated drill. A no. 2 braided, nonabsorbable suture is used to whipstitch the remaining 1 cm of continuous tendon near the bone plug, and the free suture ends are passed through the bone plug from the cortical to the cancellous side. Additionally, a no. 5 nonabsorbable suture is threaded around the bone plug, and the sutures are passed through the tunnel and placed between the tails of the no. 2 suture. This cylindrical construct offers similar biomechanical properties to the figure-of-8 construct described in previous techniques [17]. The use of both sutures increases the stability of the bone plug once fixed to the tibia, with the no. 2 suture enhancing fixation at the bone–tendon interface and the no. 5 suture adding stability to the bone plug within the cylindrical inlay. The combined press-fit and suture fixation offers a unique biomechanical stability that allows for early protected range of motion (Fig. 15.6) [14, 18].

The knee is then flexed to allow the posterior neurovascular structures to fall away from the joint space, and the inlay socket is prepared. A PCL guide is used for pin placement. The guide is set to 35–40°, so that the pin enters at a right angle to the posteriorly sloped tibia. The attachment of the posterior horn of the medial meniscus and the native PCL footprint are used as anatomic landmarks to ensure proper pin placement. The pin should exit the posterior tibia 7 mm inferior to the superior most edge of the PCL footprint. The pin is over-reamed using a 3.5 mm cannulated drill. Fluoroscopic guidance should be used to monitor the progress of the drill, especially as it approaches the posterior cortex. With the 70° arthroscope placed in the notch, cortical penetration can be visually confirmed. The wire is then exchanged for a FlipCutter (Arthrex, Naples, FL). The device is passed through the previously created tunnel until it is visualized to exit the posterior tibia (Fig. 15.7). Next, the blade is engaged by “flipping” it, such that the blade is now perpendicular to the shaft of the device. Subsequently, a 13-mm wide tibial socket is drilled in a retrograde fashion, to a depth of 10–12 mm (Figs. 15.8 and 15.9). Once this level is reached, the FlipCutter blade is “flipped” again, making the blade parallel with the shaft, and withdrawn from the tunnel.

Attention is then turned to the femur. We prefer to use an outside-in technique for drilling the femoral tunnels, as this method presents several advantages. First, the tunnel to graft angle is less severe with the outside-in technique [19]. Furthermore, since the tibial portion is fixed first, it is more practical to tension and fix the two femoral bundles using an outside-in technique. The PCL guide is centered over the medial femoral condyle, and its positioning is matched to the anatomic footprint of the two native PCL bundles. The anterolateral and posteromedial tunnels are created using the cannulated reamer (Fig. 15.10).

At this point the graft is ready for passage. The anterolateral portal is slightly enlarged, and the tibial side of the graft is introduced into the joint first. The graft is guided toward the posterior tibia utilizing suture loops. The bone plug is seated into the tibial socket, and proper placement is confirmed both arthroscopically and with fluoroscopy (Fig. 15.11). Once the cylinder’s press-fit is achieved, the no. 2 and no. 5 sutures that were previously passed through the cylindrical plug are

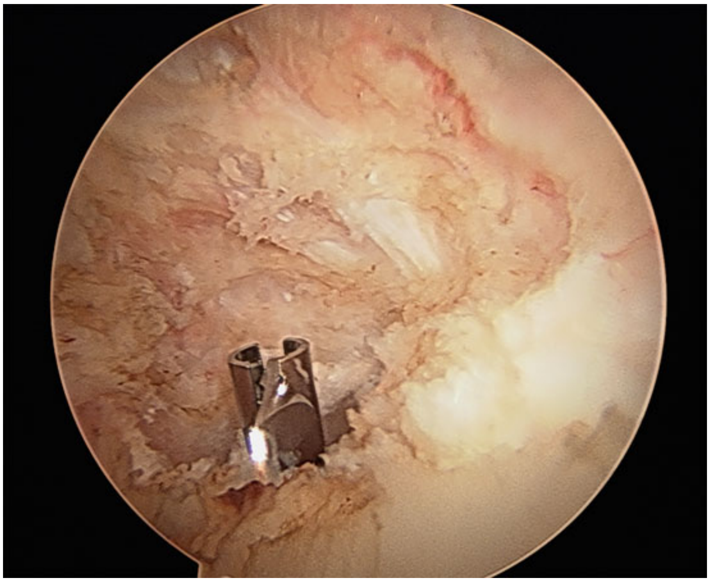


**Fig. 15.7** Arthroscopic view of the FlipCutter being introduced into the joint at the tibial attachment of the PCL. Note the blade is currently engaged

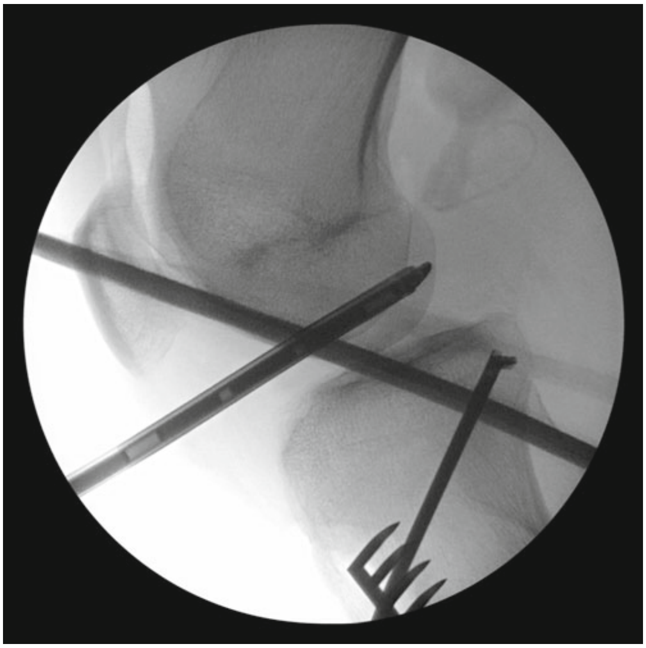


**Fig. 15.8** Fluoroscopic view of the engaged FlipCutter drilling the cylindrical socket on the posterior tibia

tightened and fixed to the anterior tibia over a four-hole plastic button. Next, the femoral bundles are pulled into their respective tunnels, and the knee is cycled with both grafts under tension. Each limb is then fixed to the femur utilizing bioabsorbable screws with the knee flexed at 90°. The anterolateral bundle should be fixed first, followed by the posteromedial bundle. Fixation can be further secured with a post if needed. The final graft arrangement is visualized with the arthroscope to confirm its correct position.

## 15.6 Surgical Technique: Posterior Cruciate Ligament Augmentation

When compared to the ACL, the PCL has improved vascularity, greater synovial coverage, and greater potential for healing [20]. By taking advantage of the healing potential of the PCL, augmentation can be utilized to treat PCL injuries in the acute setting. This treatment option should further be considered in cases of Grade II laxity on posterior drawer testing, or where

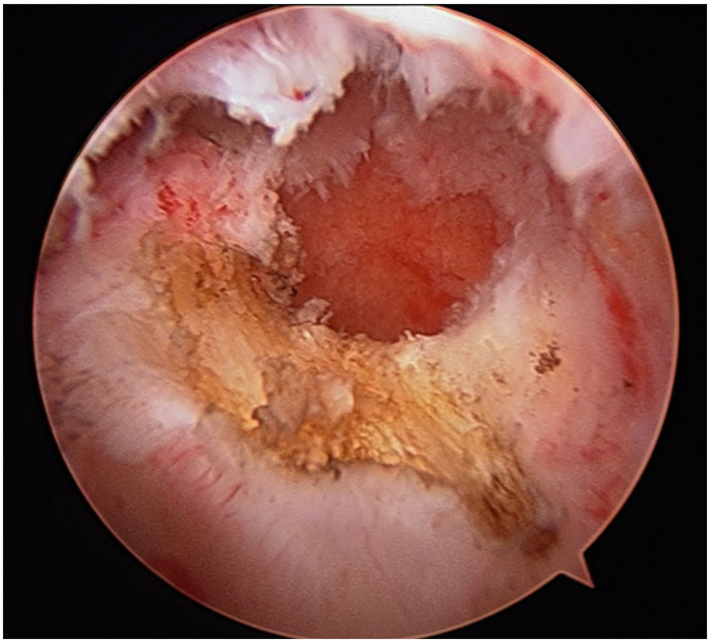


**Fig. 15.9** Arthroscopic view of the prepared inlay socket on the posterior aspect of the tibia

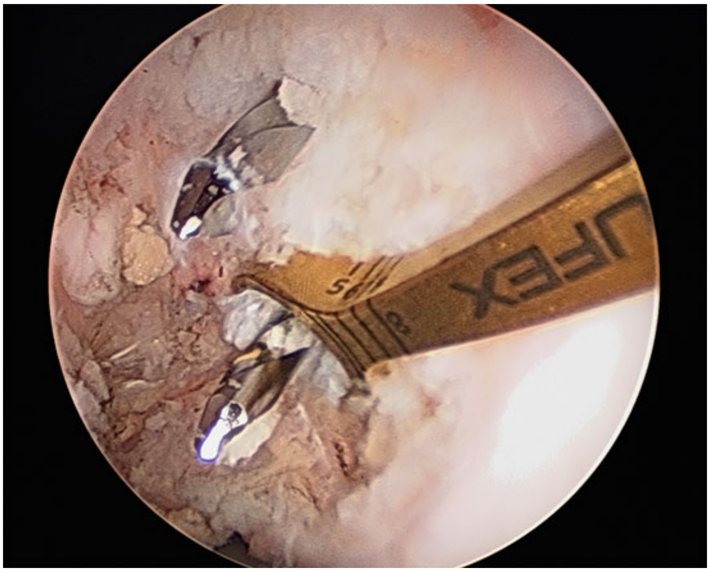


**Fig. 15.10** Arthroscopic view demonstrating outside-in drilling of the two femoral tunnels during a double-bundle PCL reconstruction

a partial tear of the PCL is identified arthroscopically. A soft tissue graft (doubled tibialis anterior allograft or quadrupled hamstring autograft) is utilized to reconstruct injured fibers using a single-bundle technique. The graft is prepared by whipstitching both ends with a no. 2 braided, nonabsorbable suture. The graft is ideally 7–8 mm wide, which allows for a strong construct without potentially damaging healthy PCL fibers.

After the diagnostic arthroscopy is completed, the injured portion of the PCL is identified. A probe can be used to examine each bundle and verify which portions of the ligament are under tension versus those that appear injured. Disrupted portions of the ligament are carefully debrided, while the remaining intact fibers are left untouched. In cases of partial tears, often the anterolateral bundle is disrupted, while the posteromedial bundle remains intact. The tibial and femoral tunnels are created in a position that avoids damaging intact portions of the ligament. Usually, the tibial tunnel is placed just distal to the distal-most attachment of the PCL and is drilled in a trans-tibial fashion using the PCL guide under fluoroscopic and arthroscopic guidance. On the femoral side, the femoral tunnel is placed near the most anterior and superior portion of the anterolateral bundle and drilled in an outside-in technique (Fig. 15.12). If only the posteromedial bundle is damaged and the anterolateral bundle is intact, tunnel positioning should be adjusted to ensure the remaining fibers are not detached. After the tunnels are prepared, a passing suture is used to pass the graft from the tibial to femoral tunnels (Fig. 15.13). The sutures of the

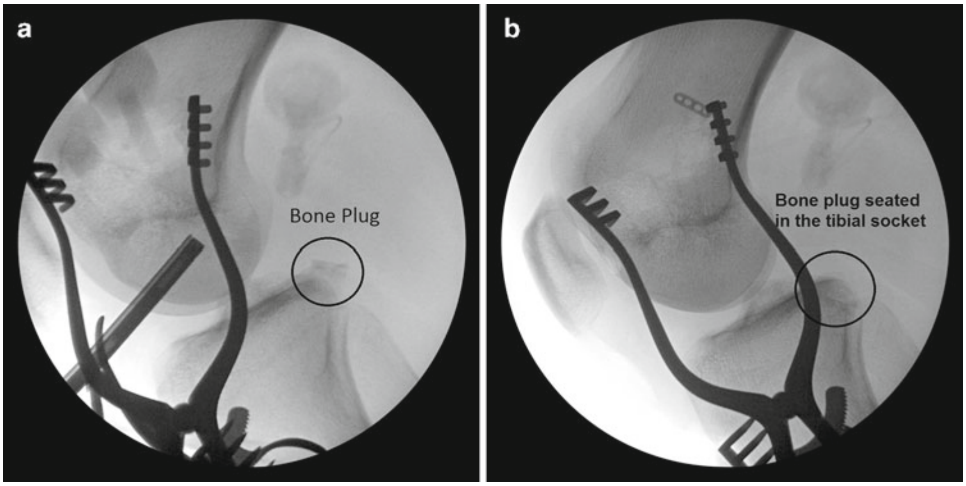


**Fig. 15.11** Fluoroscopic view of the bone plug on the PCL graft as it is directed toward the posterior tibia (*circle*) (**a**). The bone plug appears reduced once it is seated into the cylindrical socket (*circle*) (**b**)

**Fig. 15.12** Arthroscopic view of femoral tunnel placement during PCL augmentation (*black arrow*). Note the position of the tunnel relative to intact PCL fibers (*clear arrow*)

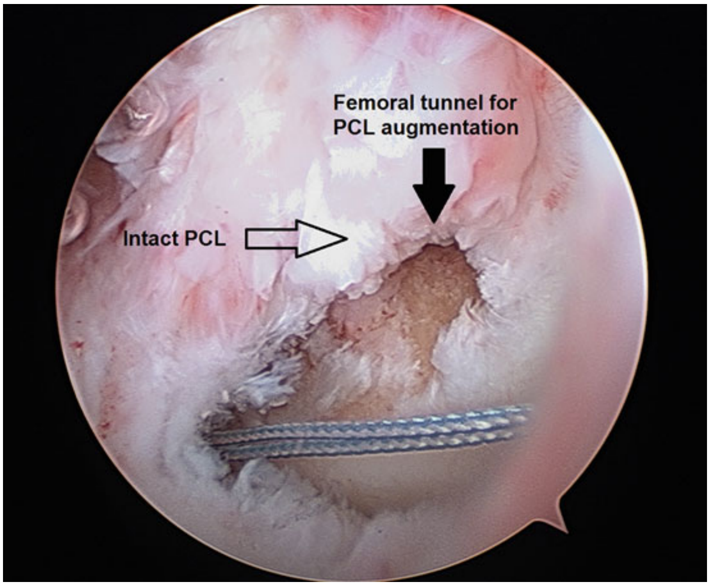
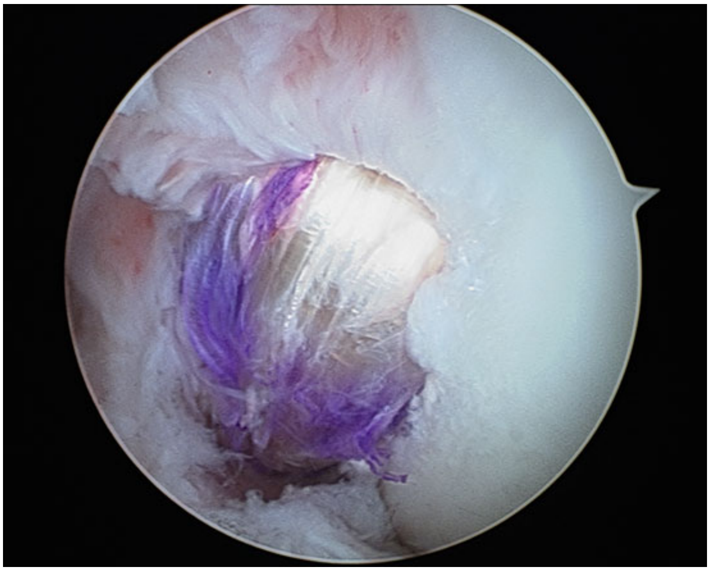


**Fig. 15.13** Arthroscopic view of after graft passage during PCL augmentation. The graft lies just anterior to native PCL fibers



femoral portion are tied over a plastic button. The tibial side of the graft is fixed with a screw and sheath type of construct with the knee flexed at 90°. An anteriorly directed force should be placed on the tibia to keep it reduced while the screw is being placed. Fixation can be augmented with a post as needed.

## 15.7 Surgical Technique: Posterolateral Corner (Acute)

Repair of the PLC should be performed within 14 days of injury but no later than 3 weeks, as early intervention offers the best outcome [21]. After 3 weeks from the injury, soft tissue retraction and scar formation makes identification and primary repair of the PLC difficult. Although some controversy remains regarding repair versus reconstruction in the acute setting, we recommend a primary repair with graft augmentation when needed.

The patient is positioned supine with a bump under the ipsilateral hip. A tourniquet is placed into the upper thigh but is not inflated during the procedure. A skin incision is made over the lateral knee along the posterior aspect of the IT band to a point between the fibular head and Gerdy's tubercle. The interval between the IT band and the biceps femoris is developed, and the PLC is exposed. In acute injuries, often the damaged structures are easily identified after minimal dissection (Fig. 15.14). A systematic approach is utilized to identify and treat injuries in the proximal, mid-substance, or distal portions of the PLC. Proximally on the lateral femur, the LCL and popliteus origins are identified on the lateral epicondyle and the popliteal sulcus. If either structure is avulsed off of its proximal femoral attachments, they can be repaired utilizing a 6.5-mm screw as a suture post, with a spiked washer to aid in soft tissue fixation. Another method of proximal fixation involves drilling 7-mm tunnels from each insertion site to the medial femoral cortex. The end of the LCL or popliteus is whipstitched and passed through to the medial side (Fig. 15.15). The sutures are tied over a post or button for fixation. If the LCL is torn mid-substance, it can be repaired in an end-to-end fashion with nonabsorbable sutures although mid-substance injuries usually require graft augmentation. Distally, the dissection is continued down to expose the proximal portion of the fibular head. If the LCL is avulsed off of its distal attachment, reattachment can be performed utilizing suture anchors or transosseous sutures in the proximal fibula, with a whipstitch placed in the injured ligament. If the PFL is avulsed off of the fibula, a similar repair can be performed.

Primary repair of any injured structure relies on the strength of the native tissue. Allograft augmentation should be considered in situations where the tissue appears attenuated, or if sufficient stability is not restored at the conclusion of the repair. We prefer tibialis anterior allograft augmentation for reinforcement. First, a 7-mm oblique tunnel is drilled in the proximal fibula in a posterosuperior to anteroinferior fashion. The femoral tunnel is created at the LCL origin on the lateral femoral epicondyle. The allograft is passed through the fibular bone tunnel and fixed to the femoral side utilizing a bioabsorbable screw or suture post.

The peroneal nerve should be identified and protected throughout the case to prevent neurologic compromise. We routinely dissect out and retract the nerve when working around the fibular head. The nerve should be visualized and freed of any adhesions or sites of constriction should they be apparent. Finally, inspect the biceps femoris, IT band, and posterolateral capsule for any injury that can be repaired. Prior to closure, the varus/rotational stability of the knee is verified at 0°, 30°, and 90° of flexion.

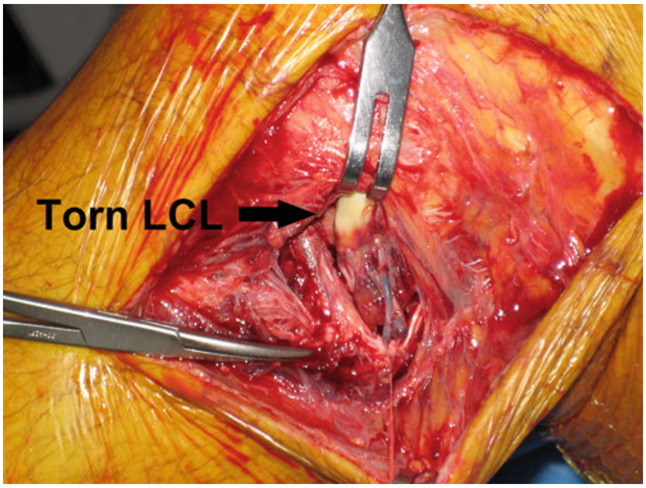


**Fig. 15.14** Intraoperative photograph of an acute injury to the lateral collateral ligament

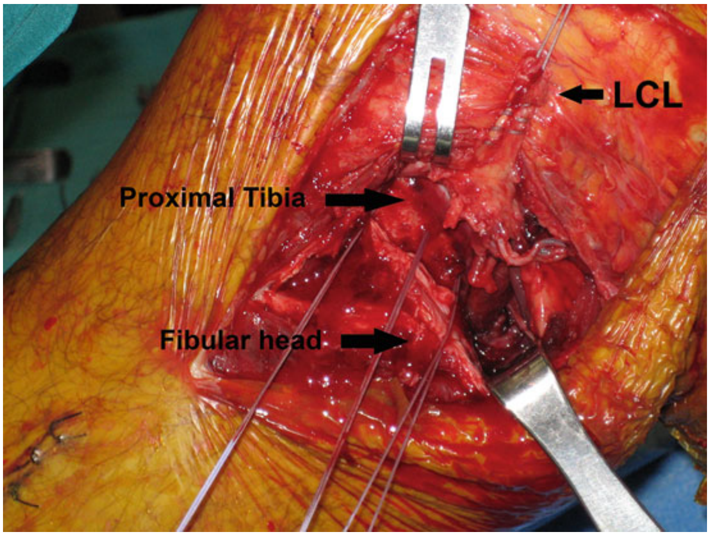


**Fig. 15.15** Photograph of an acute repair of the posterolateral corner. The proximal portion of the LCL has been whipstitched, and suture anchors have been placed in the proximal tibia to repair the lateral capsule and lateral meniscus

## 15.8 Surgical Technique: Posterolateral Corner (Chronic)

Reconstruction of the PLC should be considered if more than 3 weeks have elapsed since the date of injury. Several techniques have been developed for PLC reconstruction. Initially, nonanatomic techniques were utilized such as biceps tenodesis, bone block advancements, or using an IT band sling. Fanelli et al. described a combined PCL and PLC reconstruction involving biceps tenodesis with a posterolateral capsular shift and showed significant improvement in knee stability at 2- to 10-year follow-up [22]. Other authors have described fibular-based reconstruction techniques [21, 23]. More recently, attention has turned toward combined tibial- and fibular-based techniques, with the goal of reconstructing the three key stabilizing structures: PFL, PT, and LCL [24, 25].

We have developed an anatomic technique utilizing a single Achilles allograft with double femoral tunnels. This is our preferred method to reconstruct the PLC, as it allows for anatomic reconstruction of the PFL, PT, and LCL with a single graft (Fig. 15.16) [26].

First, the patient is placed supine on the operating table. A sandbag is taped onto the bed under the foot to help support the knee at 70° of flexion. A nonsterile tourniquet is placed on the upper thigh but not usually inflated during the procedure. A diagnostic arthroscopy is performed. The presence of a lateral drive-through sign is expected and should be documented (Fig. 15.17). Any additional pathology including meniscal tears and chondral injury should be addressed at this time.

Graft preparation begins on the back table while the patient is being positioned. The bone plug of the Achilles allograft should be fashioned to fit a 10-mm tunnel. A drill hole is placed in the bone plug, and a suture is threaded through it to aid in graft passage. Beginning 3 cm from the end of the bone plug, the tendon is split into two bundles, each measuring approximately 6–7 mm in diameter. The bundles include a longer anterior limb and a shorter posterior limb that are used for the LCL/PFL graft and the popliteus bypass, respectively. To allow sufficient length for the LCL portion of the graft, the anterior limb is left as long as possible. The posterior limb can be shortened such that the popliteus bypass graft does not exit the tibia, allowing the sutures to be tied over a button. The ends of the split tendon are whipstitched with no. 2 braided, nonabsorbable suture. The graft is kept moist in antibiotic solution and placed on the back table until it is ready to be implanted (Fig. 15.18).

Once intra-articular pathology has been addressed, attention is turned to the lateral side of the knee. A skin incision is made along the lateral aspect of the femoral shaft, starting 2 cm proximal to the lateral epicondyle, and distally to a midpoint between Gerdy's tubercle and the fibular head. There are two intervals that can be used to access the posterolateral knee: between the IT band and the biceps femoris or between the biceps femoris and peroneal nerve. We prefer the more posterior interval, as it improves access to the posterior fibular head and the posterior tibia. Additionally, the peroneal nerve is well identified and protected through this interval, thus decreasing the risk of neurologic injury. Once the interval between the biceps femoris and peroneal nerve is identified and developed, the structures of the PLC are identified. The LCL and PT attachments are identified on the lateral femur and taken down as one sleeve of tissue. They should be whipstitched with no. 2 braided, nonabsorbable suture. Divergent guide pins are placed at the anatomic insertion sites of the LCL and popliteus, aimed toward the medial femoral epicondyle. With a 10-mm reamer, a 35-mm deep tunnel is created over the pin in the

**Fig. 15.16** Schematic representation of the anatomic PLC reconstruction with a bifid Achilles tendon allograft. Reprinted with permission from [26]

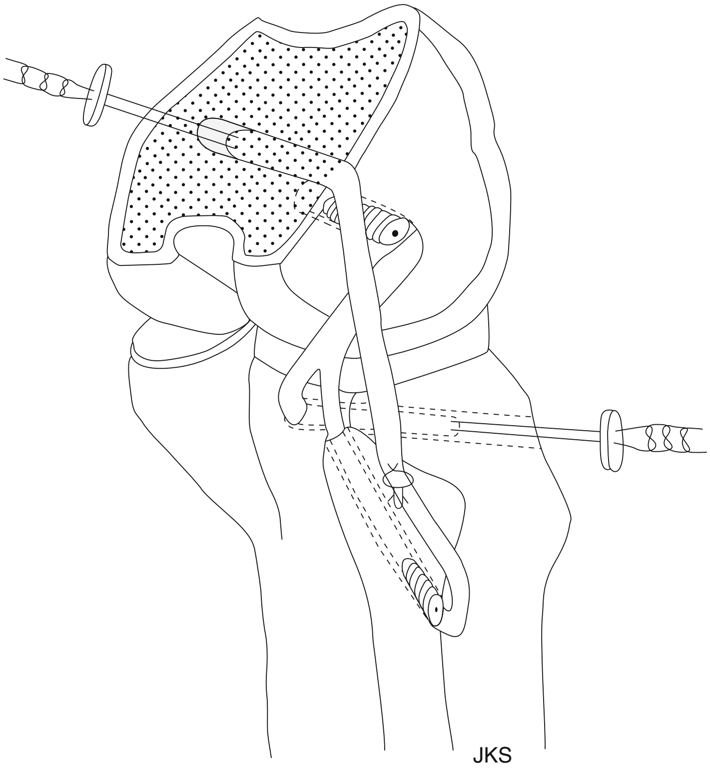
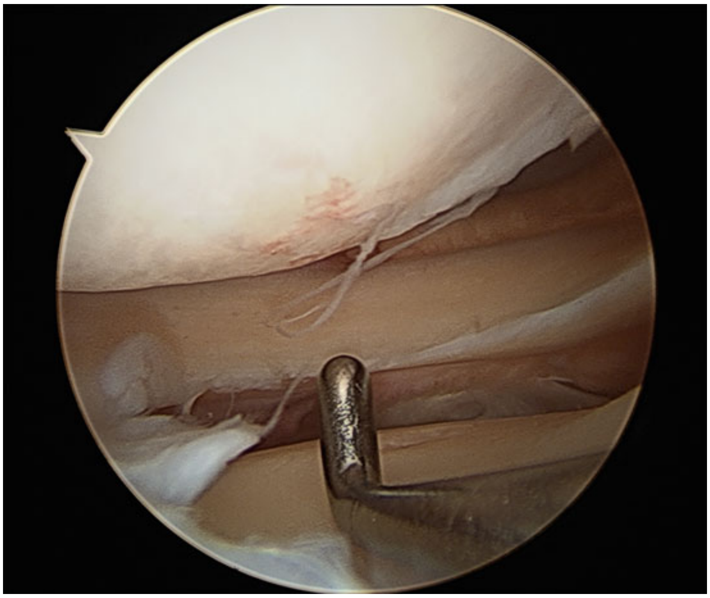


**Fig. 15.17** Arthroscopic view of a lateral "drive-through" sign, indicative of a collateral ligament injury



popliteus insertion. A 7-mm reamer is used over the guide in the LCL insertion, and a tunnel is reamed through to the medial femoral cortex.

The posterolateral head of the fibula is dissected out and the PFL is identified. Distally, the fascia over tibialis anterior is split, and the anterior fibular head is freed of soft tissue. The peroneal nerve should be protected during this dissection by visualizing its course around the fibular head. Once the proximal fibula is cleared, a guide pin is placed at the attachment of the PFL in a posterior to anterior fashion. The pin should be aimed sufficiently distally to maintain a bone bridge to prevent avulsion of the fibular head during tensioning. A 6- to 7-mm tunnel is reamed over the pin in a posterior to anterior fashion.

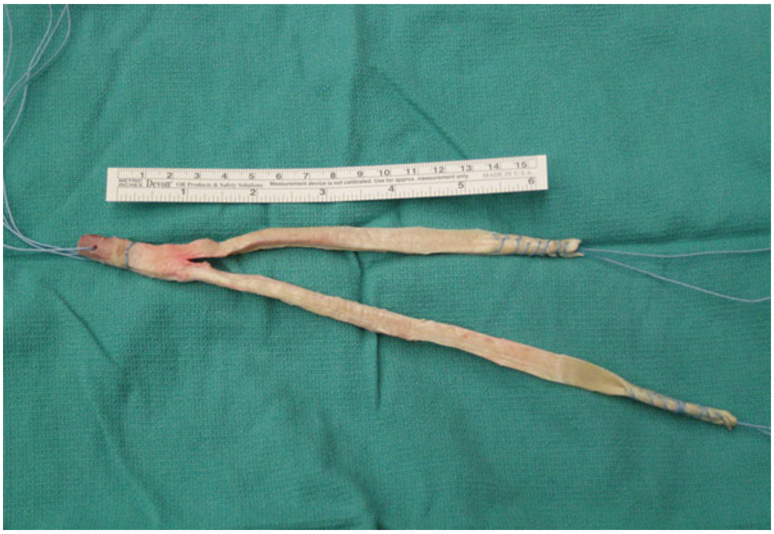


**Fig. 15.18** Photograph showing the prepared bifid Achilles tendon allograft for an anatomic PLC/LCL reconstruction

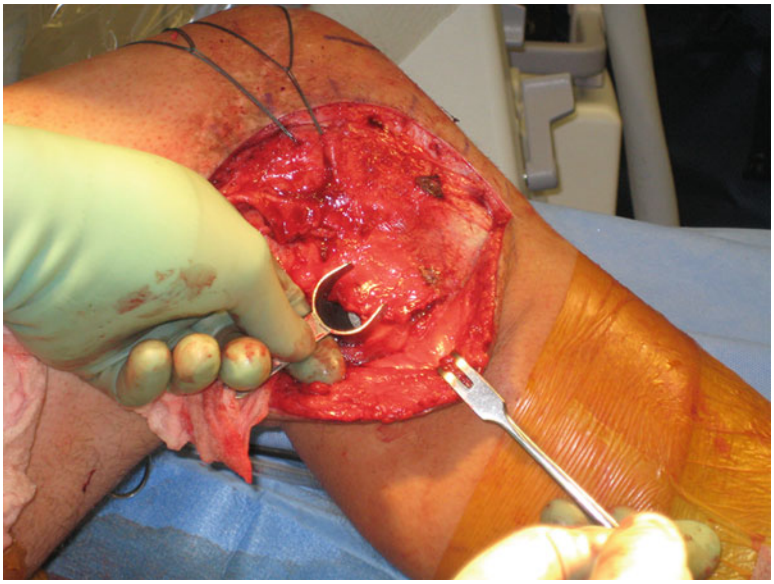


**Fig. 15.19** Photograph demonstrating placement of a meniscal retractor behind the posterolateral capsule during a PLC/LCL reconstruction

The fibular attachment of the LCL is identified, and a suture anchor is placed in the anatomic insertion site. An area just distal to the attachment is abraded to provide an area of healing.

Subsequently, the interval between the lateral head of the gastrocnemius and the posterior joint capsule is developed to expose the posterolateral tibia. A meniscal retractor is placed anterior to the lateral head of the gastrocnemius to maintain a working space and to protect the posterior neurovascular structures during pin placement and tunnel reaming (Fig. 15.19). From Gerdy's tubercle, a guide is placed aiming for the musculotendinous junction of the popliteus. We recommend the use of a standard ACL guide to assist with pin placement. The pin is overdrilled with a 6- to 7-mm reamer.

The graft is now ready for passage. The sutures from the Achilles bone plug are passed into the popliteus tunnel in the femur, along with the sutures from the native popliteus. The bone plug is secured with an interference screw (Fig. 15.20). The graft is then passed distally deep to the native tissue, with the graft splitting at the origin of the PFL off of the PT. The graft must be passed under the biceps femoris as it is advanced distally, so that it resides in the normal anatomical plane of the PFL and popliteus. The long limb (for the PFL) is passed through the fibular tunnel, and the short limb (for the popliteus bypass) is passed through the tibial tunnel. Both limbs are delivered in a posterior to anterior fashion. The knee is cycled through flexion and extension with tension on both limbs of the graft. For fixation, the knee should be held at 30° of flexion with an internal rotation force. The popliteus graft is fixed to the anterior tibia by tying the sutures over a button. The PFL graft is fixed to the fibula utilizing an interference screw. The remaining anterior limb, to be used as the LCL graft, is brought

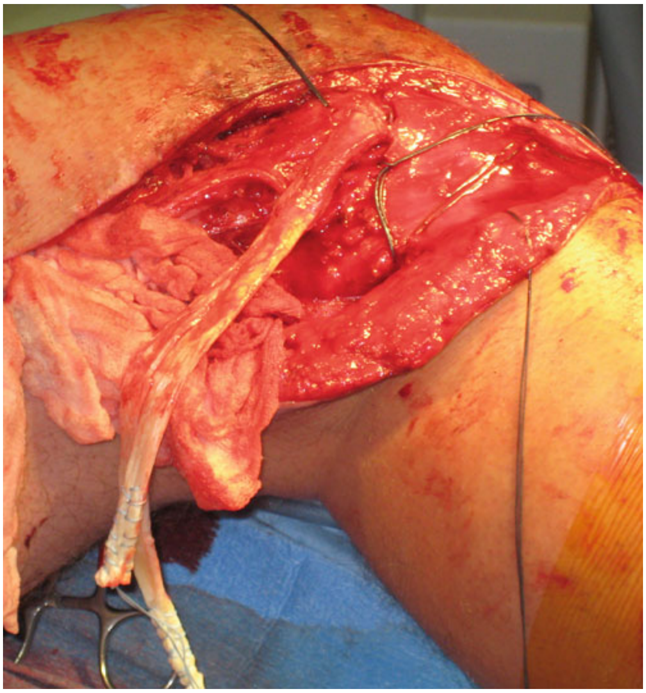


**Fig. 15.20** Photograph showing graft placement for a PLC reconstruction. The proximal portion of the allograft has been fixed to the femoral attachments of the LCL and popliteus. The two limbs will reconstruct the PFL, LCL, and popliteal bypass

proximally and delivered through the LCL tunnel over the lateral femoral epicondyle, through the medial cortex and out a separately made medial skin incision. The sutures from the previously placed anchor on the fibular attachment of the LCL are brought through the graft in a horizontal mattress fashion but will be tied down later. With tension on the proximal LCL sutures, the knee is placed through several flexion–extension cycles. The proximal sutures are tied over a button on the medial femoral cortex with the knee in 30° of flexion, under a valgus stress and internal rotatory load. A lateral-to-medial-placed interference screw can be used as backup fixation of the LCL. The sutures from the anchor at the distal LCL insertion are tied down, securing the distal portion of the graft, and augmented with figure-of-8 sutures to surrounding tissue. Finally, the sutures from the native LCL and popliteus are tied to each other over the medial femoral cortex.

Once the graft is secure, stability is verified at 0°, 30°, and 90°. Both varus and external rotation should be assessed. Retensioning the graft may be necessary if stability is inadequately restored. Full flexion and extension should also be verified, and anatomic gliding of the LCL and popliteus grafts should be noted as the knee is flexed.

We believe this technique offers several unique advantages, specifically in recreating the normal anatomy of the PLC [26]. First, it allows for reconstruction of all major components of the PLC utilizing a single graft. The PFL is anatomically reconstructed directly to its attachment on the fibular head. Additionally, because the graft is not split-up its entire course, it more closely replicates the junction of the PT and PFL. The addition of a suture anchor on the fibular head recreates the anatomic distal insertion of the LCL. Finally, utilizing the double femoral tunnel technique allows a more anatomic restoration of the popliteus and proximal LCL attachments on the femur.

## 15.9 Postoperative Rehabilitation

The patient is immediately placed into a hinged knee brace that is locked in extension. A controlled ROM program is started, with passive flexion to 90° allowed for the first 6 weeks. Partial weight bearing with crutches is permitted with the brace loaded in extension, as it allows the tibia to remain reduced on the femur. No active flexion is allowed, and passive flexion is performed prone to prevent posterior gravitational forces affecting the healing PCL and PLC.

After 6 weeks, advancement to full weight bearing is initiated. Bracing can be unlocked to allow full range of motion. Isometric strengthening and closed-chain quadriceps exercises are started under a focused physical therapy program. A stationary biking program (no foot strap) with zero resistance is also initiated.

After 3 months, gait balance should be achieved, and closed-chain strengthening exercises are further advanced. The biking program is advanced with resistance, and the patient can begin brisk walking on even ground.

After 5–6 months, a resistance-based strengthening program is further continued. A slow jogging program may be initiated; however, agility training such as plyometrics or pivoting should be avoided.

After 7–8 months, functional training is initiated to transition the patient back to sports. Jumping and pivoting are allowed. The emphasis at this point is on sports-specific training.

Return to unrestricted activities and sports can be expected after 10–12 months. Prognosis for return to high-impact pivoting sports is guarded after this devastating multiligament knee injury. At this point, the patient should be able to demonstrate 90% of strength compared to the contralateral side; show no effusion or limp with running, jumping, or pivoting activities; and have a stable clinical exam prior to returning to full activities.

## 15.10 Conclusion

Combined PCL and lateral-sided injuries to the knee present a unique challenge to the orthopedic surgeon. The synergistic biomechanical relationship of the PCL and PLC dictates their concomitant treatment in cases of combined insufficiencies. Treatment options for these injuries have evolved as our understanding of the anatomy and biomechanics of the knee has improved. In the acute setting, we recommend a combined PCL augmentation or reconstruction, with a repair of the lateral side and PLC. In chronic cases, a combined PCL/PLC reconstruction should be undertaken. We have developed a double-bundle arthroscopic inlay technique for the PCL reconstruction. For the PLC and LCL, we have developed an anatomic reconstructive technique that addresses the LCL, PFL, and PT. Appropriate identification and management of these complex injuries is paramount to help restore normal knee function and prevent recurrent instability.

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# Chapter 16
# Surgical Treatment of Combined PCL Medial Side Injuries: Acute and Chronic

**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 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 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].

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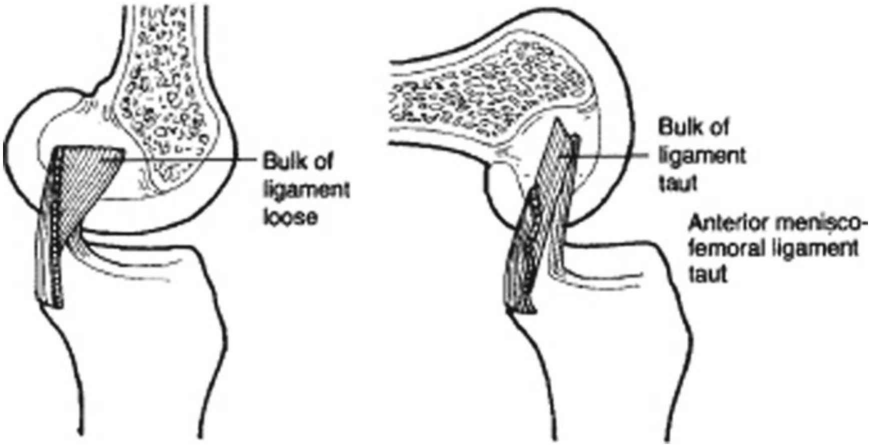


**Fig. 16.1** The anterolateral bundle of the PCL provides the primary restraint and is taught in flexion, while the posteromedial bundle is taught in extension. (From Siliski JM, Traumatic disorders of the knee. Springer; 1994. p. 17. Reprinted with permission)

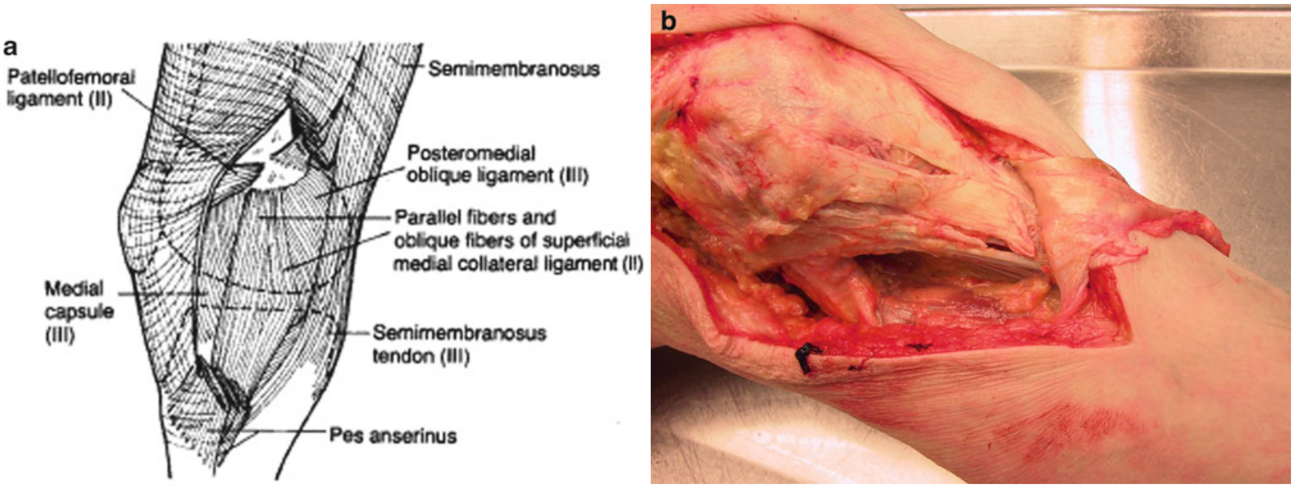


**Fig. 16.2** Anatomy of the medial knee. (**a**) Schematic drawing. (**b**) Photograph. (From Siliski JM, Traumatic disorders of the knee. Springer; 1994. p. 17. Reprinted with permission)

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 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

**Fig. 16.3** The posterior drawer test is used in the clinical diagnoses of a PCL injury

**Fig. 16.4** The posterior sag sign is indicative of a high-grade PCL injury

**Fig. 16.5** Valgus instability at 30° of knee flexion indicates MCL injury

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].

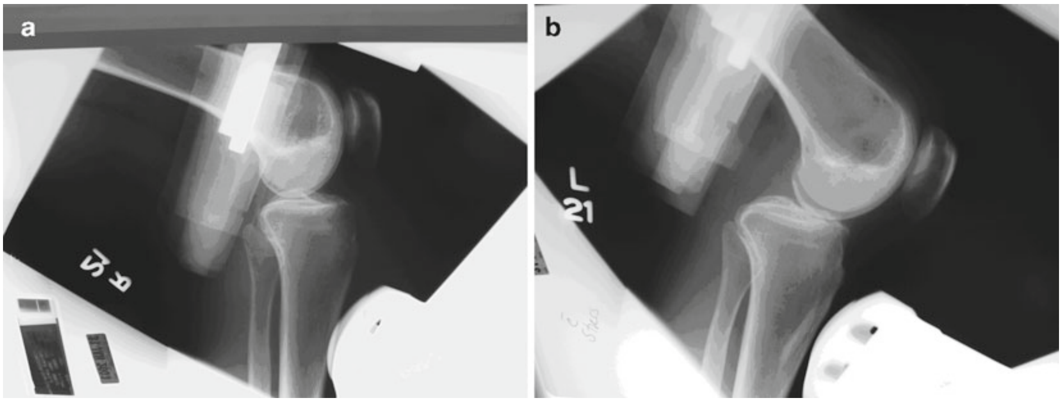


**Fig. 16.6** Instrumented stress radiography with a posterior-directed force. (**a**) Normal relationship between the distal femur and tibial plateau. (**b**) A PCL-injured knee with obvious posterior tibial translation of >10 mm

**Fig. 16.7** Valgus stress radiograph of an MCL injury showing pathologic widening of the medial joint space

## 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 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.

**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

## 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. 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 is 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 are mid-substance tears and are 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 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.

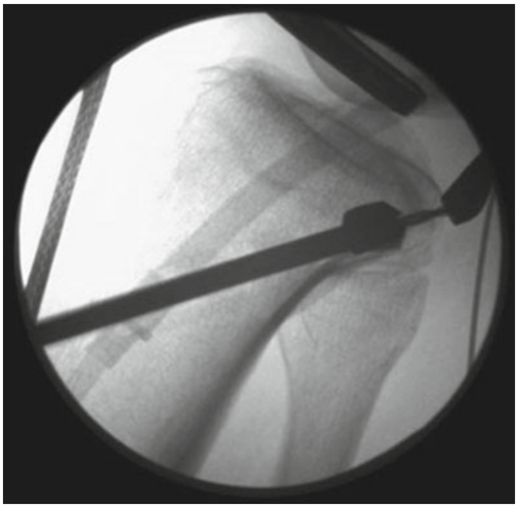
Many surgeons prefer the classic trans-tibial tunnel technique although a more recently described tibial inlay technique is also an option. These variables in technique are discussed below.

The classic trans-tibial 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 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 trans-tibial tunnel approach [19]. Highlighted is the importance of graft selection, tunnel placement, graft tensioning, graft fixation, as well as a discussion of single-bundle vs. 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 trans-tibial 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 trans-tibial 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 trans-tibial tunnel technique. Long-term cadaveric and clinical studies are required for further understanding of potential differences in outcome using these two reconstruction techniques.

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

**Fig. 16.9** Appropriate tibial tunnel placement for the trans-tibial tunnel technique during PCL reconstruction



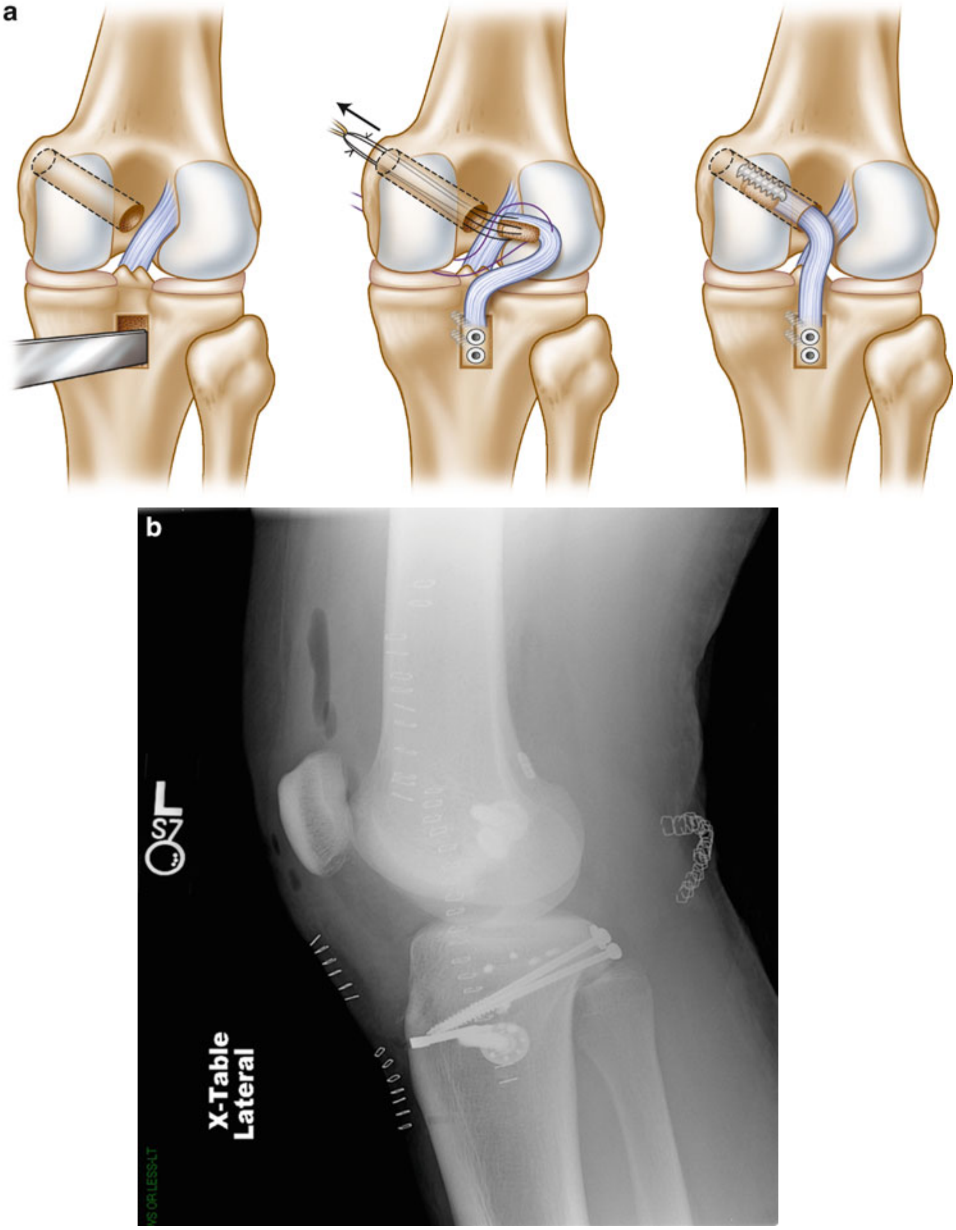


**Fig. 16.10** PCL reconstruction using the tibial inlay technique. (**a**) Schematic. (**b**) Radiograph demonstrating how tibial graft fixation is achieved with bicortical cannulated screw fixation, and the femoral graft fixation with interference screws

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 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. 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.

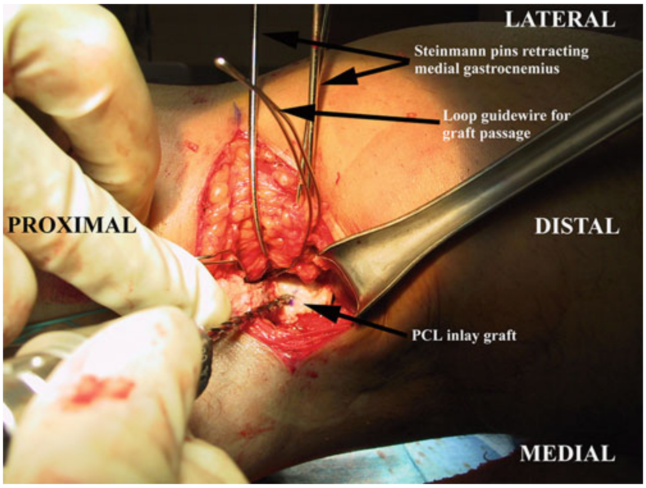


**Fig. 16.11** During the tibial inlay technique for PCL reconstruction, Steinmann pins may be used for soft tissue retraction of the medial gastrocnemius, protecting the neurovascular bundle. This provides adequate exposure of the posterior tibial sulcus for positioning of a tibial trough and subsequent graft passage using a looped 18 gauge guidewire

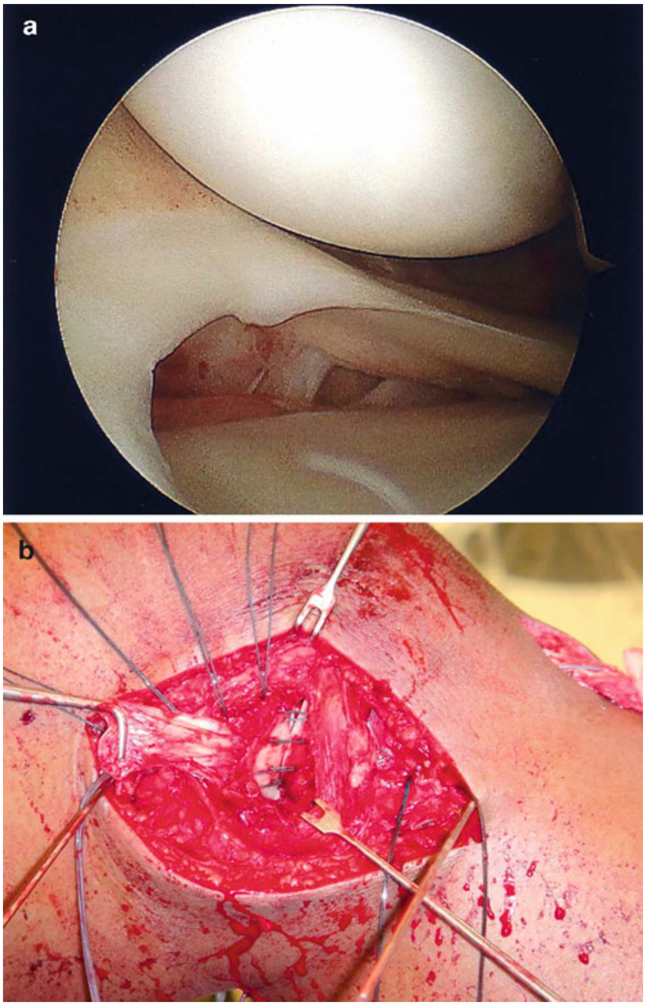


**Fig. 16.12** MCL avulsion injuries. (**a**) Arthroscopic view demonstrating a tibial-sided meniscocapsular injury as the meniscus "stays with" the femur on valgus stress. (**b**) Suture anchors for primary repair of the medial meniscus, capsule, and MCL

## 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 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

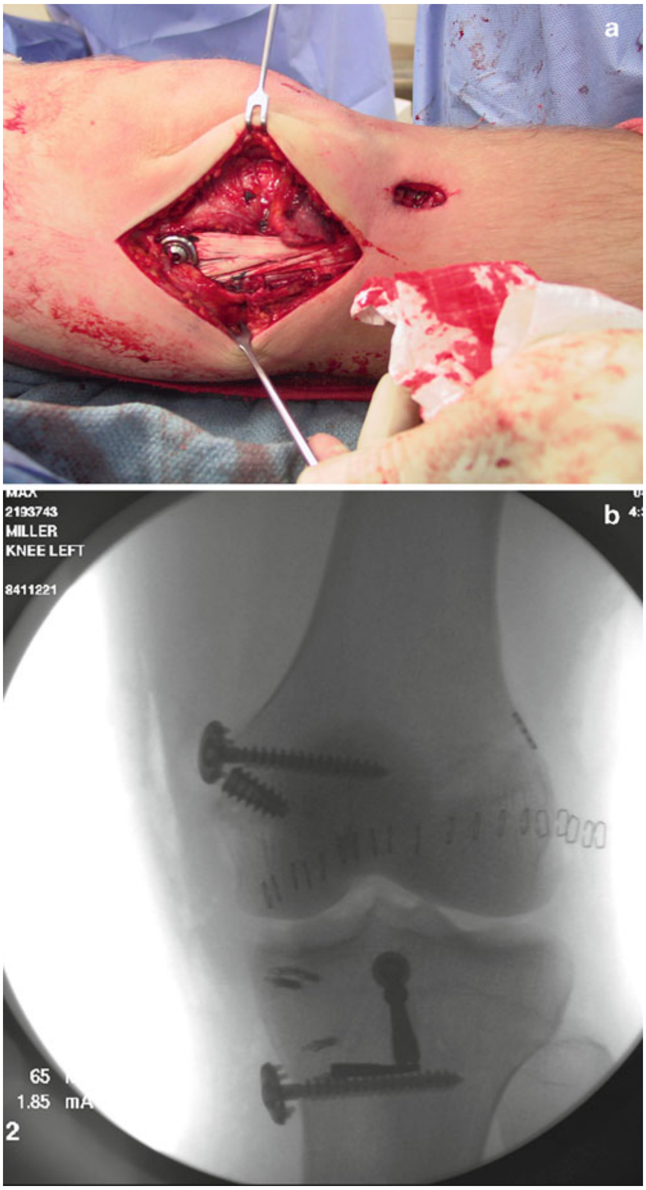


**Fig. 16.13** MCL reconstruction using the modified Bosworth technique. (**a**) The native semitendinosus tendon, with its tibial insertion intact, is looped around a screw and spike washer at the medial femoral condyle. (**b**) Proximal and distal ends of the MCL reconstruction are secured using a screw and spiked washer. Also demonstrated is femoral and tibial fixation of a PCL reconstruction using the tibial inlay technique

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 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° to 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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# Chapter 17
# Surgical Treatment of Combined PCL Medial and Lateral Side Injuries: Acute and Chronic

**James P. Stannard and Hyun Min Mike Kim**

## 17.1 Classification

The Schenk anatomic classification (Table 17.1) [1] is widely accepted and based on the anatomic structures injured rather than the direction of the dislocation. A KD I injury describes a knee dislocation where one or both of the cruciate ligaments are intact with variable degrees of collateral ligament injuries. A knee dislocation that has an intact ACL with all the other three ligamentous structures injured can be classified as a KD I injury, but this type of injuries are quite rare compared to KD III injuries from our experience.

## 17.2 Mechanism of Injury

Multiple ligament injuries of the knee can result from various types of injuries, but the vast majority of them are the result of high-energy trauma such as motor vehicle accidents [2]. The most common causes of the high-energy trauma are motor vehicle collisions (52%), motor cycle collisions (17%), and motor vehicle versus pedestrian accidents (16%). Low-energy sports injuries can also result in knee dislocations, 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

Patients often present with multiple injuries which may be life-threatening and frequently involve the ipsilateral extremity, which makes the diagnosis of a spontaneously reduced knee dislocation in the emergency room difficult. If the knee remains dislocated, closed reduction under sedation should be performed as soon as the patient's condition permits. Typically gentle longitudinal traction is sufficient for reduction. However, occasionally soft tissue interposition can prevent complete reduction, which necessitates open reduction in the operating room. Following reduction, a complete neurovascular examination is the single most important thing to do in acute knee dislocations. The knee is immobilized in slight flexion with a knee immobilizer, splint, or hinged knee brace following reduction.

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. An open dislocation should be irrigated and debrided in the operating room as soon as the patient's condition permits. If there is a significant open soft tissue injury, a spanning external fixator is used.

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**Table 17.1** Schenck 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) | Associated nerve injury |

**Table 17.2** Diagnostic tests for knee ligament injuries

| Ligament | Diagnostic tests | Positive finding: interpretation |
|---|---|---|
| MCL and PMC | Valgus stress at 30 and 0° flexion | Medial joint opening<br>Positive only at 30°: isolated MCL injury<br>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<br>MCL+PMC injury |
| FCL and PLC | Varus stress at 30 and 0° flexion | Lateral joint opening<br>Positive only at 30°: isolated FCL injury<br>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<br>Positive only at 30°: FCL+PLC injury<br>Positive at both 30 and 90°: FCL+PLC+cruciate injury |
| | External rotation recurvatum test | Knee recurvatum and varus+tibial external rotation<br>FCL+PLC injury |
| ACL | Lachman test | Anterior subluxation of tibia at 30° flexion<br>ACL injury |
| | Anterior drawer | Anterior subluxation of tibia at 90° flexion<br>ACL injury |
| | Pivot shift test | Sudden reduction of anteriorly subluxated tibia at 20–40° flexion<br>Small subluxation: ACL injury<br>Greater subluxation: ACL+PLC injury |
| PCL | Posterior drawer test | Posterior subluxation of tibia at 90° flexion<br>PCL injury |
| | Quadriceps active test/posterior sag sign | Anterior movement of posteriorly subluxated tibia with active quadriceps contraction at 90° flexion<br>PCL injury |

*MCL* medial collateral ligament, *PMC* posteromedial corner, *FCL* fibular collateral ligament, *PLC* posterolateral corner, *ACL* anterior cruciate ligament, *PCL* posterior cruciate ligament

Pedal pulse at both the dorsalis pedis artery and posterior tibial artery is examined and compared to the contralateral normal side. Subtle signs like skin temperature, color, and capillary refill are also noted but are not nearly as important as 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 serial neurovascular examinations for at least 48 h. It is not necessary to perform routine arteriography or to obtain the ankle-brachial pressure index (ABI). A thorough physical examination with documented symmetrical pedal pulse is sufficient [2, 3]. The pedal pulse is checked and compared to the contralateral normal side both before and after reduction and at 4–6, 24, and 48 h following reduction. If any of these examinations shows a pulse deficit (i.e., absence of pulse or decreased intensity), emergent angiography should 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 being on the common peroneal nerve because of the high frequency of injury.

Ligament examination is often difficult in the acute setting because of pain, swelling, and ipsilateral extremity injuries. Accurate diagnosis of instability pattern becomes crucial later in the definitive ligament repair or reconstruction and should be established with careful exam under anesthesia. The tests for the four main ligamentous structures of the knee are summarized in 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, acetabulum) is 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, foreign bodies, avulsion fractures, malalignment of the knee, and joint incongruity. A quick stress view radiograph at the end of ipsilateral fracture fixation is very helpful in determining the direction of ligament injury management. It is important to obtain knee MRI before application of any metal hardware when there is high suspicion of a knee dislocation. MRI is an important roadmap to the assessment of ligament injury pattern, particularly when there are ipsilateral extremity injuries. MRI is also useful for assessing meniscal injuries, osteochondral lesions, occult tibial plateau fractures, etc. However, examination under anesthesia is 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 that 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 will benefit nearly all patients following knee dislocations. The results of nonoperative treatment (e.g., cast, knee brace, and external fixation) from the patients who were poor candidates for reconstructive surgery are invariably poor with residual instability and stiffness. External fixation can be used as a temporary treatment prior to reconstruction in patients with open knee dislocations, severe soft tissue injuries, and initial vascular surgery due to a popliteal artery injury. If it is inevitable to use external fixation as a definitive immobilization method, 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, the fractures 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, my surgical timing is changed. Fixation of the plateau fracture is performed within the first week. This is followed by reconstruction of the PCL and PMC, and application of a Compass Knee Hinge external fixator 2–4 weeks after the initial trauma. Finally, reconstruction of the PLC is performed 3–4 months later. The reason for delaying PLC reconstruction in the presence of a tibial plateau fracture is that the tibial bone tunnel for interference screw 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

I prefer reconstruction over repair in the majority of patients with knee dislocation based on our previous study findings [4] that reconstructions have a significantly lower failure rate than repairs of the PLC. The only exception to this would be dislocation with a large avulsion fracture, which needs to be repaired primarily. For the knee dislocations with combined injuries to the PCL and both corners, the reconstruction procedure typically starts 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 the both corners are in place. The order of tensioning and fixation is then PCL first, followed by the two corners.

### *17.6.1 PCL: Anatomic Posterior Cruciate Ligament Reconstruction with a Double-Bundle Inlay Technique Using Achilles Tendon-Bone Allograft*

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 (Fig. 17.1). A pneumatic tourniquet is applied to the upper thigh but not inflated until the later part of the procedure. A simple lateral post without a circumferential leg holder is positioned at the level of the

**Fig. 17.1** Basic setup 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 later part of the procedure. A simple lateral thigh post without a circumferential leg holder is positioned at the level of the tourniquet

tourniquet to facilitate intraoperative valgus stress. A thorough examination under anesthesia is performed. The instability pattern is reassessed and compared to the preoperative diagnosis. It is often necessary to compare the laxity of the injured knee with that of the contralateral normal knee because of the variability of normal laxity among individuals. Diagnostic arthroscopy is then performed using the two conventional arthroscopic portals (i.e., anterolateral and anteromedial) and one outflow. Any meniscal or chondral injuries are addressed. Easy widening of a compartment confirms an injury to the corner on that side. The intercondylar notch is inspected for the extent of the PCL injury. Any PCL remnant or scar tissue is debrided using an aggressive shaver from the lateral surface of the medial femoral condyle until the notch is clear. Care should be taken to note the natural attachment site of the PCL on the femur.

Achilles tendon-bone allograft is prepared during the diagnostic arthroscopy. The tendon part of the graft is split longitudinally into two bundles. One bundle is of approximately the 60% of the entire width of the tendon, and the other is of the 40%. This normally makes a larger bundle with 8–9 mm thickness and a smaller bundle with 6–7 mm thickness. The larger bundle will become the anterolateral (AL) bundle and the smaller bundle the posteromedial (PM) bundle. It must be ensured that the larger AL bundle is made on the lateral part of the graft with the cancellous portion of the bone block facing anterior (Fig. 17.2). A permanent #2 suture is placed into each bundle using locked stitches. We use two different-colored sutures for accurate and quick identification of the AL and PM bundles later in the procedure. The bone block is trimmed into a rectangle that should be no less than 15 mm long by 10 mm wide by 10 mm thick. It is particularly critical to maintain a bone block thickness of at least 10 mm to minimize the risk of fracture of the bone block when the fixation screw is tightened. A 4.5-mm hole is drilled through the center of the bone block with the direction being slightly posteromedial to anterolateral to ease the screw insertion later.

A bump is then placed under the knee, and the leg hangs off the side of the table with the knee flexed approximately 90°. With the arthroscope in the anterolateral portal, a PCL guide (Arthrex, Inc., Naples, FL) is inserted through the anteromedial portal to drill a drill-tipped guide wire into the medial femoral condyle in an outside-in fashion. The AL tunnel guide pin is drilled first. The guide is placed at a location that is approximately 10 mm posterior to the articular cartilage in the proximal aspect of the notch (Fig. 17.3). It is usually located at an 11 o'clock position of a left knee and at a 1 o'clock position of a right knee. A stab incision is made on the superomedial aspect of the knee, and the guide pin is drilled into the medial femoral condyle. After drilling the AL tunnel, the guide is moved downward to locate the PM tunnel site directly inferior to the AL tunnel guide pin (see Fig. 17.3). It is important to space the two guide pins so that there will be at least a 4-mm bone bridge between the two tunnels. The guide is adjusted so that the two pins are divergent, with the AL tunnel drilled from a superomedial to inferolateral direction, whereas the PM tunnel is drilled almost parallel to the floor. An 8-cm-long skin incision that will be used for the open part of the procedure is now made and is used for drilling the PM tunnel guide pin. The incision starts from the femoral attachment of the MCL at the medial femoral epicondyle and extends down to the posteromedial border of the proximal tibia (Fig. 17.4). The tunnels are drilled the same size as the prepared AL and PM bundle grafts. Larger grafts usually yield a 9-mm AL bundle and a 7-mm PM bundle. Smaller grafts usually yield an 8-mm AL bundle and a 6-mm bundle.

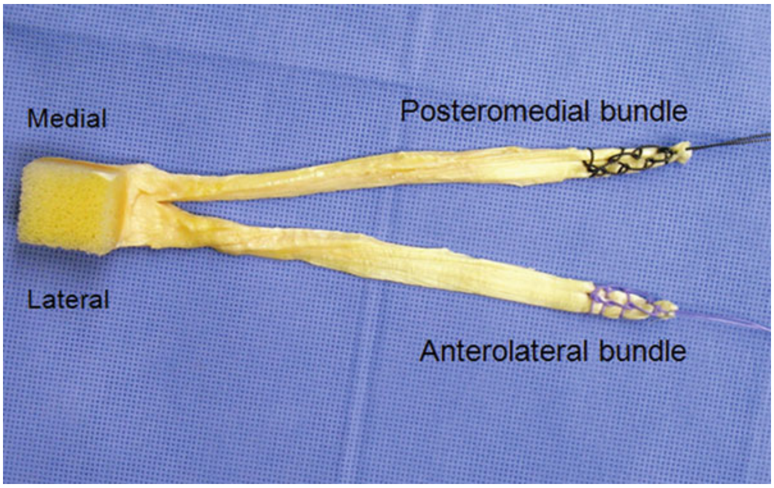

**Fig. 17.2** Achilles bone-tendon allograft for anatomic double-bundle inlay PCL reconstruction. The tendon part of the graft is split longitudinally to make the larger anterolateral (AL) bundle and a smaller posteromedial (PM) bundle. The larger AL bundle must be made at the lateral side of the graft 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

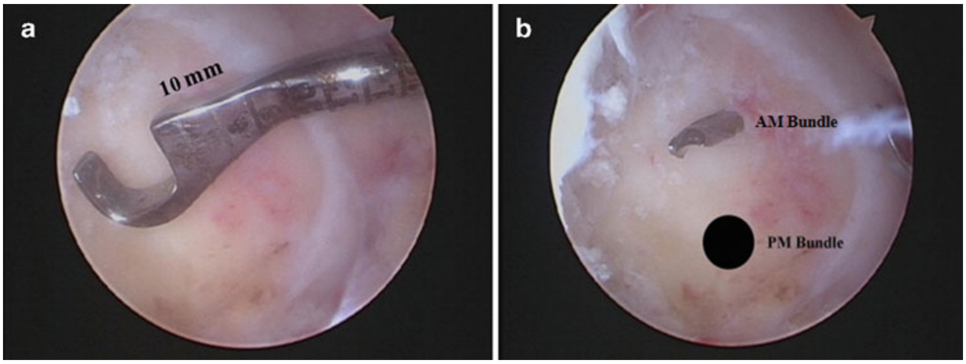

**Fig. 17.3** Positioning of the two femoral tunnels for PCL reconstruction. The AL tunnel is located approximately 10 mm posterior to the articular cartilage in the proximal aspect of the notch with the knee flexed in 90°. (**a**) It is usually located at an 11 o'clock position of a left knee and at a 1 o'clock position of a right knee. The PM tunnel is located straight inferior to the AL tunnel. (**b**) It is important to space the two guide pins so that there will be at least a 4-mm bone bridge between the two tunnels. Adapted with permission from [5]

Soft tissue at the both ends of the tunnels should be removed using a shaver or a radiofrequency probe to facilitate graft passage. A guide wire is inserted into each tunnel, and each tunnel is tapped with the same-sized tap as the drill size.

The patient's leg is positioned in a figure-of-four position for the open part of the procedure. The skin incision made for the PM tunnel drilling can be extended both proximally and distally for the posteromedial approach of the knee. This same incision will be used for the PMC reconstruction later. The incision is approximately 8–10 cm long and centered over the knee joint. Subcutaneous dissection is carried out until the pes anserinus tendons are identified. Dissection is continued immediately proximal to the pes anserinus tendons and posterior to the posteromedial tibial border. The semimembranosus may be encountered in the way and can be retracted either superiorly or inferiorly, or released and repaired later. A Cobb elevator is used to elevate the popliteus muscle off of the posterior surface of the tibia, and a blunt Hohmann retractor is placed to keep the popliteus and gastrocnemius muscles between the surgeon and the neurovascular structures (Fig. 17.5). The foot is externally rotated to facilitate the visualization of the posterior tibial surface. A ½-in. curved osteotome is used to create a trough at the site of the tibial insertion of the PCL, which starts approximately 5–10 mm inferior to the articular surface of the tibia in the midline. The allograft bone block is placed over the trough, and a guide wire for a 4.5-mm cannulated screw is passed through the drill hole of the bone block and drilled into the proximal tibia from posterior to anterior. The depth is measured, and a 4.5-mm fully threaded cannulated screw with a washer is inserted over the guide wire. Care needs to be taken to avoid placing a screw that is too long and results in a prominent tip extending through the anterior cortex. The correct placement of the screw is confirmed using fluoroscopy prior to proceeding with the case (Fig. 17.6). A Kelly clamp is used to punch a hole in the posterior capsule if one is not already present from the dislocation.

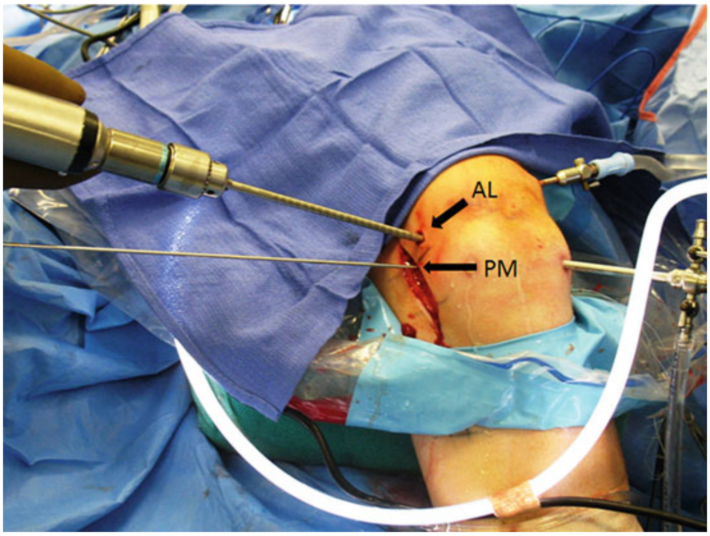

**Fig. 17.4** Incisions to accommodate graft passage through the two femoral tunnels of PCL reconstruction. A small stab incision is made for the AL bundle passage (the incision where a reamer is placed). The incision for the PM tunnel is incorporated into the incision for the posteromedial knee approach (the long posterior incision where a guide pin is placed), which will be used for the PCL bone block placement. The incision starts from the femoral attachment of the MCL at the medial femoral epicondyle and extends down to the posteromedial border of the proximal tibia

**Fig. 17.5** Posteromedial knee approach for PCL reconstruction. 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 the neurovascular structures

The arthroscope is inserted through the anterolateral portal for viewing, and a Hewson suture passer is inserted through the anteromedial portal and the posterior joint capsule opening. Care should be taken to ensure that the suture passer travels between the ACL and the medial femoral condyle. The PM bundle suture (the smaller bundle) is placed through the loop of the suture passer and pulled into the knee. The suture and graft are then pulled into the PM tunnel using an arthroscopic grasper. The process is then repeated with the AL bundle, making sure it enters the posterior capsule lateral to the PM bundle (Fig. 17.7). The two bundles are pulled out of the medial femoral condyle through the tunnels. The grafts are then left alone until after the grafts of both corner reconstructions are drilled and placed but not tensioned. At the time of final fixation, the PCL grafts are pretensioned by ranging the knee 20 times. The knee is brought off the side of table, and a bump is placed underneath the knee to give the knee an anterior drawer load during the graft fixation. With tension applied to the grafts, the AL bundle is fixed at approximately 70–80° of knee flexion, and the PM bundle is fixed at approximately 15° of knee flexion. Both bundles are secured with bioabsorbable interference screws that are the same size as the tunnel diameter. The length of

**Fig. 17.6** 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

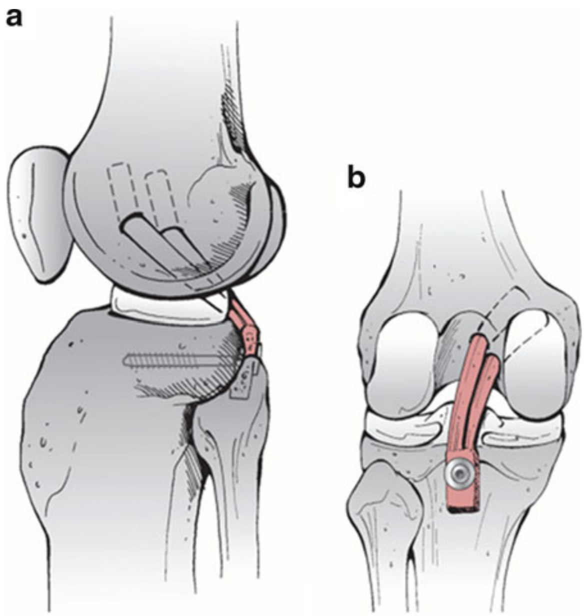

**Fig. 17.7** Schematic drawing of the final graft position for double-bundle inlay anatomic PCL reconstruction. The AL bundle enters the posterior capsule lateral to the PM bundle. Reprinted with permission from Stannard JP, Schenck RC Jr. Knee dislocations and ligamentous injuries. In: Stannard JP, Schmidt AH, Kregor PJ, eds. Surgical Treatment in Orthopaedic Trauma. New York: Thieme, 2007: 687–712

the screws varies slightly, but 23-mm screws are most commonly used. The screws should feel snug as they are tightened down. They should be inserted completely into the tunnels, and excess graft is cut.

### *17.6.2 PMC: Posteromedial Corner Reconstruction with Allograft (Tibialis Anterior or Two Semitendinosus Tendons)*

A tibialis anterior allograft is divided into two 5–6-mm-diameter grafts. Locking stitches are placed in each end of the graft to facilitate passage. Using the same posteromedial incision used for the PCL reconstruction, the isometric point on the medial femoral condyle is located using fluoroscopy. A perfect lateral view of the knee is obtained, and the isometric point

**Fig. 17.8** Intraoperative fluoroscopic image showing the location of the isometric point for PMC reconstruction. A perfect lateral view of the knee is obtained with the two femoral condyles superimposed perfectly. The isometric point is located where a line extended from the posterior femoral cortex intersects Blumensaat's line, which is at the tip of a 3.2-mm drill bit in this image

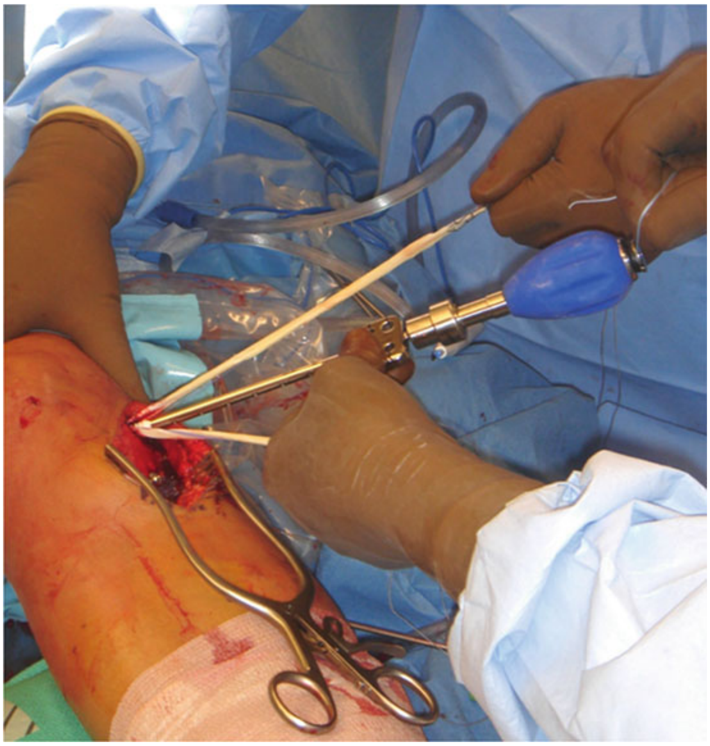

**Fig. 17.9** Femoral side graft fixation using a Bio-Tenodesis screw in PMC reconstruction. The graft is folded at its half making a loop, and a #2 permanent suture is placed at the loop. The suture is passed into a Bio-Tenodesis screw driver loaded with a Bio-Tenodesis screw. The graft is tightened down into the tunnel while the tension on the two graft limbs is maintained

is located where a line extended from the posterior femoral cortex intersects Blumensaat's line (Fig. 17.8). A 2.4-mm guide pin is drilled into the medial femoral condyle. A 7- or 8-mm reamer is drilled over the guide wire to a depth of 25 mm. The two grafts with locking sutures are passed into a Bio-Tenodesis screw driver loaded with a Bio-Tenodesis screw (Arthrex Inc., Naples, FL). The screw size varies based on the graft size, but 7 × 23 or 8 × 23 mm is the most commonly used size. The graft is tightened down into the tunnel as the tenodesis screw goes in (Fig. 17.9). A second hole is drilled with the 3.2-mm drill bit through the tibia, starting at the point of insertion of the semitendinosus tendon. A 4.5-mm bicortical screw and spiked ligament washer are placed into the hole. One limb runs posteriorly under the semimembranosus, and then turns the corner and is taken to the tibial screw and washer. This limb reconstructs the posterior oblique ligament. A route for the passage of the second limb is made underneath the fascia and soft tissue at the medial side of the knee by passing a blunt Kelly clamp

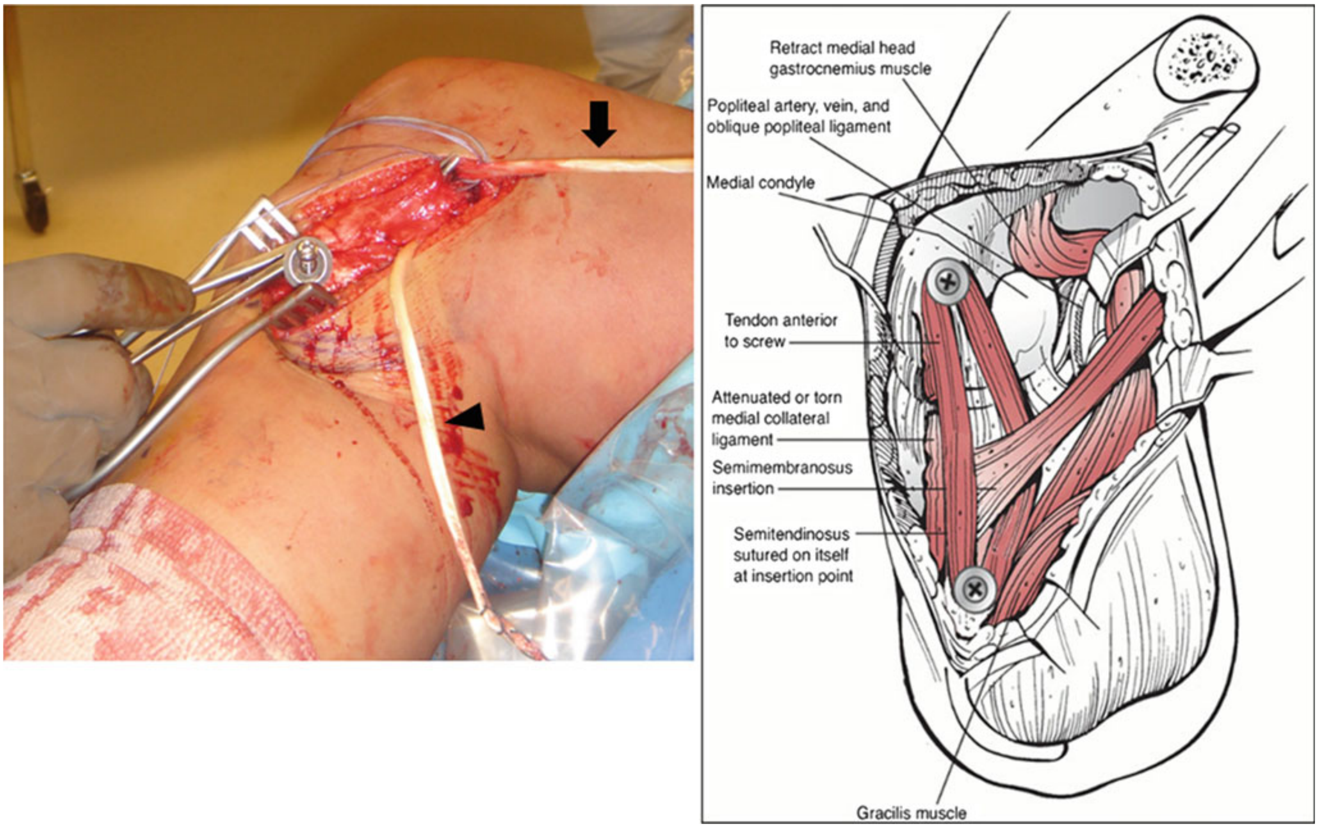

**Fig. 17.10** Graft passage for PMC reconstruction. (**a**) A Kelly clamp is passed underneath the fascia and soft tissue to retrieve one of the two graft limbs (*arrow*). The graft has been fixed at the isometric point of the medial femoral condyle. This graft limb will be passed straight down to the tibial screw to reconstruct the deep MCL. The other graft limb has been passed underneath the semimembranosus to reconstruct the oblique popliteal ligament (*arrow head*). (**b**) A schematic drawing of the final graft position for PMC reconstruction. The screw and washer used for the graft fixation at the femoral condyle are now replaced with Bio-Tenodesis screws. Reprinted with permission from Stannard JP, Schenck RC Jr. Knee dislocations and ligamentous injuries. In: Stannard JP, Schmidt AH, Kregor PJ, eds. Surgical Treatment in Orthopaedic Trauma. New York: Thieme, 2007: 687–712

from the tibial screw site to the femoral screw site (Fig. 17.10). This limb is also brought around the tibial screw and washer. The graft is then tensioned in approximately 40° of knee flexion. Additional stability can be attained by placing some permanent sutures to draw the two limbs together near the tibial screw. This maneuver will tighten further the PMC.

### *17.6.3 PLC: Posterolateral Corner Reconstruction: Modified Two-Tailed Technique*

Either tibialis anterior or tibialis posterior allograft is used. A minimum graft length of 27 cm is necessary, but to be on the safe side, we prefer a graft that is 30 cm or longer. This procedure anatomically reconstructs three critical components of the PLC: the popliteus tendon, the popliteofibular ligament, and the FCL. 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 with the knee flexed 90°, allowing relaxation and protection of the peroneal nerve. 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 overlying fascia are identified. The deep fascia is opened using scissors immediately posterior to the biceps tendon along the direction of the tendon, and the peroneal nerve is identified and dissected out from the fibular neck (Fig. 17.11). A Penrose drain is placed around it for gentle retraction (Fig. 17.12). No clamps or other surgical instruments should be placed on the Penrose drain as the tension on the nerve over the course of the operation can lead to a permanent traction injury. With sufficient dissection of the nerve, the entire proximal fibula is made readily assessable. Blunt dissection is carried out to define the plane anterior to the lateral head of the gastrocnemius. The posterior aspects of the fibula and tibia and the PCL bone block are readily palpated with a finger. It is critical to never stray posterior to the lateral head of the gastrocnemius as it places the popliteal neurovascular structures at risk. Then, 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. 17.13). The popliteus tendon runs deep to the FCL to attach to its femoral insertion that is 1–2 cm anterior and distal to the FCL attachment site.

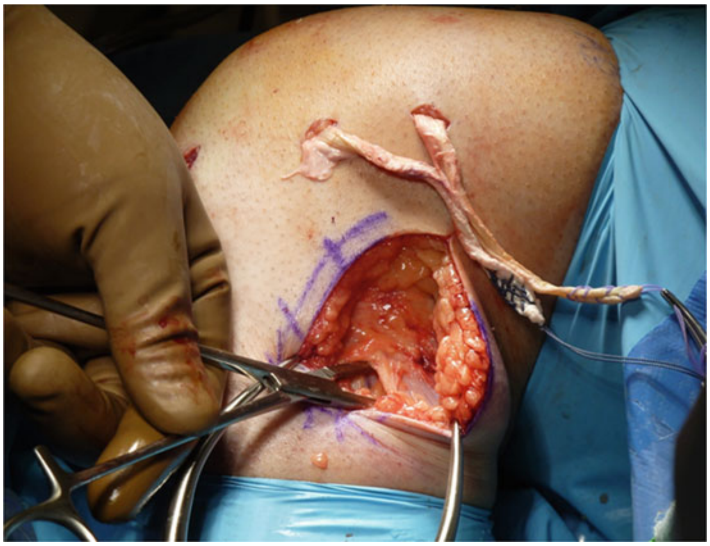

**Fig. 17.11** Posterolateral approach of PLC reconstruction in a left knee. The skin incision is placed in line with the fibular head and carried in a straight line proximally and distally. The biceps tendon, iliotibial band, and the overlying fascia are identified. A pair of scissors is placed immediately 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 particular patient

**Fig. 17.12** A Penrose drain placed around the peroneal nerve during the posterolateral approach of the knee

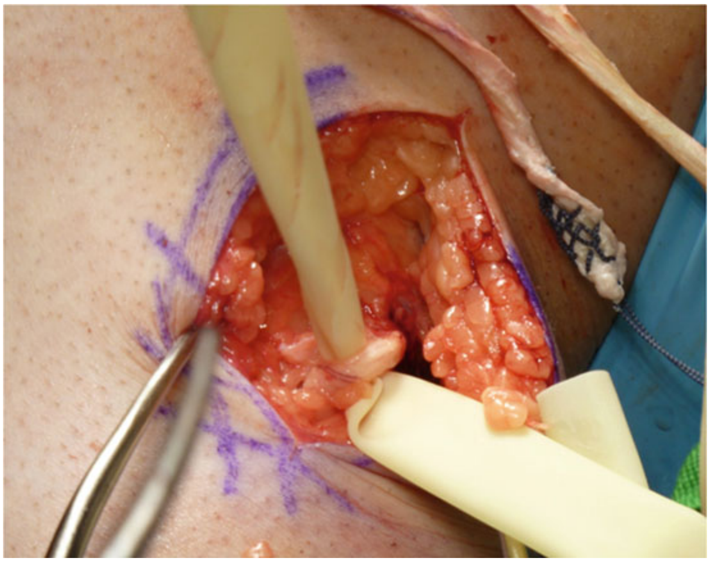

**Fig. 17.13** The interval between the biceps femoris tendon and iliotibial band is opened along the direction of their fibers. This allows for the evaluation of the status of the FCL and popliteus tendon, and facilitates graft passage underneath the biceps tendon and iliotibial band later

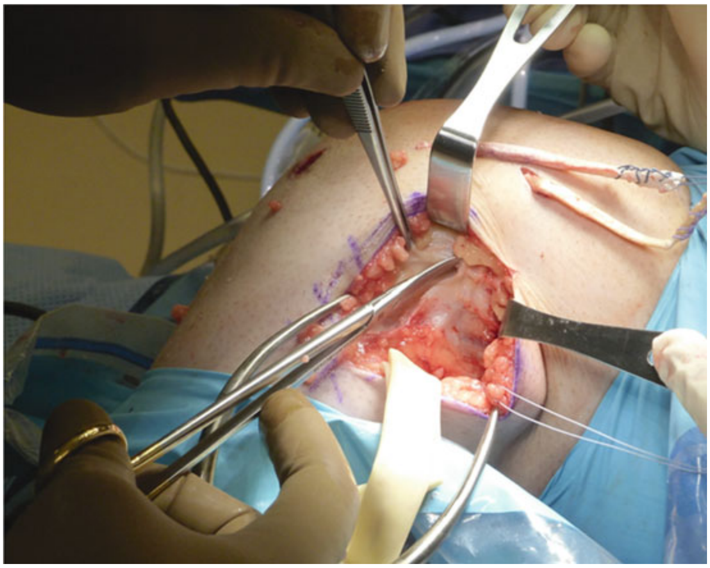

**Fig. 17.14** A 4.5-mm bicortical screw is being inserted with a spiked ligament washer into the isometric point of the lateral femoral condyle for the fixation of a PLC graft. It is important to direct this screw approximately 30° anterior and 30° proximal to avoid this screw crossing the femoral tunnel, which will interfere with the femoral tunnel placement of a future ACL reconstruction

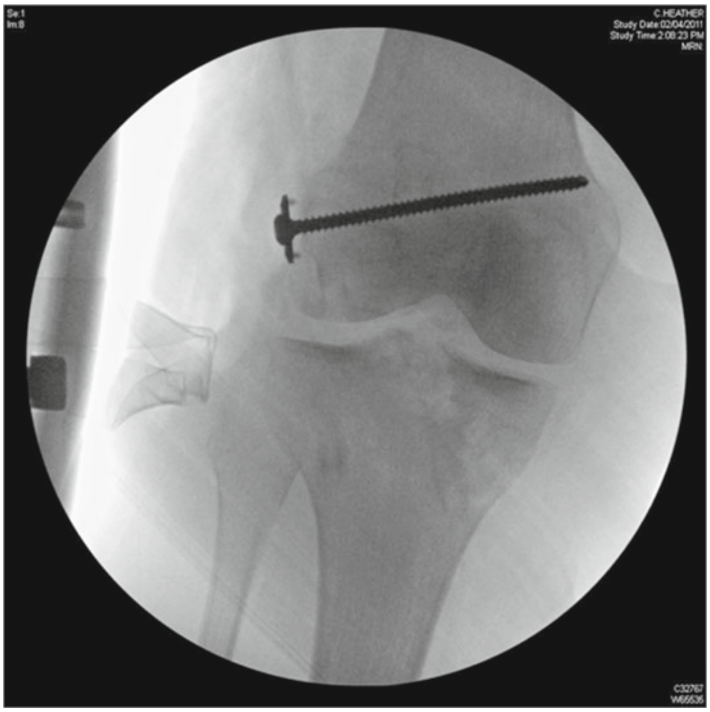

**Fig. 17.15** Intraoperative fluoroscopic image showing the placement of the femoral screw for PLC reconstruction. The screw is directed approximately 30° anterior and 30° proximal to avoid the potential femoral tunnel of a future ACL reconstruction

The isometric point is located approximately halfway between these two attachment sites. 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. The normal anatomy is frequently disrupted in patients with knee dislocations. The isometric point on the lateral femoral condyle is then located using fluoroscopy similarly to that of the PMC reconstruction. A perfect lateral view of the knee is obtained, and the isometric point is located where a line extended from the posterior femoral cortex intersects Blumensaat's line. The isometric point is drilled with a 3.2-mm drill bit, and a 4.5-mm bicortical screw is inserted with a spiked ligament washer from lateral to medial. It is important to direct this screw approximately 30° anterior and 30° proximal to avoid this screw crossing the femoral tunnel, which will interfere with the femoral tunnel placement of a future ACL reconstruction (Figs. 17.14 and 17.15). An osteotome is used to decorticate the bone around the screw, allowing the allograft to heal to bone in the anatomic locations of the FCL and popliteus.

A 5-mm drill bit is used to make a hole through the lateral tibia in an anterior to posterior direction. The drill enters the tibia directly inferior to the anterolateral arthroscopic portal, well below the joint line, and exits the posterior tibial cortex lateral to the PCL bone block. This corresponds to the area where the popliteus tendon crosses the posterior joint line. A free hand technique is used for the drilling and involves positioning the index finger of the nondominant hand at the posterolateral

**Fig. 17.16** Creating the tibial tunnel using a free hand technique in PLC reconstruction. With the index finger of the nondominant hand placed at the posterolateral edge of the tibia, a 5-mm drill bit is drilled through the lateral tibia in an anterior to posterior direction. The drill exits the posterior tibial cortex just lateral to the PCL bone block, which corresponds to the area where the popliteus tendon crosses the posterior joint line

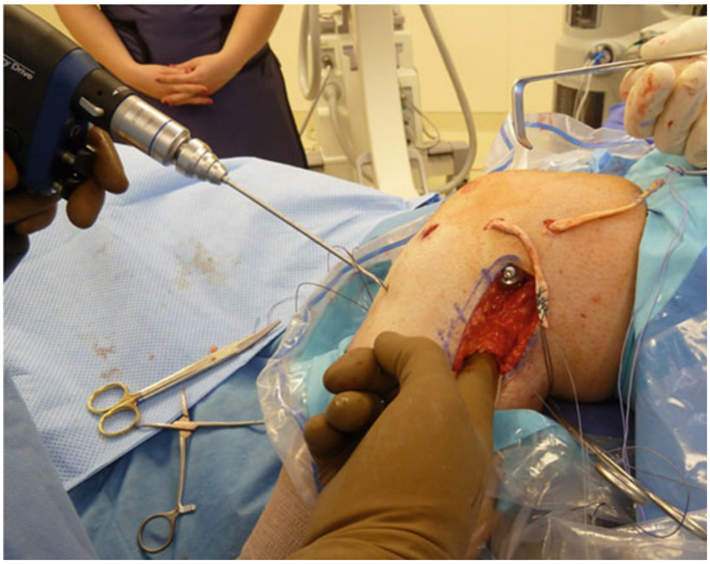

**Fig. 17.17** Creating the fibular head tunnel in PLC reconstruction. Note that the drill bit is directed from anterolateral to posteromedial to reproduce the routes of the FCL and popliteofibular ligament

edge of the tibia through the interval described above, approximately 1 cm distal to the joint line (Fig. 17.16). The tibial tunnel is tapped with a 7-mm tap, and the graft is passed into the tibial tunnel from posterior to anterior using a Hewson suture passer. The graft is fixed in the tibial tunnel with a 7 × 30-mm bioabsorbable interference screw.

A second 5-mm drill hole is made through the fibula head, aimed from anterolateral to posteromedial to reproduce the routes of the FCL and popliteofibular ligament (Fig. 17.17). The graft is passed deep to the iliotibial band, biceps tendon, and adjacent fascia (Fig. 17.18). The graft is coursed from the posterior tibia, up and around the screw and washer, back down to the fibular tunnel, through the tunnel, and back up to the screw and washer (Fig. 17.19). The graft is tensioned and fixed at the femoral screw and washer with the foot slightly internally rotated and the knee flexed approximately 40°.

In some cases, patients have only an FCL and popliteofibular injury with intact popliteus tendon. These patients present with a positive varus stress test at 30° knee flexion but a negative dial test. In such patients, reconstruction of the FCL and popliteofibular ligament is all that needs to be done. A figure-of-eight reconstruction using allograft is a quick and successful technique for this purpose. The graft preparation is almost identical except for that the graft length does not have to be as long as 30 cm. Only the femoral isometric point and the fibular tunnel are drilled for graft passage in the same way as described above. No tibial tunnel is drilled. The graft is passed around the screw and washer, and the two limbs of the graft are crossed. One of the two limbs is passed through the fibular tunnel and brought back to the screw and washer. Again, care needs to be taken to pass the graft deep to the iliotibial band, biceps tendon, and adjacent fascia. The screw and washer are tightened down while the graft is being tensioned with the foot slightly internally rotated and the knee flexed approximately 40°.

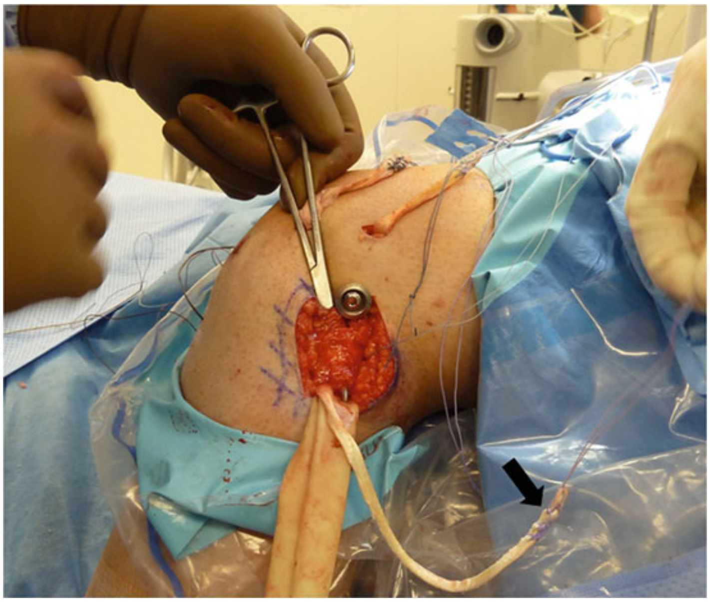

**Fig. 17.18** Graft passage in PLC reconstruction. A Kelly clamp is passed underneath the iliotibial band, biceps tendon, and adjacent fascia to retrieve the graft that has been passed through the tibial tunnel (*arrow*). The graft will be passed underneath these tissues and brought to the femoral screw and washer

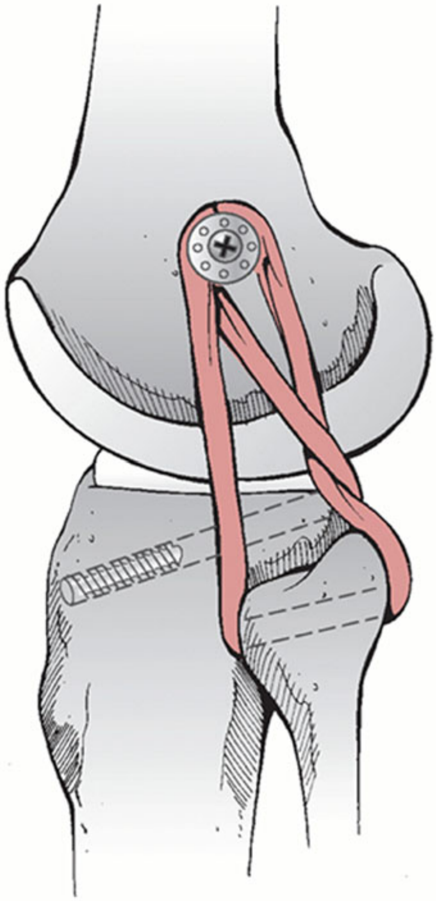

**Fig. 17.19** Reconstruction of the posterolateral corner using the modified two-tailed technique. Reprinted with permission from Stannard JP, Schenck RC Jr. Knee dislocations and ligamentous injuries. In: Stannard JP, Schmidt AH, Kregor PJ, eds. Surgical Treatment in Orthopaedic Trauma. New York: Thieme, 2007: 687–712

## 17.7 Postoperative Care

Most patients with multi-ligament reconstruction require 3–4 days of hospitalization. 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 (e.g., sequential compression device) and pharmacological prophylaxis (low molecular weight heparin; subcutaneous injection of 30 mg Lovenox twice a day) during inpatient hospitalization. On discharge, they are prescribed one pill of baby aspirin per day as DVT prophylaxis until the patient resumes full normal weight-bearing ambulation.

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 at 0–30° on the first postoperative day and progress as tolerated. 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 weeks, the hinged knee brace is unlocked during weight-bearing activities. Physical therapy is begun 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 in this phase because the patella is frequently involved in arthrofibrosis following multi-ligament knee injuries. By 6 weeks, 0–90° of active and passive knee motion, good patellar mobility, and normal gait without crutches are expected to be achieved. Once all these goals have been achieved, the strengthening phase is begun. The brace is discontinued any time 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.

Return to heavy work and sports is gradually allowed during the period of 6–12 months. For patients who have sustained a multi-ligament injury, full recovery frequently involves a 12- to 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 convincingly have regained the 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 out of 54) [5] 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 a 1+ posterior drawer. When knee stability was measured in the anteroposterior direction with KT-2000 arthrometer at 30 and 70°, excellent stability was found. 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 unpublished study, the failure rate of PMC reconstruction was found to be 4% compared to a 20% failure rate with PMC repair.

Following reconstruction of the PCL and other ligaments, 90% of patients were able to return to some type of work [5]. 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 orthopaedic surgeons. The neurovascular may be injured and result in a limb-threatening situation. Concomitant injuries to the ipsilateral extremity further complicate the diagnosis and treatment. The clinical outcomes have often been discouraging, and complications are frequent. It is not uncommon for patients to have chronic pain, stiffness, residual instability, early posttraumatic 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 reconstructing the MCL and posterior oblique ligament. 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 with patient evaluation and surgical technique, the clinical outcomes have shown a steady improvement in recent years.

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# Chapter 18
# ACL, PCL, and Medial-Sided Injuries of the Knee

**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).

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G.C. Fanelli (ed.), *The Multiple Ligament Injured Knee: A Practical Guide to Management*,
DOI 10.1007/978-0-387-49289-6_18, © Springer Science+Business Media New York 2013

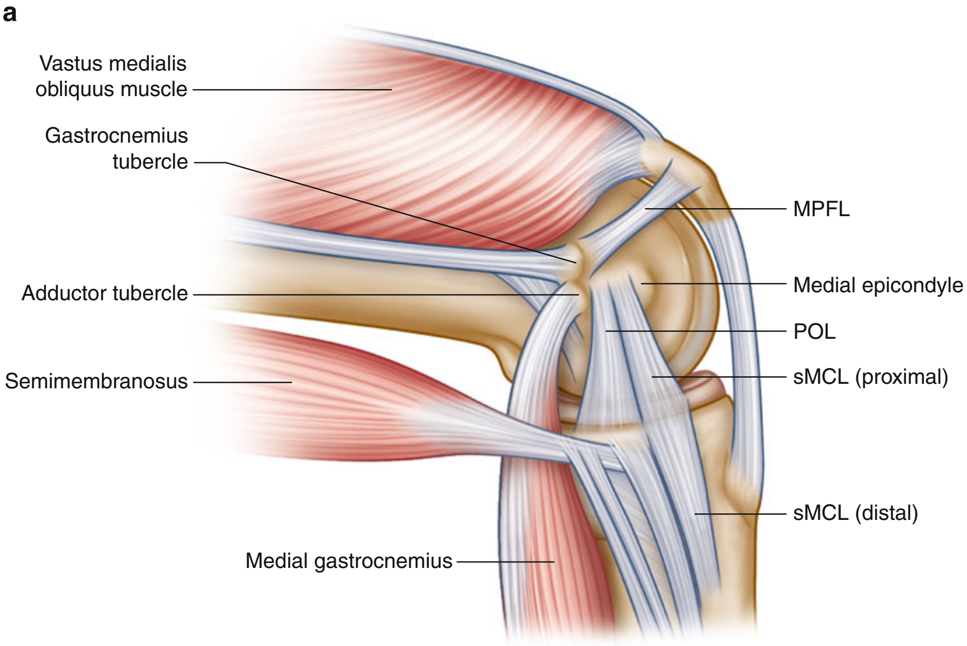
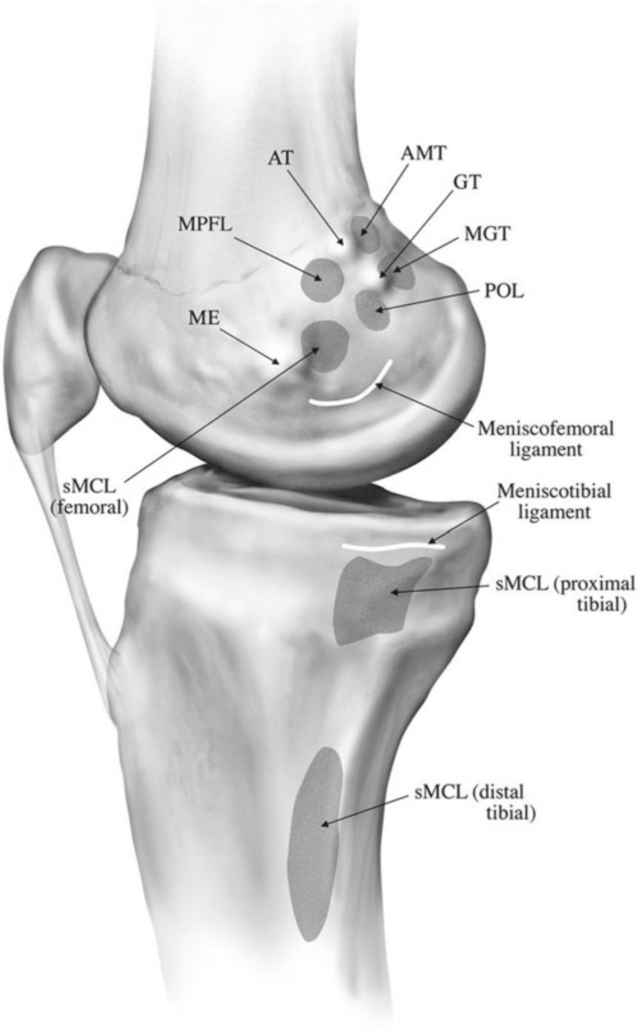


**Fig. 18.1** Anatomic diagram of MCL and POL ligaments. From Wijdicks CA, Griffith CJ, LaPrade RF, et al. Radiographic identification of the primary medial knee structures. J Bone Joint Surg Am. 1 Mar 2009;91(3):521–529. Reprinted with kind permission from JBJS, Inc

**Fig. 18.2** Anatomic diagram of the insertion sites for medial-sided structures. From LaPrade RF, Engebretsen AH, Ly TV, Johansen S, Wentorf FA, Engebretsen L. The anatomy of the medial part of the knee. J Bone Joint Surg Am. Sep 2007;89(9):2000–2010. Reprinted with kind permission from JBJS, Inc



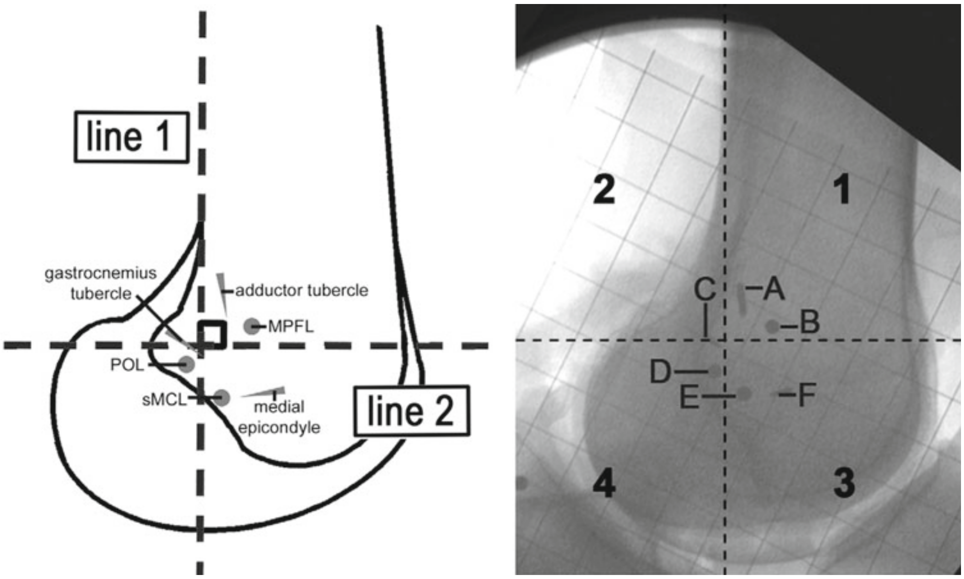


**Fig. 18.3** Fluoroscopic and pictorial diagram for locating the MCL femoral insertion site. From Wijdicks CA, Griffith CJ, LaPrade RF, et al. Radiographic identification of the primary medial knee structures. J Bone Joint Surg Am. 1 Mar 2009;91(3):521–529. Reprinted with kind permission from JBJS, Inc.

## 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 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 periarticular 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).

## 18.8 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.

## 18.9 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.

## 18.10 Delayed (>3 Weeks)

Surgical delay greater than three 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.

**Fig. 18.4** Coronal T-2 MRI depicting the superficial MCL trapped within a medial tibial plateau rim fracture

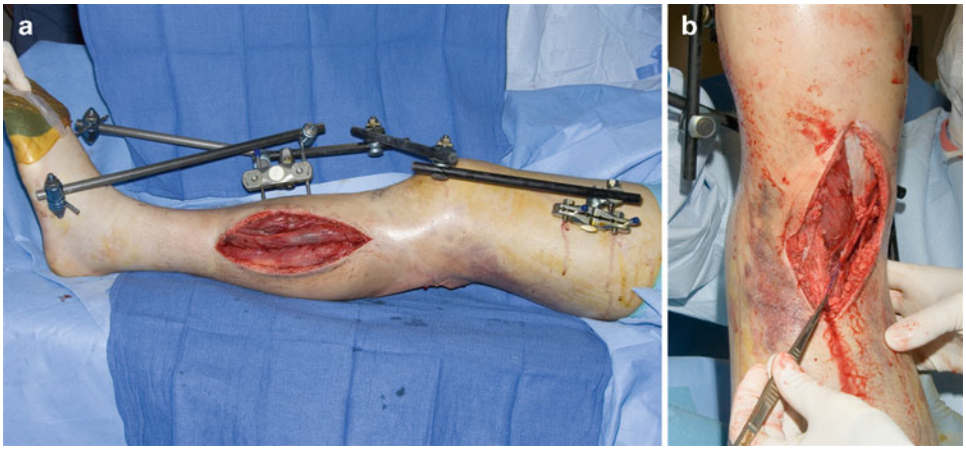


**Fig. 18.5** Clinical photographs of lateral (**a**) and prone (**b**) views depicting severe soft tissue swelling following a knee dislocation requiring vascular repair and fasciotomies

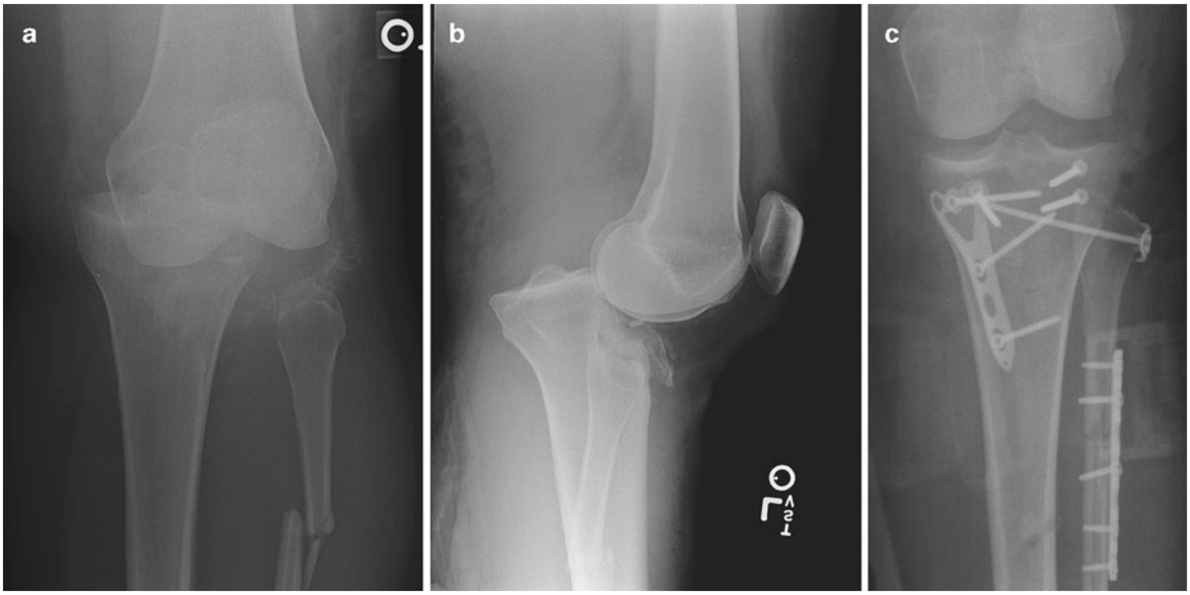


**Fig. 18.6** (**a**) Anteroposterior (AP) and (**b**) Lateral radiographs of open tibial plateau, proximal tibiofibular joint dislocation, and fibular neck fracture that required multiple débridements C, Open reduction and internal fixation (ORIF)

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.

## 18.11 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 a single strand Achilles tendon allograft supplemented with platelet-rich fibrin matrix. The graft is fixed on the femur with an interference screw and on the tibia with a bioabsorbable interference screw and a bone anchor.

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.

## 18.12 Medial-Sided Repair/Reconstruction

### *18.12.1 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 sutured to the posterior border of the MCL without imbrication with the knee positioned in full extension.

## 18.13 MCL Reconstruction

### *18.13.1 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

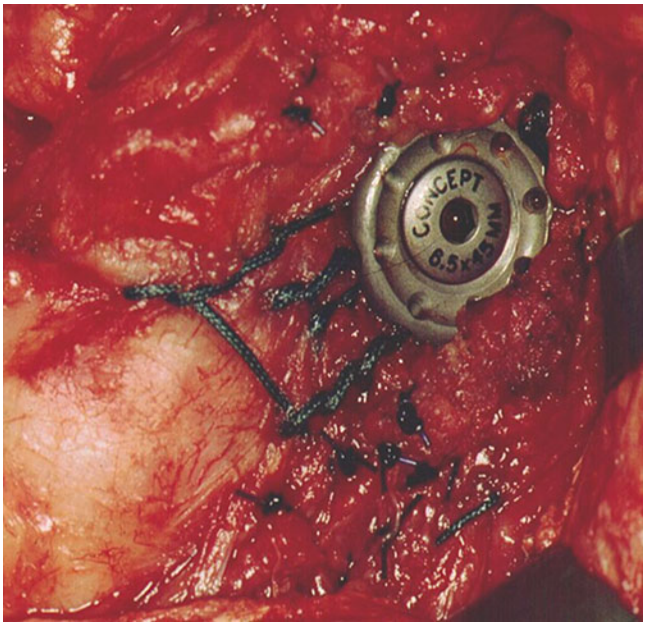


**Fig. 18.7** Clinical photo of suture post and ligament washer construct

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.

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. 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 18.10–18.13 depict a case example of ACL/PCL/MCL reconstructions with hamstring autograft MCL reconstruction and medial meniscal transplantation.

A summary of our current strategy for ligament reconstruction sequence in the setting of ACL, PCL, and MCL injury is presented in Table 18.1.

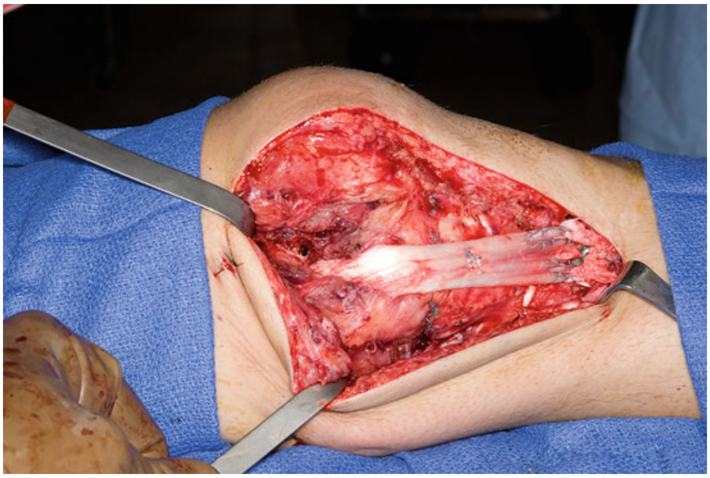


**Fig. 18.8** Clinical photo of an Achilles MCL reconstruction

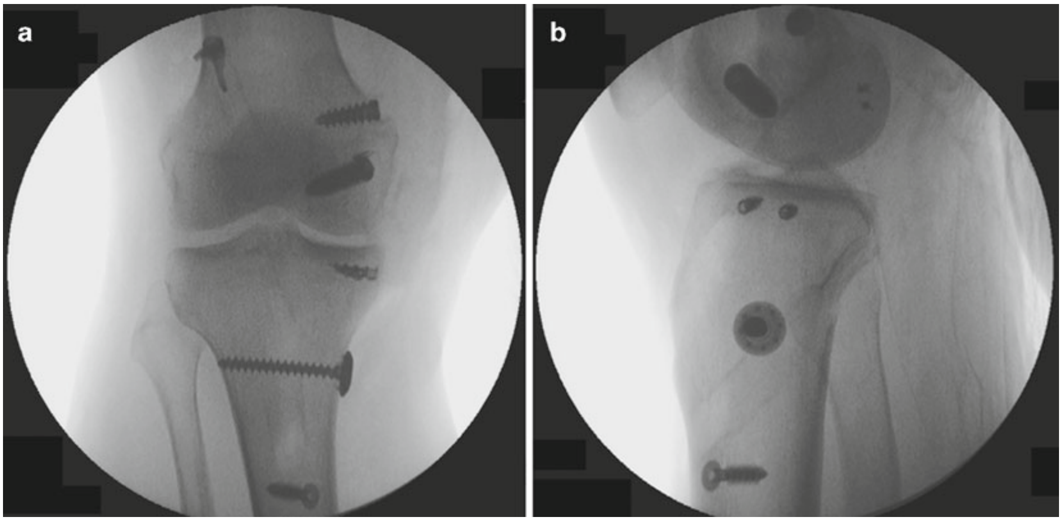


**Fig. 18.9** Example of AP (**a**) and lateral (**b**) fluoroscopy after ACL/PCL/MCL reconstructions with Achilles allograft MCL reconstruction

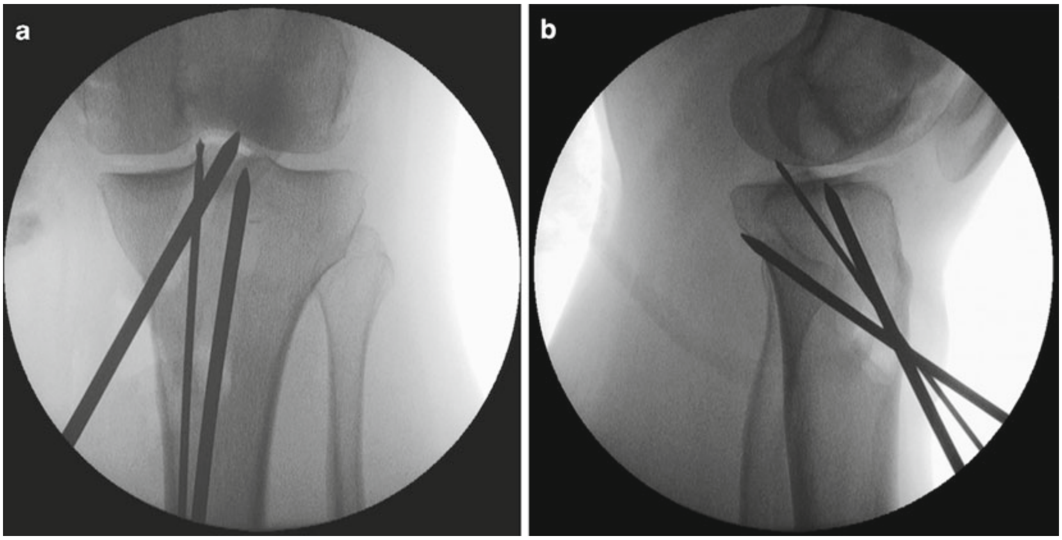


**Fig. 18.10** Intraoperative AP (**a**) and lateral (**b**) fluoroscopy of ACL/PCL/MCL/meniscus allograft reconstructions. Note the position of the trocars for the ACL and PCL tunnels and guide pin position for the medical meniscus posterior horn

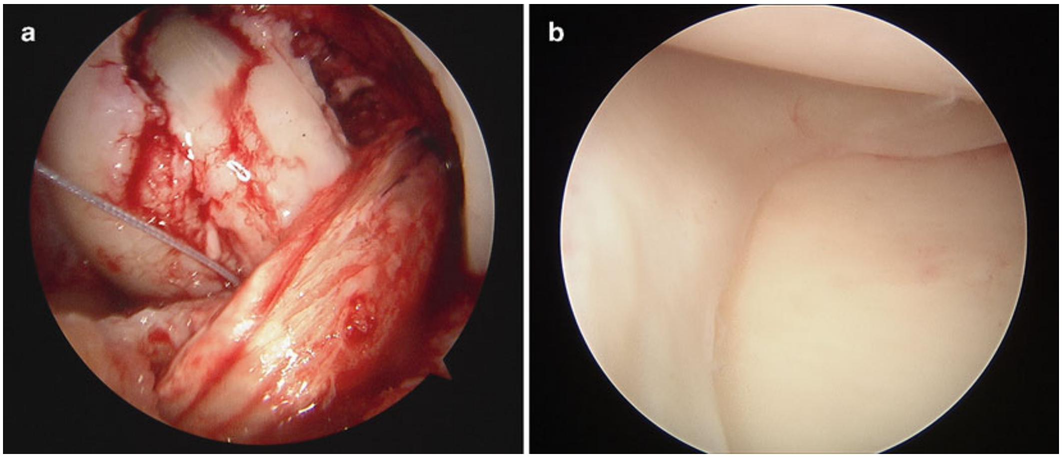
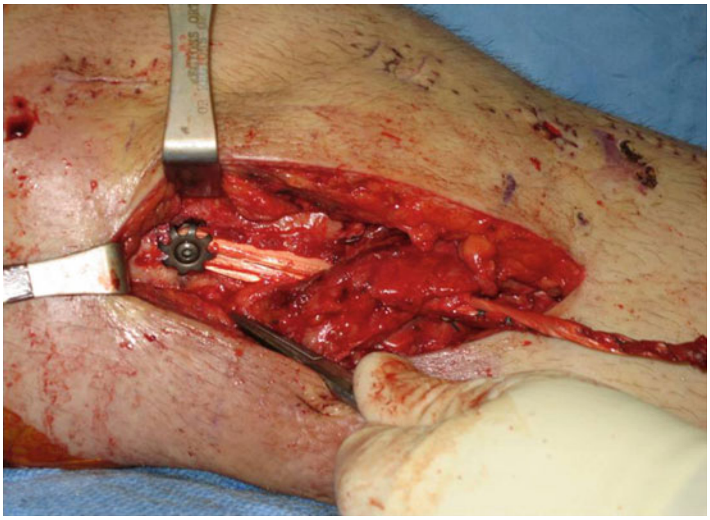


**Fig. 18.11** Arthroscopic views of ACL/PCL single bundle ligament reconstructions (**a**) and meniscus transplant (**b**)

**Fig. 18.12** Clinical photo of hamstring autograft MCL reconstruction



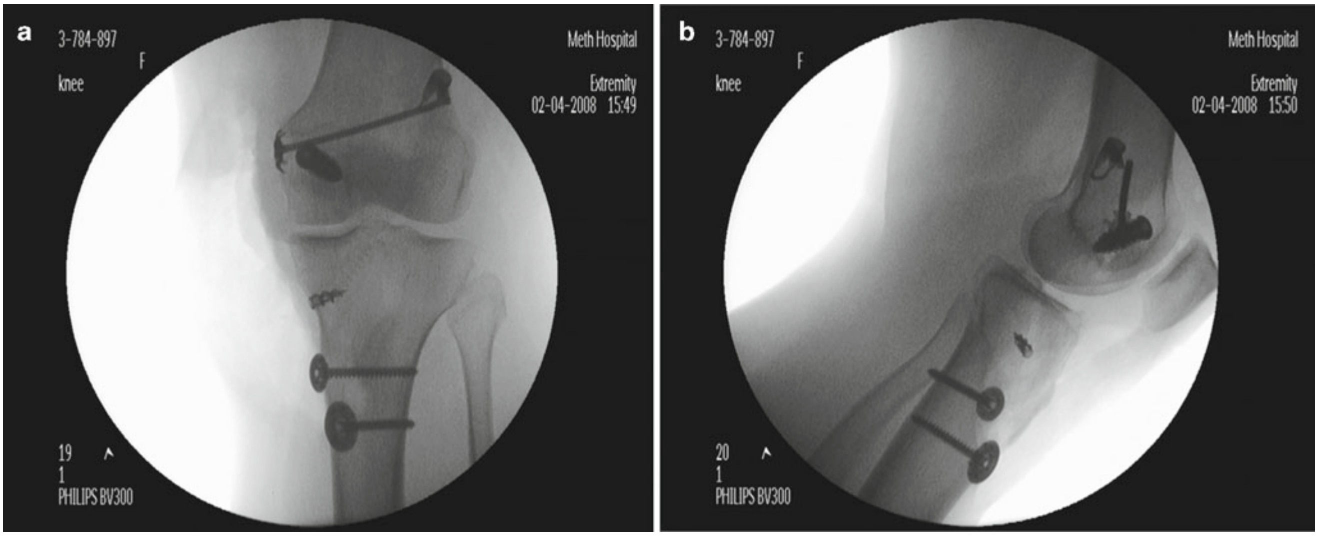


**Fig. 18.13** AP (**a**) and lateral (**b**) fluoroscopy after ACL/PCL/MCL reconstructions with hamstring autograft MCL reconstruction

**Table 18.1** Summary of ligament reconstruction sequence

(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

## 18.14 Postoperative Rehabilitation

We follow the rehabilitation protocol as described by Edson and Fanelli (5). 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° 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.

## 18.15 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 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 (6).

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 (7). 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 (8). 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 (9).

Of the studies that reported on *reconstruction* of the MCL in the multiligament injured knee, only two 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 patients sustained a bicruciate injury with MCL disruption, all of whom reported near-normal knee function at final follow-up (10). 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 (11).

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 (12).

More recently, 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 (13).

No prospective randomized trials have been performed to our knowledge comparing *repair* to *reconstruction* of the MCL. However, 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 (14, 15).

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 (16).

## 18.16 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.

Due to the lack of higher levels of evidence to help guide treatment, we currently 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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# Chapter 19
# Surgical Management of ACL, PCL, and Lateral-Sided Injuries: Acute and Chronic

**Jonathan P. Marsh and Peter B. MacDonald**

## 19.1 Introduction

Although rare, multiligamentous injuries to the knee pose great challenges to both patients and treating surgeons. They represent <0.02% of all orthopedic injuries, but they 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 and are a cause of failed cruciate ligament reconstructions [3, 4].

The complex anatomy of the PLC of the knee, in addition to the heterogenicity of injuries, has resulted in a lack of consensus regarding specific treatment algorithms. Historically, these injuries were treated nonoperatively, but there has been a shift toward surgical management in recent years. Many surgeons now recommend acute reconstruction within 3 weeks of injury [5–8]. 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.

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 of damaged structures, graft choices, which ligaments require reconstruction, surgical techniques, and postoperative rehabilitation protocols are all topics of debate. In this chapter, we will aim to clarify some of the controversies and describe our preferred treatment methods.

## 19.2 Anatomy and Biomechanics

### *19.2.1 Cruciate Ligaments*

The central pivot of the knee is made up of the anterior cruciate ligament (ACL) and the posterior cruciate ligament (PCL) (Fig. 19.1). Both are intra-articular, extrasynovial ligaments each comprised of two large bundles, with blood supplied by the middle geniculate artery. The innervation is from the posterior articular branch of the tibial nerve. It mainly provides proprioceptive feedback, which may be relevant to patients' altered function post-injury.

The ACL has attachments to the medial aspect of the lateral femoral condyle and the anterior tibial spine. It is composed of a large anteromedial bundle, which is tight in flexion, and a smaller posterolateral bundle, which is tight in extension. Various fibers of each bundle are taught in all angles of knee flexion, providing a primary restraint to anterior tibial translation and a secondary restrain to internal tibial rotation and to varus/valgus forces. The restraint is greatest in full extension.

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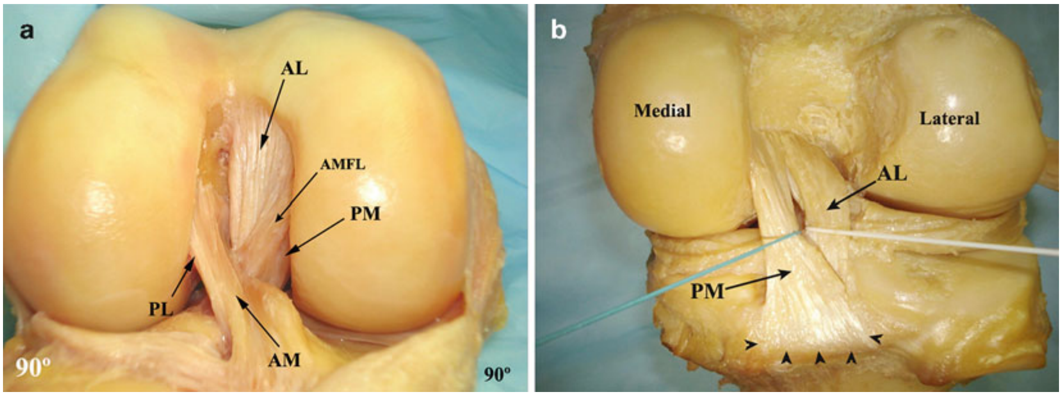

**Fig. 19.1** Anterior view (**a**) and posterior view (**b**) of a cadaveric dissection of the knee demonstrating the attachment sites of the anterolateral (AL) and posteromedial (PM) bundles of the PCL, the anteromedial (AM) and posterolateral (PL) bundles of the ACL, and the anterior meniscofemoral ligament (AMFL). From: [71]. Reprinted with permission from JBJS, Rockwater

The PCL attaches to the lateral aspect of the medial femoral condyle and has a broad attachment to the posterior aspect of the proximal tibia. Similarly to the ACL, it is made up of two bundles: a large anterolateral bundle, which is tight in flexion, and a smaller posteromedial bundle, which is tight in extension. Together they provide a primary restraint to posterior tibial translation and a secondary restraint to external tibial rotation, to varus/valgus forces, and to hyperflexion.

### *19.2.2 Posterolateral Structures*

The anatomy of the PLC of the knee can be extremely confusing for a variety of reasons. Inconsistent nomenclature in the literature, variable anatomy in vivo, and the absence of the popliteofibular ligament (PFL) in texts for almost 60 years have led some authors to describe this as the "dark side of the knee" [9]. In addition to these factors, surgical dissection of the disrupted lateral structures is infrequently as elegant as pictorial descriptions. Many biomechanical studies have been undertaken to determine the exact role of each ligament, but it is important to realize that the posterolateral structures as a unit primarily resist varus stress and external tibial rotation and they secondarily resist both anterior and posterior tibial translation [3, 4, 10–14].

The anatomy of the PLC is often described in three layers [15]. In the superficial layer are the biceps femoris and the iliotibial band, which insert onto the fibular head and Gerdy's tubercle, respectively. The middle layer consists of the quadriceps retinaculum anteriorly and the patellofemoral and patellomeniscal ligaments posteriorly. The deep layer is the most complex and is the main focus of surgical reconstruction (Fig. 19.2). It consists of the posterolateral joint capsule and a multitude of ligaments and capsular condensations, but there are three main structures most relevant to surgical reconstruction: (1) The lateral collateral ligament (LCL) attaches to the posterior aspect of the lateral epicondyle of the femur and to the superolateral aspect of the fibular head. It primarily resists varus stress. (2) The popliteus muscle originates on the posteromedial aspect of the proximal tibia. Its tendon travels proximally, anteriorly, and laterally, deep to the LCL, and intra-articularly through the popliteus hiatus in the lateral meniscus and inserts anterior to the lateral epicondyle. It primarily resists external tibial rotation. (3) The PFL attaches to the popliteus tendon at the musculotendinous junction and to the posterior aspect of the fibular head to primarily resist external tibial rotation. This ligament has recently gained popularity in the biomechanical literature, leading some authors to consider it a critical structure that should be addressed with all reconstructions of the PLC [12, 16–18].

Much of what is known regarding knee biomechanics is from sectioning structures in cadaveric studies [10, 11, 16, 19]. Sectioning of all PLC structures results in varus opening and increased external tibial rotation, which are greatest at 30° of knee flexion. The PLC provides secondary restraint to anterior and posterior tibial translation, but isolated sectioning of these structures causes little tibial translation. Sectioning of the PCL in addition to the PLC causes marked increase in posterior tibial translation at all knee flexion angles and further exaggerates the varus opening at 30° and the external tibial rotation at 30° and 90°. Sectioning the ACL in addition to the PLC causes increased anterior tibial translation and internal tibial rotation, which is greatest at 30°. A number of studies have demonstrated that sectioning of the PLC causes increased stress on the cruciate ligaments [4, 20, 21]. Unaddressed injury to the PLC has been shown to cause failure of ACL and PCL grafts, further demonstrating the importance of injury recognition.

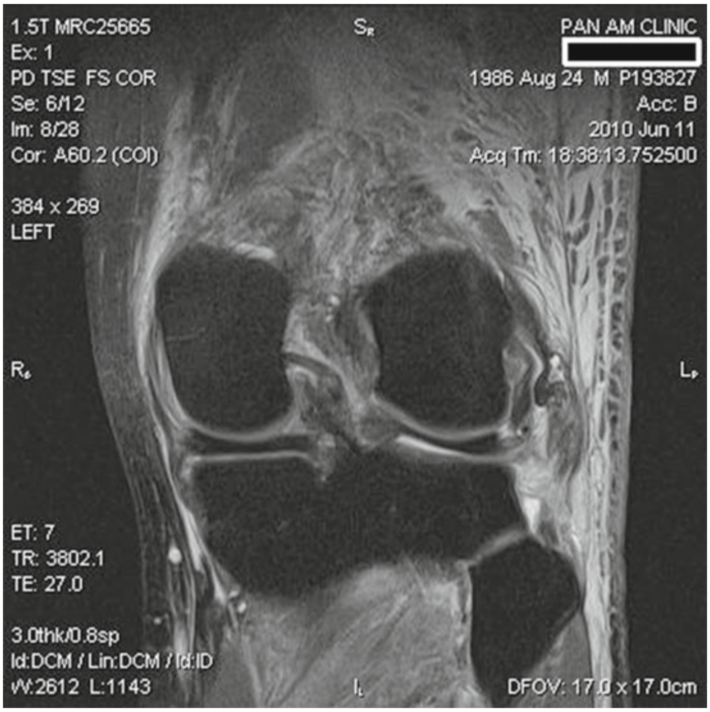

**Fig. 19.2** MRI showing acute posterolateral ligament avulsion

## 19.3 History and Physical Examination

The majority of multiligamentous injuries are associated with knee dislocations. These often occur from high-energy mechanisms, such as dashboard injuries in motor vehicle accidents, although some authors have reported low-energy mechanisms as the cause in up to 75% of multiple ligament injured knees [22]. These generally are the result of sporting injuries although minor trauma, such as a fall from standing height, has been described, particularly in obese patients [23]. Combined cruciate and PLC injuries are usually caused by extreme hyperextension, severe varus stress, or forced external tibial rotation.

A high index of suspicion is necessary to diagnose these injuries in the acute setting, as the knee may have spontaneously reduced. Patients will describe an acute onset of knee pain, swelling, and gross deformity with the inability to bear weight due to instability and discomfort. Up to 41% of patients with cruciate and PLC injuries present with peroneal nerve injury, therefore a history of neurologic symptoms should be ascertained [24]. In the chronic setting, patients will often describe posterolateral knee pain and vague instability with the inability to participate in sporting activities.

The physical exam of a patient with an acute multiligamentous knee injury should aim to identify limb-threatening conditions and then to diagnose the pattern of injury. Vascular injury has been reported in 20–40% of knee dislocations, and an amputation rate of 86% after 8 h of ischemia demonstrates the importance of early identification [25, 26]. One series of 63 patients demonstrated that revascularization of traumatic popliteal artery injuries within 6 h resulted in no amputations [27]. Serial neurovascular exams including ankle brachial indices (ABI) and compartment checks should be performed every 4 h for the first 48 h as they are highly sensitive and specific [28]. If suspicion of a vascular injury is high, a vascular imaging study, such as a computed tomography angiogram, and consultation with a vascular surgeon should be obtained emergently. The knee should also be examined for signs of open injury, which is associated with infection in 43% of cases and a 15% rate of amputation [29].

Combined cruciate and PLC injuries result in increased anterior and posterior tibial translation. These are tested with the anterior and posterior drawer tests and the Lachman test. External tibial rotation may be observed with the posterior drawer test, and a posterior sag sign may be present. The knee may fall into external rotation and recurvatum when held up by the great toe. Varus opening and external tibial rotation are best observed at 30° of flexion, but the associated PCL injury will also cause increased external tibial rotation at 90° of flexion. A reverse pivot shift is very sensitive for combined injuries, although this test may be positive in up to 35% of normal subjects [30]. It is positive when the posteriorly displaced lateral plateau reduces with extension of the flexed knee while applying a valgus stress and external tibial rotation. It is useful to examine both limbs for comparison. Patients with chronic injuries may demonstrate a varus thrust gait with knee hyperextension. The knee may be kept flexed through the stance phase of gait in an attempt to prevent hyperextension.

## 19.4 Imaging

Plain films 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 posteroproximal tibia may reflect PCL injuries. Avulsions off the fibular head or lateral epicondyle can be the result of LCL injury. A Segond fracture, resulting from avulsion of the anterolateral capsule off the tibia may also be apparent. These are all important to recognize in the acute setting as they should be primarily repaired. The plain films should also be used to assess bony varus malalignment, which may affect surgical management (Fig. 19.3).

Computed tomography scans of the knee are useful to further delineate bony anatomy. They are generally obtained to preoperatively plan the open reduction and internal fixation of distal femur and proximal tibia fractures. In the presence of a floating knee, surgeons must have a high index of suspicion for ligamentous instability, which is present in up to 53% of cases [31].

Various vascular imaging modalities are available including computed tomography angiograms (CTA), magnetic resonance angiograms (MRA), Doppler ultrasound, and conventional angiograms. Although most are extremely sensitive and specific, they need not be ordered for every patient with an acute multiligamentous knee injury. Patients with abnormal vascular exams, including serial ABI, warrant vascular imaging studies, unless the leg is frankly ischemic. In this setting, many vascular surgeons opt to revascularize the limb immediately and not delay surgery with imaging. There are several advantages of CTA over conventional angiography, which has rendered it the imaging modality of choice at our institution. There is less radiation, it is noninvasive, and a radiologist does not need to be present to administer the test. That said, the most appropriate vascular imaging modality is that which is most readily available given the resources at each institution [32].

Magnetic resonance imaging (MRI) is among the best modalities to visualize soft tissues about the knee, and one should be obtained, if possible, for all multiligament knee injuries. In addition to being critically important for the diagnosis of ligamentous injury, MRI may also reveal chondral defects, bone contusions, meniscal tears, and tendon avulsions [22].

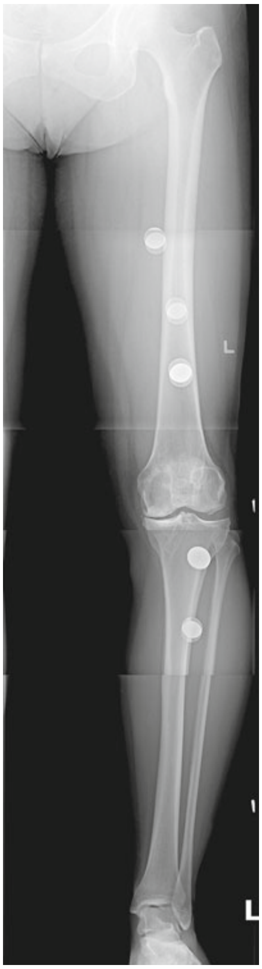

**Fig. 19.3** Three-foot standing X-ray of a failed ACL reconstruction from varus malalignment

Ideally, an MRI should be obtained prior to the insertion of hardware for fracture fixation as this may cause metal artifact. MRI-compatible external fixators with carbon fiber bars are available and should be used if an external fixator is indicated.

## 19.5 Initial Management

The initial management of a patient with an acute multiple ligament injured knee first includes identification of life-threatening injuries that may be associated with the musculoskeletal trauma. The appropriate advanced trauma life support care should be provided, followed by a secondary survey to identify other injuries.

Reduction of a dislocated knee is of paramount importance and should be undertaken early in the course of treatment, even before obtaining plain films of the knee. It should be immobilized in an extension brace and postreduction X-rays must be obtained. Indications for an external fixator are (1) the inability to maintain reduction in a brace, (2) vascular compromise requiring repair, and (3) an open dislocation to provide ease of wound care [8]. Open wounds should be addressed with early antibiotics, preliminary irrigation and debridement, tetanus toxoid if not up to date, and a sterile dressing. If an external fixator is applied across the knee, care must be taken to keep the pin sites remote from the definitive surgical incisions as to minimize the risk of infection.

Vascular integrity of the limb is assessed with a thorough physical exam as previously described including compartment checks and serial ABIs every 4 h for the first 48 h. If the limb is perfused, but the ABI is <0.9, an urgent CTA and a vascular surgery consult are obtained. If the limb is frankly ischemic, the patient is brought immediately to the operating room for preliminary stabilization with an external fixator and emergent revascularization. Whether the external fixator is applied before or after the limb is revascularized is a topic of debate, and therefore communication with the vascular surgeon is of utmost importance to determine the timing of each intervention. Fasciotomies are frequently performed following revascularization to prophylax against postoperative compartment syndrome.

There is no consensus in the literature regarding venous thromboembolism prophylaxis, but the rate of DVT has been reported as 3.5% for knee dislocations [33]. The American College of Chest Physicians has recommended DVT prophylaxis for patients with orthopedic trauma proximal to the knee or those who have sustained polytrauma [34]. A balance of the risks and benefits of anticoagulation must be made, but we choose to chemoprophylax our patients with low molecular weight heparin unless a contraindication exists. With prophylaxis, the surgeon must be vigilant to monitor for hematoma formation and for the development of a compartment syndrome.

## 19.6 Surgical Considerations

Historically, the treatment of the multiple ligament injured knee has been that of “watchful neglect” [8]. However, within the past 25 years, surgical techniques, rehabilitation protocols, and our understanding of knee biomechanics have improved, making surgical management the mainstay of treatment.

Four recent studies including one meta-analysis have compared operative versus nonoperative treatment of multiple ligament injured knees [35–38]. They reported higher International Knee Documentation Committee scores, improved Lysholm scores, and higher Tegner scores in those treated operatively. Patients who received surgery were more likely to return to work and return to sport, but there was no difference in range of motion between groups.

### *19.6.1 Timing of Surgery*

Although it is clear that surgical intervention is generally warranted, what has not been well established is the ideal timing of surgery, which remains one of the most controversial topics in this field. “Early” surgery usually refers to operative intervention within 3 weeks of injury and “delayed” surgery is anything beyond 3 weeks. The rationale for performing early surgery is that primary repair of damaged structures is possible and the tissue planes may still be discernible due to the lack of scar tissue formation [7]. Proponents of late surgery feel that early surgery results in unacceptable rates of arthrofibrosus, which has been shown in early isolated ACL reconstruction [39–41]. In addition, there is a theoretic risk of causing an iatrogenic compartment syndrome from fluid escaping the joint through an acutely torn capsule during early arthroscopy, although this risk diminishes after 2 weeks post-injury.

**Fig. 19.4** Opening wedge high tibial osteotomy

Five studies have compared early versus delayed surgery, and they report higher Lysholm scores and higher sports activity scores on the Knee Outcome Survey in the early treatment groups [42–46]. Although there was no difference between groups in most other parameters, including final knee range of motion, this has led many authors to suggest early surgical treatment within 3 weeks of injury [7].

### *19.6.2 Associated Fractures*

A significant number of patients with multiligament injured knees present with fractures involving the tibial plateau, distal femur, tibia, or fibula [47]. 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 a later date. The hardware often must be removed once the fractures are healed in order to allow for appropriate tunnel placement.

### *19.6.3 Bony Varus Malalignment*

Patients presenting with chronic PLC injuries should be assessed for bony varus malalignment. This may be congenital or the result of a medial tibial plateau fracture. Varus of more than 3° increases the stress on lateral-sided grafts and should be addressed prior to considering ligamentous reconstruction. Unaddressed bony varus has been shown to result in higher rates of PLC failure following surgery [48]. We recommend treating varus malalignment of greater than 3° with a medial opening wedge high tibial osteotomy and allowing it to heal prior to ligamentous reconstruction (Fig. 19.4). Some patients, particularly those with low demands, may be satisfied following osteotomy and may not require ligament reconstruction.

### *19.6.4 Repair Versus Reconstruction*

Historically, the definitive surgical management of multiligament injured knees was to repair damaged tissue. However, recent work by Stannard has demonstrated that acute repair of the lateral structures produces significantly higher rates of PLC failure when compared to reconstruction using a modified "two-tailed" technique [12]. Critics of this study highlight that the patients were subjected to an early aggressive rehabilitation protocol, which may have put more stress on the repairs. However, most authors now agree that acute reconstruction is superior to repair [5, 6, 8].

### *19.6.5 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 nonanatomic procedures based on how accurately they recreate the normal anatomy of the PLC. In a series evaluating reasons for PLC surgery failure, Noyes described anatomical reconstructions as those where "a graft was placed in anatomical ligament attachment sites with secure internal fixation" [48]. Capsular advancements, suture repairs, extra-articular iliotibial band augmentations, and biceps tendon rerouting methods were therefore considered "nonanatomical" and resulted in higher rates of failure. The anatomical reconstructions recreate the LCL, the popliteus, the PFL, or a combination of these structures. Fibular-based techniques have been described to recreate the LCL and in part, the PFL. These involve a graft that runs through a fibular tunnel and attaches to the femur at the isometric point. Another option is to affix one end of the graft to the anatomic femoral attachment of the LCL and the other at the popliteus insertion site. Other reconstructions attempt to recreate the PLC even more anatomically by adding a tibial tunnel. The heterogeneity of the injuries and the differences in patient characteristics and rehabilitation protocols render comparative studies of surgical techniques very challenging. However, many authors are of the opinion that more anatomic reconstructions may produce superior results [5]. Stannard and Laprade have described two popular reconstruction techniques that we use in our department and are discussed in detail in the Author's Preferred Technique section.[49, 50].

Another area of controversy is the timing of ACL reconstruction. The rates of arthrofibrosus and limited knee motion following early reconstruction of isolated ACL injuries have led some authors to delay the ACL reconstruction in the setting of multiple ligament injuries. They opt to first reconstruct the PLC and then reconstruct the ACL only if the patient complains of persistent instability. Once the patients have regained full range of motion and improved muscle strength, the ACL is reconstructed. However, there has been suggestion that cruciate ligament deficiency puts higher stresses on PLC grafts and may result in higher failure rates if not reconstructed at the same setting [48].

### *19.6.6 Graft Selection*

A variety of options exist when choosing graft material for multiple ligament reconstruction. The first consideration is whether to use the patient's own tissue as autograft or to use cadaveric allograft. When reconstructing the ACL in isolation, most surgeons opt to use hamstrings or bone-patellar-tendon-bone autograft. However, the multiple ligament injured knee poses different challenges. In the acute setting, the 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 [42, 46, 51–53]. Allograft tissue also allows for choice of graft size. However, with any transplanted tissue comes a small risk of disease transmission and possibly a higher risk of graft failure as reported in the ACL literature [54–56].

Synthetic grafts have fallen in and out of favor over time. Originally they were associated with high rates of synovitis, infection, and lack of incorporation. However, more recent work using synthetic grafts for ACL reconstruction has been promising, but more work is required before synthetic grafts will play a large role in multiligament reconstruction [57–60].

Most surgeons now use allograft tissues for multiligament reconstructions about the knee. We prefer an Achilles allograft with a calcaneal bone block for the PCL and a tibialis anterior allograft for the ACL reconstruction. Both are robust grafts that are readily available in a variety of sizes. The optimal graft for the lateral structures is dependent on the type of reconstruction performed, but we tend to use either a tibialis anterior allograft or an Achilles allograft with a calcaneal bone block, which we divide into a two-tailed graft.

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.

## 19.7 Author's Preferred Technique

Following an acute injury, the patient's knee is immobilized with either an extension splint or an external fixator if indicated. Definitive surgery is 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 minimizing problems with wound closure.

If an external fixator was initially applied, it is removed 1 week prior to definitive surgery, and irrigation and debridement of the pin sites is undertaken. This is usually 2 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, potentially reducing the risk of postoperative infection. Use of an external fixator is avoided whenever possible, unless indicated based on the criteria previously mentioned.

If surgery is delayed longer than 3 weeks, acute repair of damaged structures and suture fixation of avulsion fractures may no longer be possible. 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 arthrofibrosus [47, 61]. If at that point the patient complains of persistent pain or instability, a delayed reconstruction is offered.

Once in the operating room, the patient is placed supine and a careful examination under anesthesia is performed. This provides clinical corroboration to the MRI findings and helps plan the reconstruction. Preoperative antibiotics are given 30 min prior to tourniquet inflation [62]. If the patient had a vascular reconstruction, we do not use a tourniquet, as there is an increased risk of occluding the bypass graft. A low anterolateral arthroscopy portal and a high anteromedial arthroscopy portal with a sub-vastus medialis outflow portal are used to perform diagnostic arthroscopy of the knee. The ACL and PCL remnants are debrided, and meniscal tears are addressed with either debridement or repair if indicated. The PCL is reconstructed first, followed by the ACL, and finally the lateral structures.

### 19.7.1 PCL Reconstruction

Although many surgeons reconstruct isolated cruciate ligament injuries with a double bundle technique, we prefer single bundle cruciate reconstructions for multiple ligament injured knees. This is to reduce the theoretic risk of avascular necrosis and to diminish the risk of tunnel convergence and possible fracture through the tunnels, which has been reported in the literature [63].

We perform a single bundle, arthroscopically assisted, tibial tunnel PCL reconstruction with Achilles allograft. A posteromedial 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 regress from the knee and potentially reduces the risk of iatrogenic compartment syndrome. A shaver is inserted into the posteromedial portal, and 2–3 cm of posterior capsule is debrided from the proximal tibia. Release of the capsule is often necessary to reduce the knee if it is chronically subluxed, and this also allows for direct visualization of the tibial tunnel drilling. In the setting of a vascular reconstruction, this portal can be placed posterolaterally to avoid a medial bypass graft. It is placed directly posterior to the lateral femoral condyle and immediately anterior to the biceps femoris tendon with the knee in 90° of flexion in order to avoid the peroneal nerve.

The tibial drill guide is inserted through the anterolateral 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 posteromedial portal. Anteriorly, the guide is positioned slightly lateral to the tibial tubercle to decrease the “killer turn” of the graft. The guide pin is inserted through the guide and its exit posteriorly is visualized through the posteromedial portal while a curved curette is placed through the anteromedial 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. An alternative to this technique is to use a posteromedial safety incision and palpate the pin and drill as they perforate the tibia. Finally, intraoperative fluoroscopy may be used to confirm pin placement prior to drilling the 10–11-mm tibial tunnel. If repositioning of the pin is required, parallel guide pins may be useful.

Early literature vaguely described femoral tunnel placement as “the anatomic location of the PCL” [64, 65]. 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 [66]. 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 guide pin is inserted through the medial condyle midway between the medial epicondyle and the articular surface. Once appropriate pin position is confirmed, the 10–11-mm femoral tunnel is drilled. Care must be taken to drill anatomically placed tunnels, which may be difficult in a posteriorly subluxed knee. In multiligament reconstruction, we drill the PCL and ACL tunnels prior to passing any graft material in order to avoid inadvertently damaging the grafts.

### *19.7.2 ACL Reconstruction*

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 PCL. A low anteromedial accessory portal is made to drill the femoral tunnel. The guide pin is inserted through this portal and placed at the 10 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, 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. An alternative to this technique is to first drill the tibial tunnel and then use the transtibial tunnel technique to drill the femoral tunnel. We use XO 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. When passing the reamer through the knee, care must be taken to avoid damage to articular cartilage on the medial femoral.

The Howell tibial guide (Arthrotek, Warsaw, IN) is set at 65° and placed on the anteromedial subcutaneous border of the proximal tibia. This is usually 2 cm medial to the tibial tubercle. The guide is passed through the anteromedial 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 the PCL. The guide pin is then inserted through the tibia and is visualized from the anterolateral portal as it enters the knee. Fluoroscopy can be used to assess pin position prior to tibial tunnel drilling. The 8–9-mm tibial tunnel is then drilled with a curved curette used to protect the femoral articular cartilage.

The edges of all tunnels are smoothed with a rasp prior to passing graft material. The calcaneal bone plug on the Achilles allograft is trimmed to accommodate the femoral PCL tunnel. A looped-wire suture is passed through the tibial PCL tunnel into the joint. It is then passed out 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.

The loop and button are affixed to the 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.

### *19.7.3 Lateral Surgical Approach*

With the knee in 90° of flexion to allow the peroneal nerve to relax posteriorly, a curved skin incision is made. It begins midway between Gerdy's tubercle and the fibular head and extends proximally over the lateral epicondyle paralleling the posterior border of the iliotibial band. Subcutaneous dissection is taken through to the deep fascia which is carefully incised with 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 (Fig. 19.5).

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. Although most injuries are axonotmesis from traction, if transected, the ends should be tagged with suture for repair or nerve grafting by a plastic surgeon [24].

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.

### *19.7.4 Acute Lateral Reconstruction*

In the acute situation, we reconstruct the lateral side of the knee with the "two-tailed" technique described by Stannard using a tibialis anterior allograft [50]. Blunt dissection between the biceps femoris and the peroneal nerve is used to gain access to the posterior proximal tibia. A guide pin is inserted freehand anterior to posterior across the lateral side of the tibia. It parallels the articular surface of the tibia and runs 2 cm distal to the joint line. The entry point anteriorly should be proximal and lateral

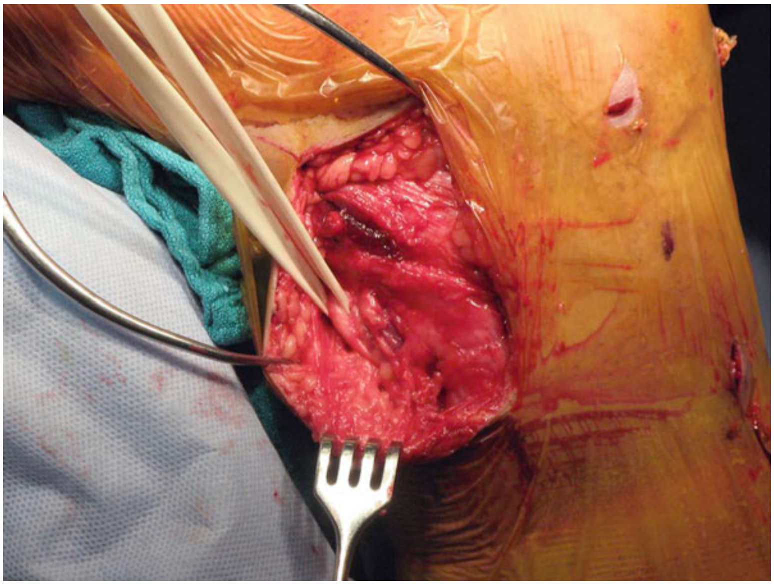

**Fig. 19.5** Intraoperative photograph of the lateral dissection of the knee. The peroneal nerve has been identified and tagged with a latex tube drain

to the tibial tunnel for the PCL. Since the width of proximal tibia is significantly narrower than the plateau at 2 cm distal to the joint line, care must be taken not to miss the bone when placing the tibial guide pin. The tibial tunnel is then drilled with a 5-mm reamer taking great caution not to plunge as the popliteal artery, vein, and tibial nerve lie directly posterior. A Cobb elevator is used to protect the neurovascular structures, and final perforation of the posterior cortex is undertaken by hand. Another 5-mm tunnel is then drilled through the head of fibula in an anterolateral to posteromedial direction.

The isometric point of the femur is identified just anterior to the intersection of the LCL and the popliteus tendon. A Steinman pin is inserted at this point. A suture is passed through the fibular tunnel and around the Steinmann pin followed by cycling of the knee through a range of motion. Consistent loading of the suture in flexion and extension confirms the isometric point of the femur, and the Steinman pin is adjusted if necessary. On X-ray, this is the junction of the posterior cortex line and Blumensaat's line. We recommend intraoperative fluoroscopy to verify accurate identification of the isometric point.

The tibialis anterior allograft is trimmed to accommodate the tunnels and is passed from posterior to anterior through the tibia. Tibial fixation is achieved with a 7-mm bioabsorbable interference screw. A screw and washer is inserted into the femoral tunnel but not tightened. The graft is passed from the posterior tibia up around the screw and washer on the femur from anterior to posterior. It is then passed distally toward the fibula where it wraps anteriorly around itself before passing from posterior to anterior through the fibular tunnel and back up to the anterior aspect of the screw and washer on the femur (Fig. 19.6). Final tensioning of the lateral graft does not take place until after the ACL and PCL grafts have been tensioned.

### *19.7.5 Chronic Lateral Reconstruction*

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. 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 [48]. Osteotomy alone may be particularly effective in low-demand patients.

For chronic symptomatic lateral-sided injuries requiring reconstruction, we use the technique described by LaPrade with an Achilles allograft [49, 67]. This is often described as the most anatomically accurate reconstruction (see Fig. 3.11).

Preparation of the tibial and fibular tunnels is the same as previously described for acute reconstructions using Stannard's technique, but the fibular tunnel is reamed to 7 mm and the tibial tunnel is reamed to 9 mm [50]. Two femoral tunnels are used in this technique. An eyelet-tipped guide pin is inserted at the femoral attachment site of the LCL and another at the femoral

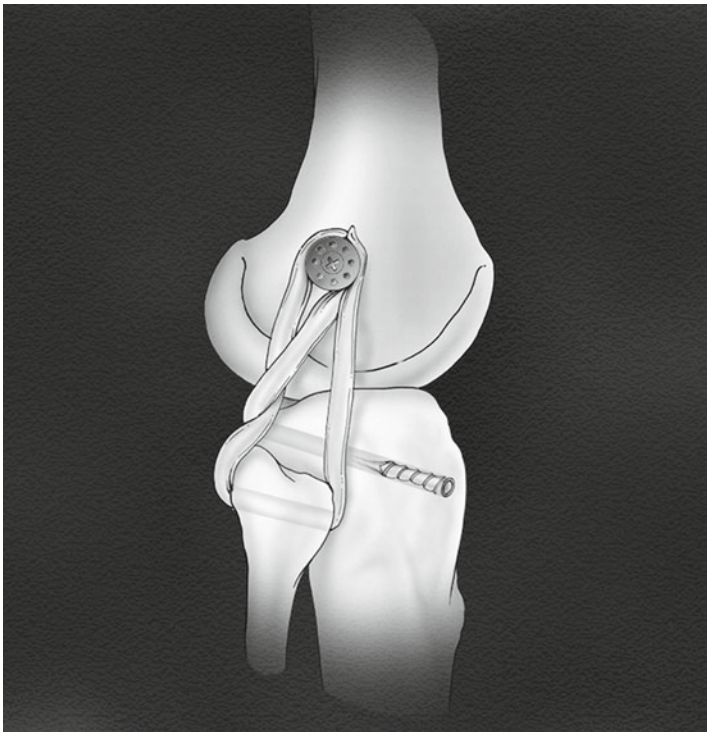

**Fig. 19.6** Stannard's modified two-tailed posterolateral reconstruction of the knee. From: Stannard JP, Brown SL, Farris RC, McGwin G, Jr., Volgas DA. The posterolateral corner of the knee: repair versus reconstruction. Am J Sports Med. 2005;33(6):881–8. Reprinted with permission from Sage Publications

insertion of the popliteus tendon. They are aimed in an anteromedial direction and passed through the femur and out the skin medially. A 9-mm reamer is used over the guide pins to drill the tunnels to a depth of 20 mm.

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 iliotibial band to 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.

### *19.7.6 Graft Tensioning*

The grafts are tensioned after all ligaments have been reconstructed. The ACL is tensioned first with the knee in full extension, and a bioabsorbable interference screw is used for tibial fixation. The PCL is tensioned next with the knee in 90° of flexion while manually translating the tibia anteriorly to create 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 a 35-mm bioabsorbable screw that is 1 mm oversized with respect to the tunnel. A screw and washer is used for supplementary fixation.

Once the ACL and PCL are tensioned, attention can be paid to the lateral reconstruction. If using Stannard's technique, the lateral-sided graft is tensioned with the knee in 30° of flexion with slight internal rotation of the tibia. Care should be taken not to overconstrain the graft with excessive internal rotation. The graft is affixed in the fibula and the tibia with bioabsorbable interference screws. If using 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. 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.

Once all grafts are tensioned and affixed appropriately, range of motion of the knee is tested to ensure the knee is not overconstrained. 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 iliotibial 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.

## 19.8 Postoperative Rehabilitation

Although many authors describe detailed rehabilitation protocols, there is a paucity of data supporting one over the other. Recurrent instability is one of the greatest concerns following reconstruction of the multiple ligament injured knee, which has resulted in conservative rehab protocols by most surgeons. However, this must be balanced with the risk of stiffness, which can be significantly disabling. Therefore, the principles of rehabilitating the knee are to allow early range of motion while protecting the reconstruction or repair [8].

Most surgeons fit their patients with a hinged knee brace postoperatively. However, a prospective study at the University of Alabama at Birmingham is comparing the results of a hinged knee brace to a hinged external fixator for knee dislocations. Preliminary data suggests that the rate of recurrent instability with the use of the hinged external fixator may be significantly lower [68].

We use a rehabilitation protocol similar to that described by Fanelli and Edson, which has demonstrated very good results [69, 70]. All patients are kept non-weight bearing for the first 6 weeks. Patients with acute injuries are encouraged to begin gentle prone range of motion exercises immediately. Those with chronic reconstructions are immobilized in extension for 3 weeks prior to beginning range of motion exercises with the brace unlocked. By the 7th week they begin progressive weight bearing in the brace. At 9 weeks, closed chain strengthening is initiated on the stationary bike. At 18 weeks postoperatively, open chain exercises are begun, and once the affected limb regains 70% of strength as compared to the unaffected limb, straight jogging and proprioceptive exercises are permitted. Return to sport does not generally take place until 10–12 months.

## 19.9 Summary

Multiple ligament injured knees involving the lateral side are particularly challenging problems 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 within 3 weeks of 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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# Chapter 20
# Surgical Treatment of Combined PCL-ACL Medial and Lateral Side Injuries (Global Laxity): Acute and Chronic

**Gregory C. Fanelli**

## 20.1 Introduction

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-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 [1–5]. 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 bicruciate 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 postreduction stability. Delayed or staged reconstruction of 2–3 weeks post injury has demonstrated a lower incidence of arthrofibrosis in our experience [6, 7].

Surgical timing in acute ACL-PCL-lateral side injuries is dependent upon the lateral side classification [8]. Arthroscopic combined ACL-PCL reconstruction with lateral side repair and reconstruction with allograft tissue is performed within 2–3 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 3–6 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 4–6 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

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allograft tissue is performed within the first 2 weeks after injury, followed by arthroscopic combined ACL-PCL reconstruction 3–6 weeks later [6, 7, 9–12].

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 timing modifiers include the injured extremity vascular status, open wounds, reduction stability, skin conditions, multiple system injuries, other orthopaedic injuries, and meniscus and articular surface injuries [9, 10]. 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 bicruciate multiple ligament knee injuries often present to the orthopaedic surgeon with functional instability and, possibly, some degree of posttraumatic 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, 5, 13–19].

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 [5]. 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, to confirm the accuracy of the PCL tibial tunnel, and to facilitate the flow of the surgical procedure.

**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 curved over-the-top PCL instruments (Biomet Sports Medicine, Warsaw, IN) 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, IN) 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

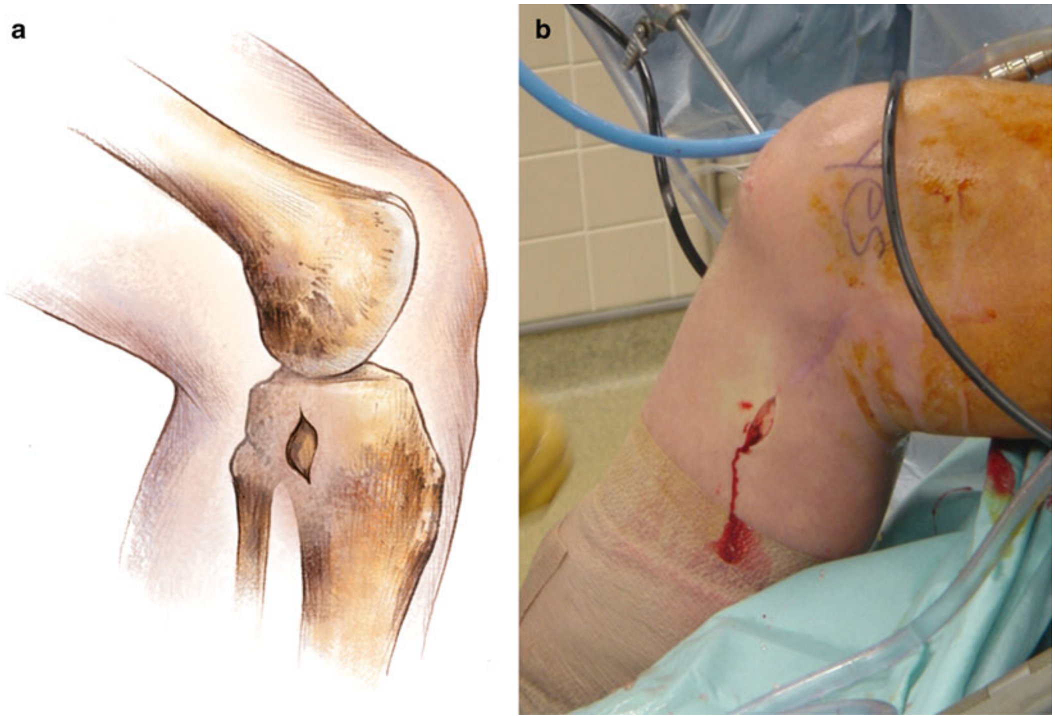


**Fig. 20.2** (**a**) Extracapsular extra-articular posteromedial safety incision. From Fanelli GC. Rationale and surgical technique for PCL and multiple knee ligament reconstruction. Second Edition. Biomet Sports Medicine, Warsaw, IN, 2008. Reprinted with permission. (**b**) Intraoperative photograph of the posteromedial safety incision

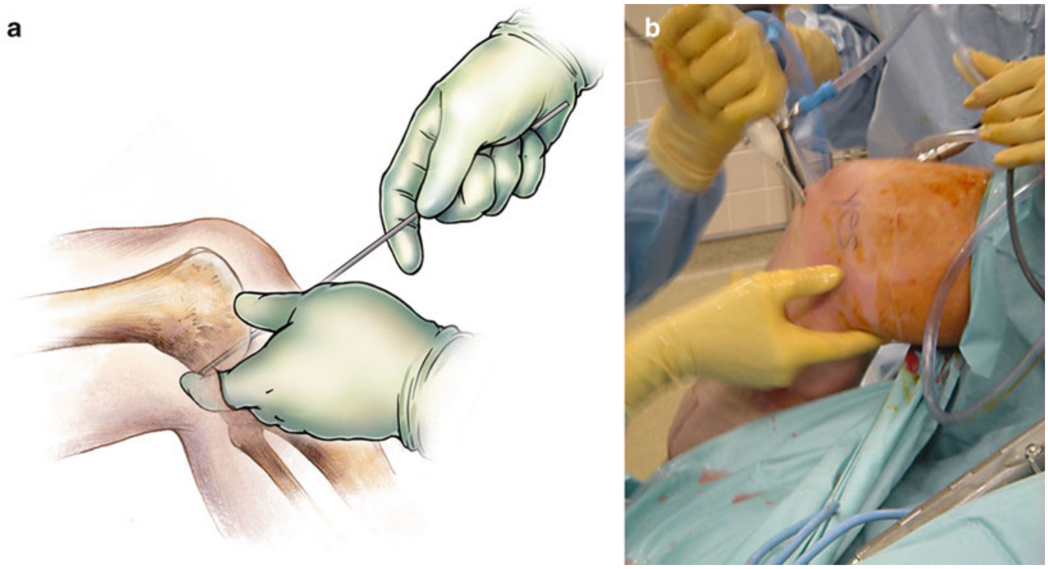


**Fig. 20.3** (**a**) The surgeon is able to palpate the posterior aspect of the tibia through the extracapsular extra-articular posteromedial safety incision. This enables the surgeon to accurately position guide wires, to create the tibial tunnel, and to protect the neurovascular structures. From Fanelli GC. Rationale and surgical technique for PCL and multiple knee ligament reconstruction. Second Edition. Biomet Sports Medicine, Warsaw, IN, 2008. Reprinted with permission. (**b**) Intraoperative photograph of posterior instrumentation with the surgeon's finger in the posteromedial safety incision

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 the tibia (Fig. 20.6). The tip of the guide, in the

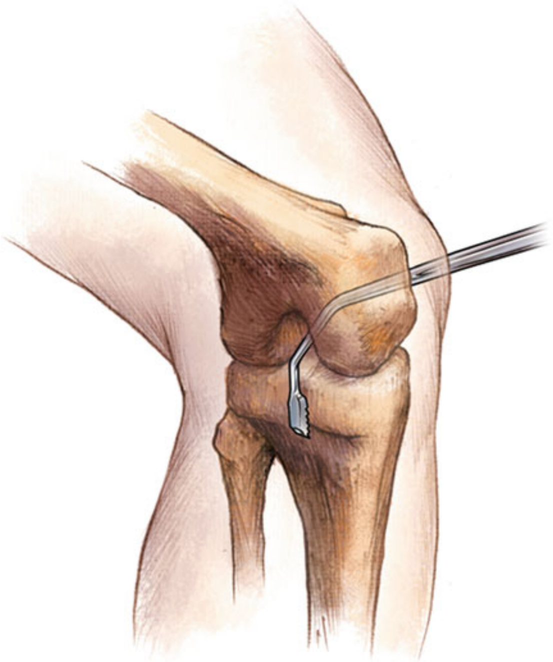


**Fig. 20.4** Posterior capsular elevation. From Fanelli GC. Rationale and surgical technique for PCL and multiple knee ligament reconstruction. Second Edition. Biomet Sports Medicine, Warsaw, IN, 2008. Reprinted with permission

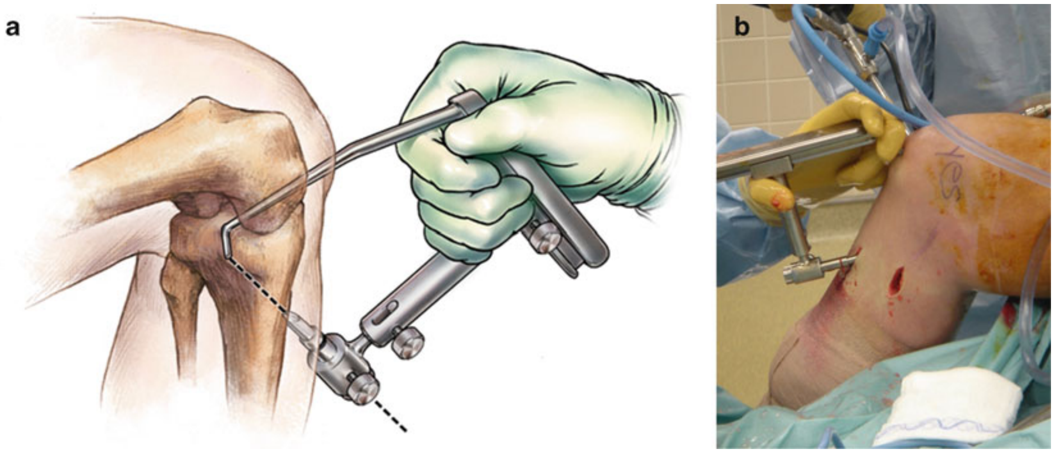


**Fig. 20.5** (**a**) PCL-ACL drill guide positioned to place guide wire in preparation for creation of the transtibial PCL tibial tunnel. From Fanelli GC. Rationale and surgical technique for PCL and multiple knee ligament reconstruction. Second Edition. Biomet Sports Medicine, Warsaw, IN, 2008. Reprinted with permission. (**b**) Intraoperative photograph of the drill guide positioned to create the PCL tibial tunnel

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 posteromedial 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 (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, IN). The appropriately sized double-bundle aimer or endoscopic reamer is inserted through a low anterolateral patellar arthroscopic portal to create the posterior cruciate ligament anterolateral bundle femoral tunnel. The double-bundle aimer or endoscopic reamer is positioned directly

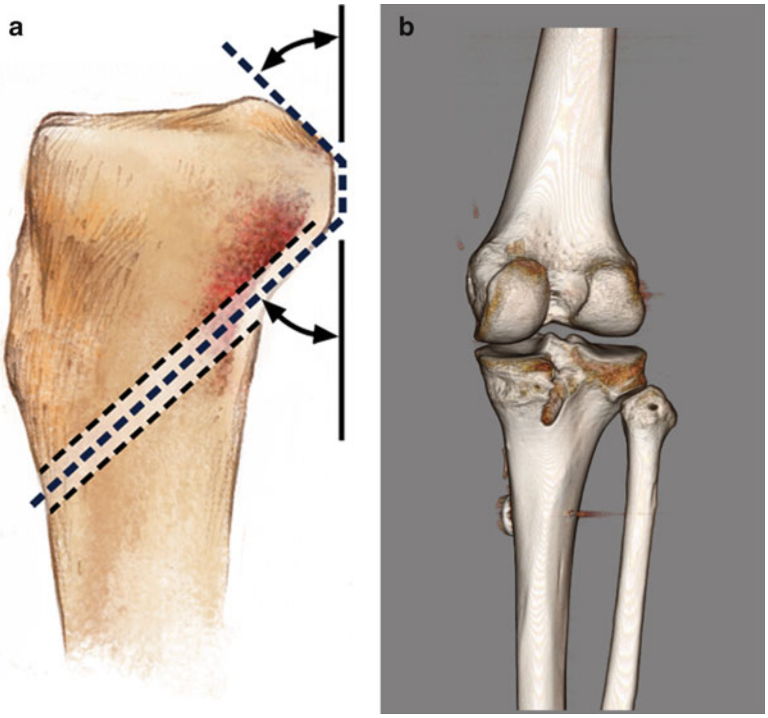


**Fig. 20.6** (**a**) Drawing demonstrating the desired turning angles the PCL graft will make after the creation of the tibial tunnel. From Fanelli GC. Rationale and surgical technique for PCL and multiple knee ligament reconstruction. Second Edition. Biomet Sports Medicine, Warsaw, IN, 2008. Reprinted with permission. (**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

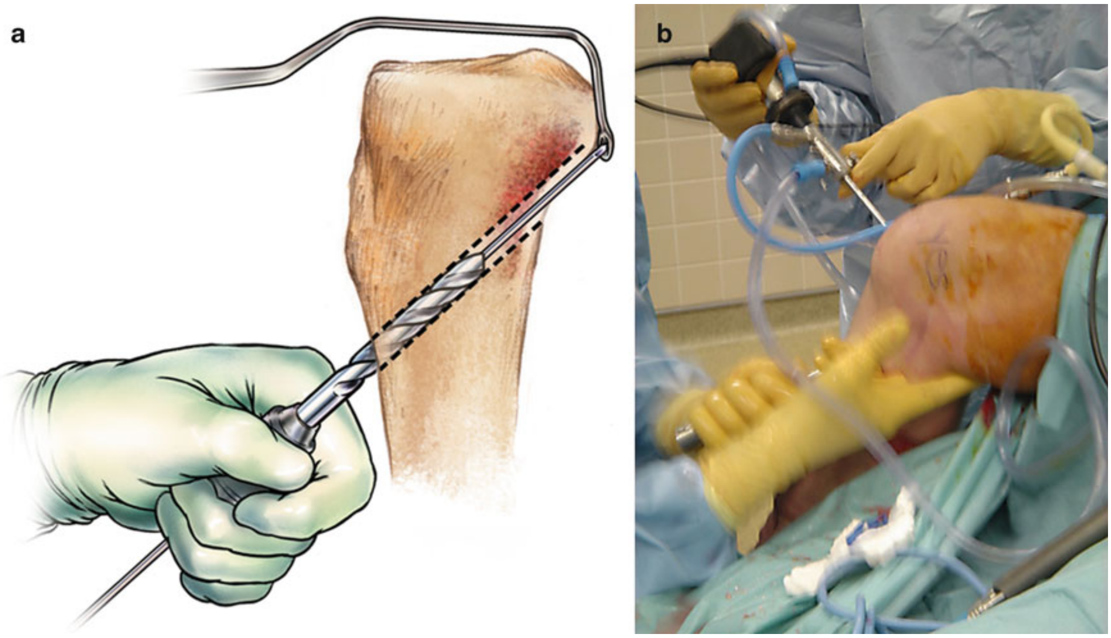


**Fig. 20.7** (**a**) Final PCL tibial tunnel reaming by hand for an additional margin of safety. From Fanelli GC. Rationale and surgical technique for PCL and multiple knee ligament reconstruction. Second Edition. Biomet Sports Medicine, Warsaw, IN, 2008. Reprinted with permission. (**b**) Intraoperative photograph of hand finishing of the PCL tibial tunnel

on the footprint of the femoral anterolateral bundle posterior cruciate ligament insertion site (Fig. 20.8). 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 anterolateral posterior cruciate ligament femoral tunnel from inside to outside (Fig. 20.9). When the surgeon chooses to perform a double-bundle double-femoral tunnel PCL reconstruction, the same process is repeated for the

**Fig. 20.8** Double-bundle aimer positioned to drill a guide wire for creation of the PCL anterolateral bundle tunnel. From Fanelli GC. Rationale and surgical technique for PCL and multiple knee ligament reconstruction. Second Edition. Biomet Sports Medicine, Warsaw, IN, 2008. Reprinted with permission

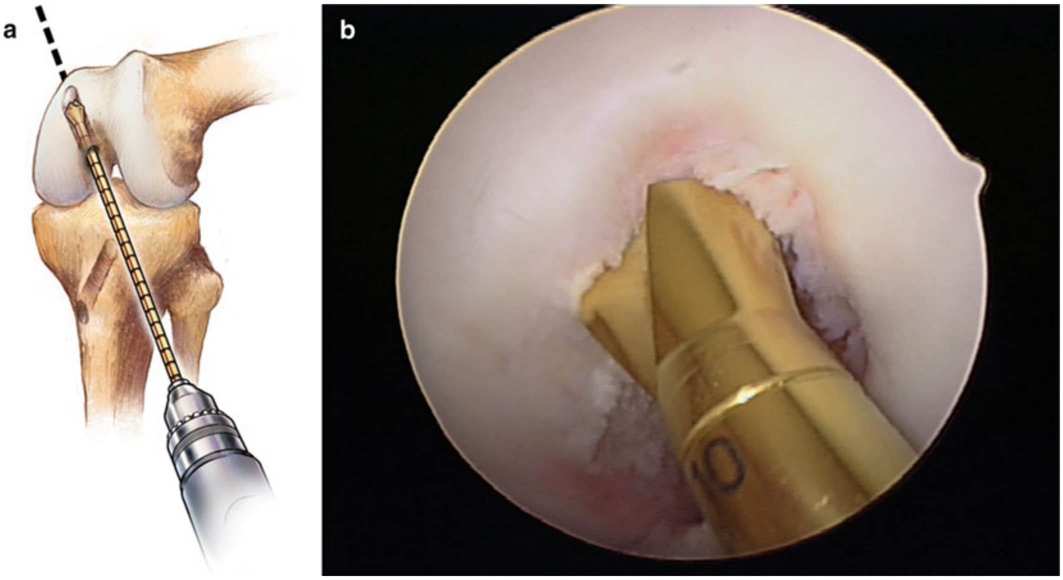


**Fig. 20.9** (**a**) Endoscopic acorn reamer is used to create the PCL anterolateral bundle femoral tunnel through the low anterolateral patellar portal. From Fanelli GC. Rationale and surgical technique for PCL and multiple knee ligament reconstruction. Second Edition. Biomet Sports Medicine, Warsaw, IN, 2008. Reprinted with permission. (**b**) Intraoperative view of an endoscopic acorn reamer is positioned to create the PCL anterolateral bundle femoral tunnel

posteromedial 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

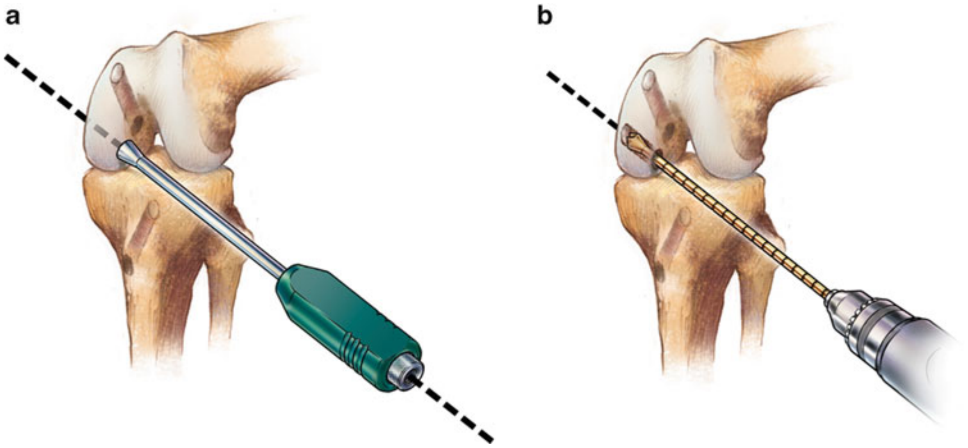


**Fig. 20.10** (**a**) Double-bundle aimer positioned to drill a guide wire for creation of the PCL posteromedial bundle femoral tunnel through the low anterolateral patellar portal. (**b**) Endoscopic acorn reamer is used to create the PCL posteromedial bundle femoral tunnel. A 5-mm bone bridge is maintained between tunnels. From Fanelli GC. Rationale and surgical technique for PCL and multiple knee ligament reconstruction. Second Edition. Biomet Sports Medicine, Warsaw, IN, 2008. Reprinted with permission

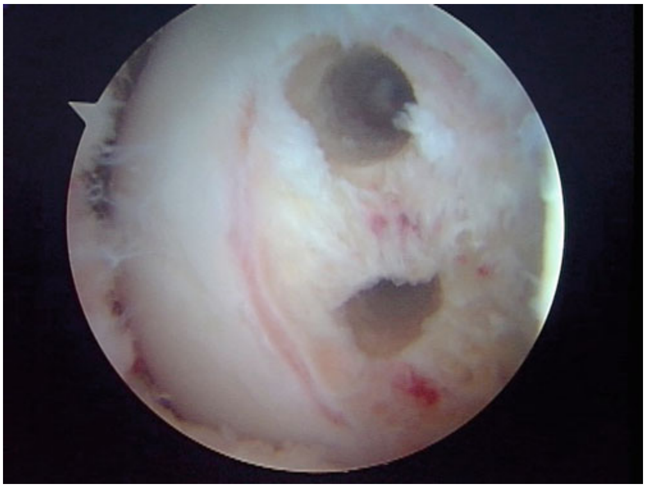


**Fig. 20.11** Completed PCL anterolateral and posteromedial bundle tunnels fill the anatomic footprint of the posterior cruciate ligament. Five-millimeter bone bridge is maintained between the tunnels

or endoscopic reamer on the anatomic foot print of the anterolateral or posteromedial posterior cruciate ligament insertion site under direct visualization (Fig. 20.13).

A Magellan suture retriever (Biomet Sports Medicine, Warsaw, IN) 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 backup 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 [20]. 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, IN) (Fig. 20.15). 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. 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 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 backup 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 anteromedial proximal tibia externally at a point midway between the posteromedial border of the tibia and the

**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

**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 anterolateral or posteromedial posterior cruciate ligament insertion site under direct visualization

anterior tibial crest just above the level of the tibial tubercle. A 1-cm 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

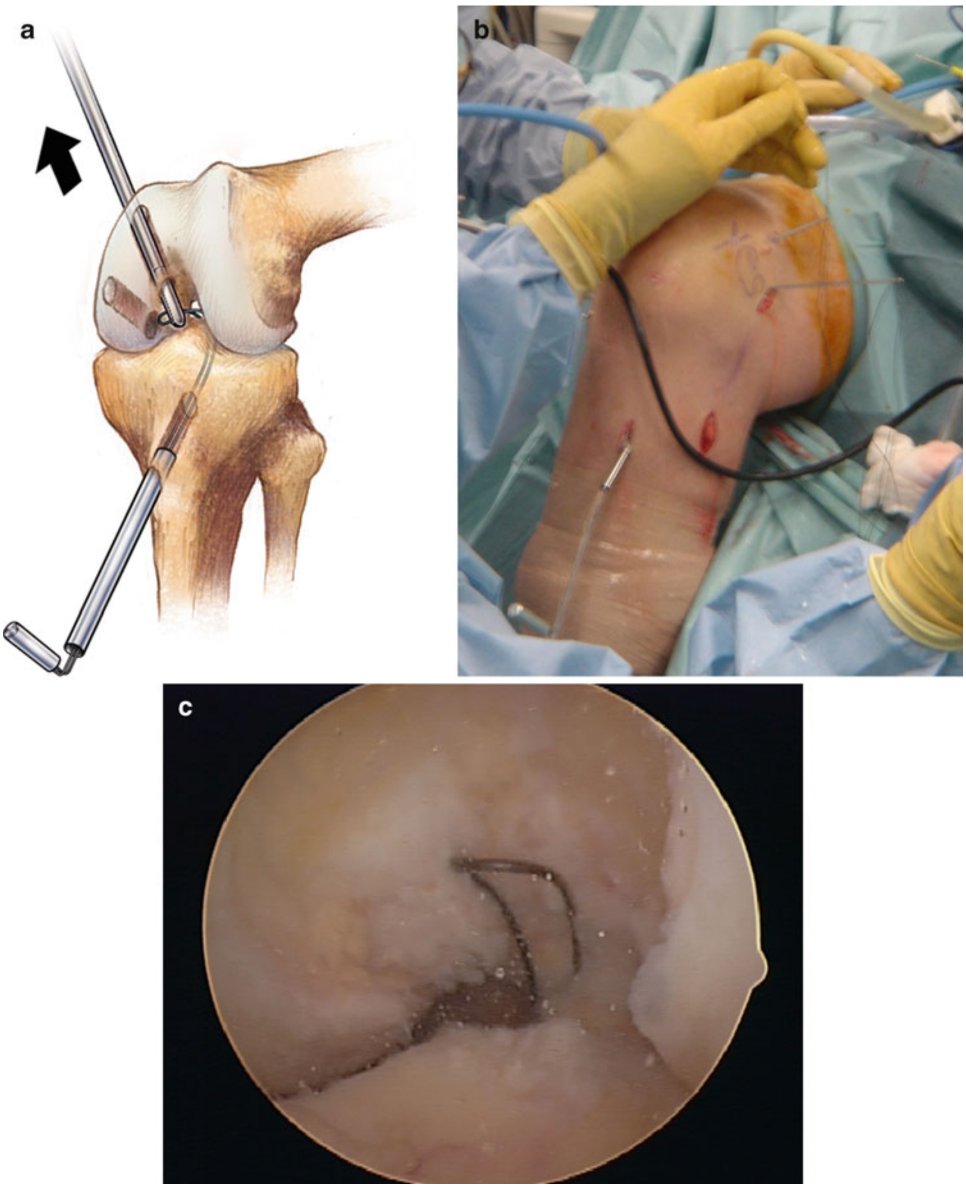


**Fig. 20.14** (**a**) Magellan suture passing device. From Fanelli GC. Rationale and surgical technique for PCL and multiple knee ligament reconstruction. Second Edition. Biomet Sports Medicine, Warsaw, IN, 2008. Reprinted with permission. (**b** and **c**) Intraoperative external and arthroscopic views demonstrating the positioning of the Magellan suture and graft passing device

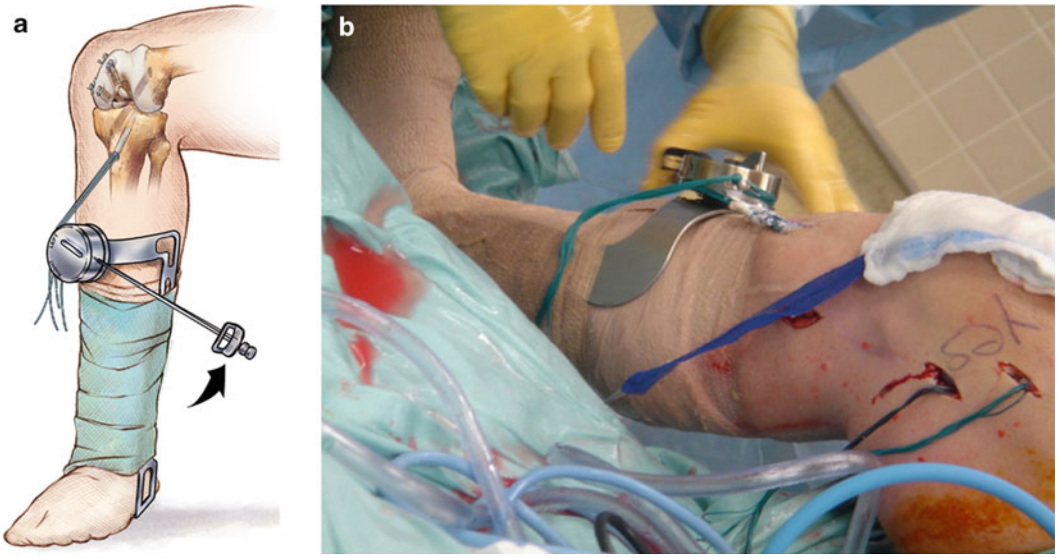


**Fig. 20.15** (**a**) Knee ligament graft-tensioning boot is used to tension the PCL graft. This mechanical tensioning device uses a ratcheted torque wrench device to assist the surgeon during graft tensioning. From Fanelli GC. Rationale and surgical technique for PCL and multiple knee ligament reconstruction. Second Edition. Biomet Sports Medicine, Warsaw, IN, 2008. Reprinted with permission. (**b**) Intraoperative photograph of Biomet tensioning boot applied to the tibia to tension the PCL reconstruction graft

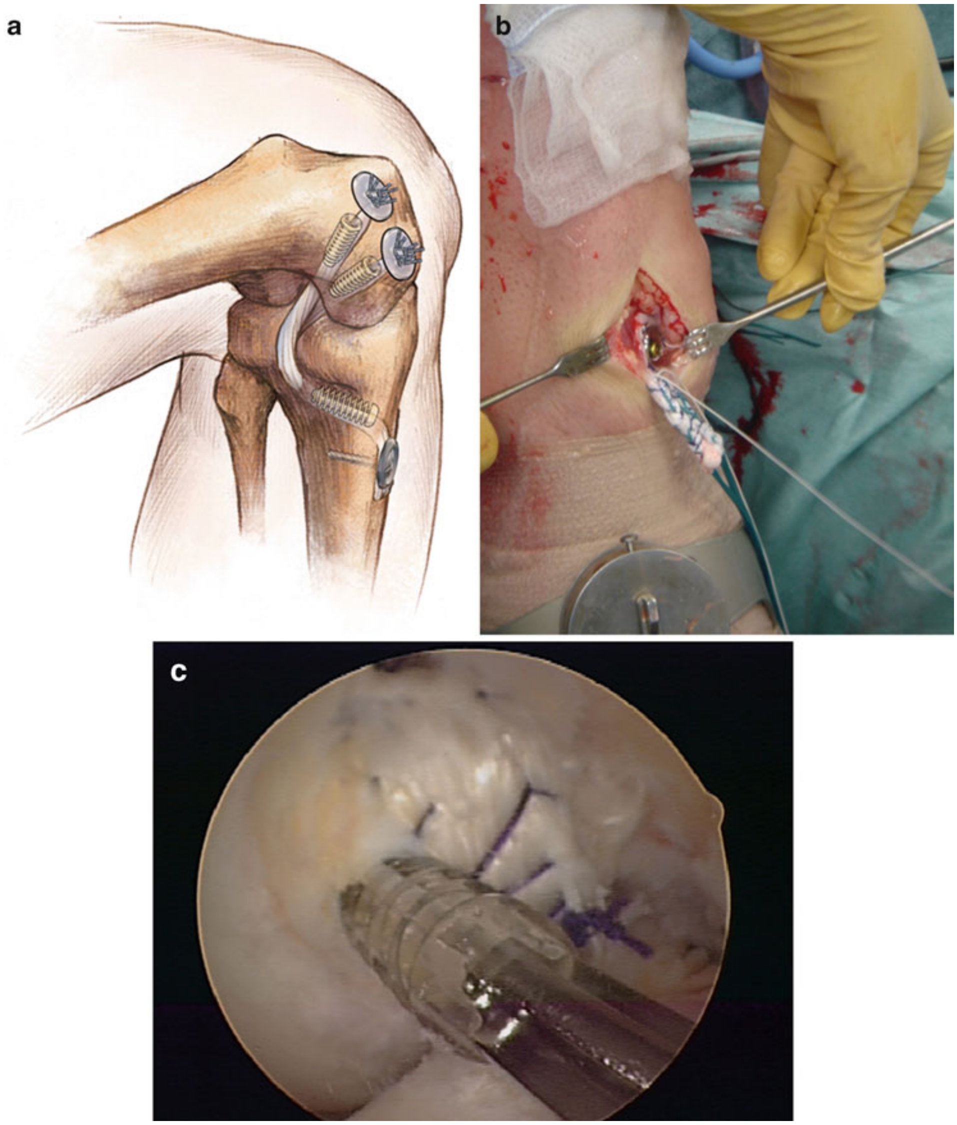


**Fig. 20.16** (**a**) PCL final graft fixation using primary and backup fixation. From Fanelli GC. Rationale and surgical technique for PCL and multiple knee ligament reconstruction. Second Edition. Biomet Sports Medicine, Warsaw, IN, 2008. Reprinted with permission. (**b**) PCL final tibial fixation. (**c**) Interference fit fixation of PCL graft in femoral tunnel

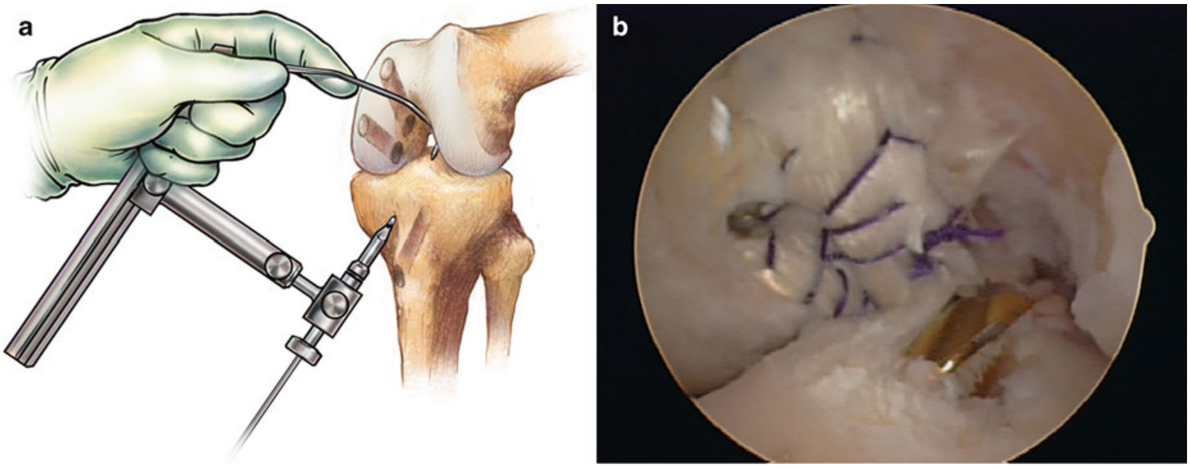


**Fig. 20.17** (**a**) The PCL-ACL drill guide is positioned to create ACL tibial tunnel. From Fanelli GC. Rationale and surgical technique for PCL and multiple knee ligament reconstruction. Second Edition. Biomet Sports Medicine, Warsaw, IN, 2008. Reprinted with permission. (**b**) ACL tibial tunnel orientation and position to approximate the tibial and femoral anatomic insertion sites of the anterior cruciate ligament

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 backup 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 [20] (Biomet Sports Medicine, Warsaw, IN). Traction is placed on the anterior cruciate ligament graft sutures with the knee in 0° 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 30° of flexion, and fixation is achieved on the tibial side of the anterior cruciate ligament graft with a bioabsorbable interference screw and backup fixation with a polyethylene ligament fixation button (Fig. 20.19).

## 20.5 Lateral Posterolateral Reconstruction

My most commonly utilized surgical technique for posterolateral reconstruction is the free graft figure-of-eight technique utilizing semitendinosus 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 corner. When there is a disrupted proximal tibiofibular joint, or severe hyperextension external rotation recurvatum deformity, a two-tailed (fibular head, proximal tibia) posterolateral 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 with 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 semitendinosus 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 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 abovementioned 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. 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 abovementioned 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) posterolateral reconstruction is utilized combined with a posterolateral capsular shift. A 7- or 8-mm 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 nonabsorbable sutures

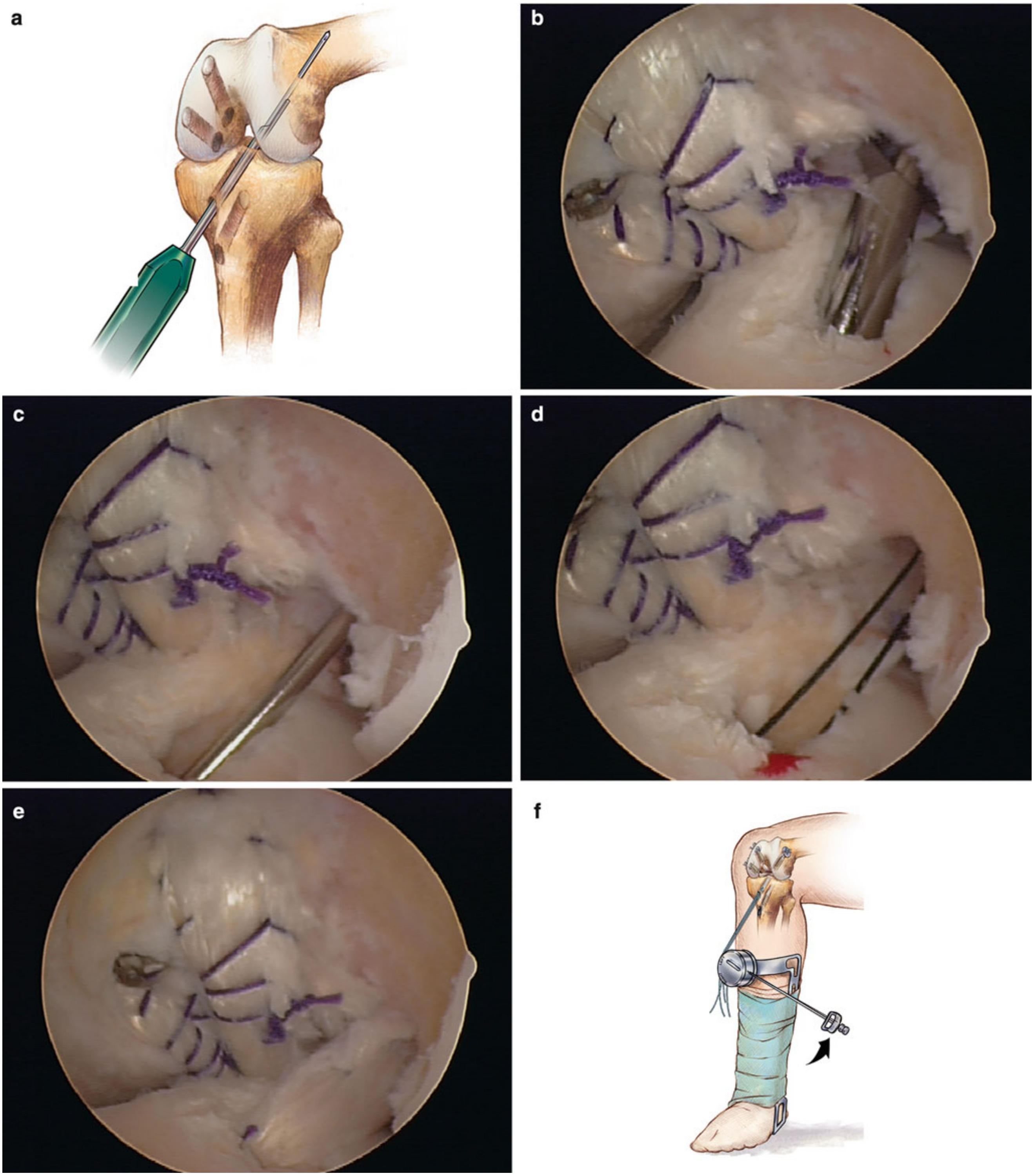


**Fig. 20.18** (**a**) Transtibial ACL femoral tunnel is created with the help of an over-the-top femoral aimer to approximate the ACL femoral insertion site. From Fanelli GC. Rationale and surgical technique for PCL and multiple knee ligament reconstruction. Second Edition. Biomet Sports Medicine, Warsaw, IN, 2008. Reprinted with permission. (**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 position. (**f**) Final tensioning of the ACL graft using the Biomet graft-tensioning graft. From Fanelli GC. Rationale and surgical technique for PCL and multiple knee ligament reconstruction. Second Edition. Biomet Sports Medicine, Warsaw, IN, 2008. Reprinted with permission

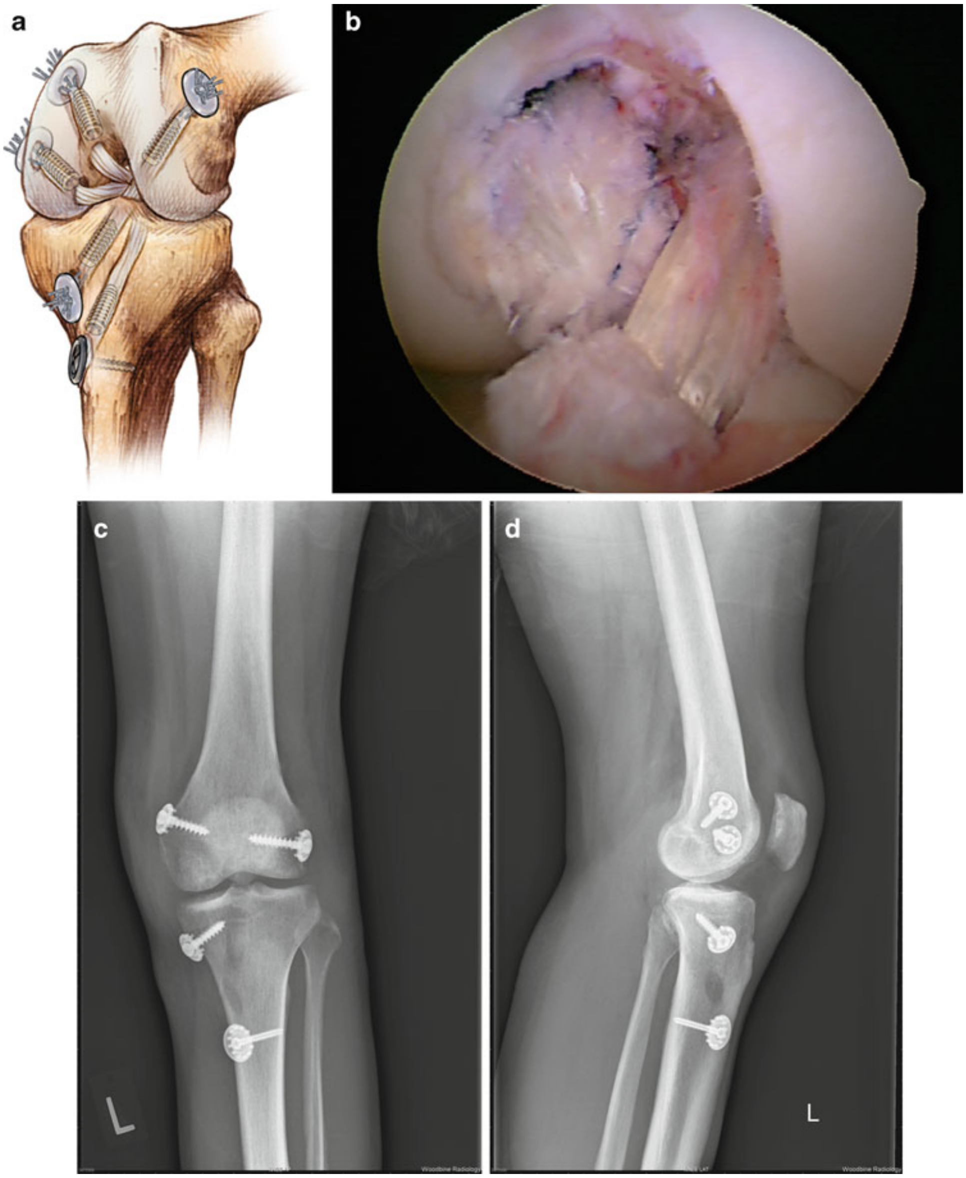


**Fig. 20.19** (**a**) Drawing of final fixation of PCL and ACL grafts. Note primary and backup fixation of each graft. From Fanelli GC. Rationale and surgical technique for PCL and multiple knee ligament reconstruction. Second Edition. Biomet Sports Medicine, Warsaw, IN, 2008. Reprinted with permission. (**b**) Arthroscopic view of completed PCL-ACL reconstruction. (**c, d**) Postoperative anteroposterior and lateral radiographs of completed combined PCL, ACL, lateral, and medial side reconstructions

at the popliteus tendon anatomic femoral insertion site. The knee is cycled through multiple sets of full flexion and extension cycles, placed in 90° 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. 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 is positioned on the extended operating room table in a supported flexed knee position, and 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,

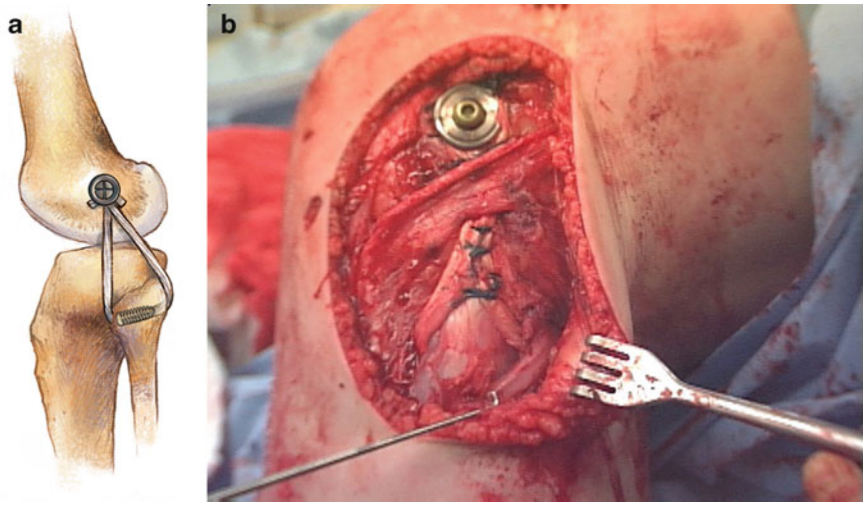
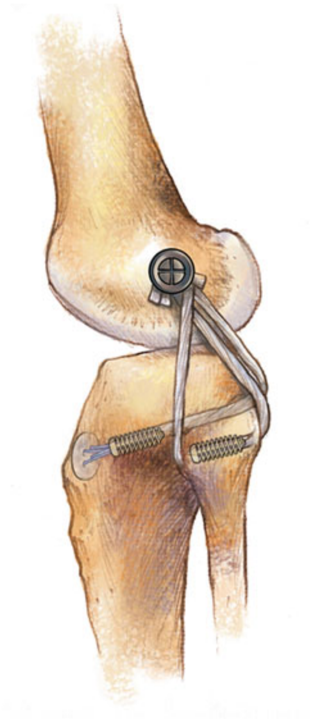


**Fig. 20.20** (**a**) Posterolateral reconstruction using fibular head-based figure-of-eight allograft tissue. From Fanelli GC. Rationale and surgical technique for PCL and multiple knee ligament reconstruction. Second Edition. Biomet Sports Medicine, Warsaw, IN, 2008. Reprinted with permission. (**b**) 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. Rationale and surgical technique for PCL and multiple knee ligament reconstruction. Second Edition. Biomet Sports Medicine, Warsaw, IN, 2008. Reprinted with permission



screws, and washers and with 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 posteromedial 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

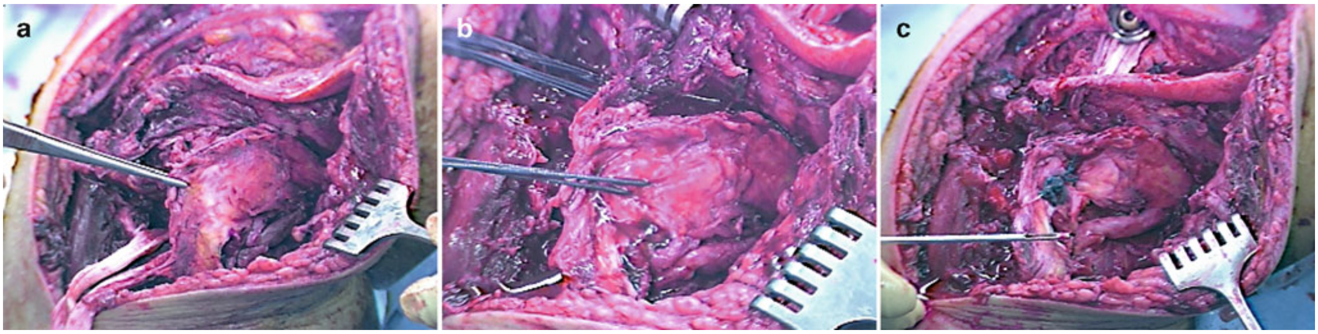


**Fig. 20.22** (**a**) Acute severe lateral side injury. (**b**) Lateral posterolateral primary repair with a combination of suture anchors and transosseous sutures. (**c**) Augmentation of acute lateral posterolateral primary repair with fibular head-based figure-of-eight allograft semitendinosus lateral posterolateral reconstruction. Probe is pointing to peroneal nerve neurolysis, a very important part of the procedure

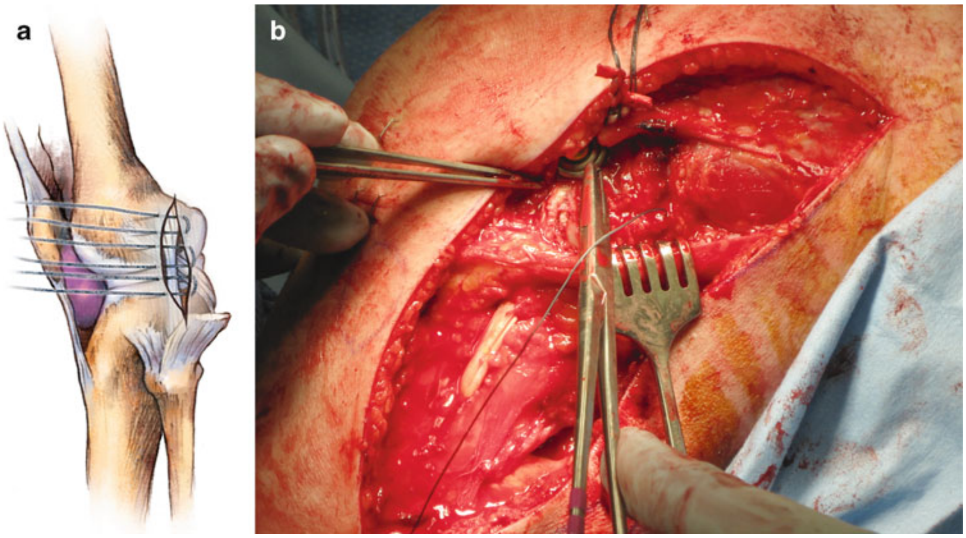


**Fig. 20.23** (**a**) Posterolateral capsular shift is used to decrease redundant posterolateral capsular volume in combination with posterolateral allograft reconstruction. From Fanelli GC. Rationale and surgical technique for PCL and multiple knee ligament reconstruction. Second Edition. Biomet Sports Medicine, Warsaw, IN, 2008. Reprinted with permission. (**b**) Intraoperative photograph of posterolateral shift using number two Ethibond suture material

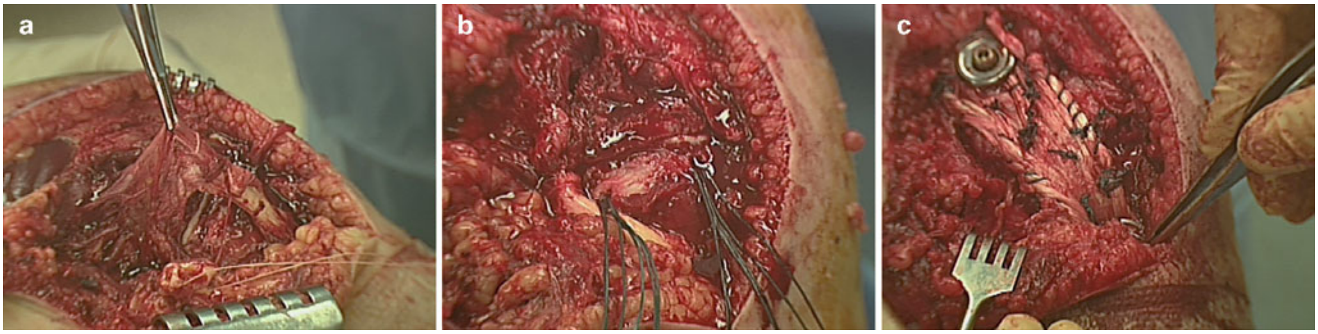


**Fig. 20.24** (**a**) Acute severe medial side injury. (**b**) Medial posteromedial primary repair with a combination of suture anchors and transosseous sutures. (**c**) Augmentation of acute medial posteromedial primary repair with allograft medial posteromedial reconstruction

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 sutures.

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 (Fig. 20.26). This graft material is attached at the anatomic insertion sites of the superficial medial collateral ligament on the

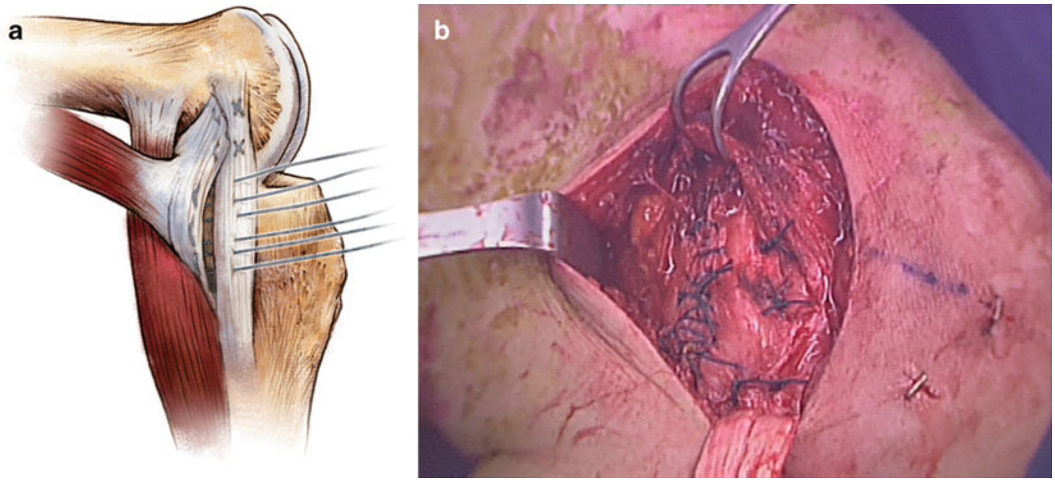


**Fig. 20.25** (**a**) Posteromedial capsular shift utilized in medial posteromedial reconstruction. From Fanelli GC. Rationale and surgical technique for PCL and multiple knee ligament reconstruction. Second Edition. Biomet Sports Medicine, Warsaw, IN, 2008. Reprinted with permission. (**b**) Intraoperative photograph of posteromedial capsular shift procedure using number two Ethibond

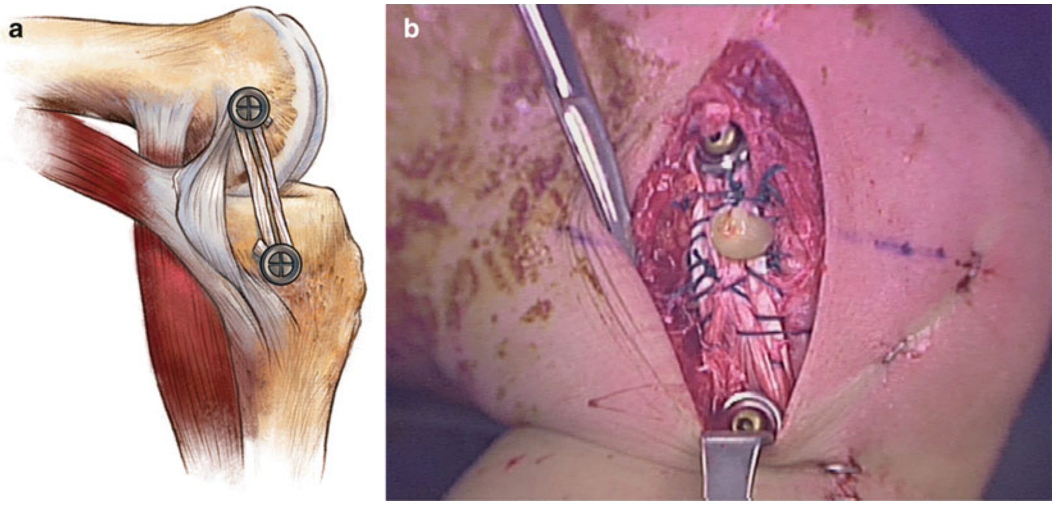


**Fig. 20.26** (**a**) Allograft medial side reconstruction is used in combination with posteromedial capsular shift procedures for severe medial posteromedial instability. From Fanelli GC. Rationale and surgical technique for PCL and multiple knee ligament reconstruction. Second Edition. Biomet Sports Medicine, Warsaw, IN, 2008. Reprinted with permission. (**b**) Allograft reconstruction of superficial medial collateral ligament. This reconstruction combined with the posteromedial capsular shift procedure controls valgus and axial rotation instability

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, IN). This reduces the tibia on the femur in full extension and restores the anatomic tibial step-off. The knee is cycled through a full range of motion multiple times to allow pretensioning 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, IN) 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 pretensioning 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 backup fixation. During cruciate ligament reconstruction, primary aperture fixation is achieved with bioabsorbable interference screws, and backup 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 backup fixation is achieved with multiple number two Ethibond reinforcing sutures. Mechanical tensioning of the cruciates at 0° of knee flexion (full extension) and restoration of the normal anatomic tibial step-off at 70–90° of flexion have provided the most reproducible method of establishing the neutral point of the tibiofemoral relationship in our experience. 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 5 weeks non-weight bearing. Progressive range of motion occurs during postoperative weeks 6–10. Progressive weight bearing occurs at the beginning of postoperative week 6 progressing at a rate of 20% body weight per week during postoperative weeks 6–10. Progressive closed kinetic chain strength training, proprioceptive training, and continued motion exercises are initiated very slowly beginning at postoperative week 11. The long leg range of motion brace is discontinued after the 10th 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 [3, 4, 21–23]. 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. 32 of this book.

### *20.9.1 Author's Results*

Our results of multiple ligament injured knee treatment without mechanical graft tensioning are outlined below [7]. 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. 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 Sports Medicine graft-tensioning boot was used in this series of patients (Biomet Sports Medicine, Warsaw, IN).

Postoperative physical examination results revealed normal posterior drawer/tibial step-off in 16/35 (46%) of knees and 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. Thirty-degree varus stress testing was normal in 22/25 (88%) of knees and grade 1 laxity in 3/25 (12%) of knees. Thirty-degree 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 were measured at 90° of knee flexion, and 32 pounds 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 [10]. 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, IN). 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. PCLs were reconstructed with allograft Achilles tendon in all 15 knees. ACLs 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 pounds 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 reconstructions in the PCL-based multiple ligament injured knee revealed the following [1, 2, 4]. 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 arthrometer, and 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 double-bundle PCL-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 were 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 were 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 were 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 were 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 were 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 were 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.

## 20.10 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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# Chapter 21
# Revision Surgery in the Posterior Cruciate Ligament and Multiple Ligament Injured Knee

**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, and proximal tibial osteotomy.

The failed PCL and multiple ligament injured knee reconstruction is a difficult problem that necessitates 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 the 23-year clinical experience of the senior author.

## 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 in the senior author's practice is a missed posterolateral corner injury. Other common causes are listed in Table 21.1.

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G.C. Fanelli (ed.), *The Multiple Ligament Injured Knee: A Practical Guide to Management*,
DOI 10.1007/978-0-387-49289-6_21,

**Table 21.1** 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 pathology |
| Biologic |
| Failure of graft incorporation (especially with allograft) |
| Soft tissue graft elongation |
| Traumatic |
| "Aggressive" early rehab before adequate biological healing |
| Major trauma/reinjury |
| 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 [19–24]. 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, 25].

Associated injuries include damage to the patellar tendon, possibility the IT band, popliteal vascular structures, and the common peroneal nerve as well as bony avulsion fractures [26, 27]. As with all knee injuries, appropriate diagnosis and classification is based on an accurate history, thorough physical exam, and appropriate timely imaging studies [28–32].

## 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. Though the history is obtained from the patient and family members, a review of the patient's old records is essential for 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 all provide the revision surgeon with vital information for preoperative planning. This information is of particular importance if the original procedure was performed by a different surgeon at another institution. Key information to glean from old records includes the timing of surgery, results of the exam 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, 33]. 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, smoking 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.

### *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 exam of both lower extremities in their entirety should be performed [16–18]. Exam findings

**Table 21.2** 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)

are often time dependent. Key physical exam findings to evaluate are listed in Table 21.2. 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 range of motion [16–18, 27, 34–38]. 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. Medial and lateral patellar glide as well as of patellar tilt and lateral apprehension testing helps to determine the status of the medial checkrein structures [16–18].

Joint line tenderness as well as the flexion McMurray's test is utilized to assess the status of the meniscus medially and laterally. Ligamentous laxity patterns are then evaluated using the Lachman, anterior and posterior drawer, pivot shift, quadriceps active, varus and valgus stress, and posterolateral rotator instability tests [16–18, 39, 40]. Anterior and posterior drawer tests should be performed in internal, neutral, and external rotation. Varus and valgus stress tests should be performed in 0° and 30° of flexion, and PLRI tests in 30° and 90° of flexion. Keep 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 [41]. These tests should be meticulously performed and graded and then compared to the uninjured limb to determine asymmetry.

## *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

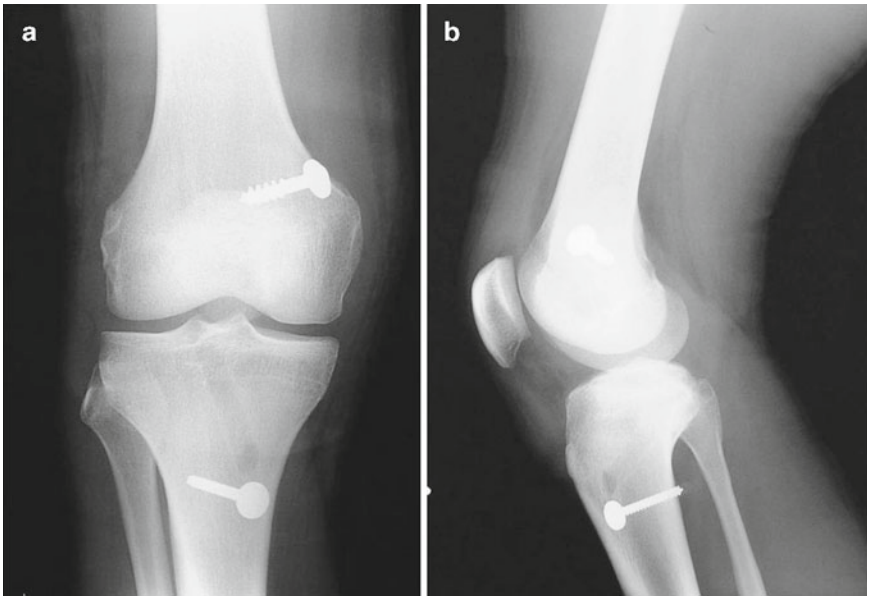

**Fig. 21.1** AP (**a**) and lateral (**b**) X-rays of a 31-year-old female soccer player with recurrent instability after failed PCL reconstruction

flexion X-ray, a bilateral 30° merchant view X-ray, bilateral lateral views, and a standing bilateral long cassette image. 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. Figure 21.1 shows the preoperative bilateral AP radiographs after a failed PCL reconstruction.

#### 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 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, 42, 43].

#### 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, 27, 44]. Spasm, intimal injury, or complete tear may all alter vascular status of the injured limb and must be thoroughly evaluated prior to revision surgery [45–49]. 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, 49–51]. Figure 21.2 demonstrates a preoperative arteriogram in a patient with popliteal artery occlusion after a knee dislocation.

#### 21.3.3.4 Venous Duplex Doppler Ultrasound

All patients with combined ligamentous injuries and failed reconstructions should undergo a venous duplex Doppler ultrasound to rule out deep vein thrombosis. 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.

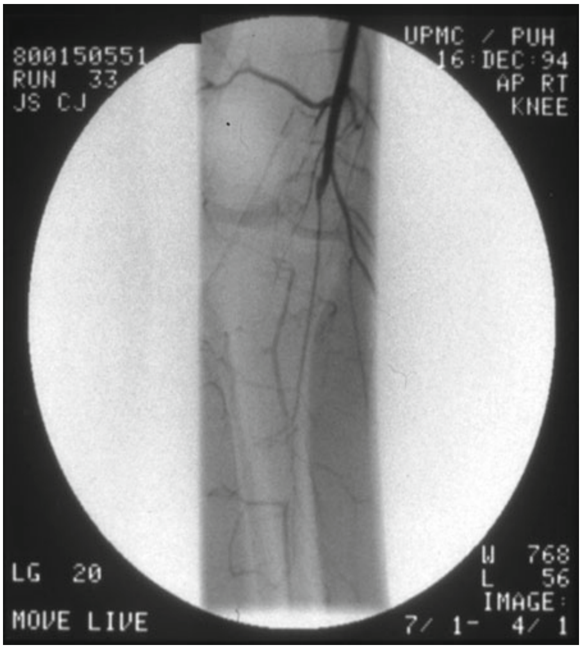

**Fig. 21.2** Preoperative arteriogram demonstrating a popliteal arterial injury

### *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, rehab 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 use of tobacco products may further delay or inhibit the patient's healing ability postoperatively, and efforts should be made to discontinue tobacco use.

## 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 [52, 53]. Contraindications to revision reconstruction include severe loss of range of motion, fixed posterior subluxation, advanced osteoarthritis, and active 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

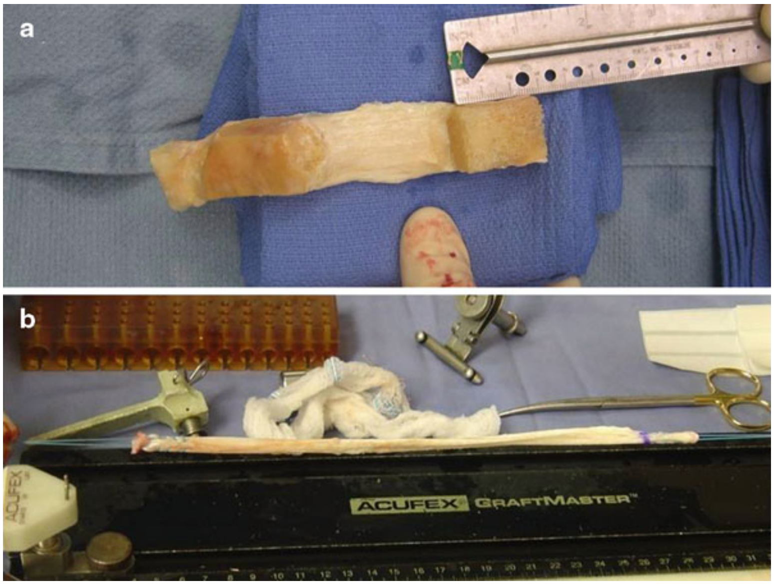

**Fig. 21.3** Two commonly used allograft options for MLI reconstructions. From top to bottom: (**a**) bone-patellar tendon-bone and (**b**) anterior tibialis allografts

hospital discharge, and the presence of active infection. Available equipment must include desired allografts, necessary fixation devices, and intraoperative fluoroscopy [16–18, 26, 40]. 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 or allograft availability, previously used graft type, surgeon experience, and surgeon preference. In the revision situation it is prudent to consider allograft reconstruction particularly for MLI cases. This is done in order to limit the amount of soft tissue disruption inflicted on an already traumatized soft tissue envelope. If autograft reconstruction is chosen, it is crucial to be aware of the type of any previously used autograft to assure intraoperative availability of the graft. Review of previous operative notes is essential for assuring graft availability and operative efficiency.

Autograft tissue may be harvested from the ipsilateral or contralateral extremity and has the advantage of better graft incorporation and remodeling [16–18]. At our institution, Achilles tendon and tibialis anterior allografts have been traditionally favored for revision reconstructions [1]. 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, 52–54]. Risks of allograft usage include an increase in cost, delay in incorporation, elongation of the soft tissue portion, and potential disease transmission [55]. Figure 21.3 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 incision 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

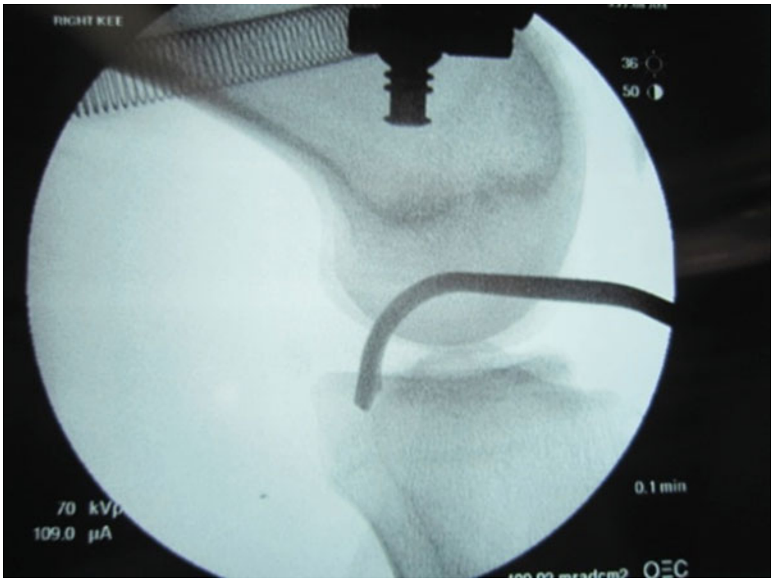

**Fig. 21.4** Intraoperative fluoroscopic image showing positioning of PCL tibial tunnel guide

width. Preoperative radiographs should be scrutinized and tunnel widths noted. These results should then be compared with operative notes 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 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].

#### 21.4.2.5 Intraoperative Fluoroscopy

Intraoperative fluoroscopy has become an invaluable tool in primary as well as revision knee ligament reconstruction. 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 exam under anesthesia [16–18]. With fluoroscopic exam 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 21.4 shows an intraoperative lateral fluoroscopic knee X-ray with a PCL tibial tunnel guide positioned for guide pin placement.

### 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)

#### 21.4.3.1 Anesthesia

The choice of anesthesia is made in conjunction with the surgeon, the anesthesiologist, and the patient. The 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. At our institution, preoperative femoral and sciatic nerve blocks are routinely used. The nerve blocks not only provide anesthesia for the surgical procedure but also provide up to 12 h of postoperative pain relief. 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.

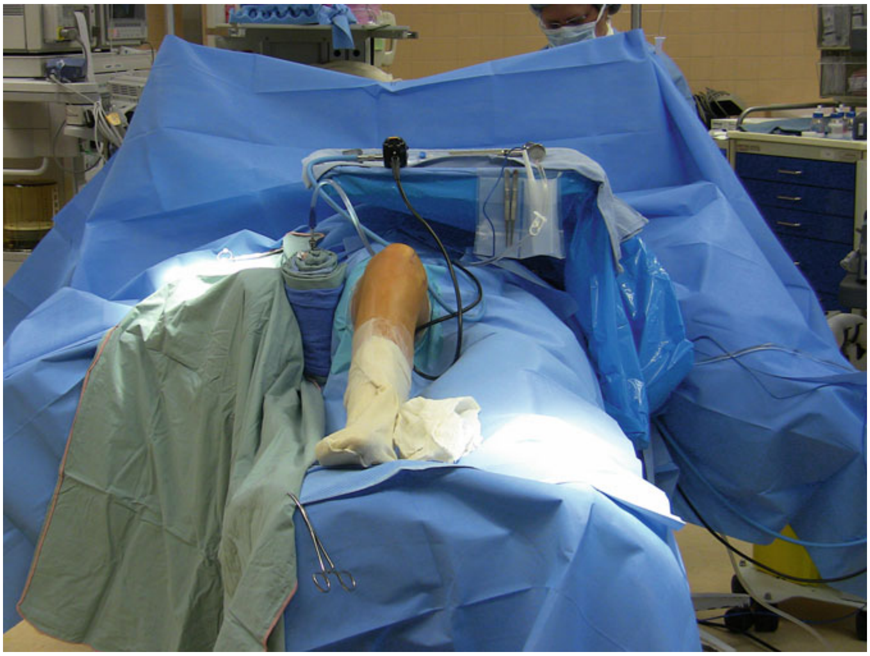

**Fig. 21.5** OR setup. No tourniquet or leg holder. Mini C-arm available

#### 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. A sandbag 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 21.5 demonstrates the senior author's operative setup for limb positioning and available fluoroscopic imaging.

#### 21.4.3.3 Examination Under Anesthesia

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. Passive range of motion is first tested, noting any deficits or asymmetry to the uninjured limb. The anterior drawer, Lachman, and pivot shift tests are then performed to evaluate the ACL.

Posterior tibial sag and translation with posterior drawer testing are then used to evaluate the PCL. The knee is then placed into the figure-four position, and the LCL is palpated with a bowstring test. Varus and valgus stress is then applied to the knee in 0° and 30° of flexion to evaluate the LCL and MCL, respectively. Posterolateral corner structures are then evaluated by applying an external rotation force to the proximal tibia and fibula at 0° and 90° of flexion with the proximal tibia held in a reduced position. Degree of external rotation is then referenced with the uninjured limb. Greater than a 15° increase in external rotation is an indication of PLC injury.

#### 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 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. The anterolateral arthroscopy portal is placed adjacent to the lateral border of the patella above the joint line. The anteromedial arthroscopy portal is placed approximately 1 cm medial to the patellar tendon at the same level. A superolateral outflow portal is placed 1 cm proximal to the superior pole of the patella and posterior to the quadriceps tendon.

A longitudinal 3-cm incision originating 2 cm distal to the joint line and 2 cm medial to the tibial tubercle is drawn 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.

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 limited notchplasty is performed. The fat pad should be preserved if at all possible to prevent 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, 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 template 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

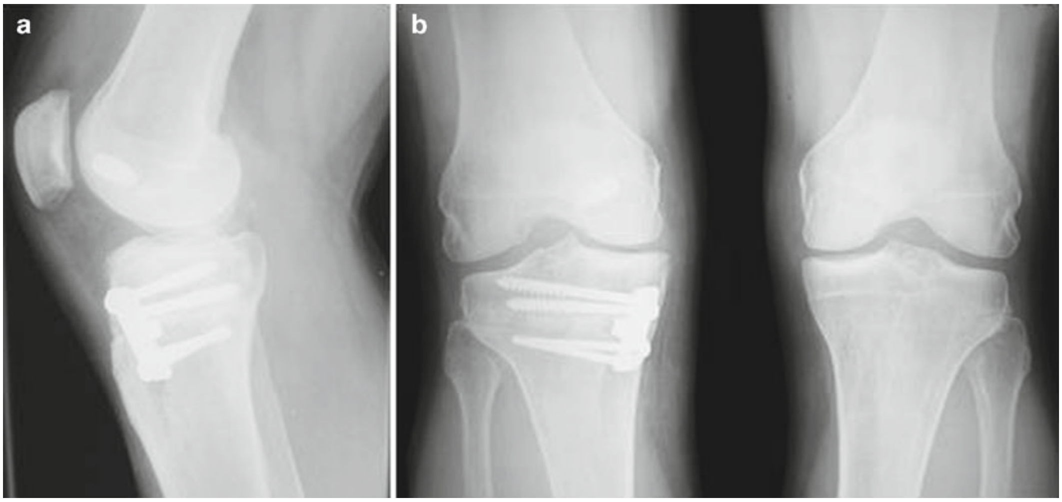

**Fig. 21.6** Postoperative lateral (**a**) and AP (**b**) X-rays after a biplanar osteotomy and plate fixation with PCL reconstruction

biplanar effect. The alignment of the leg is again checked using the Bovie cord and fluoroscopy, with the cord recreating the mechanical axis of the knee joint. The axis should cross 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 21.6 shows the AP and lateral X-rays after.

#### 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.

##### 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 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 allograft 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 is 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.

#### 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

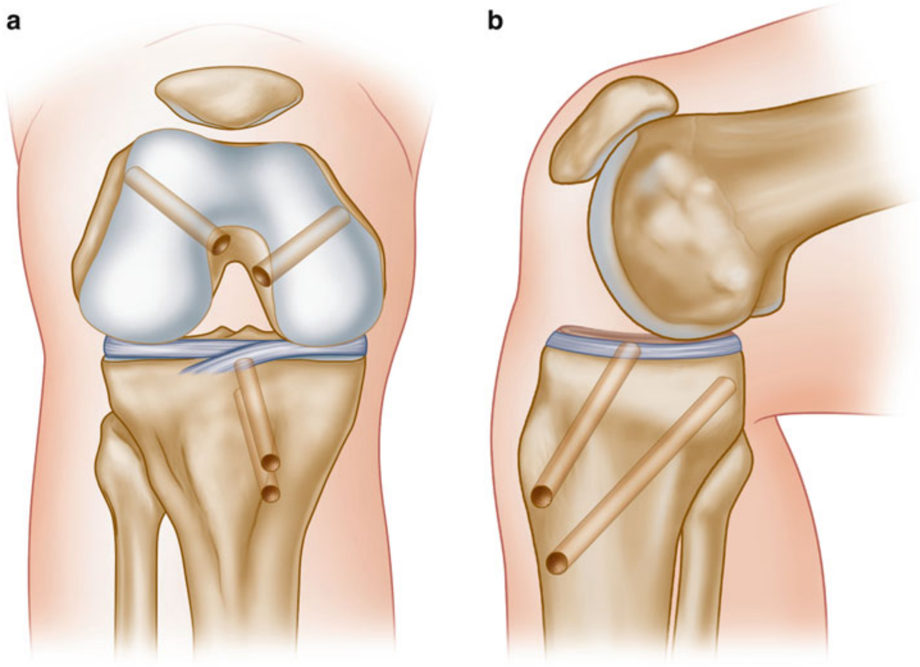

**Fig. 21.7** Diagram AP (**a**) and lateral (**b**) projections of tibial and femoral tunnel positions for ACL and PCL reconstruction (adapted from Chhabra, Management of Knee Dislocations, JBJS, supplement 1, March 2005, with permission from JBJS/Rockwater)

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 3/32-mm Kirschner wire into the desired position and perforate the far cortex of the tibia at the PCL insertion; this is done under direct arthroscopic visualization. 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 while the K-wire is advanced. The location of this pin placement is then confirmed with the mini C-arm fluoroscopy machine 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 K-wire for the PCL tibial tunnel 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 3/32-mm guidewire 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 projection with the mini C-arm machine. The guidewire 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. 21.7).

After acceptable placement of the ACL and PCL tibial tunnel guidewires 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 is passed under direct arthroscopic visualization with a 30° arthroscope that is introduced through the posteromedial portal. This 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 with a 9-mm compaction drill. 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 K-wire 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 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 or over the top position of the femur and “northwest” or “northeast” position for right and left knees, respectively. We prefer the medial portal technique to the traditional transtibial technique due to the ability to place a more anatomically positioned insertion site on the femur. The K-wire is overdrilled with the 9-mm compaction drill to a depth of 25–35 mm. This tunnel is then expanded as before to a diameter of 10 mm with the dilators in 0.5-mm increments.

### *21.4.4 Graft Passage*

In the case of multiple ligament reconstruction, the graft for the PCL is passed first. A looped 18-gauge 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-gauge 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 passed from the tibial tunnel into the femoral tunnel with arthroscopic assistance. 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 femoral cortex. The grafts are not tensioned, however, until the end of the case.

For reconstruction of the LCL, the tendinous portion of the Achilles allograft is secured to the LCL insertion by means of drill holes or suture anchors. The native LCL is then imbricated to the tendinous portion of the allograft using a whipstitch. The injured LCL is dissected free from its distal insertion site if possible. A tunnel is then drilled along the longitudinal axis of the fibula. The bone plug is tensioned and secured in the tunnel use with an interference screw. Alternatively, the tendinous portion of the graft may be recessed into the lateral femoral epicondyle via a small bone tunnel and tied over a post.

#### 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 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 guidewire is then passed 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 guidewire 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. A diagram of the popliteofibular ligament reconstruction is shown in Fig. 21.8.

#### 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.

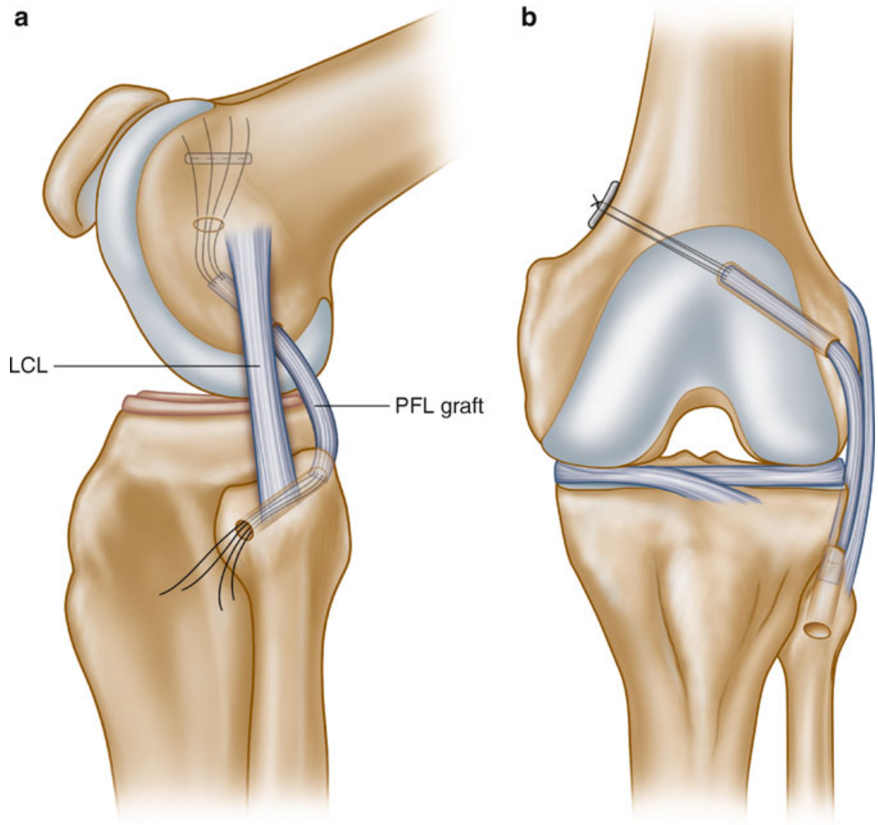

**Fig. 21.8** Popliteofibular ligament reconstruction. From Elattrache, NS. (2007). Surgical Techniques in Sports Medicine. Philadelphia, Lippincott Williams & Wilkins, with permission from Wolters Kluwer

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 in approximately 15° 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.

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 30° 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.

**Fig. 21.9** A hinged knee brace locked in extension is applied immediately post-op and discontinued when quadriceps function returns

### 21.5.1 *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 is 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 silky Polydek nonabsorbable sutures. The subcutaneous tissues are then closed with 2-O absorbable suture and the skin is reapproximated with either staples or 4-O Caprosyn suture in a subcuticular fashion. Arthroscopic portals are then closed using 3-O nylon suture.

Prior to application of dressings, a vascular exam using either direct palpation or Doppler ultrasound is performed to ensure the presence of a dorsalis pedis and posterior tibial pulse. The calf musculature is then palpated to assure that iatrogenic compartment syndrome has not occurred. Dressings consisting of Adaptic, sterile 4×4 gauze, ABDs, Webril, and an ACE wrap are applied to the extremity. Finally, a hinged knee brace locked in full extension is applied to the knee (Fig. 21.9). Tight, constrictive braces and dressings should be avoided to prevent increasing the risk for compartment syndrome and peroneal nerve injury.

## 21.6 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. Give appropriate preoperative and postoperative antibiotics. Prophylactic anticoagulation with subcutaneous enoxaparin should be used in all high-risk patients. Aspirin is indicated in low-risk patients. In the senior author's practice, smoking and the use of oral contraceptive pills are considered to be risk factors for thrombosis.

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.

## 21.7 Rehabilitation Protocol

An appropriate and individualized postoperative rehabilitation program is integral to optimizing patient outcomes after revision surgery [37]. Immediately post-op the limb is placed into a hinged knee brace locked in extension. A foot drop splint may be used 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 2–3 weeks postoperatively. Active flexion should be avoided 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 range 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. In the senior author's practice approximately 10–20 % of patients require manipulation under anesthesia between 8 and 12 weeks to reach 90° of flexion.

Active quadriceps exercises are progressed to open-chain knee extension exercises beginning at 4 weeks [56]. 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 until 6 months [56]. 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.

## 21.8 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, 57]. 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 listed in Table 21.3.

**Table 21.3** Common and severe complications of revision PCL and multiple knee ligament reconstruction

- Preoperative
  - Vasculature
    - Arterial
      - Spasm
      - Intimal injury
      - Complete tear
    - 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

**Table 21.4** 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, vascular backup) |
| (3) | Adequate imaging studies (X-rays, MRI, arteriogram/CT-angiogram, venous duplex Doppler) |
| (4) | Pad all extremities well 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 physical therapists |

The key to treatment of these complications is prevention, which involves detailed preoperative planning, proper surgical technique, and a specific postoperative rehabilitation program. Table 21.4 illustrates the senior author's top ten key points for prevention of complications with revision PCL and MLI knee reconstruction.

## 21.9 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 much less predictable for revision reconstruction than for primary reconstruction [16, 58].

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 rehab program are essential for treatment success and prevention of complications.

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# Part VIII

# Other Considerations

# Chapter 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 materials, mechanical graft tensioning, secure graft fixation, and a deliberate postoperative rehabilitation program. This chapter will concentrate on my experience using a mechanical graft-tensioning boot, the Biomet graft-tensioning boot (Biomet Sports Medicine, Warsaw, IN), during posterior cruciate ligament and anterior cruciate ligament reconstruction in 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.

## 22.2 The Mechanical Graft-Tensioning Device

The graft-tensioning boot (Biomet Sports Medicine, Warsaw, IN) 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.

## 22.3 Combined PCL–ACL Reconstruction Surgical Technique Using Mechanical Graft Tensioning

My surgical technique for combined PCL–ACL medial and lateral side reconstruction is presented in Chap. 20 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 [1–10]. 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.

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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

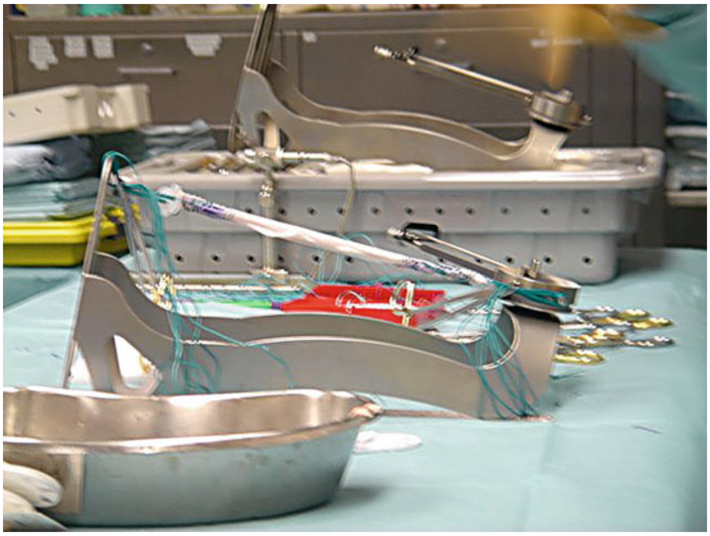


**Fig. 22.2** The graft-tensioning device is used to pretension the prepared allograft or autograft tissue prior to implantation. After completion of graft preparation, the allograft or autograft tissue is placed on the tensioning boot, and tension is gradually applied to pretension the graft tissue 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

**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

Allograft tissue is prepared prior to bring 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 1 in. 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, IN) 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, IN) 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, with the 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, IN). 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 of 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 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 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, IN) 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 backup 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 1 cm 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 is achieved on the femoral side using a bioabsorbable interference screw, while cortical suspensory backup fixation is achieved with a polyethylene ligament fixation button. Additional drawings and photographs of this surgical technique are presented in Chap. 20 of this book [9].

## 22.4 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 follow those 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, IN) (Fig. 22.4). 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 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

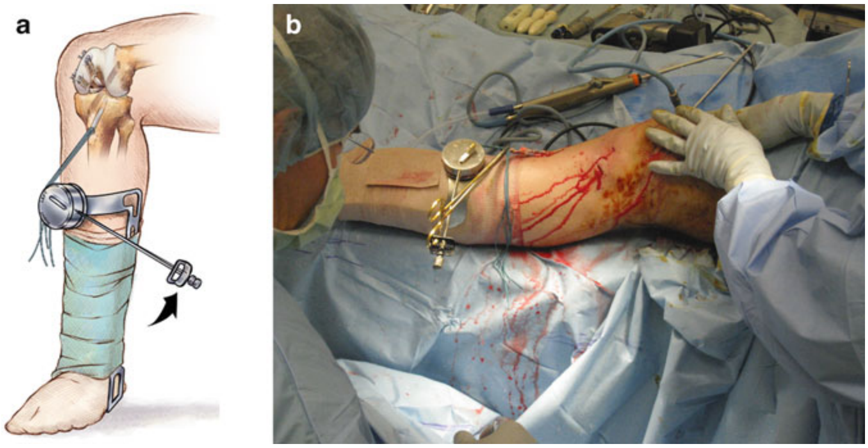
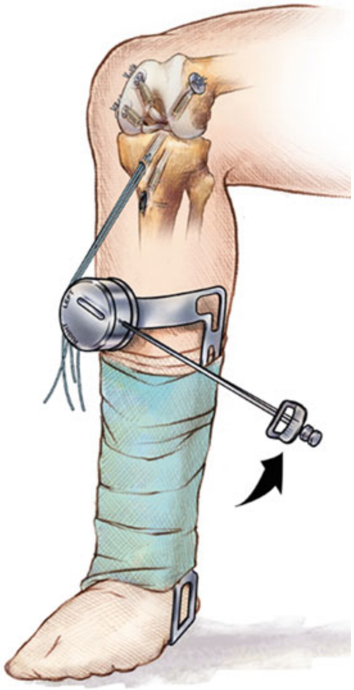


**Fig. 22.4** (**a**) The graft-tensioning boot is applied to the traction sutures of the posterior cruciate ligament graft. From Ref. [1]. Reprinted with permission. (**b**) Tension is gradually applied with the knee in zero degrees of flexion (full extension) reducing the tibia on the femur. This restores 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 intraoperative examination of the knee, and full range of motion of the knee

**Fig. 22.5** When the tensioning sequence described in this chapter 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 backup 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 Ref. [1]. Reprinted with permission



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 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 backup 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, IN) 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 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

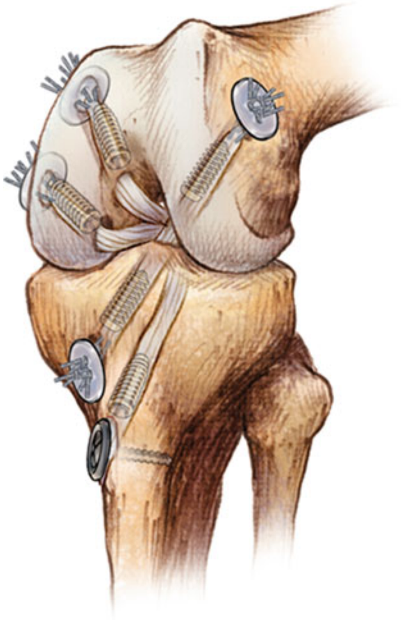


**Fig. 22.7** This figure shows final fixation of the posterior and anterior cruciate ligament grafts. From Ref. [1]. Reprinted with permission

the cycling and readjustment processes but are not indicators of final tension in the graft. The 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 backup fixation with a polyethylene ligament fixation button (Fig. 22.7).

## 22.5 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, KT1000 arthrometer testing, stress radiography, and physical examination [11, 12]. 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 examination 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. Thirty degree 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). 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 ten-year results of combined ACL–PCL reconstructions without the Biomet Sports Medicine graft-tensioning boot have been published by Fanelli and Edson in 2002 [13]. 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, and 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, three 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 and 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. Thirty degree varus stress testing was normal in 22/25 (88%) of knees and grade 1 laxity in 3/25 (1%) of knees. Thirty degree 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 HHS is Hospital for Special Surgery 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 [12]. These data present 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 six ACL PCL PLC injuries, four ACL PCL MCL injuries, and five ACL PCL PLC MCL injuries. The Biomet Sports Medicine 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. PCLs were reconstructed with allograft Achilles tendon in all 15 knees. ACLs 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 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%) of knees, and normal pivot shift tests in 14/15 (93.3%) of knees. Posterolateral stability was restored to normal in all knees. When evaluated with the external rotation thigh–foot angle test, nine knees were equal to the normal knee and two knees were 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 3–7 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 off and posterior drawer examinations improved to 86.6% of the PCL reconstructions in the study group.

## 22.6 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 the 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 [2, 3, 14].

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# Chapter 23
# Management of Arterial and Venous Injuries in the Dislocated Knee

**John L. Gray and Matt Cindric**

## 23.1 Introduction

Catastrophic vascular injury regularly accompanies multiligamentous dislocation of the knee. It is the most common reason for medicolegal litigation with this entity. Only with a high clinical index of suspicion, rapid diagnosis, evaluation, and correction can this undesirable outcome be avoided. Those who have experienced the severe complications resulting from a missed vascular injury associated with this clinical entity are unlikely to forget its indelible imprint. Those who have not are in the majority and remain at risk underappreciate its severity.

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 compromise. Modern diagnostic imaging, particularly MRI, has increased the ability to diagnose this orthopedic condition. 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. Secondly, 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

Multiligamentous 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 contusion 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

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G.C. Fanelli (ed.), *The Multiple Ligament Injured Knee: A Practical Guide to Management*,
DOI 10.1007/978-0-387-49289-6_23,

**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 (1961) [1] | 14 | 7 (50%) | 11 (92%) |
| Kennedy (1963) [2] | 22 | 10 (33%) | 5 (23%) |
| Green et al. (1977) [3] | 245 | 78 (32%) | 31 (13%) |
| Donnell et al. (1977) [4] | 10 | 10 (100%) | 2 (20%) |
| Jones et al. (1979) [5] | 22 | 10 (45%) | 1 (5%) |
| Sisto et al. (1985) [6] | 20 | 2 (10%) | 0 (0%) |
| Roman et al. (1987) [7] | 30 | 10 (33%) | 0 (0%) |
| Varnell et al. (1989) [8] | 30 | 12 (40%) | 2 (7%) |
| Treiman et al. (1992) [9] | 115 | 23 (20%) | 1 (<1%) |
| Kaufman et al. (1992) [10] | 19 | 6 (32%) | 0 (0%) |
| Dennis et al. (1993) [11] | 38 | 9 (24%) | 0 (0%) |
| Kendall et al. (1993) [12] | 37 | 6 (16%) | 1 (3%) |
| Wascher et al. (1997) [13] | 47 | 11 (23%) | 1 (2%) |
| Martinez et al. (2001) [14] | 21 | 7 (33%) | 0 (0%) |
| Abou-Sayed et al. (2002) [15] | 53 | 13 (25%) | 1 (2%) |
| Miranda et al. (2002) [16] | 35 | 7 (20%) | 0 (0%) |
| Mills et al. (2004) [17] | 38 | 11 (29%) | 1 (3%) |
| Stannard et al. (2004) [18] | 138 | 138 (7%) | 0 (0%) |
| Total | 934 | 241 (26%) | 57 (6%) |

environmental contact for motorcycle riders. These mechanisms most commonly result in posterior dislocations. The next largest group of 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 branches, 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. This 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 are 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 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 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.

**Fig. 23.1** Intimal disruption resulting in popliteal artery thrombosis. Figure courtesy of Robert P. Garvin, MD

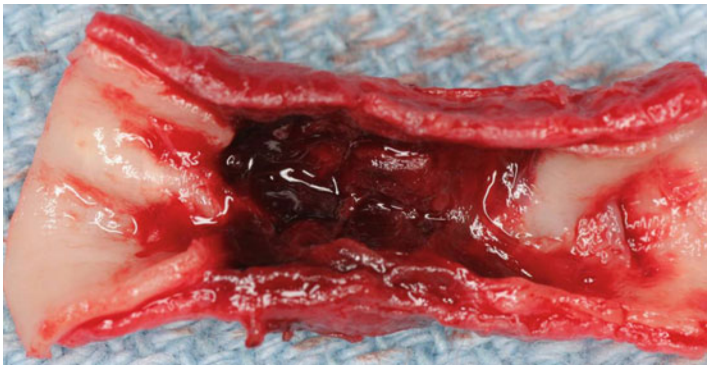

**Fig. 23.2** Close-up of intimal injury. Figure courtesy of Robert P. Garvin, MD

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 became a claudicant. 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. This is thought due to the increasing frequency of dashboard trauma from motor vehicle crashes.

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 multiligamentous 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 multiligamentous 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 scrupulously followed in every case. 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 a disastrous outcome. The key to making the diagnosis is a high index of suspicion. Because the minority of multiligament 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, non-catheter-, and 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 physical exam include coolness, delayed capillary refill, and pale, cyanotic, or mottled coloration. 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 pursued. If not present, some 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.

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

**Fig. 23.3** Technician performing ankle brachial index measurement of lower extremities. Figure courtesy of Robert P. Garvin, MD

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 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.

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]. This is not ideal but 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 but not necessarily urgent imaging by noninvasive modalities would identify these lesions and facilitate their repair before the patient's dramatic re-presentation with a delayed diagnosis of a vascular injury.

### 23.5.2 *Catheter-Based Arteriography (Fig. 23.4)*

Arteriography is still largely 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 mandatory fashion. All studies agree that the incidence of significant vascular injury identification is extremely low when hard signs of vascular injury are absent. Thus, in the majority of patients, it does not provide information which affects management. Consequences of arteriography include iatrogenic arterial injury, contrast nephropathy, radiation exposure, and expense.

When hard signs of vascular injury are present, arteriography identifies significant injury in most but not all. If one excludes the patients with the most certain of the hard signs, incontrovertible evidence of malperfusion, or bleeding, its yield is modest. The patients with clear hard signs of vascular injury should be taken without delay for operative exploration or intraoperative arteriography. This is facilitated by the increasing availability of excellent imaging equipment in the operating room as a consequence of the predominant role of imaging in modern vascular surgery.

Outcome is best when confirmation and correction of vascular injury is made rapidly [23]. Delays in excess of 6–8 h most frequently end in tissue loss and amputation. Arteriography obtained outside the operating room added 50 min to 2 h of delay to the revascularization delay. The amount of delay will vary by institution but is best avoided altogether.

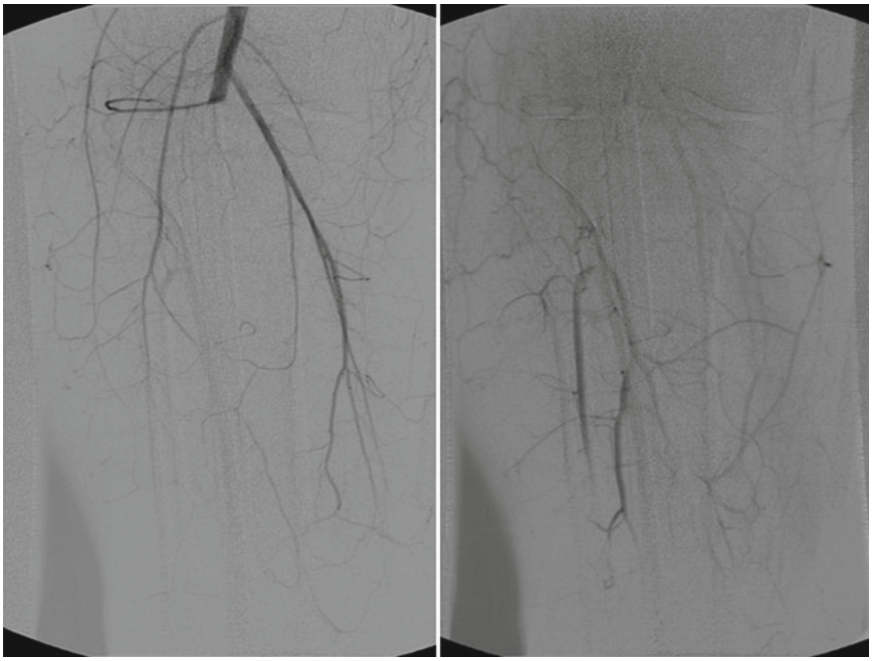

**Fig. 23.4** Popliteal injury after knee dislocation: arteriogram showing popliteal artery occlusion (*left image*) at joint space with geniculates reconstituting proximal anterior tibial and peroneal arteries (*right image*). Figure courtesy of Robert P. Garvin, MD

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 tissue transmits ultrasound frequencies well. 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 this, there is an expectation that this technology would have excellent sensitivity in the detection or exclusion of significant injury. It is noninvasive, safe, and inexpensive compared to catheter-based arteriography. It is far cheaper than CT- or MR-based arteriography and portable. Availability of an experienced sonographer around the clock and on weekends is a major limitation in most centers. Duplex ultrasound will likely see an expanded role in the evaluation of potential vascular injury associated with knee dislocation in the future.

### 23.5.4 Computed Tomographic Arteriography (Fig. 23.5)

Advanced CT imaging is available 24/7 in nearly every facility and certainly at all trauma centers in the current era. Using modern CT scanners and intravenous contrast injection, images which rival catheter-based arteriographic studies can be rapidly obtained. Radiologic interpretation is frequently available instantaneously or with minimal delay. This has the dramatic appeal of promptly and simultaneously evaluating the orthopedic and vascular injuries and providing direction for management. In a general study of extremity trauma patients with suspected vascular injury, this modality demonstrated

**Fig. 23.5** CTA of popliteal artery occlusion of right lower extremity. Figure courtesy of Robert P. Garvin, MD

sensitivity and specificity in excess of 90% [26]. CTA is routinely used to plan vascular surgical procedures for a wide range of pathologies. 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 is its major drawback.

### *23.5.5 Magnetic Resonance Arteriography*

Its major disadvantage and reason for lack of widespread acceptance is its unavailability 24/7. From an imaging perspective, MR technology provides exceptional orthopedic evaluation and is the study of choice for that consideration. It can offer vascular evaluation and images that are comparable to CTA and catheter-based arteriography. 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 limited accessibility of the patient during the scan which generally requires longer scanning 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 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. This would be an infrequent contraindication in the knee dislocation population (Fig. 23.6).

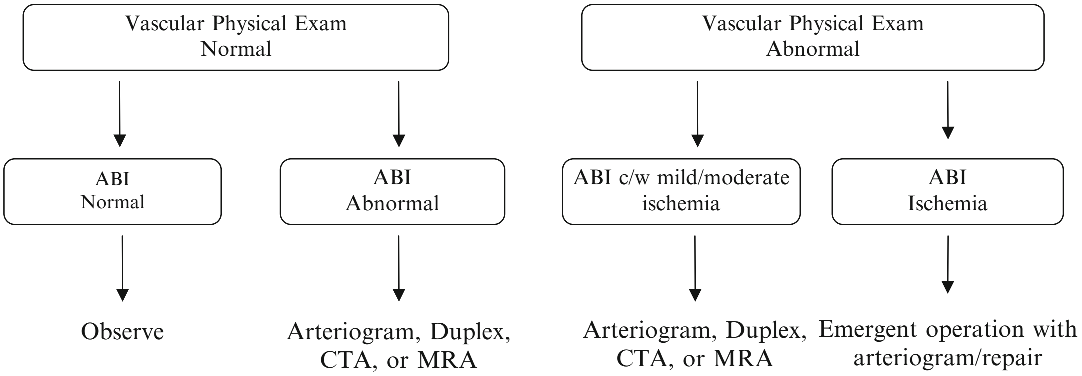

**Fig. 23.6** Simplified management algorithm for vascular evaluation with knee dislocation. In hospitals with limited availability of vascular reconstructive services, routine arteriography and/or transfer to a higher level of care facility is recommended

## 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 elucidated and aggressively managed. 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 or peritoneal cavity. 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.

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.

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 ~12-cm incision that is positioned over the anterior border of the distal sartorius or inferior margin of femur [27]. Once the subfascial plane is entered, the sartorius is retracted posteriorly. The distal popliteal artery is exposed through a separate ~12-cm incision parallel and one fingerbreadth posterior to the proximal tibia. The medial head of the gastrocnemius muscle is retracted posteriorly. Often the soleus requires mobilization off the tibia to facilitate exposure of the neurovascular bundle. At this location, the popliteal vein may be single or paired.

The posterior approach requires prone positioning of the patient. It is imperative to first provide adequate cushioning for both lower extremities; 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 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].

Each surgical approach has practical advantages and limitations. The medial approach permits supine position for the entire procedure (fixation, vein harvest, reconstruction). Provided there is 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 synthetics (Dacron, ePTFE). The most appropriately sized saphenous vein is located in the proximal thigh. GSV terminates into the common femoral vein at the fossa ovalis; an incision beginning 2 cm laterally and inferior to the pubic tubercle is a useful landmark for initiating the dissection. A suitable length is then dissected free distally, tying off side branches and noting the craniocaudad orientation. Of paramount importance, both legs ought to 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. Catheter thrombectomy to restore patency and remove any thrombus is next with local heparinization. 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.

Once the venous conduit is harvested and popliteal artery exposed (from either surgical approach), proximal and distal control is obtained. The level of injury is identified. Whether transected from injury or not, the popliteal artery should be 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); this may require extensive mobilization of the popliteal artery with ligation and division of geniculate collateral vessels. 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. Localized arterial repairs are most common with a posterior approach as direct exposure of the precise region of arterial injury is most likely with this approach. The medial approach often exposes the artery above and below but not at the actual site of injury.

Most often, an interposition graft using GSV is required. The choice of reversed or nonreversed vein is less important than an appropriate size match; if a nonreversed 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 reapproximation is performed using 5-0 or 6-0 nonabsorbable monofilament suture (Fig. 23.7).

On completion of the anastomoses, adequacy of the distal circulation is ascertained. Some surgeons routinely use angiography at this point, whereas others will selectively employ this modality for instances when pedal pulses are not immediately palpable following repair. Either a small gauge (#20) butterfly needle or small 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. In the setting of questionable perfusion, suboptimal results on angiography necessitate further intervention, based on findings present. Often this entails dismantling a suture line at the distal popliteal artery and performing thrombectomy via balloon catheter down the individual tibial vessels. Alternatively, direct cutdown on distal tibial vessels and retrograde thrombectomy may be required. Intraoperative use of thrombolytics is avoided if possible and used when no contraindications exist if other methods fail to resolve thrombosis in the distal circulation.

Repair of popliteal venous injuries is less straightforward. Options include simple ligation, venorrhaphy, and interposition grafting. In the 1960s, the fashion was one of mandatory reconstruction of all venous injuries. Proponents suggested that the ensuing venous hypertension from venous ligation will compromise the patency of 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 culminate in thrombosis. 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 reapproximation, 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 may

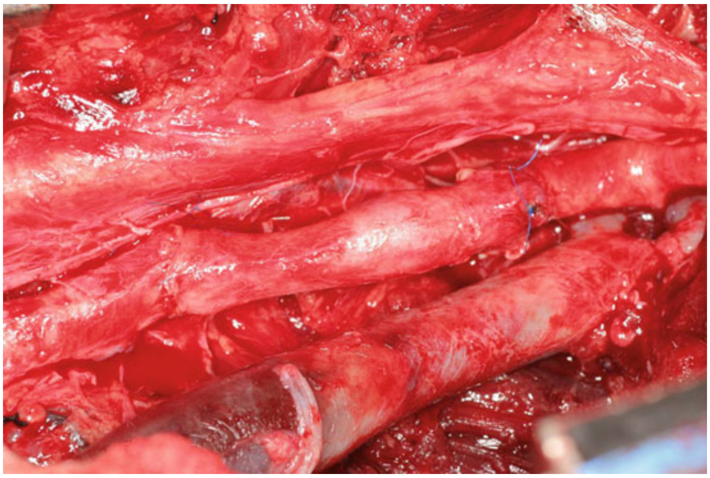

**Fig. 23.7** Completed repair of popliteal artery with interposition saphenous vein graft. Figure courtesy of Robert P. Garvin, MD

be 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.

Four-compartment fasciotomy should be strongly considered at the time of arterial reconstruction. Prophylactic fasciotomy is advised in 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 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 is clearly indicated.

Optimal outcomes after knee dislocation with arterial and venous injuries can be accomplished with an appreciation that these two injuries occur simultaneously in a large minority 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. In the vast majority of cases vascular reconstruction can be satisfactorily performed and the clinical outcome salutary. 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 knee dislocations.

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# Chapter 24
# Drop Foot After Knee Dislocation: Evaluation and Treatment

**Gerard J. Cush, Patrick J. Maloney, and Kaan Irgit**

## 24.1 Introduction

Injuries to the common peroneal nerve (CPN) are commonly associated with knee dislocations. Secondary to its anatomic location and firm attachment to surrounding soft tissue structures, the CPN is more vulnerable to injury than many other peripheral nerves in proximity to the knee joint [1, 2]. The reported incidence of injury to the CPN during knee dislocation varies between 4 and 50% [3–12]. Including patients with incomplete paresthesias, Owens et al. reported CPN injury in up to 75% of patients presenting with knee dislocations [13]. Multiple studies demonstrated that CPN injuries are more prevalent in high-velocity injury mechanisms (e.g., motor vehicle or industrial accidents), open dislocations, and knee dislocations associated with posterior cruciate ligament and posterolateral corner (PLC) injuries [1, 10, 13–16]. In additional to paresthesia, from incomplete injuries, complete nerve palsy causes motor weakness in dorsiflexion of the ankle and toes, as well as foot eversion. This motor dysfunction can cause significant disturbances in the gait pattern.

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 damage and/or persistent functional deficits. Controversy exists regarding the timing and type of surgical intervention. This chapter discusses the anatomy of the CPN, how to evaluate it, the associated pathophysiology, and treatment options for drop foot.

## 24.2 Anatomy

The CPN originates from L4-S3 roots as a portion of the sciatic nerve. The sciatic nerve divides into the tibial and CPNs in the distal aspect of the posterior thigh, deep to the biceps femoris muscle (Fig. 24.1). The CPN continues distally and enters the PLC immediately deep to the superficial layer of fibers and superficial to the biceps femoris tendon (Fig. 24.2) [18]. It travels superficial to the popliteus tendon and the tendinous attachment of the soleus. The CPN then curves around the neck of the fibula, where it lies directly over fibular periosteum for approximately 6 cm. At this level, the nerve is covered only by skin and subcutaneous tissue [19].

The CPN typically divides into three branches (Fig. 24.3). The first branch, the lateral articular nerve, innervates the inferolateral 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

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**Fig. 24.1** Anatomy of the posterior aspect of the knee. Pay attention to the proximity of the CPN to the posterolateral structures. © 1995 American Academy of Orthopaedic Surgeons. Reprinted from the J Am Acad Orthopaedic Surg. 3(5):284–292 with permission

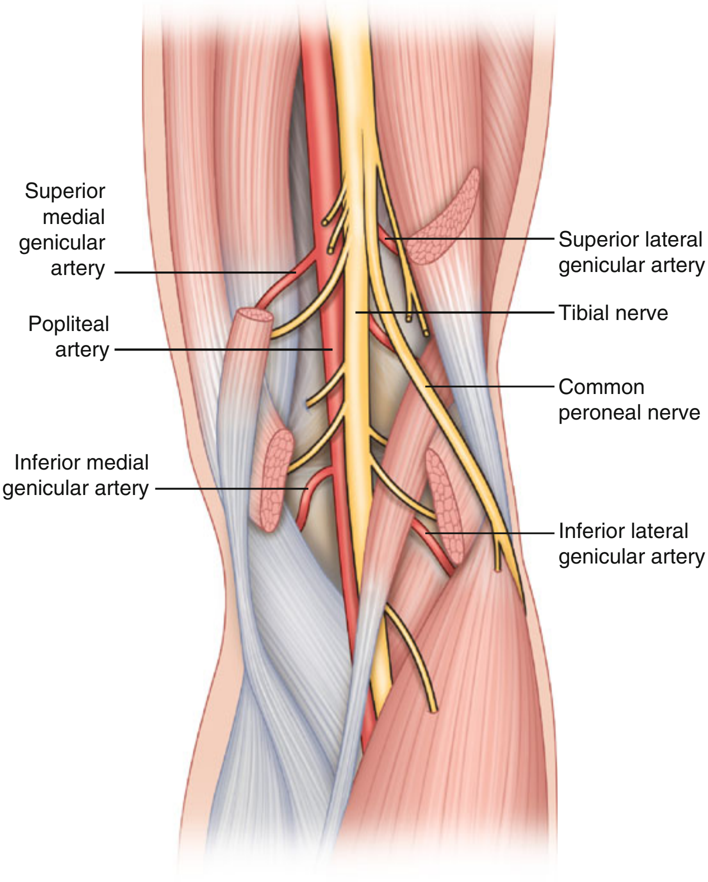
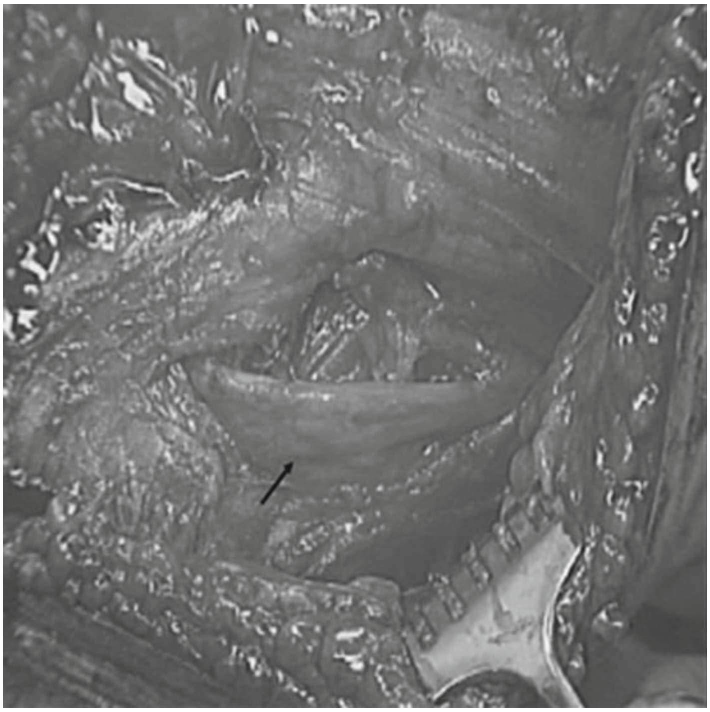


**Fig. 24.2** Exploration of CPN: *arrow* shows intact CPN



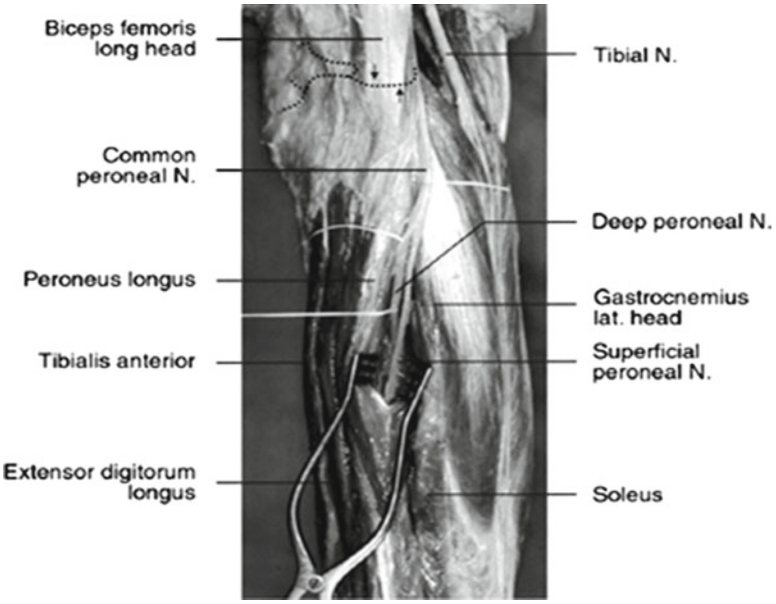


**Fig. 24.3** Three branches of the CPN. The superficial and deep peroneal nerves are seen in the distal popliteal fossa; the articular nerve branch is added to the original picture as dashed lines. Articular nerve courses underneath the biceps femoris. From Kim DH, Murovic JA, Tiel RL, Kline DG. Management and outcomes in 318 operative common peroneal nerve lesions at the Louisiana State University Health Sciences Center. Neurosurg. 2004;54(6):1421–1429. Reprinted with permission from Wolters Kluwer Health

between the peroneus longus and brevis muscles and innervates both. The superficial branch also provides sensory innervation to the anterolateral aspect calf and the dorsum of the foot.

The deep peroneal nerve (anterior tibial 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. The remaining muscles assist with ankle dorsiflexion and extend the toes. Within the foot, the deep peroneal nerve also 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.

## 24.3 Injury Mechanism and Pathoanatomy

Knee dislocations are classified by energy level of the injury or according to the anatomic classification system [20]. Kennedy described knee dislocations as anterior, posterior, medial, lateral, or rotatory [4]. This description refers to the position of the proximal tibia in relation to the distal femur.

The posterior dislocation pattern can cause direct disruption of the neurovascular structures. When the nerve is subjected to varus and hyperextension forces, as in anterior and anteromedial dislocations, it is vulnerable to traction injuries. These stretch injuries occur due to the firm periosteal attachment in the region of the fibular neck. Traction mechanism injuries can range from mild stretch to complete rupture of the nerve. Among all dislocations, the posterolateral mechanism is most likely to cause severe and permanent peroneal nerve injury [3, 21–23].

The energy level of injury is important to recognize and evaluate because it provides information concerning the risk of soft tissue injury and the risk of arterial injury and will likely influence the surgical approach. High-velocity mechanisms such as motor vehicle accidents, pedestrian versus motor vehicle, motorcycle accidents, and falls from a height are more prone to have associated neurological injuries. Peroneal nerve injuries in traumatic knee dislocation are also common in sports injuries [24, 25]. Additionally, morbidly obese patients may sustain knee dislocations during daily activities, and CPN palsy after these ultra-low-energy knee injuries has been reported [25, 26].

Mechanisms of injury to the peroneal nerves include laceration, compression, traction, and focal ischemia [27]. An injury causing elongation to 15% of 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 [28]. Tomaino et al. demonstrated that a stretch injury

**Table 24.1** Nerve injury classifications and related outcomes

| Classification | | Outcome |
|---|---|---|
| Seddon | Sunderland | |
| Neuropraxia | 1 | Full recovery is expected |
| Axonotmesis | 2 | Functional recovery can be expected |
| | 3 | Full recovery is unlikely unless the intrafascicular fibrosis is excised |
| | 4 | Generally surgical excision is needed |
| Neurotmesis | 5 | Recovery is impossible without surgery |

Seddon classified nerve injuries into three major groups: neuropraxia, axonotmesis, and neurotmesis. Sunderland classified nerve injuries from 1 to 5

mechanism may result in a longer overall zone of injury compared to a complete rupture [29]. Prognosis is poor in every scenario, where full recovery of motor and sensory function is unlikely.

Stretch injuries may also rupture the vasa 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, surgical release will likely provide immediate relief and possible full recovery [30].

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, 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, 30–33]. 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 [34].

The Seddon or Sunderland classification systems are widely used for classifying peripheral nerve injuries (Table 24.1) [34, 35]. 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. Examination of the ligaments and neurovascular structures should be obtained pre- and postreduction. During the examination, care should be taken not to place further strain on neurovascular structures.

Some knee dislocations are reduced prior to presentation to the hospital. In these cases, it is crucial to have a high index of suspicion of neurovascular injury. Neurological examination should include 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 CPN should be assessed [36]. The MRC scale is a 0–5 graded scale where grade 0 equates to no evidence of motor function and grade 5 denotes normal strength (Table 24.2). 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. 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 lesions of the peroneal nerve, 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 [37]. Sensory deficits secondary to compartment syndrome are typically in a stocking pattern and do not

**Table 24.2** 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 |

follow the standard dermatomal pattern. Intact sensation in the presence of an incomplete motor deficit is suggestive of an incomplete nerve injury [38].

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 [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 [39].

## 24.5 Diagnostic Studies

### 24.5.1 EMG

Electromyography (EMG) and nerve conduction velocity (NCV) testing are commonly used diagnostic tools. They are able to help determine the site and severity of peripheral nerve injuries and to predict recovery [31]. When clinical evidence of nerve recovery exists on examination, electrodiagnostic studies are unnecessary. Findings on EMG that indicate nerve injury include positive sharp waves, fibrillation potentials, and polyphasic potentials [1, 38]. 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. Absence of recovery at 3–6 months post-injury is an indication for nerve exploration.

Complete injuries may not successfully conduct a signal, and incomplete nerve injuries result in slowing of the conduction velocity and prolonged latency [31, 40]. 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 [41, 42].

### 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 [25, 43]. 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, 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 [24, 43]. 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 [25].

### 24.5.3 *Ultrasound*

Gruber et al. proposed utilizing ultrasonography to assess nerve injuries that warrant surgical intervention secondary to knee dislocations. This method is superior to EMG because an EMG is unable to distinguish neuropraxia from axonotmesis, nor does it provide information about extraneural impairments (e.g., obstructing hematomas, encasing scar) [44]. In a small prospective study, sonographic results of four patients during surgical intervention were evaluated. The authors concluded that sonography allowed visualization of the neural and extraneural pathology and was able to define the exact level and extent of the lesion. However, appropriate use of this technique remains operator dependent and requires advanced sonography equipment, which may not be available at every institution.

## 24.6 Treatment

The objective in the treatment of drop foot is to restore the normal heel-toe gait pattern. Despite the relatively high incidence of peroneal nerve injury in the setting of knee dislocation, little consensus has been reached regarding preferred treatment. Several recent studies report successful outcomes using a combination of nonoperative and operative treatments. Techniques range from physical therapy and bracing to neurolysis, nerve repair and grafting, and tendon transfers. All treatment options are directed at improving function, gait, and ambulation.

### 24.6.1 *Nonoperative Treatment*

Initial treatment for the majority of CPN injuries is conservative. When there is a complete lesion of the CPN, the foot drifts into plantar flexion and inversion. Initial splinting and physical therapy can avoid contracture. These patients require an ankle foot orthosis (AFO) or other bracing for toe clearance during gait. AFO is comprised of a molded sheet of plastic, polypropylene or polyethylene, which wraps around the posterior aspect of leg and under the foot with fabric straps across the ankle to secure the heel. It holds the ankle at neutral ankle flexion. Recently, semihinged and more comfortable designs were released [45, 46]. Nevertheless, AFO does nothing to address the underlying pathology, and it does not produce active dorsiflexion.

Physical therapy should include strengthening of the remaining functional muscles and stretching of the posterior capsule of the tibiotalar joint. Daily stretching is needed to prevent Achilles contracture [32]. If contracture develops, patients may no longer tolerate bracing.

Conservative treatment is recommended if there are signs of reinnervation during the course of follow-up. Even with some signs of regeneration, conservative therapy may not be successful [47]. If transection of a nerve or complete axon loss lesion is present, strengthening of the denervated muscles is not appropriate.

### 24.6.2 *Surgical Treatment*

The selection of a specific surgical technique depends on whether the lesion is in continuity and has NAPs present. Functional outcomes after reconstruction of CPN are often disappointing when compared with other frequently injured nerves. Platt and Lond recommended exploration of peroneal nerve injuries within 3–4 weeks after the injury [48]. However, 3–4 weeks can be 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, surgical exploration should be considered [41, 49, 50]. Bowman et al. supported early exploration of the nerve during ligament reconstructions as well as waiting 9 months for reexploration of the persistent nerve dysfunction in cases with continuity [51]. The duration between the trauma and surgery did not influence outcome in a retrospective study by Siedel [42].

### 24.6.3 Neurolysis

Several authors recommend early exploration and neurolysis [8, 17, 38]. Some surgeons advocate this neurolysis during the preliminary operative procedures for ligament reconstruction (Fig. 24.4) [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 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 demanding 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. The results stated that 30 of 31 patients (97%) had an improvement in neurological symptoms following exploration and external neurolysis [52]. 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 [41]. Additionally, contractility of the peroneal muscles is typically observed at 5 months following neurolysis. Tibialis anterior contraction can be seen at 12 months. Overall, the average recovery period ranged from 12 to 30 months [41]. Siedel et al. demonstrated positive functional results in 73% of patients after treatment with a similar algorithm [42].

### 24.6.4 Nerve Repair

Nerve repair is rarely indicated in stretch or avulsion injuries that may involve several centimeters of damaged nerve. However, refinement in microsurgical techniques and nerve conduction studies, as well as advancements in timing for microsurgical intervention, have led to significant improvements in outcomes, making nerve repair worthwhile in most cases [53]. Acute peroneal nerve repair would require knee immobilization, but current surgical techniques for ligament construction recommend 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.

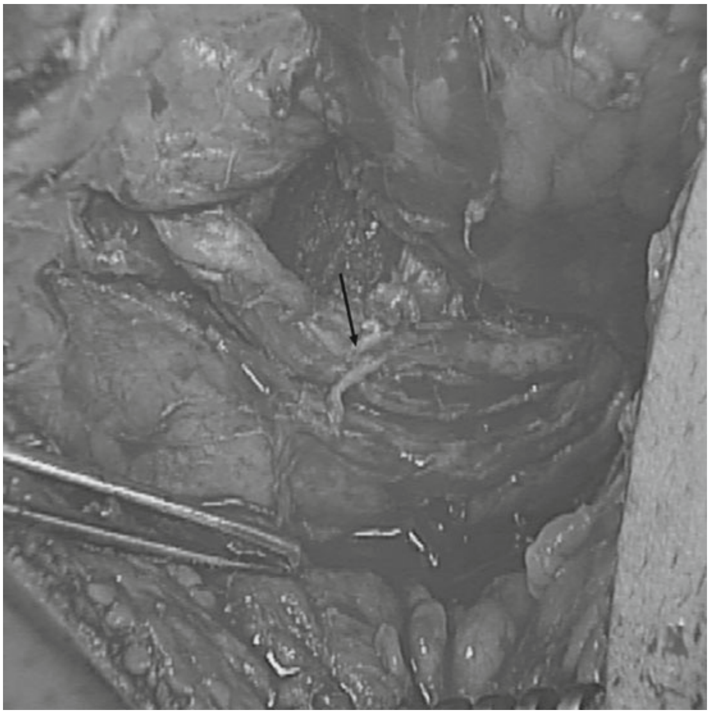


**Fig. 24.4** Exploration of nerve during ligament reconstruction. Nerve is found to be in partial continuity. *Arrow* shows damaged fascicles

showed surgical interventions performed 6 months after the index surgery had less success than earlier operations [52]. Due to the excessive length of the nerve and abundance of connective tissue, CPN repair has a poorer prognosis compared to other peripheral nerves [54, 55].

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 [56]. 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 [57].

### *24.6.5 Nerve Grafting*

When a neuroma in continuity that does not conduct NAPs across the lesion is present, 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 6 cm [41, 42, 58]. Graft length is the main predictor of outcome when grafting CPN [42].

In a group of 138 patients receiving interfascicular nerve graft repairs for grafts <6 cm long, Kim et al. reported 75% of patients had successful functional recovery. Thirty-eight percent 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 [41].

### *24.6.6 Tibialis Posterior Tendon Transfer*

Tibialis posterior (TP) tendon transfer to the forefoot is an accepted technique for the restoration of drop foot. It can be used when nerve repair is not a treatment option, when nerve function does not return after repair, or simultaneously with nerve repair to facilitate nerve recovery. Controversy exists regarding the route of transfer (circumtibial versus interosseous), type of fixation (bone insertion versus tendon-to-tendon fixation), and to which tendons the transfer will be made [59–61]. The posterior tibial tendon can be affixed to either bony structures such as the medial cuneiform or directly to the tendon of the tibialis anterior [60]. The tendon may also be split for simultaneous attachment to the peroneus longus tendon [62]. 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 [60, 63, 64].

Milesi suggested that reinnervation could be impaired by the force imbalance between the active plantar flexor muscles and the passively stretched denervated foot and finger extensors. In fact, muscle atrophy in the anterior tibialis becomes obvious within 2 weeks. Due to the excessive contraction of the Achilles tendon, the foot position becomes fixed shortly thereafter. Supporters of Milesi's theory advocate combined tibialis tendon transfer with nerve repair in a one-stage protocol in order to rebalance the forces and allow better reinnervation [54]. Garozzo et al. reported 96% of patients had evident reinnervation at EMG and 74% reported excellent or good results with TP tendon transfer combined with nerve repair with grafting or decompression [54]. Other authors advocate that nerve grafting would give better results when applied with additional posterior tendon transfer [60, 65].

## 24.7 Author's Preferred Operative Treatment

Many patients with peroneal nerve injury and residual drop foot present with previous knee ligament stabilization and neurolysis. Each patient will undergo 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 at 3 months and recovery to normal strength in the intact posterior tibial muscle, the posterior tibial tendon transfer is offered.

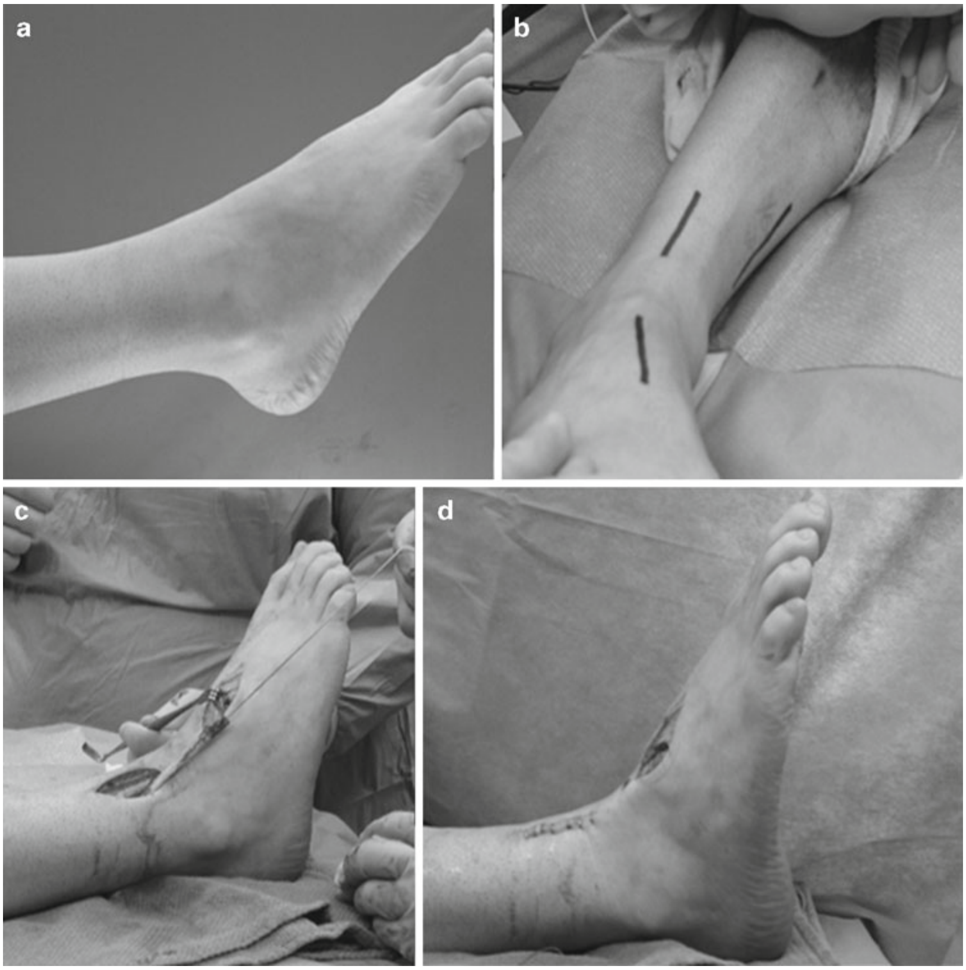


**Fig. 24.5** Tibialis posterior transfer from interosseous membrane. (**a**) Complete drop foot preoperatively. (**b**) Intraoperative view of incision plans. (**c**) TP tendon resected from the distal end and passed from the interosseous membrane. (**d**) After fixation of the tendon

The posterior tibial tendon is detached from its distal insertion on the naviculum through a medial incision on the foot (Fig. 24.5). Great care is taken to maximize the length of the tendon. The sheath in the inframalleolar region can be released through this incision. Attention is then directed along the medial calf 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 [59, 66]. Our experience suggests the tendon be transferred directly into bone to avoid creep and loss of tensioning. This is performed 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.

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 reeducation. Active dorsiflexion can be initiated as early as 6–8 weeks from the time of surgery.

## 24.8 Posttransfer Issues

Careful preoperative evaluation of the standing alignment of the foot and ankle is needed. In the patient population with preexisting valgus alignment of the hindfoot, additional considerations are needed. With transfer of the posterior tibial tendon and loss of the plantar flexion inversion force, an iatrogenic pes planovalgus deformity can progress [67]. This deformity can be prevented with additional procedures performed in conjunction with posterior tibial tendon transfer. A subtalar arthrodesis screw can be used to block valgus progression of the hindfoot. Schon et al. described its use in treatment of posterior tibial tendon dysfunction in patients treated with flexor digitorum longus (FDL) transfers. A medial displacement calcaneal osteotomy and FDL transfer can also be used when there is a posterior tibial tendon deficient deformity [68]. Osteotomies in junction with soft tissue balancing can allow for a plantigrade foot to be maintained after posterior tibial tendon transfer.

## 24.9 Conclusion

Drop foot is a common complication of knee dislocations, especially with high-velocity injuries, open dislocations, and when the PLC is involved. Surgeons should document the CPN function with every suspected knee dislocation through a thorough motor and sensory physical examination. Prospective studies documenting the treatment of CPN palsies are lacking in the literature. Thus a standardized treatment algorithm is difficult to establish. Early exploration and neurolysis are advocated during ligament reconstruction. If nerve functioning 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 6 cm in length. Posterior tibialis tendon transfer still remains the most common surgery and offers the most reliable outcomes.

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# Chapter 25
# The Role of Osteotomy

**Claude T. Moorman III and Katherine J. Coyner**

## 25.1 Introduction

Reconstruction of the multiple ligament-injured knee can be challenging due to the many factors necessary to achieve a stable, functional joint. Historically the treatment of multiple ligament-injured knees has been based solely on soft tissue constraints, which has lead to some disappointing results. Recent evidence suggests that joint alignment may be just as important in maintaining joint stability, particularly in cases of chronic ligamentous laxity. A tibial osteotomy needs to be seriously considered under these two circumstances in the patient with a multiple ligament knee injury: for chronic posterolateral rotatory instability in a patient with varus malalignment and as an adjunct to the patients with ACL/PCL deficiency. The former is managed with coronal correction of the malalignment and the latter by alterations in the tibial slope. This chapter discusses the role of osteotomy in the unstable knee as a means of ensuring success in the long-term outcome of ligament reconstructions.

## 25.2 Evaluation of Patients

### *25.2.1 History*

The ideal candidate for an osteotomy associated with an unstable knee is a thin, active individual without patellofemoral symptoms with full knee range of motion. You must consider the patients purposed activity level that they desire to return to as well as their expectations. Obesity has been associated with lower success rates after HTO because the surgical technique and postoperative immobilization are more difficult in these individuals [1]. The long-term clinical results are also worse in individuals who exceed their ideal body weight by 1.32 times [1]. A thorough history must be obtained regarding previous surgical procedures and obtaining operative reports when necessary. Patients that have had previous medial and lateral meniscectomy have disappointing outcomes [2, 3].

### *25.2.2 Examination*

Limb inspection should confirm the presence of axial malalignment. The location of previous skin incisions, which may affect the planned surgical exposure, should be noted. The ipsilateral hip function should be assessed for pain, range of motion, and degenerative changes. The neurovascular status must be assessed and documented.

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### 25.2.3 Limb Alignment

First it is imperative to define the mechanical axis, which is based on a line connecting the centers of the femoral head and the tibiotalar joint. This is measured on full-length standing radiographs. The normal mechanical axis averages 1.2° of varus. Then one must assess the ligamentous anatomy and corresponding constraint or laxity. Also the gait must be inspected for a varus and/or hyperextension thrust. Meniscal or cartilage loss of either the medial or the lateral compartment will lead to increased varus or valgus alignment, respectively.

Noyes et al. classified varus alignment of the knee into three categories: primary, double, and triple varus [4]. Primary varus refers to the overall tibiofemoral varus osseous alignment, including varus alignment secondary to the loss of medial meniscus and articular cartilage. Double varus refers to the tibiofemoral varus osseous alignment and separation of the lateral tibiofemoral compartment owing to a deficiency of lateral soft tissues. Triple varus is attributable to the combination of primary varus, double varus, and increased external rotation and hyperextension caused by posterolateral instability.

### 25.2.4 Triple-Varus Knee

In the ACL-deficient knee, varus malalignment can develop over time as a result of preexisting varus deformity, progressive medical compartment osteoarthrosis, or medial meniscal injury. As the medial compartment narrows, the weight-bearing line shifts medially, leading to primary varus. With progressive narrowing, the posterolateral soft tissue restraints become lax, leading to double varus. As the malalignment becomes more chronic, excessive lateral stress may lead to a hyperextension recurvatum deformity referred to as triple varus [5–7]. In this situation, ACL reconstruction will decrease anterior tibial translation but will not correct the underlying varus deformity, placing increased stress on the reconstructed ACL. Continued stress on the posterolateral structures will lead to increased laxity and a sensation of giving way. By combining ACL reconstruction with a valgus osteotomy, tension on the ACL can be minimized and stability enhanced. Acute injury to the posterolateral complex in combination with ACL deficiency with preexisting varus simulates a triple-varus knee. Additional injury to the posterior cruciate ligament (PCL) augments hyperextension deformity. Combined ACL, PCL, and posterolateral corner injuries can further magnify hyperextension varus and external rotational deformities. Therefore, it is important to distinguish osseous as well as ligamentous deformity prior to planning surgical reconstruction.

### 25.2.5 Posterior Tibial Slope (Sagittal Tibial Alignment)

Ultimately one must also take into account the posterior tibial slope, typically measured from a lateral radiograph with a line down the center of the tibia and a second line perpendicular to the first that sits parallel to the articular surface from anterior to posterior. Malalignment in the sagittal plane can also affect knee stability in the setting of ligamentous injury. Increased tibial slope allows increased anterior tibial translation because the femur tends to slide posteriorly along the tibial slope [8–10]. In cases of ACL deficiency, anterior tibial translation can be magnified in the presence of an increased slope. In contrast, PCL-deficient knees are stabilized by increasing tibial slope by reducing the posterior translation [11].

### 25.2.6 Unicompartmental Degeneration with Malalignment

In the chronic situation, particularly in the presence of meniscal or articular cartilage injury, chronic ligamentous laxity may present with malalignment with unicompartmental joint overload and degeneration [12]. The indication for osteotomy in these conditions may be the need to unload the degenerative compartment to help with instability or thrust. These conditions most commonly associated with chronic PCL or ACL deficiency. Therefore surgery may be staged or combined, depending on the symptomatology, age, and activity level of the patient. Numerous algorithms exist in the literature for dealing with combined knee laxity and arthrosis [12].

## 25.3 Indications for Tibial Osteotomy in the Unstable Knee

In all cases of instability, arthrosis, or combined instability and arthrosis, the need for realignment should be deliberately assessed. Varus or valgus deformity should be addressed in the coronal plane, and the need to adjust the sagittal plane or tibial slope should be determined based on the cruciate status. Indications for valgus opening wedge osteotomy include primarily pain relief and correction of mechanical axis. In the presence of unilateral medial compartmental degenerative symptoms, osteotomies have been routinely performed with good results [2, 13, 14]. More recently, however, these indications have been expanded to include posterolateral laxity and varus hyperextension thrust, ACL deficiency and varus thrust or alignment, and combined ligamentous laxity with varus of posterolateral thrust. Osteotomy has also been used when necessary to protect the medial compartment (following meniscal or cartilage transplantation/resurfacing) from excessive loading [12].

## 25.4 Operative Technique

There are many osteotomy techniques available, including tibial lateral closing wedge, tibial medial closing wedge, medial opening wedge, dome osteotomy, femoral medial closing wedge, and femoral lateral opening or closing wedge; we prefer the tibial opening wedge osteotomy. Its advantages include multiplanar correction, avoidance of the proximal tibiofibular joint and peroneal nerve, and ease of intraoperative adjustment. In the collateral ligamentously lax knee, distraction by opening wedge osteotomy may provide some tightening and improve the laxity. Disadvantages include possible need for bone graft and difficulty in correcting severe deformity. In these unstable knees, the correction required is often a mild to moderate one, from 5° to 15°, so that an acute opening wedge is acceptable.

### *25.4.1 Preoperative Planning*

Preoperative planning is essential to achieve an adequate correction with a successful outcome. The location and severity of the arthritis as well as the malalignment are determined with standing anteroposterior, lateral, intercondylar notch, and skyline patellar views. Tibiofemoral subluxation, excessive bony erosion, and diffuse arthritic involvement are associated with poorer outcomes. The mechanical axis is determined on a full-length weight-bearing radiograph from the hips to the feet. These long films can also help identify whether deformities of the tibia or femur exist and the effect that these deformities have on the overall mechanical axis.

To correct the coronal deformity we recommend using the method of measurement of correction of Dejour et al. It is used to determine the size and location of the osteotomy [15]. The width of the tibial plateau is measured and marked at 62.5% from the medial side. A line is drawn from the center of the femoral head to this mark. In a similar fashion, a line is drawn from the center of the talus to this mark. The angle that is created becomes the angle of correction. This angle is then adjusted for distraction of the tibiofemoral joint surfaces allowed by ligamentous laxity and articular cartilage deficiency. By using the understanding the slack collateral ligamentous restraint causes angular deformity, and each millimeter of tibiofemoral separation requires subtraction of roughly 1° per millimeter to avoid overcorrection (the correction factor will change depending on the actual proximal tibial width) [16].

To correct sagittal deformity, the lateral film and tibial slope are assessed. If recurvatum or hyperextension is the problem, then the wedge needs to be positioned anteromedially causing an increase in slope and obliterating the hyperextension. If anterior translation or chronic ACL deficiency needs to be addressed, anterior closing is necessary; therefore, the opening wedge needs to be as far posterior as possible to effectively decrease the posterior slope.

### *25.4.2 Surgical Technique*

The patient is positioned supine with a thigh tourniquet in place and the extremity prepped and draped. If ipsilateral iliac crest autograft is being used, this area is also prepared. A small vertical medial incision is placed over the pes anserinus insertion halfway between the tibial tubercle and the posteromedial tibial cortex, and the sartorial fascia is exposed. This fascia is incised parallel to the underlying hamstring tendons, and it is done sharply so that the fascia can be repaired when closing the wound. If the hamstrings needed to be harvested for ACL/PCL reconstruction, this can be done at this point. Otherwise the hamstrings are retracted medially, exposing the superficial medial collateral ligament (MCL). An elevator is used to release the superior portion of the MCL attachment and expose the posteromedial border of the tibia. Anteriorly, the fascia is dissected to the level of the patella tendon attachment at the tibial tubercle. Blunt retractors are placed under the MCL and patella tendon to allow adequate exposure and visualization of the osteotomy site.

Under fluoroscopic imaging, a guidewire is drilled across the proximal tibia in a medial-to-lateral direction. The guide is positioned at the level of the superior aspect of the tibial tubercle, approximately 4 cm distal to the medial joint line and orientated obliquely to end approximately 1 cm below the joint line at the lateral tibial cortex. The tip of the fibular head can be used as a reference point. The orientation of the osteotomy is marked, taking in to account any increase or decrease in tibial slope. An oscillating saw is placed on the underside of the pin and is used to begin the osteotomy through the medial and posteromedial cortex. This minimizes the risk of intra-articular fracture. Then thin flexible osteotomes are used to complete the osteotomy, ending approximately 1 cm short of the lateral tibial cortex. Frequent imaging should be performed to protect the lateral tibial cortex. Once the osteotomy is completed (the anterior and posterior cortices are penetrated), the medial opening is created with an osteotomy wedge in a slow and careful fashion to the predetermined size.

Fluoroscopic imaging is used intraoperatively to evaluate the mechanical axis and ensure it is appropriate. When the desired opening has been achieved with the appropriate correction of the tibial slope, the osteotomy is secured with either a Puddu plate (Arthrex, Inc., Naples, FL) or a Tomofix plate (Synthes) while the leg is in extension (using two 6.5-mm cancellous screws proximally and two 4.5-mm cortical screws distally). Bone grafting is often necessary and is commonly performed to ensure bony union. Autograft as well as allograft or synthetic bone matrix may be used; we also like to add the addition of platelet-rich plasma. Wounds are irrigated and closed.

The osteotomy is protected in a hinged knee brace initially non-weight bearing for 4 weeks, followed by 4 weeks of touch down weight bearing then an additional 4 weeks of 50% weight bearing. Radiographs should then be obtained, and weight bearing advanced as consolidation and union are confirmed.

## 25.5 Results

The high tibial osteotomy (HTO) has increased in popularity in the multiple ligament-injured knee for a variety of reasons. Although the procedure was once thought to be contraindicated in this setting, recent evidence has suggested that in cases of varus malalignment with ACL or PCL deficiency, good functional results can be expected. In his study on HTO in ACL-deficient knees, Noyes reported reduction of pain in 71%, elimination of giving way in 85%, and resumption of light recreational activities in 66% [6]. Dejour's earlier results demonstrated a 91% satisfaction rate; however, there was only a 65% rate of return to leisurely sports activities [15]. Both studies examined the effect of a closing wedge osteotomy in the chronically ACL-deficient knee.

In the PCL-deficient knee 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 the opening wedge osteotomy led to anterior tibial translation in the normal and ACL-deficient knee at all flexion angles [17]. They demonstrated in the PCL-deficient knee that anterior opening wedge osteotomy caused anterior tibial translation, potentially restoring normal knee biomechanics [17–19]. 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. These patients all had a posterolateral thrust corrected by anteromedial opening wedge osteotomy [11]. All these patients were young and active, returning to a higher activity level postoperatively.

Although experience with this technique is limited, early results of the correction of underlying malalignment in the setting of chronic knee instability are encouraging. In the acute setting there may also be a role for correction of malalignment; however, this has not yet been explored. The multiple ligament-injured knee represents a complicated situation in which long-term results of reconstruction have been inconsistent. In some of these cases, superimposed malalignment may be a contributing factor that should not be overlooked. The role of osteotomy in this setting has shown promising early results but will need longer term evaluation before definitive recommendations can be made.

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# Chapter 26
# Management of Chronic Tibial Subluxation in the Multiple-Ligament Injured Knee

**Travis G. Maak and Thomas L. Wickiewicz**

## 26.1 Introduction

Both single and multiligamentous knee injury may lead to chronic tibial subluxation. In addition, repair or reconstruction of the injured ligaments may not fully eliminate the potential for this tibial subluxation. While every clinical scenario in this setting is different, fundamental similarities exist that aid in effective evaluation and management. Each injured ligament complex in chronic tibial subluxation in the multiligamentous knee including the anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), posterolateral corner (PLC), and posteromedial corner (PMC) separately influences the position and subsequent impact of the subluxation on the clinical scenario.

This chapter will describe the specific role of each ligament including the ACL, PCL, PCL, and PMC as it relates to chronic tibial subluxation in multiligamentous knee injury. A detailed process of effective evaluation and management for each ligament in isolation and then as a constellation in multiligamentous knee injury will also be described.

## 26.2 Anterior Cruciate Ligament

### *26.2.1 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 exists 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].

### *26.2.2 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 risk of knee

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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 elimination of the fixed anterior tibial subluxation and restoration of normal knee kinematics. However, no data currently exists evaluating this possibility.

## 26.3 Posterior Cruciate Ligament

### *26.3.1 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 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 an abnormal tibiofemoral relationship is 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 kinemics and resultant increased pressures and concentration of loads have been associated with increased osteoarthritic changes, especially in the medial and patellofemoral compartment [12–14].

Similarly 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].

### *26.3.2 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. 26.1). 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. 26.2) [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].

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 injures 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 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 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 use of patellar tendon graft at the index reconstruction, long-standing history of PCL insufficiency, male sex, and prior PCL surgery.

**Fig. 26.1** Lateral plain radiograph in 90° of flexion. The fixed posterior tibial subluxation is demonstrated by residual posterior sag

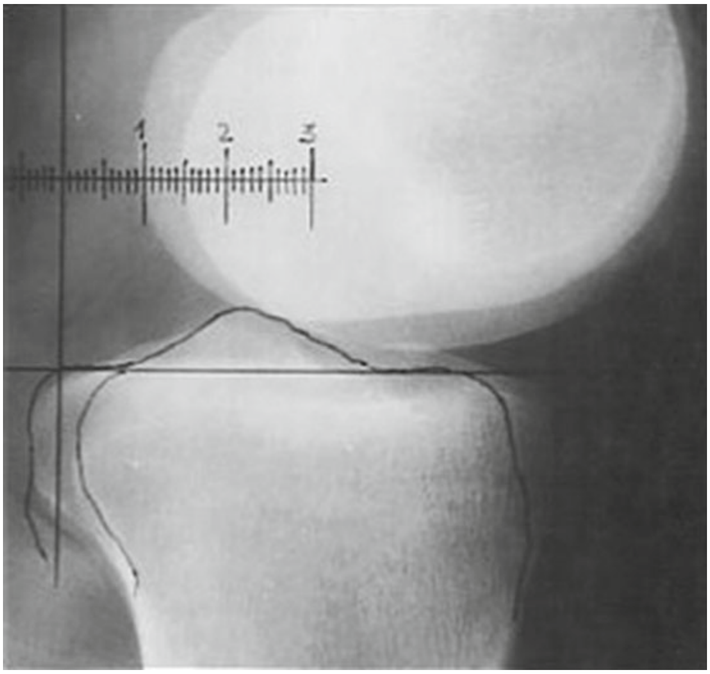

**Fig. 26.2** A posterior stress radiograph with a posteriorly directed force of a patient with a fixed posterior subluxation demonstrating posterior tibial displacement

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 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.

## 26.4 Posterolateral Corner

### *26.4.1 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].

### *26.4.2 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.

## 26.5 Multiligamentous Injury

### *26.5.1 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].

### *26.5.2 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 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 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. 26.2). 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 recent advances including the compass hinge fixator 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 has 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 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].

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 subsequent improved patient outcomes.

### *26.5.3 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 a 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

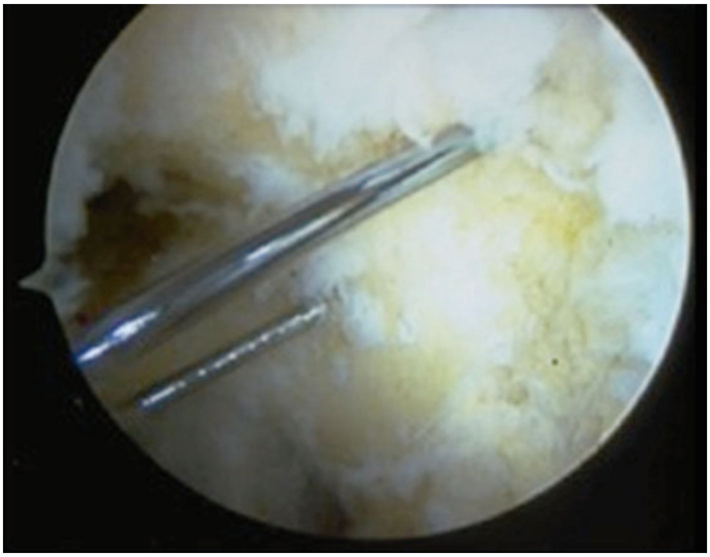

**Fig. 26.3** Arthroscopic image of the femoral double tunnel technique allowing recreation of the anterolateral and posteromedial bundles during PCL reconstruction

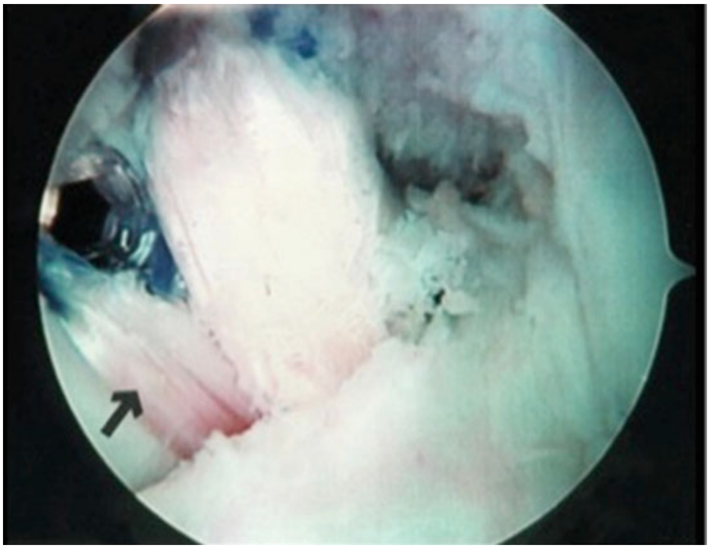

**Fig. 26.4** Arthroscopic image demonstrating the completed double bundle femoral PCL reconstruction. Tensioning of the PCL and ACL should be completed prior to collateral ligament reconstruction to provide a central axis of rotation

the tibial PCL aperture. A transtibial and femoral single drill hole technique is employed during PCL reconstruction (Fig. 26.3). 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. 26.4).

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 aforementioned reconstruction, while allowing controlled functional motion, is crucial to maintaining joint stability and reducing the inherent risk of arthrofibrosis and resultant decreased range of motion. Both bracing and external hinge fixation are reasonable options in this regard. External hinge fixation use incurs the potential risk of increased 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, the authors suggest using a hinged brace following a stable multiligament reconstruction with allowed range of motion to 120° and reserving use of the hinged external fixator to only when absolutely necessary. Nevertheless, this technique has been effectively employed previously for cases of extreme instability and to provide protection following nerve release [29]. If the decision is made that application of an external compass hinge fixator is necessary for protection of the aforementioned reconstruction, this should be performed at this time.

If this option is selected, extreme care should be used during placement of the centering pin. This pin establishes the knee axis of rotation and will function as the foundation upon with stability and functional motion is based. Centering pin placement should occur at the isometric point on both the medial and lateral femoral condyles. In order to identify the isometric point, temporary pins should be placed 3 cm distal to the joint line in the middle of the medial and lateral collateral insertions on the tibia and the fibula, respectively. Sutures can then be tied to each pin and then placed proximally on the medial and lateral femoral condyles at the perceived isometric point. The knee should then be placed through a range of motion, and the isometric point on the femoral condyles can be confirmed when the aforementioned sutures do not change in length during motion. It is at these lateral and medial isometric positions that the centering pin should enter and exit, respectively.

Following centering pin placement, the centering pin holes on the hinge fixator can then be placed over the centering pin to ensure optimal placement of the hinge based upon the previously placed centering pin. At this point, the knee should be placed in extension, and two 5.0-mm Schanz pins should be placed in the femur and the tibia through the semicircular rings on the hinge fixator. Placement of these pins will provide secure osseous fixation of the hinge fixator. The semicircular rings provide multiple options for positioning of the Schanz pins. In this fashion, the surgeon should avoid pin placement through the quadriceps muscle and extensor mechanism. Note that hinge placement should always occur with the knee in full extension. The authors have found that in vivo placement of the hinge fixator is most reproducible with the knee in full extension.

Fluoroscopy should be used throughout this procedure to confirm the adequacy of reduction of the knee throughout a range of motion from 0° to 90°. This confirmation should occur following PCL and ACL reconstruction as well as following PLC reconstruction and placement of the hinge fixator.

### *26.5.4 Postoperative Protocol*

The authors suggest that a continuous passive motion machine be used immediately postoperatively with the hinge fixator in place. The patient should remain non-weight-bearing for 4–6 weeks. The hinge fixator can then be removed at 6 weeks postoperatively. An exam under anesthesia should be conducted following removal of the hinge fixator but prior to removal of the Schanz pins or centering pin. If adequate stability and range of motion are confirmed, then the remainder of the pins should be removed. Following hinge removal, the patient may begin progressive weight bearing in a prefabricated functional ACL brace. 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.

## 26.6 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 a 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. During reconstruction the surgeon should employ 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, recreation of the central axis of the knee during ACL and PCL tunnel positioning and graft tensioning, and isometric placement of the central pin if a compass hinge external fixator is selected, postoperative stable and functional immobilization is critical to maintain knee stability and range of motion with both nonoperative and operative management. 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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# Chapter 27
# Fracture-dislocations: Evaluation and Treatment

**Andrew L. Merritt, Kyle F. Chun, and Christopher J. Wahl**

## 27.1 Overview

Multiple-ligament knee injuries and knee dislocations occur after dramatic perturbations of the knee joint and gross deformity of the tibiofemoral articulation. While these injuries may occur after high-velocity (e.g., motor vehicle collisions), low-velocity (e.g., sports injuries), or ultra-low-velocity mechanisms (e.g., a fall in a morbidly obese person), they are by definition high-energy injuries. As such, aside from the ligamentous component of the injury, there are often numerous other associated coincident injuries, including neurovascular compromise and or bony fractures of the tibia, fibula, femur, or patella. These fractures are related to the mechanism of injury and the position of the knee at that time and, as a result, some common fracture-dislocation patterns have been described. This chapter aims to review knee fracture-dislocations that have been reported in the literature and evaluate treatment strategies for these complex injuries. To aid in this goal, the chapter is divided into three different categories of fracture-dislocation. First, we will describe our preferences and principles of timing, surgical rationale, and the order of treatment. The specific associated fracture patterns are then discussed in this light. The first section reviews avulsion and marginal impaction fractures that suggest a multiligament knee injury but do not involve the main articular weight-bearing sections of the knee. These are fractures that may or may not require operative fixation but clearly must alert the orthopaedist or radiologist to the presence of a multiple-ligament injury and the potential for serious coincident neurovascular injury. The second section encompasses articular and periarticular fractures of the knee in the setting of a knee dislocation where both the fracture and the ligamentous injury must be understood and treated. These intra-articular fractures can significantly change the timing, rationale, and surgical tactic of ligament reconstruction. The third section reviews fractures that are remote to the knee but can occur with knee dislocations. These fractures will also greatly affect the planned treatment and rehabilitation.

## 27.2 Classification of Fracture-dislocations

Knee dislocations were classified in 1963 by Kennedy by position of the tibia in relation to the femur [1]. This classification is difficult to utilize clinically because most knee dislocations are reduced upon presentation and thus cannot be readily classified. More recently, Schenck described an anatomical classification that describes the ligaments and structures that are injured [2]. An injury to a single cruciate knee dislocation is described as a Knee Dislocation I (KD-I) and a bicruciate injury is a KD-II. Three ligament injuries included bicruciate tears involving medial structures (KD-IIIM) or lateral and posterolateral structures (KD-IIIL). A KD-IV injury involves all four ligaments. The classification was modified by Wascher et al. to include fracture-dislocations (KD-V) and that group was subsequently subdivided to identify the ligamentous injury associated with the fracture-dislocation (Table 27.1) [3, 4]. The KD-V classification is reserved for periarticular fractures and is not generally used for avulsion fractures or fractures remote to the knee (i.e., femoral neck or calcaneus fracture).

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**Table 27.1** Commonly used anatomic knee dislocation classification system originally described by Schenck and modified by Wascher and Stannard

| Classification | Subclass | Injury pattern |
|---|---|---|
| KD-I | | Single cruciate dislocation (associated with MCL and/or LCL/PLC) |
| KD-II | | Bicruciate injury only: ACL and PCL |
| KD-III | | Bicruciate with medial or lateral disruption |
| | KD-IIIM | Bicruciate with medial injury: ACL, PCL, and MCL |
| | KD-IIIL | Bicruciate with lateral/posterolateral corner injury: ACL, PCL, and LCL/PLC |
| KD-IV | | Bicruciate with medial and lateral/posterolateral injuries: ACL, PCL, MCL, and LCL/PLC |
| KD-V | | Knee dislocation with an associated fracture |
| | KD-V1 | ACL or PCL with associated fracture |
| | KD-V2 | ACL and PCL with associated fracture |
| | KD-V3M | ACL, PCL, and MCL with associated fracture |
| | KD-V3L | ACL, PCL, and LCL/PLC with associated fracture |
| | KD-V4 | ACL, PCL, MCL, and LCL/PLC with associated fracture |

For any class or subclass, a vascular injury is designated C and a nerve injury is designated N
From Merritt AL, W. CJ. Rationale and treatment of multiple injured knees: the Seattle perspective. Oper Tech Sports Med. 2011. Reprinted with kind permission from W.B. Saunders Co.

## 27.3 Surgical Timing, Rationale, and Order of Fixation

The nature of the multiple-ligament injured knee and coincident injuries make it such that a dogmatic approach to such injuries is not possible—the timing, extent, and nature of the repair and/or reconstructions must be weighed against several factors. These include the medical stability of the patient due to coincident other injuries or factors, the stability and surgical approachability of the soft tissue envelope, and considerations for healing of a tissue, ligament, or fracture given the stability of the kinematic environment of the knee. Obviously all fractures of necessity that carry the risk of patient morbidity or mortality are treated acutely. These include coincident long bone fractures, pelvic and acetabular trauma, spinal injuries and soft tissue injuries that are a risk for continued infection. The knee bony and ligament injury can be delayed until the patient is sufficiently medically stable.

As a general rule, the senior author (CJW) prefers to address the ligamentous injuries within 2 to 3 weeks of the trauma and not to stage the reconstructions and repairs of the multiple-ligament injured knee. This preference stems from several theoretical advantages:

- The patient avoids the need for multiple procedures.
- The injured soft tissues, repaired/reconstructed/augmented ligaments, and fractures heal in a completely restored kinematic environment, which may prevent interval loosening or abnormal stresses.
- The patient has a single and potentially shorter rehabilitation period.

The single-stage approach is possible for most patients who have been medically stabilized and after long bone fractures, if present, have been treated with intramedullary fixation. This single-stage approach is also preferred in the presence of tibial plateau fractures outside of the weight-bearing surface (tibial eminence fractures and marginal plateau variants). We consider fractures of the weight-bearing tibial plateau (Schatzker II–VI, AO/OTA 41-A2 to 41-C3) a relative contraindication to immediate reconstruction of the central pivot. In such cases, we will attempt to repair or repair and augment collateral ligament structures at the time of plateau ORIF and delay the reconstruction of the central pivot until at minimum 6 weeks following fracture fixation.

Tibial plateau fractures involving the majority of the weight-bearing surface (excepting tibial eminence fractures and marginal tibial plateau variants) are anatomically reduced and fixed acutely using standard AO principles. If it is convenient for the surgeon and will not compromise anatomic fixation or stability, the placement of intramedullary nails and metaphyseal screws and plates should be respectful of the anticipated and potential need for tibial and femoral reconstruction tunnels. However, ligamentous stability is a secondary factor to an anatomic articular surface reconstruction. There is little use in a ligamentously stable joint that will be too painful to weight-bear or a stable joint that will fail because of malalignment. In general, intra-articular fractures are addressed anatomically and braced during a 6- to 8-week recovery period during which range of motion is maintained. Ligament reconstructions are then performed around existing fixation, or some limited screw removal is performed to permit the correct tunnel placement.

When a definitive single-stage fixation of the knee is possible, the repairs generally progress in the following order:

1. Anatomic dissection of the medial and lateral collateral structures, which are tagged for identification and repair
2. Open reduction and internal fixation (ORIF) of marginal or intra-articular eminence fractures (41-A1 and marginal 41-B variants)
3. Restoration of the central pivot (anterior and posterior cruciate ligaments) by direct repair, reconstruction, or augmentation
4. Fixation, repair, and augmentation of the collateral ligament structures

## 27.4 Avulsion and Impaction Fractures that Suggest a Multiligament Knee Injury

Over 50% of knee dislocations spontaneously reduce prior to evaluation by a practitioner so radiographs of frankly dislocated knees are uncommon [5]. Most knee dislocations are reducible, and indeed, it is prudent to attempt a reduction in any setting (playing field, training room, emergency room, or clinic) immediately rather than to delay the reduction to obtain deformity X-rays. Regardless of mechanism, knee radiographs must be examined carefully for periarticular fractures that suggest a significant ligamentous injury. Moore first reported on these fractures that did not fit into standard plateau classifications and were more commonly associated with ligament disruptions [6]. Large Segond fractures, tibial spine avulsions, “reverse-Segond” fractures, tibial plateau compression fractures, fractures at the fibular head, avulsions of the popliteus, and marginal tibial plateau fractures should alert the physician of a possible reduced knee dislocation. This is important because if these fractures are overlooked, then the true extent of the injury may be missed as well as associated neurovascular injuries that are common with knee dislocations. In our experience, the rate of vascular injury associated with a multiple-ligament knee injury is 13%. Neurologic injuries, specifically those involving the common peroneal nerve, occur in 23% of injuries [7]. These are consistent with the existing literature on the subject, which suggest a vascular injury rate of 7.5–14% and neurologic injury rate of 14–25% [8–11].

Large Segond fractures, tibial spine and PCL avulsions, “reverse-Segond” fractures, tibial plateau compression fractures, fractures of the fibular head, avulsions of the popliteus, and marginal tibial plateau fractures are all associated with ligamentous injuries. Treatment goal of these knee fracture-dislocations is to regain stability of the knee joint and avoid stiffness. Since these fractures are generally part of the instability, they can be repaired primarily, if indicated, along with the ligamentous reconstruction. Primary repair of avulsion fractures is advocated in the literature [12–14]. Segond fractures and marginal tibial plateau fractures can also be fixed by ORIF at the time of ligamentous reconstruction if indicated. When avulsions are fixed with primary repair, they may need to be backed up with a supplemental reconstruction [7]. Since these fractures are part of the stability surgery, they do not need to be planned in a staged reconstruction like some periarticular fractures of the femoral condyle or the articular weight-bearing portion of the tibial plateau [7].

Segond fractures are bony avulsions off of the tibia just distal to the lateral tibial plateau. They were described originally by Segond in 1879 as a result of excessive varus and internal rotation [15]. They have since been associated with significant knee derangements including ACL tears, meniscal tears, injury to the posterolateral corner, and other ligamentous injuries (Fig. 27.1) [6, 16–21]. They are most commonly associated with ACL tears with incidence reported in literature of 75–100%. Any patient with a Segond fracture in the trauma setting should be evaluated for a multiple-ligament knee injury with special attention to a detailed vascular examination. Avulsion fractures at the tibial insertions of the ACL and PCL are common and can be associated with multiple-ligament knee injuries (Fig. 27.2). One case report identified a tibial spine fracture as part of a complex knee dislocation that included tears of the PCL and MCL, and extensor mechanism rupture [22].

Our preference is to treat Segond fractures in the acute and semi-acute setting (2- to 6-week post-injury). After dissection of the lateral aspect of the knee, the iliotibial band (ITB) can be split along its fibers to the region of Gerdy’s tubercle down to the avulsed segment. There is usually obvious hematoma at the distal ITB with some disruption of the ITB fibers as well as the small bony avulsion fragment. When approached within the first 2 to 3 weeks, large (>2 cm) avulsion fragments can be reduced and repaired using standard AO principles and lag screw fixation with or without a small washer plate (see Fig. 27.1). Small bony avulsions are freshened along the undersurface with a motorized shaver and reduced using a suture anchor tied over the capsular/ITB structures. After 6-weeks post-injury, unrepaired capsular structures generally shorten and the tissue can become diminutive. Anatomic reduction can become difficult or impossible after this time. Upon exploration, if significant stripping of the capsular structures persists, it can be repaired in situ using suture anchors.

Avulsion fractures off of the medial tibia plateau have been termed “reverse-Segond” fractures and are associated with meniscoligamentous derangements of the knee. Moore noted this “rim avulsion fracture” to be present on the medial side in only one patient of his 132 patient series and Hall and Hochman described the medial lesions in association with a combined PCL, MCL, and medial meniscus tear [6, 23]. This fracture has been thought to be due to valgus and external rotation forces of the flexed knee and therefore has been linked the combined PCL and MCL injuries [23, 24]. Two patients with this radiographic finding have been reported as having combined PCL/ACL/MCL (KD-IIIM) injuries, with one also sustaining a medial meniscus root avulsion [24, 25]. Another case report of the “medial Segond” fracture was associated with a combined PCL/ACL/LCL/PLC (KD-IIIL) injury [26].

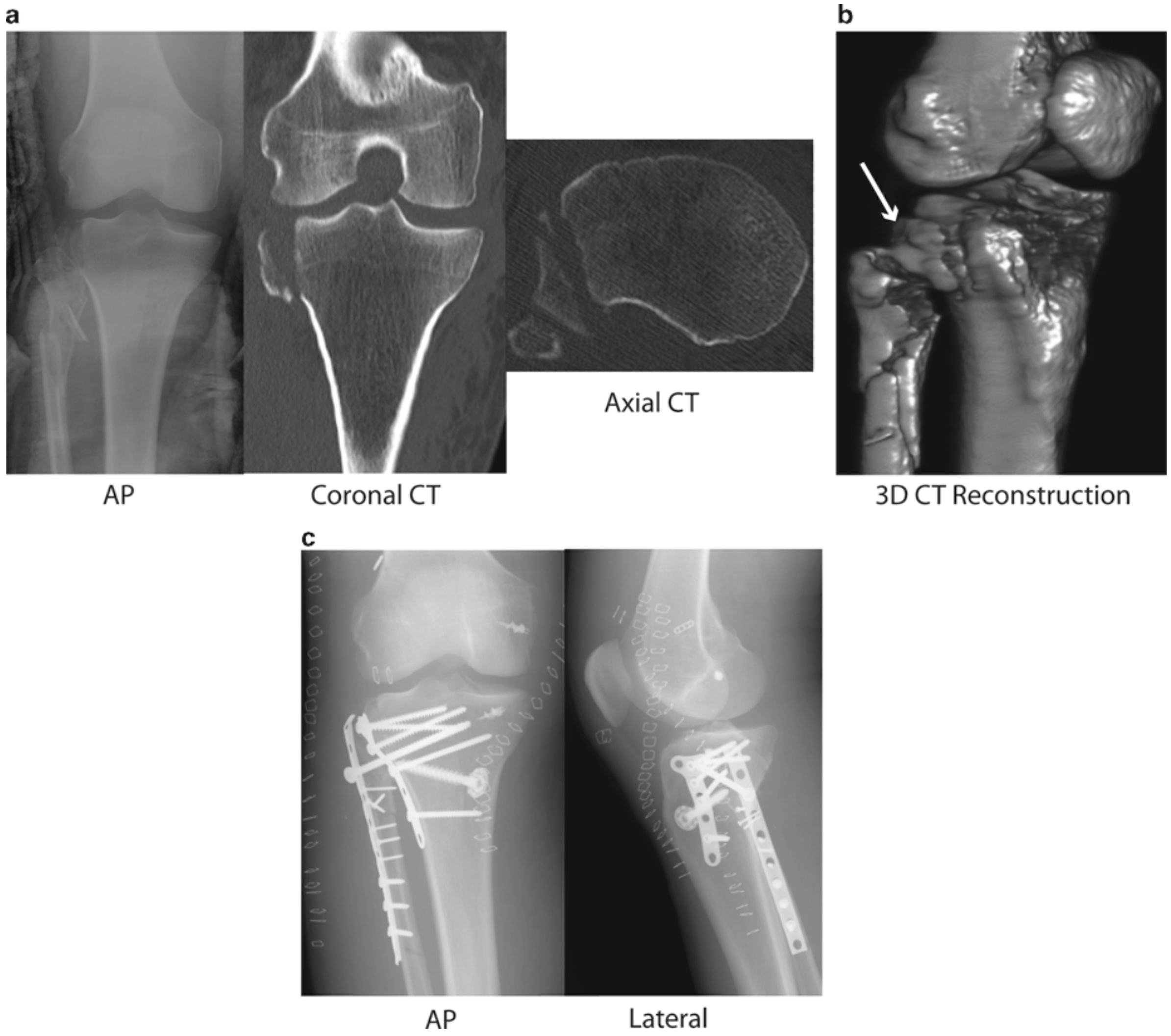


**Fig. 27.1** Large Segond fracture and fibular head fracture. A 68-year-old male who sustained a knee dislocation after a motorcycle accident with complete tear of the ACL, MCL, and LCL/PLC and an incomplete tear of the PCL. The initial X-ray/CT interpretation was "Schatzker II tibial plateau fracture." (**a**) AP X-ray and coronal and axial CT suggest that the injury is in fact a massive Segond fracture with a comminuted fibular head and neck. (**b**) 3D CT of the same injury. In this injury the insertions of the LCL, biceps femoris, and iliotibial band are all fractured and no longer in continuity with the tibia and central pivot. This fracture pattern is characteristic of *de facto* ligament compromise. (**c**) The Segond fracture and the comminuted fibular head and neck fracture were treated with open reduction and internal fixation. He also underwent an ACL reconstruction, MCL repair and augmentation, and repair of the LCL and PLC, and lateral meniscus repair

The 'reverse-Segond" pattern can be part of any spectrum of medial-sided injuries that can include: intrasubstance tears of the superficial, deep, and/or posterior oblique fibers of the medial collateral ligament; extensive "stripping" injuries in which the collateral and musculo-ligamentous structures are avulsed en masse from the skelatonized proximal tibia, or smaller bony avulsions of the deep MCL insertions. In our experience, soft tissue skeletonization off the tibia has been more common than the "reverse-Segond" lesion. In the acute setting, the stripped medial structures can be easily anatomically dissected through an anteromedial approach and repaired anatomically using suture anchors or screws with soft tissue washers (Fig. 27.3).

The tibiofemoral deformity during dislocation can expose the plateau to compression resulting in impaction fractures [6, 27–29]. These are not avulsion fractures and the mechanism is thought to be very different. These fractures are compressive fractures resulting from a hyperextended knee undergoing loading (see Fig. 27.4). Moore described equal incidence between the medial and lateral side in his 16 patients with rim compression fractures [6]. These fractures are associated with PCL and PLC/LCL injuries, but one case report also had an intrasubstance ACL injury resulting in a KD-IIIL knee dislocation [28]. Impaction fractures of the posteromedial tibial plateau have also been described and are associated with ACL and medial meniscus tears [30, 31]. This is not a semimembranosus avulsion, as once believed, but an articular impaction fracture from medial compartment anterior subluxation after an ACL tear.

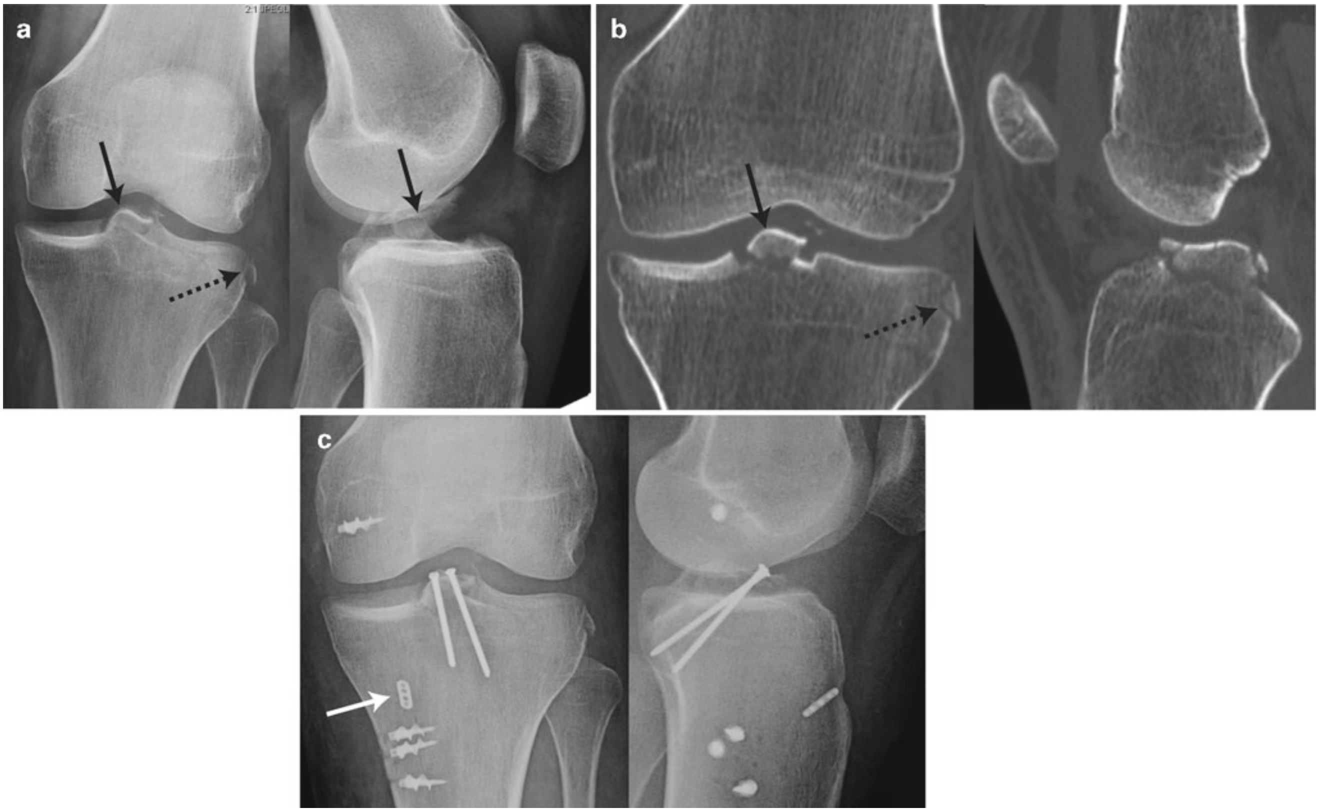


**Fig. 27.2** Tibial spine avulsion fracture. An 18-year-old male who sustained a multiple-ligament knee injury after a fall from height. He had a tibial-sided ACL avulsion fracture and complete disruption of the medial structures with avulsion off of the tibial insertion. (**a**) AP and lateral X-rays demonstrating the tibial spine fracture (*solid arrow*) and the Segond fracture (*dotted arrow*), both signs of an ACL disruption. (**b**) Coronal and sagittal CT scan of the same knee demonstrating the tibial spine fracture and the Segond fracture. (**c**) After fixation of the tibial spine fracture and reconstruction with supplemental augmentation of the medial side of the knee. Two different techniques were used to fix the tibial spine fracture: first, screw fixation was used to hold the fracture fragment in place and then Krakow sutures were placed into the ACL and were tunneled through the anterior tibia and tied over a washer (*white arrow*). The medial avulsion was repaired using corkscrew anchors

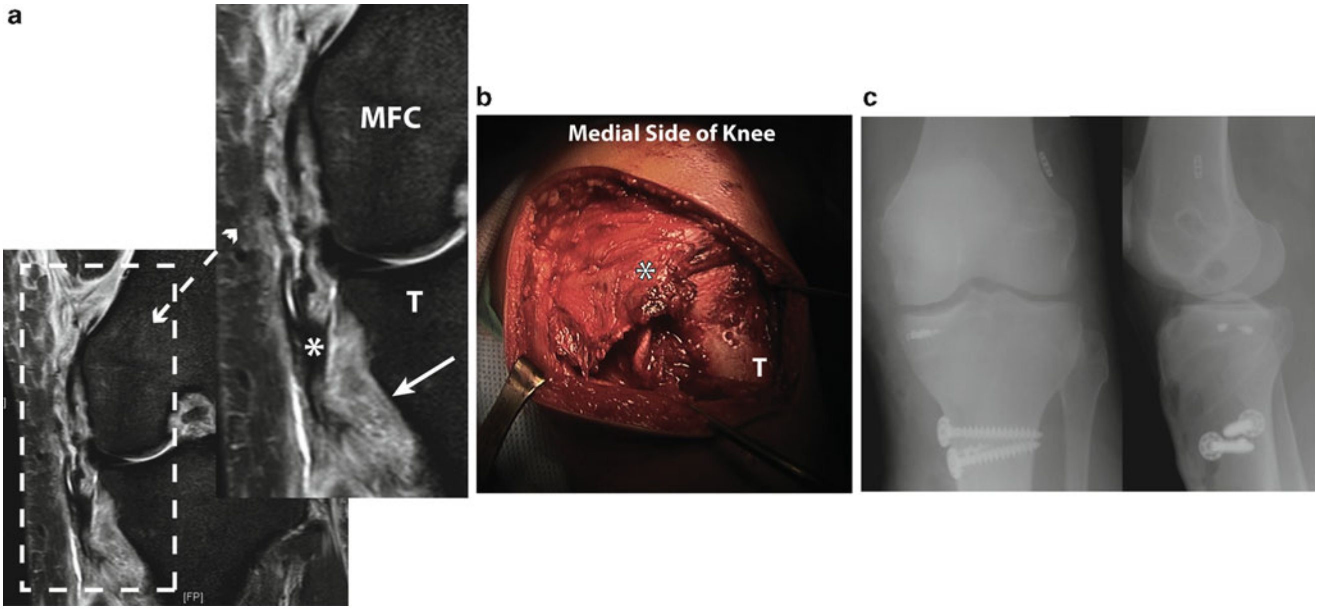


**Fig. 27.3** Complete tibial-sided medial avulsion. A 30-year-old male with a KD-IV injury to his left knee with complete avulsion of the medial tibial structures. In our practice this pattern is more common than the "reverse-Segond" fracture, but they are structurally equivalent. (**a**) Coronal MRI of the knee with a zoomed in portion of the medial side of the knee showing the medial femoral condyle (MFC) and the tibia (T). The MCL, pes anserinus, and periosteum of the medial tibia pulled off the tibia (*arrow*) as one unit and retracted proximally (*asterisks*). (**b**) An intraoperative picture of the medial side of the knee demonstrating a completely skeletonized medial tibia (T) and the retracted medial structures (*asterisks*). (**c**) He underwent a single-stage ACL and PCL reconstruction, an MCL repair by fixing the retracted mass back to the tibia with two screws and washers, an MCL augmentation to reinforce the repair, an LCL and PLC repair and augmentation, and a medial meniscal root avulsion repair

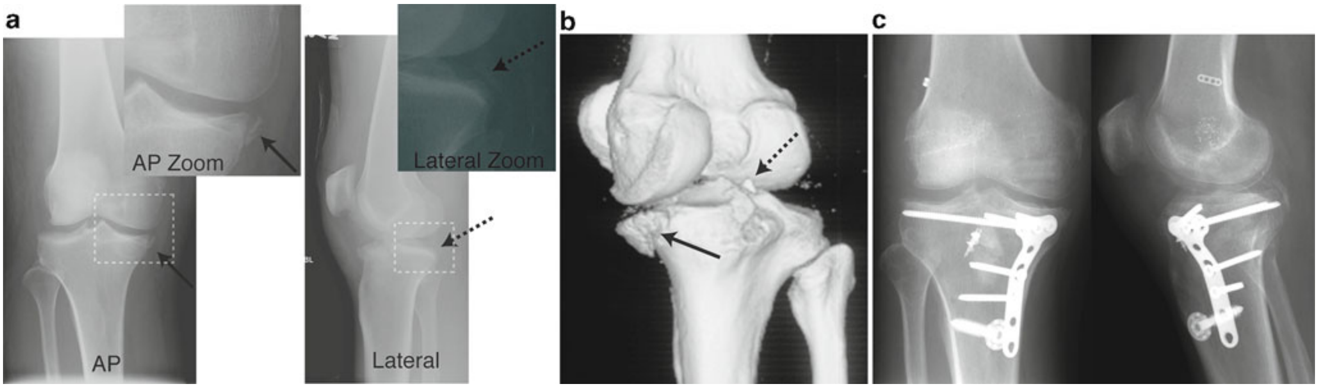


**Fig. 27.4** Marginal tibial plateau fracture. A 38-year-old male involved in an equestrian accident and sustained a knee dislocation and complete tears of the ACL, PCL, MCL, and LCL/PLC and a tear of the medial meniscus. (**a**) The only radiographic findings of this four-corner injury were a marginal tibial plateau fracture (*solid arrow*) and a PCL avulsion (*dotted arrow*). (**b**) 3D CT of the same injury. This is a fracture pattern consistent with a knee dislocation. (**c**) After ligamentous reconstruction and ORIF of the marginal plateau fracture. Note the spread of the subchondral screws to allow the tibia ACL tunnel to pass without obstruction

We prefer to treat such fractures acutely at the same time as the ligamentous reconstruction. After anatomic elevation of the depressed subchondral surface, small buttress or "washer" plates are used with small-diameter cortical screws placed in a manner to act as "joists" immediately under the subchondral surface (see Fig. 27.4). The screws are placed to avoid interference with the anticipated anterior or posterior cruciate ligament tunnels. This is usually possible if screws are "fanned" or directed either anteriorly or posteriorly to anticipated reconstruction osseous tunnels placement in an interval between screws.

Alternatively, bony compression fractures of the distal femoral articular surface have been described [32]. These impaction fractures result from abnormal loads placed across the dislocated joint most commonly with an ACL tear and joint subluxation (Fig. 27.5). When these impactions are small or on the periphery of the weight-bearing surface, they are left alone. Defects with greater than 1-cm depth can often be treated with "retrograde disimpaction" in the acute setting. We have performed this according to the technique described by Sadlo and used an ACL reamer to create a small bone tunnel from extra-articularly to just deep to the subchondral bone of the impaction defect [33]. Placing an oversized interference screw into the drilled tunnel pushes out the subchondral bone and can then restore the defect (see Fig. 27.5). The screw is removed and bone graft packed into the tunnel.

The lateral collateral ligament, biceps femoris tendon, and popliteofibular ligament all have insertions into the fibular head. The LCL and the popliteofibular ligament are critical stabilizers of the knee to external rotation and varus. Avulsions of these ligaments or fractures of the fibular head can represent instability of the lateral side and posterolateral corner of the knee. Avulsions of the fibular head have been called the "arcuate sign" and are seen on AP radiographs as a sleeve of bone pulled away from the fibular head (Fig. 27.6) [34, 35]. This finding is consistent with posterolateral instability [34, 36]. Relating the size and location of the fibular head avulsion on radiographs can help to identify the involved structures because the LCL, popliteofibular ligament, biceps, fabellofibular, and arcuate ligaments insert at different places on the fibular head [35]. Larger avulsions and comminuted fibular head fractures may indicate that the injury may include the LCL, popliteofibular ligament complex, and biceps femoris insertion. It is not uncommon for the entire complex including the popliteofibular ligament, lateral collateral ligament, and biceps insertion to avulse en masse from the fibula without a bony injury, so even a fleck avulsion does not exclude the possibility of a remarkable lateral injury involving all structures. More comminuted fractures of the fibular head lead to the same instability pattern, and concern for an underlying multiple-ligament knee injury should be maintained. These fractures make the reconstruction far more challenging. Popliteus avulsions have been reported as a result of external rotation in slight flexion and can occasionally be seen on plain AP radiographs [37].

Large avulsed fragments of the proximal fibula can occasionally be repaired using screw fixation, but the screw and fracture site can make augmentation to the reconstruction challenging (Fig. 27.7). In some cases, the surgical goal may be to establish a repair only with the intent of resorting normal bone anatomy and stock for delayed augmentation if loosening develops. When irreparable comminution involving small fragments of the proximal fibula is encountered, the tissues connected to the comminution can be sutured individually or en masse using #2 Krakow sutures. The sutures can be repaired to a bone tunnel in the proximal fibular metaphysis. When a complete loss of proximal fibular anatomic congruity is lost, we prefer to perform open reduction internal fixation of the proximal fibula, repairing the avulsed structures to a stoutly repaired construct (see Fig. 27.1).

Tibial eminence fractures are normally indicative of injury to the ACL and/or PCL as well as almost certain disruption to some or all of a meniscal root. When the fracture does not extend extensively into the plateau weight-bearing surface and the articular plateau remains in continuity with the metaphyseal and diaphyseal bone, we prefer to treat the eminence fractures

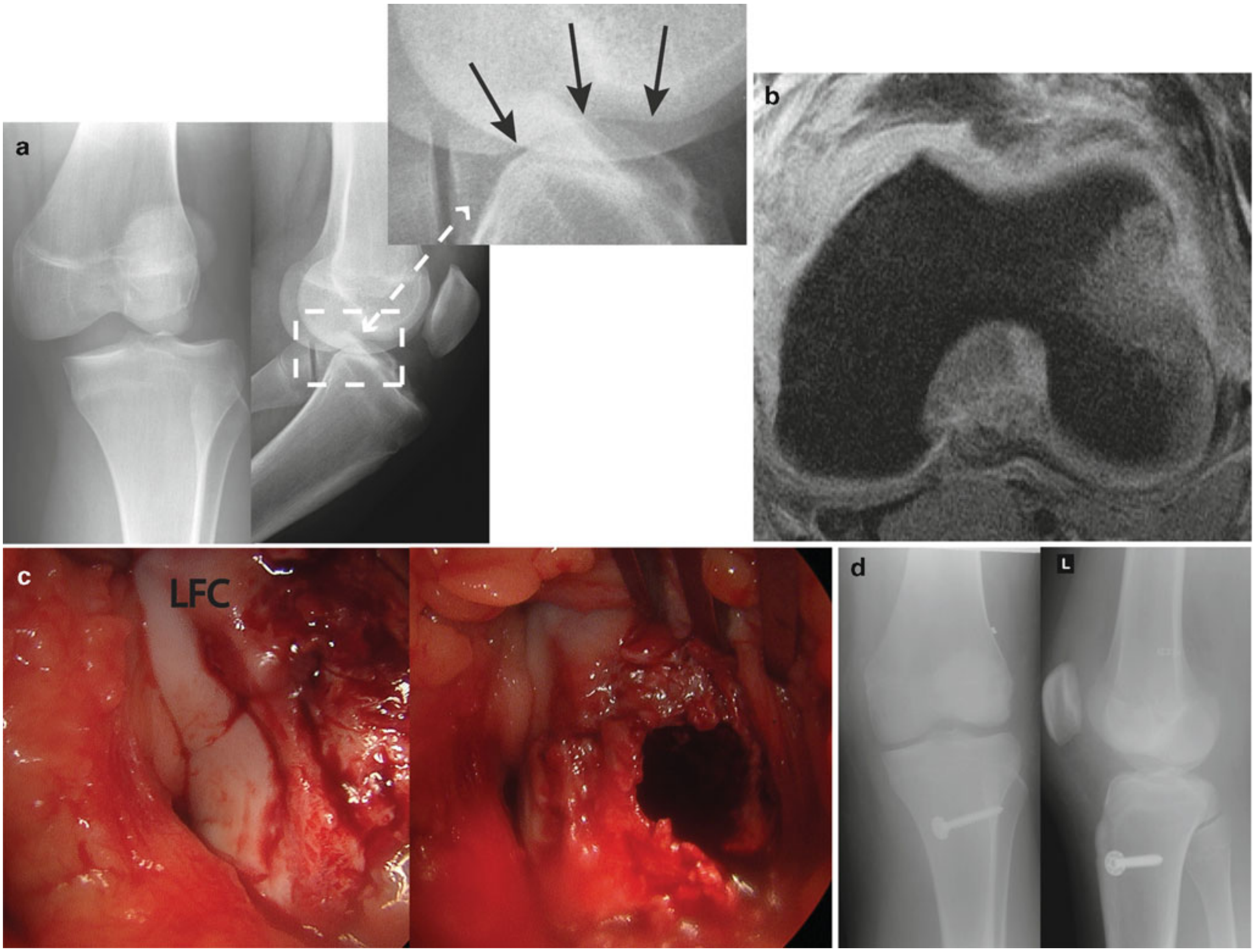


**Fig. 27.5** Femoral condyle impaction fracture. A 17-year-old male who sustained a knee dislocation with a complete ACL and MCL tear, attenuation of the PCL, tear of the medial patellofemoral ligament, and an impaction fracture of the lateral femoral condyle. (**a**) AP and lateral X-rays of the dislocated knee with a zoomed in portion showing impaction of the lateral femoral condyle on the posterior tibial plateau. (**b**) An axial CT scan showing the impaction of the tibial lateral femoral condyle. (**c**) Intraoperative photographs of the lateral femoral condyle (LFC) showing abnormal concavity due to the impaction (*left frame*). The fracture was disimpacted using an oversized interference screw that was subsequently removed (*right frame*). The void left by the removed screw was subsequently filled with bone graft leaving a more normal convexity to the condyle. (**d**) Final X-rays

acutely along with collateral ligament repair. Such repairs can be performed arthroscopically, but when significant disruption to the lateral or medial anterior meniscal root is also present, a small arthrotomy and anatomic ORIF using mini-fragmentary lag fixation can be performed. For small avulsion fragments, Krakow sutures can be placed arthroscopically through the ligament and tensioned through small bone tunnels entering the joint in the footprint of the avulsed structure (see Fig. 27.2).

## 27.5 Articular and Periarticular Fractures that Are Associated with Knee Dislocations

Knee dislocations associated with severe fractures of the distal femur or proximal tibia represent a very different problem than avulsion and marginal impaction fractures. These fractures are high energy in nature and require surgical management of the fracture independent of the stability procedure. Despite appropriate management of the fracture and the ligamentous injury, functional outcomes are reported to be worse than isolated ligamentous knee dislocations. These fractures include supracondylar femur fractures, femoral condyle fractures, tibial plateau fractures, and tibial metaphyseal fractures. The treatment of these fractures at the same time as the ligamentous reconstruction is controversial with authors recommending both a single operation and a staged approach.

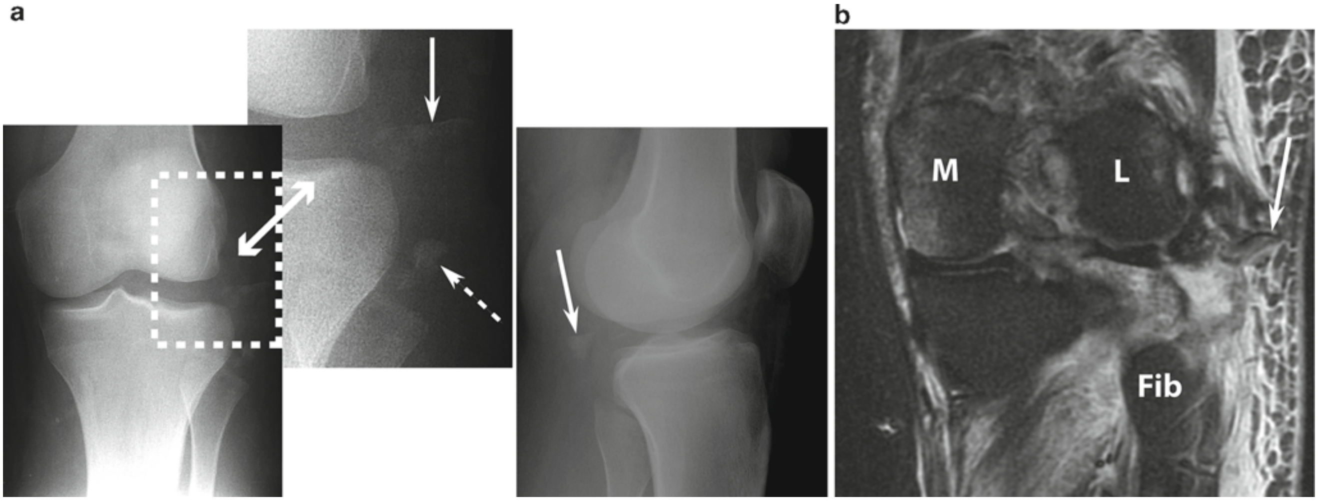


**Fig. 27.6** Fibular head avulsion fracture (arcuate sign). A 22-year-old female who was struck by a car and sustained a knee dislocation with complete tears of the ACL and PCL, and distal avulsions of the LCL, biceps femoris, and the popliteofibular ligament. (**a**) AP and lateral X-ray of the left knee with a zoom in on the lateral side of the knee (*dotted box*). There are two avulsion fractures from the fibular head. The LCL and biceps femoris are attached to the larger fragment that is retracted proximally (*solid arrow*), and the popliteofibular ligament is attached to the smaller fragment (*dotted arrow*). (**b**) A single coronal slice of an MRI demonstrating the fibula (fib) and displaced larger fragment (*arrow*). She required reconstruction of the ACL and LCL/PLC, but the PCL tightened up prior to surgery and did not require any reconstruction

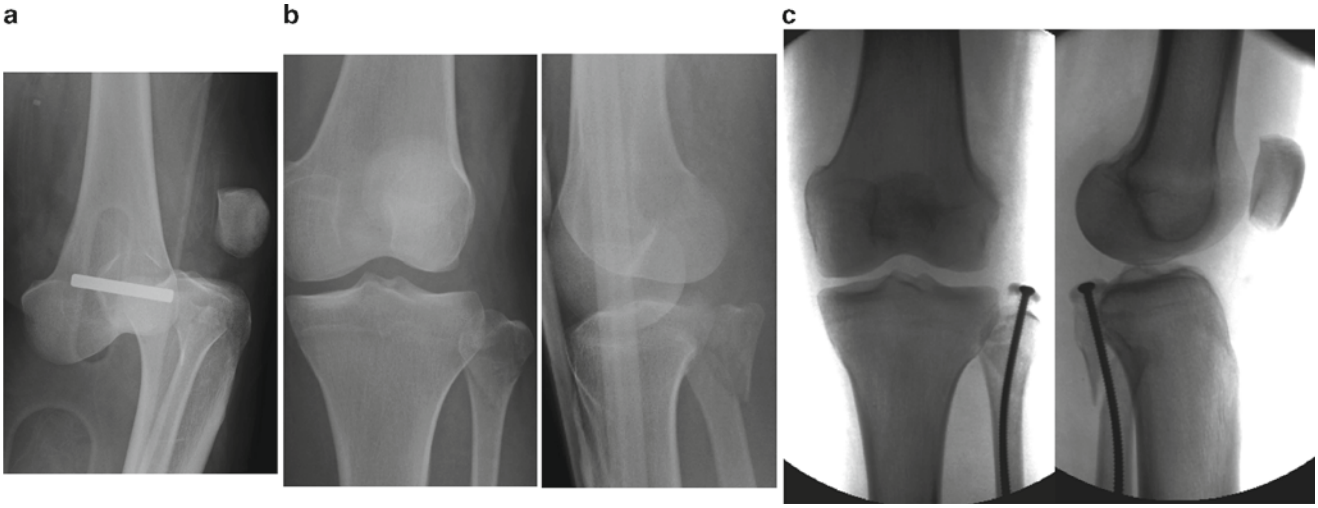
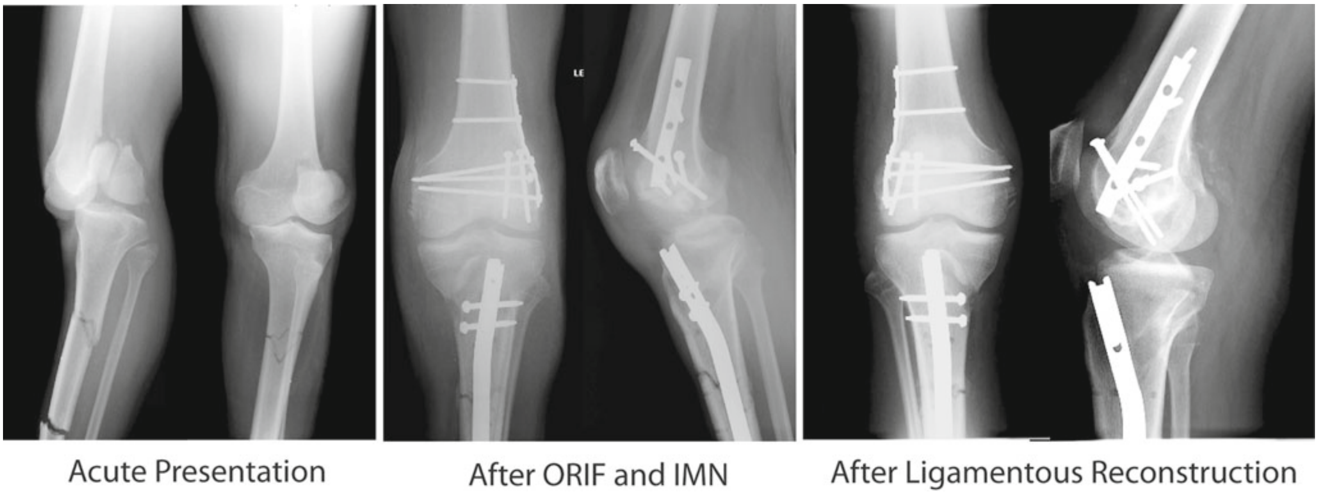


**Fig. 27.7** Fibular head fracture. A 19-year-old female with bilateral KD-IV knee dislocations and bilateral popliteal artery lacerations. Her left knee had a large fibular head fracture that was able to be fixed with open reduction and internal fixation using a large intramedullary screw. (**a**) Dislocated X-ray. (**b**) After reduction demonstrating the fibular head fracture. (**c**) After ORIF of the fracture

## 27.6 Femoral-Sided Fracture-dislocations

Supracondylar femur fractures have been reported to be associated with ligament injuries of the knee, but we are unaware of any specific reports of associated supracondylar fractures and knee dislocations. ACL injuries are the most common associated ligament injury, and Siliski et al. reported 8 ACL tears, 1 PCL, and 1 LCL with no multiple-ligament knee injuries [38, 39].

Femoral condyle fractures have been associated with knee dislocations in the literature. Schenck first reported 4 femoral-sided fracture-dislocations and noted that in 2 cases, the PCL remained attached to the medial femoral condyle fragment [40]. They found that ORIF of the medial condyle stabilized the PCL. Unfortunately, these patients had only fair to good results with limited range of motion. The authors recommended a single-stage operation but acknowledged that this approach is debatable. The “Hoffa” fracture is associated with extensor mechanism disruption because the mechanism is usually a posterior-directed force of a flexed knee causing shearing of the femoral condyles by the tibial plateau. In one case, the rup-



Acute Presentation

After ORIF and IMN

After Ligamentous Reconstruction

**Fig. 27.8** Femoral-sided fracture-dislocation. X-ray series of a 27-year-old male involved in a high-speed MVC. This patient was treated with ORIF of the distal femur fracture and IMN of the tibia. Three and a half weeks later he was taken back to the operating room for his PCL and LCL/PLC reconstruction. He subsequently developed a deep infection that required two irrigation and debridements with long-term antibiotics. Since this time, we have changed the treatment strategy for intra-articular fractures. We now wait until at least 6 weeks after ORIF for the reconstruction, and our infection rate had dropped precipitously. (From Merritt AL, Wahl CJ. Rationale and treatment of multiple injured knees: the Seattle perspective. Oper Tech Sports Med. 2011. Reprinted with kind permission from W.B. Saunders Co.)

tured extensor mechanism became incarcerated behind the fractures lateral femoral condyle causing an irreducible fracture-dislocation (KD-V2). Case reports suggest that stiffness is a greater problem than stability in distal femur fracture-dislocations. As a result, some have recommended nonoperative management of the ligamentous injuries or a staged approach with ligamentous reconstruction only after healing of the fracture and regaining range of motion [7, 40, 41]. The authors have previously reported a 75% infection rate when intra-articular fractures were treated simultaneous or in close time frame to ligamentous reconstruction and have abandoned this approach for a staged procedure with better results [7]. This increased infection rate is thought to be due to higher energy trauma in fracture-dislocations, more soft tissue injury, and more extensive surgery when treated in one stage (Fig. 27.8). Whether a single or staged approach is used, the recommended treatment for femoral condyle fractures is anatomic reduction with perpendicular lag screw fixation [42]. This can be arthroscopically assisted but is generally performed through an open parapatellar approach [42–45].

## 27.7 Tibial-Sided Fracture-dislocations

Tibial plateau fractures have long been associated with ligamentous knee injuries [14]. Schatzker initially identified only 7.4% of plateau fractures as having a ligament injury, but since then it has been reported that ligament injuries occur in 20–50% of plateau fractures and in all fracture types [14, 46–49]. Isolated depression and split-depression fractures were most commonly associated (Table 27.2). While the literature most often reports plateau fractures with single ligament injuries, they do occur with true knee dislocations (Fig. 27.9).

The first large study evaluating tibial plateau fracture characteristics in knee dislocations was performed by Tillman M. Moore in 1981 [6]. In this landmark study he classified 132 fracture-dislocations of the tibial plateau into five different patterns (Fig. 27.10). Two of the types he described (Type 3 and Type 4) are marginal plateau fractures and are discussed in the previous section. The remaining three types are:

Type 1: A split fracture of the posteromedial plateau that leaves the anterior medial plateau in place but displaces the posteromedial fracture fragment distally. This fracture enters into the tibial spines and can even cross the entire tibial eminence and originate in the lateral compartment. This was the most common fracture pattern he reported and found that 58% of these fractures had a ligamentously unstable knee.

Type 2: A fracture of the entire medial or lateral tibial plateau that originates in the opposite compartment and undercuts the tibial eminence. This is equivalent to ligament rupture of one or both of the cruciates. He noted that 60% of these fracture patterns were unstable, and some were associated with avulsions or ruptures of the lateral ligaments of the knee (Fig. 27.11).

**Table 27.2** Incidence of soft tissue injury based on tibial plateau fracture pattern

| | | Schatzker classification (no. fractures) | | | | | |
|---|---|---|---|---|---|---|---|
| | | I | II | III | IV | V | VI |
| Soft tissue pathology | | (*n*=3) | (*n*=62) | (*n*=0) | (*n*=7) | (*n*=17) | (*n*=14) |
| Collateral ligaments | Complete LCL tear | 33 | 18 | – | 57 | 35 | 57 |
| | Partial LCL tear | 67 | 53 | – | 43 | 35 | 21 |
| | Complete MCL tear | 0 | 36 | – | 29 | 24 | 36 |
| | Partial MCL tear | 33 | 48 | – | 57 | 77 | 64 |
| Cruciate ligaments | ACL footprint avulsion | 67 | 42 | – | 57 | 71 | 57 |
| | ACL partial tear | 33 | 29 | – | 29 | 64 | 64 |
| | ACL complete tear | 0 | 15 | – | 14 | 7 | 7 |
| | PCL footprint avulsion | 67 | 15 | – | 29 | 35 | 14 |
| | PCL partial tear | 33 | 45 | – | 43 | 35 | 57 |
| | PCL complete tear | 0 | 10 | – | 29 | 0 | 0 |
| Posterolateral corner | Popliteofibular ligament tear | 100 | 52 | – | 57 | 41 | 79 |
| | Popliteus tendon tear | 0 | 16 | – | 14 | 12 | 0 |

–, data not available

Modified from Gardner MJ et al. The incidence of soft tissue injury in operative tibial plateau fractures: a magnetic resonance imaging analysis of 103 patients. J Orthop Trauma. 2005;19(2):79–84 with permission from Wolters Kluwer Health

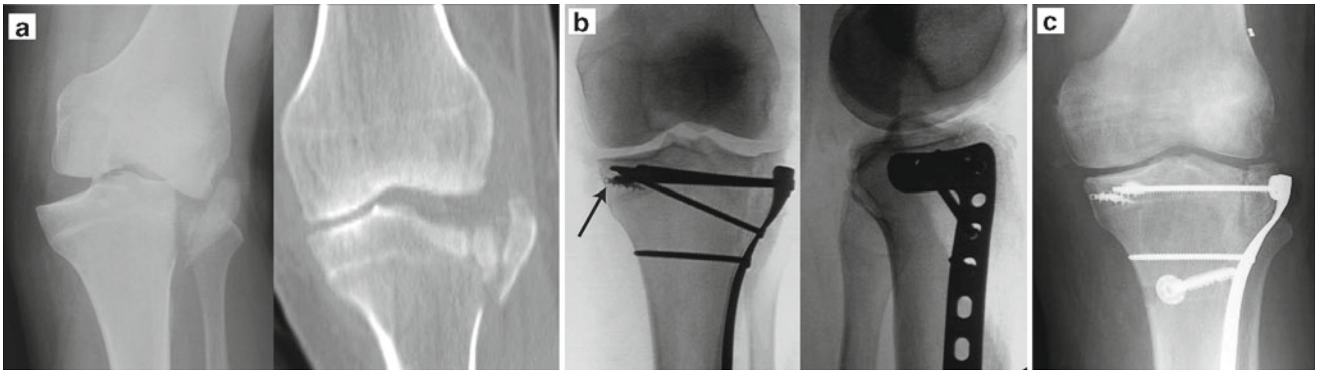


**Fig. 27.9** Tibial plateau fracture-dislocation. A 57-year-old male involved in a motorcycle accident who sustained a knee dislocation with a split-depression (Schatzker Type II) tibial plateau fracture and complete tears of the ACL and PCL, and a tibial-sided avulsion of the MCL. (**a**) AP X-rays and a coronal CT demonstrating a comminuted lateral split-depression tibial plateau fracture. (**b**) He underwent ORIF of the tibial plateau and primary repair of the MCL using a corkscrew anchor (*arrow*). (**c**) He was subsequently referred to our practice 8 months later with knee stiffness (ROM 10–85) but valgus and anterior/posterior laxity and subjective instability. We have termed this difficult situation a FLASCId knee (Flexion Loss with Axial, Sagittal, and/or Coronal Instability following dislocation). We subsequently performed a manipulation, debridement of scar tissue in all compartments, excision of heterotopic ossification, MCL reconstruction, and ACL reconstruction. We did not perform a PCL reconstruction to decrease the risk of recurrent arthrofibrosis. The ROM increased only slightly (3–90°) postoperatively, but his subjective feeling of instability completely resolved despite continued Grade B posterior drawer

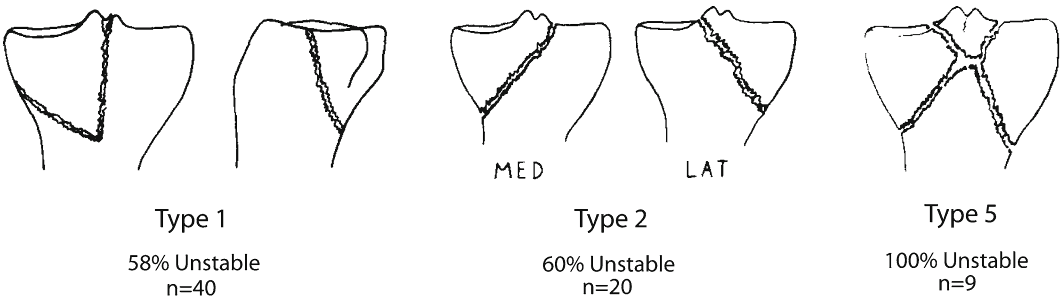


**Fig. 27.10** Common tibial-sided fracture-dislocations modified from Moore's 1981 article. In his description, Type 1, Type 2, and Type 5 fractures were described as involving the weight-bearing portion of the joint. Included are the number of these fractures he evaluated in his series and the percent that were identified as having instability. (From Moore TM. Fracture-dislocation of the knee. Clin Orthop Relat Res. 1981;(156):128–40. Reprinted with permission from Wolters Kluwer)

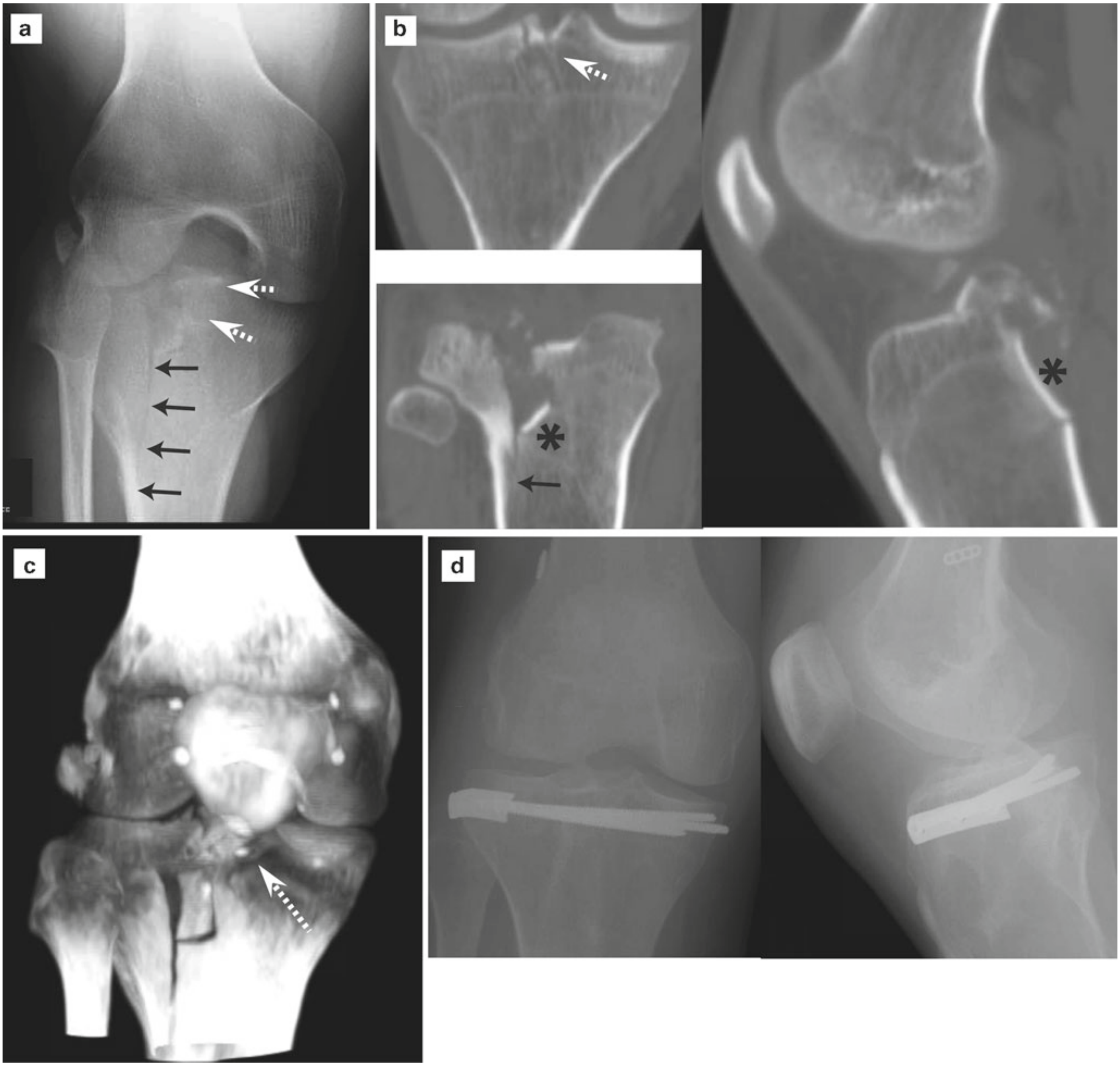


**Fig. 27.11** Moore Type II fracture dislocation. A 29-year-old male who sustained a noncontact twisting injury to his knee during soccer. The lateral tibial plateau fracture involved the tibial eminence and extended to the lateral side of the medial compartment. This is equivalent to a Moore Type 2 fracture-dislocation. His injuries included this minimally displaced fracture, impaction of the metaphysis posteriorly, an ACL tear, an MCL tear, a partial tear of the popliteus, a medial meniscus tear, and a bucket handle lateral meniscus tear. (**a**) AP X-ray demonstrates the condylar fracture extending distally (*solid arrow*) and the extension into the medial aspect of the tibial eminence (*dotted arrow*). (**b**) Two coronal and one sagittal CT scan cuts demonstrating the fracture into the tibial eminence (*dotted arrow*), the distal extension of the minimally displaced condylar fracture (*solid arrow*), and the posterior impaction from when the knee dislocated anteriorly (*asterisk*). (**c**) A 3D CT of the fracture. (**d**) He underwent ORIF of the fracture with disimpaction and bone grafting, reconstruction of the ACL at the same time, and repair of the meniscus tears. This was done in one stage because the articular injury was actually very minimal in this low-energy injury. The only comminution was in the eminence and posteriorly at the metaphysis, and the articular extension of the condylar fracture was non-displaced. Stiffness was an issue during the postoperative course and at final follow-up he had 0–114 degree of motion and a stable knee with no pain

Type 5: This high-energy comminuted bicondylar tibial plateau fracture distinguishes itself from a typical bicondylar tibial plateau fracture by comminution and separation of the entire tibial eminence. Moore reported that all 9 patients who were evaluated demonstrated instability with this fracture pattern.

Treatment of knee dislocations in the setting of a tibial plateau fracture must be customized to the patient. Avulsion fractures of the tibial spine must be fixed primarily during the ORIF of the plateau fracture [12–14, 22]. We have been referred a number of cases of significant extension loss combined with sagittal plane instability owing to malreduction of the eminence fracture. On the other hand, cruciate reconstructions at the same time as fixation of the plateau fracture is discouraged because of interference with anatomic reduction, postoperative stiffness, and infection. Stiffness is reported as a significant problem in these injuries, and most authors note that the cruciate reconstruction can be done if symptomatic after full range of motion is obtained and the fracture has healed [6, 7, 46, 50]. Moore reported that many patients did not require late reconstruction of the cruciates, but Schatzker noted many poor results in untreated ACL injuries in his plateau series.

Timing of the repair or reconstruction of the collateral ligaments has been debated in the literature. If a simple repair is done, we and other authors recommend doing this at the time of the plateau fixation [6, 14]. This recommendation is based on significant late coronal instability if the collaterals are left untreated and potential for abnormal stress upon the repaired articular surface. On the other hand, if the collateral injury requires reconstruction and a separate soft tissue dissection from the plateau injury, we have previously advocated a staged approach [7]. The rationale for staged repair is due to the high-energy nature of these injuries and the inability of the soft tissues to tolerate a large procedure. Furthermore, motion can reliably be obtained with good stability in a hinged knee brace until collateral reconstruction or alternatively the placement of a hinged external fixator if gross instability is present.

## 27.8 Patella Fractures and Extensor Disruptions in Knee Dislocations

The extensor mechanism of the knee can be injured in the setting of a knee dislocation by rupture of the patellar ligament or fracture of the patella. Kosanovic has reported the only case series of patella fractures in the setting of knee ligament injuries [51]. He noted that out of 112 patella fractures, 6 (5%) had ligamentous injuries to the knee and 4 had knee dislocations. Three patients had a KD-V3M injuries and one had a KD-V3L injury. The patella fractures were all comminuted and underwent osteosynthesis at the same time as ligamentous reconstruction. While they did not report any organized outcomes data, it appears that stiffness and residual laxity was an issue. In our series of 139 operatively treated knee dislocations, we had only 2 patella fractures and both patients had KD-V4 ligamentous injuries. These dislocations were high energy and associated with other injuries (ipsilateral hip dislocation and acetabular fracture, aortic laceration, contralateral Lisfranc fracture, occipital condyle fracture) (Fig. 27.12). Treatment was patellar osteosynthesis at the same time as ligamentous reconstruction performed through the open patellar fracture. Exceptional results can be obtained, but motion losses are not uncommon.

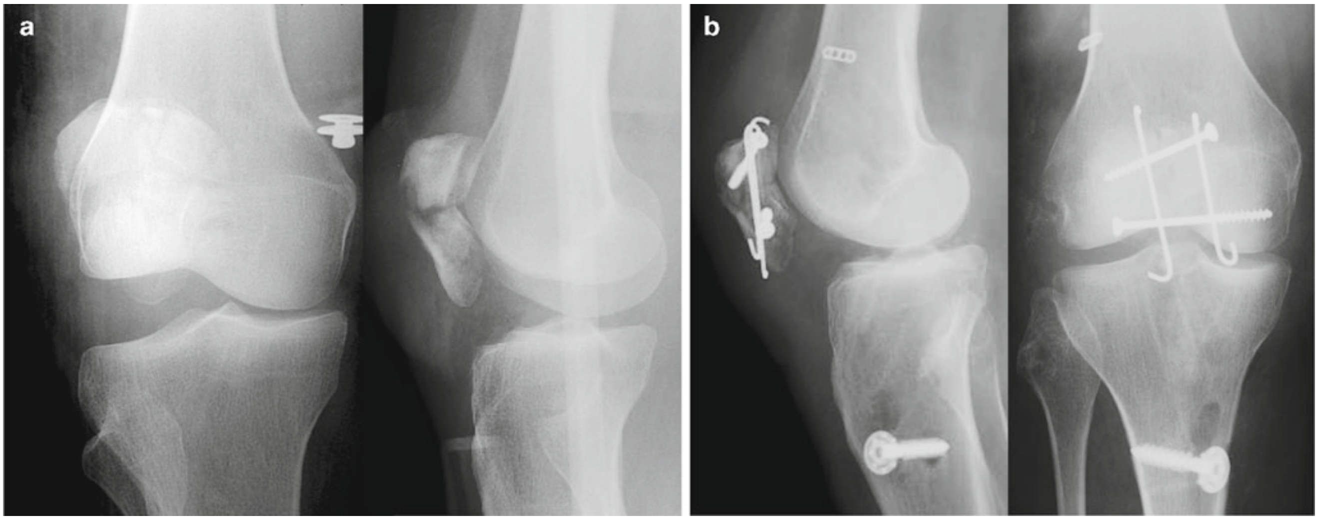


**Fig. 27.12** Patella fracture with a knee dislocation. A 54-year-old female involved in a snowmobile accident and sustained a KD-V4 knee dislocation with a comminuted patella fracture. She also sustained a contralateral tibial shaft fracture. (**a**) AP and lateral X-rays of the right knee with a stellate patella fracture and obvious ligamentous disruption causing widening if the lateral compartment. (**b**) She underwent ORIF of the patella, reconstruction of the ACL, PCL, MCL, and PLC/LCL during one operation. At 2 1/2-year follow-up she had a stable knee with full extension and 118° of flexion. Her postoperative protocol was limited CPM with range of motion of 0–60° for 5 weeks and then to resume our standard postoperative multiple-ligament knee dislocation protocol as previously published [7]

Non-bony extensor mechanism disruptions will also complicate management. In such cases, the surgeon is faced with seemingly opposing rehabilitation goals: immobilization to allow adequate healing of the extensor mechanism versus early mobilization to avoid arthrofibrosis following the ligament reconstruction. Again, the surgical priority must be an intact extensor mechanism. If a staged reconstruction is to be performed, the extensor mechanism should be restored to anatomic height, but the repair should be robust enough to allow early mobilization and range of motion. We prefer to repair and augment extensor mechanism disruptions acutely along with ligament reconstruction. Most often, we will utilize the ipsilateral semitendinosus or an allograft to augment the extensor repair through a transverse bony tunnel in the patella. Range of motion is begun 1 week following surgery.

Optimal treatment of these fracture-dislocations is difficult. Postoperative knee motion is critical to prevent stiffness, but injury to the extensor mechanism can make aggressive range of motion contraindicated. Furthermore, it is known that early ligament reconstruction increases the risk of arthrofibrosis, but early treatment is needed for fracture osteosynthesis [52]. The case series of 4 patients and our treatment algorithm has been to perform a single procedure with ORIF of the patella and ligament reconstruction. The optimal management of these injuries is a subject of further study.

## 27.9 Fractures Remote to Knee Dislocations

Fractures remote to knee dislocations (e.g., pelvis/acetabulum, hip, femoral and tibial shaft, distal tibia, plafond, foot, and upper extremity) are indicative of the mechanism and energy of the injury and are predictive of concomitant multisystem injury. They have a profound effect on clinical course and outcome. These fractures may be confined to the ipsilateral extremity, contralateral extremity, upper extremities, and axial skeleton. Concomitant injury to the CNS, thoracic cavity, and intra-abdominal structures is common. The vast majority of these patients are involved in high-speed trauma, usually in the form of motor vehicle collisions and pedestrians struck by vehicles. Aside from the complications brought about by these specific fractures, the energy absorbed by the limb causes significant injury to the surrounding soft tissues of the joint, leading to higher risks of postoperative infection, hematoma, and delayed wound healing.

We reviewed 139 knee dislocation procedures performed over a 5-year period. Sixty-eight (49%) were classified as high-energy mechanisms (motor vehicle collision/pedestrian struck/bicyclist struck). Within this population, 22% sustained an ipsilateral femoral shaft fracture, 9% a tibial shaft fracture, 26% a pelvic ring/acetabular fracture, 9% an ipsilateral posterior hip dislocation, and 43% an upper extremity fracture. Taken in total ($n = 139$), there were 15 ipsilateral femoral shaft fractures (11%), 6 ipsilateral tibial shaft fractures (4%), 21 pelvic ring/acetabular fractures (15%) with 6 ipsilateral posterior hip dislocations (4%), and 31 upper extremity fractures (22%). Almost all of the above injuries were sustained in the high-velocity population, aside from a few pelvic ring injuries sustained in low-energy falls. There were a total of 8 postoperative wound infections requiring antibiotics or a formal irrigation and debridement. Three of the infections (38%) occurred in the high-energy population, with the remaining in patients with BMIs in the morbidly obese range.

As a general rule, ipsilateral lower extremity injuries are more easily rehabilitated, as the patient may have a healthy contralateral limb on which to weight bear. In such cases, surgery can proceed according to standard principles for all extremity injuries, and the patient can begin assisted weight bearing on the time frame of the most tenuous repair or fracture procedure. Contralateral injuries can be extremely challenging, as the patient is left literally without a leg to stand on. When the multiligament injury is the only factor involving the extremity opposite a significant fracture or dislocation that will preclude weight bearing, the surgeon must weigh the benefits of early reconstruction against the risks of a bedridden patient. If reconstruction is to be performed, early range of motion and weight bearing are instituted as best as possible. Alternatively, the knee can be braced in extension for a brief period (7–14 days), and if stable in a brace, weight bearing can be instituted with the plan to resolve and residual coronal, sagittal, and rotational instabilities after the contralateral injuries can be used to weight bear (6 to 12 weeks).

## 27.10 Hip and Acetabulum

Fractures and fracture-dislocations of the acetabulum are not uncommonly seen in association with knee dislocation after high-velocity injuries. In our experience, the most common variant is a posterior dislocation of the hip with a fracture of the posterior wall of the acetabulum caused by a high-energy dashboard injury. Many other variants of acetabular fractures exist depending on the position of the leg at the time of injury and the direction of force. Associated pelvic ring and lumbopelvic injury do occur but are less predictable. Given the implied mechanism and direction of force in a posterior hip fracture-dislocation, the high index of suspicion should be maintained when examining the patient for a PCL/PLC injury. Depending on the treatment of the acetabular pathology, rehabilitation may be limited secondary to weight bearing and hip flexion precautions; this can sometimes preclude the use of continuous passive motion (CPM) and even manual ROM. Anatomic reduction, repair, and fixation of the hip and acetabulum should precede knee ligament reconstruction.

## 27.11 Fractures of the Femoral and Tibial Shaft

Multiple studies have cited the association of femoral shaft fractures with ligamentous injury to the knee [40, 53–60]. Dickob and Mommsen, in a follow-up study of 59 operatively treated femoral shaft fractures found that 18.6% of the patients had a ligamentous injury to the central pivot identified after fixation [60]. This association reflects a high-energy mechanism of injury including dashboard injuries (posterior-directed force on the flexed knee with the hip flexed) and severe varus and valgus moments.

Associated fracture of the tibial metaphysis and diaphysis is less common than that of the femoral shaft [50, 57, 61–63]. The literature consists of mostly case reports, some of which are combined femoral and tibial shaft fractures associated with a knee dislocation. The lower incidence of tibial shaft fractures with knee dislocation is likely a reflection of the "dashboard injury" mechanism responsible for most ipsilateral fracture-dislocation injuries.

The association of a femoral or tibial shaft fracture presents additional complexity to managing a knee dislocation. Of primary concern is the initial stabilization of the patient, likely with intramedullary nailing of all amenable fractures of the femoral and tibial shafts. These injuries represent an orthopaedic urgency with potential fatal consequences if left untreated (resultant hemorrhage or fat emboli syndrome). Because the patient is treated urgently as part of the initial resuscitation, the astute surgeon can utilize some strategies to facilitate subsequent ligamentous reconstruction. In the case of intramedullary nailing of femoral shaft fractures, the surgeon may consider leaving the nail a few centimeters short of the distal end of the femur to allow easier placement of femoral tunnels. Additionally, maintaining anatomic alignment and rotation of the distal femur is paramount in avoiding patellofemoral maltracking after recovery. When treating tibial fractures with an intramedullary device, very little can be done with placement of the nail. Instead, tunnel placement can be modified; ACL tunnels will usually start medial enough to miss the nail, and the PCL tunnel can be lateralized over the tibial crest and under the anterior compartment of the leg. Intraoperative fluoroscopy can be beneficial. Rehabilitation of the extremity is also significantly affected, taking into account the need to obtain bony union in addition to maintaining motion and strength. Intramedullary nail removal or shortening has not yet been required in our experience, although occasionally an interlocking screw or screws can be temporarily removed during tunnel drilling and replaced after the ligament is passed.

## 27.12 Upper Extremity

Upper extremity fractures are frequently seen in our population with knee dislocation, but the location and fracture pattern are not predictive of ligamentous injury to the knee and related purely to the energy of the mechanism. Common injury patterns include elbow dislocations (open and closed), clavicle fractures, humerus fractures, and fractures of the bones of the hand. It is not uncommon to see bilateral upper extremity fractures, and treatment and rehabilitation/mobilization need to be tailored based on restrictions of activity and weight bearing.

## 27.13 Conclusion

Multiple-ligament injuries are not uncommonly associated with fractures. These fall into three broad categories:

1. Small intra-articular avulsion (eminence/meniscal root) fractures or marginal impaction/compression fractures to the tibial plateau or distal femur. Such fracture patterns, while often underappreciated or overlooked altogether, are highly suggestive of a multiple-ligament injury and portend concern for vascular or neurologic injury. In most cases, these fractures are treated concomitantly with the ligament reconstruction.
2. Tibial plateau fractures or distal femoral fractures involving a substantive portion of the weight-bearing surface. The restoration of anatomic alignment and restoration of an anatomic articular surface are critical and a priority over ligament

reconstruction. In our hands, concomitant ORIF and ligament reconstruction showed less favorable results compared to concomitant plateau/femoral ORIF and medial/lateral ligament repair to protect the articular surface from gross coronal-plane stress. After interval healing of the articular surfaces, indicated ligament reconstructions can be performed at 6 to 12 weeks.

3. Fractures remote to the knee injury. Preference should be given to reestablishing the rotational and axial alignment of the extremity. In most cases, ligament reconstructions can be performed within 2 to 6 weeks after the injury. These injuries can have significant impact upon the successful rehabilitation of the knee ligament injury (and vice versa), particularly when they occur in the contralateral extremity.

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# Chapter 28
# Articular Cartilage Restoration in the Multiple Ligament Injured Knee

**Kevin F. Bonner and Carly Rachel Noel**

## 28.1 Introduction

Multiple ligament injured patients present a heterogeneous patient population, which often present with a spectrum of complex injury patterns. The strict definition of a multiligament injured knee is at least two combined ligament tears, but the focus of this book describes the treatment of the relatively less common, more complex, three or even four ligament injury often associated with a knee dislocation. 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 multiligament 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 multiligament 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 multiligament 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 multiligament knee injuries, there is currently no good evidence that a focal articular cartilage injury in this setting will necessarily be symptomatic or be 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 [15, 17–22].

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]. 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. Therefore, it may be prudent to treat the majority of these lesions with easy, low morbidity, expeditious, available procedures in the acute setting [20]. Since surgical intervention within 3 weeks of injury is currently recommended in most cases, cartilage restorative options are more limited in this setting [3]. Many of these lesions may never require further treatment until more global joint degeneration occurs with time (Fig. 28.1). For the subset of lesions that cause persistent symptoms despite primary acute treatment, secondary articular cartilage resurfacing procedures are performed according to accepted treatment algorithms. The goal of addressing these symptomatic lesions is to improve symptoms and hopefully delay the need for arthroplasty procedures. Consideration

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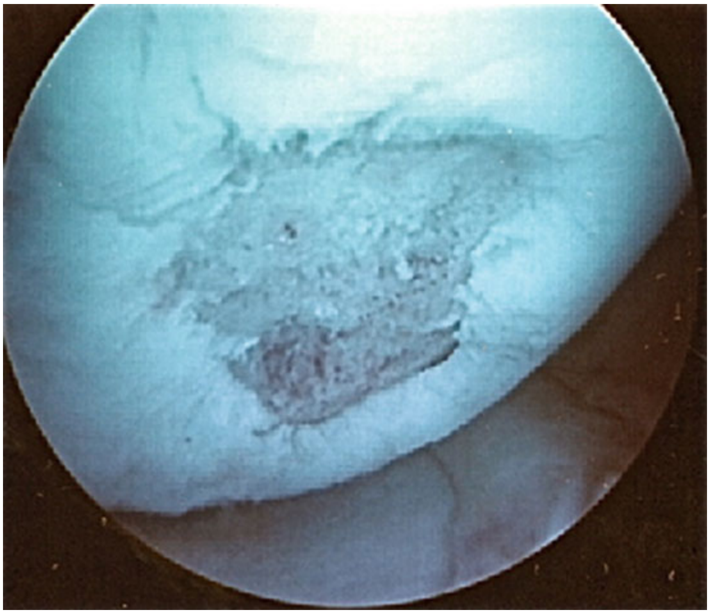


**Fig. 28.1** This medial femoral condyle lesion associated with a multiligament knee injury has remained asymptomatic for 9 years following a microfracture performed at the time of acute reconstruction

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 resurfacing procedure [1].

Multiligament injured knee patients can be extremely challenging with relatively high rates of chronic pain, which may not necessarily be related to 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]. It is unknown at this time if the treatment of either asymptomatic or symptomatic articular cartilage lesions will alter this course [20]. Many patients will likely eventually require an arthroplasty to address progressive degeneration.

## 28.2 Acute Treatment of the Articular Cartilage Lesion Associated with a Multiple Ligament Injured Knee

Considerable debate exists within the orthopaedic community regarding the most appropriate surgical treatment for a symptomatic articular cartilage lesion [23–26]. 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, 27–29]. In the acute setting of a multiligament injury, it is often impossible to determine if a chondral lesion is symptomatic. We also do not yet have an understanding which lesions will remain or become symptomatic with time [16, 27, 29]. Many articular cartilage lesions associated with both ACL or multiligament injuries may not become symptomatic or necessarily be the major contributing factor to the development of degenerative changes or even affect outcomes [1, 4, 11, 16–18, 27]. 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, 27]. However, there is also data that this may not always be the case and these focal lesions can cause significant morbidity [21, 29, 30]. For this reason, at this time, it is reasonable to treat an incidental high-grade lesion. However, the senior author (KFB) favors expeditious, less invasive techniques that minimize morbidity when treating chondral lesions in this acute treatment cohort.

Perhaps in the future we will be able to better determine if “more invasive” cartilage procedures or even acute treatment at all will change the natural history in the multiligament injured knee. Currently, there are no trials that investigate the effect of treatment versus no treatment. Additionally, there are no comparisons among treatments in not only the multiligament injury group but also the much larger isolated ACL reconstruction population. Several investigators have published case series of combined ACL reconstruction and osteochondral autograft transfer, microfracture, or autologous chondrocyte implantation (ACI) with reasonable short-term outcomes [11, 21]. There have been no comparison groups in these studies, however.

Although it makes sense to try and resurface a high-grade defect based on our experience with treating symptomatic defects, the results of any cartilage restoration procedure for an acute traumatic or incidental lesion may have optimal results relative to other cohorts. However, since certainly some patients with higher-grade lesions do go on to become symptomatic

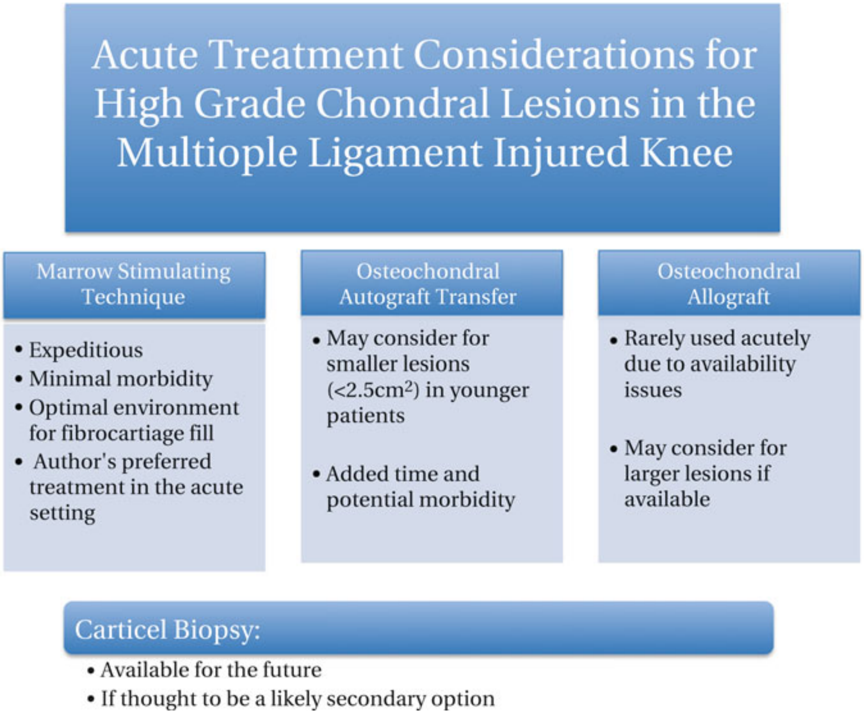


**Fig. 28.2** Acute treatment algorithm for a high-grade chondral lesion in the multiple ligament injured knee

in others and our experience, treatment over nontreatment is reasonable in this setting [11, 21, 30]. An acute treatment algorithm is proposed based on available options yet attempting to minimize morbidity when treating full-thickness defects in an often young individual (Fig. 28.2). The senior author acknowledges 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, 30].

## 28.3 Debridement/Chondroplasty

When encountering a partial thickness articular cartilage lesion (Outerbridge 2 or less) with unstable edges or fragments, an arthroscopic chondroplasty is the treatment of choice. When the lesion is Outerbridge grade 3 or 4, this may also be appropriate based on lesion and patient factors. The senior author will tend to still utilize a simple arthroscopic chondroplasty even in an Outerbridge grade 3 lesion if there is a layer of articular cartilage over the calcified cartilage layer. If the defect is down to the calcified cartilage layer or subchondral bone (Outerbridge Grade 4, ICRS Grade 3), then other options are typically preferred in younger individuals.

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. Only loose and unstable flaps of cartilage 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, 31]. There is continued concern regarding cell death related to the use of thermal devices.

## 28.4 Microfracture

Microfracture and other marrow-stimulating techniques involve debridement of the lesion followed by penetration of the subchondral plate in order to induce fibrin clot formation. The goal is to induce a stable fibrin clot containing mesenchymal stem cells within the defect [32]. These pluripotent cells can differentiate into fibrochondrocytes, which produce a fibrocartilage repair tissue within the site (Fig. 28.3) [33]. This fibrocartilage repair tissue contains varying amounts of type I and II collagen and has inferior biomechanical and wear characteristics relative to hyaline cartilage [33]. Radiologic follow-up studies reveal variable rates of fibrocartilage fill which seem to correlate to patient outcomes in the short-term [23, 34, 35]. Short-term follow-up magnetic resonance imaging (MRI) studies reveal good fibrocartilage fill between 54 and 85% of patients with isolated defects treated with microfracture [23, 34, 35].

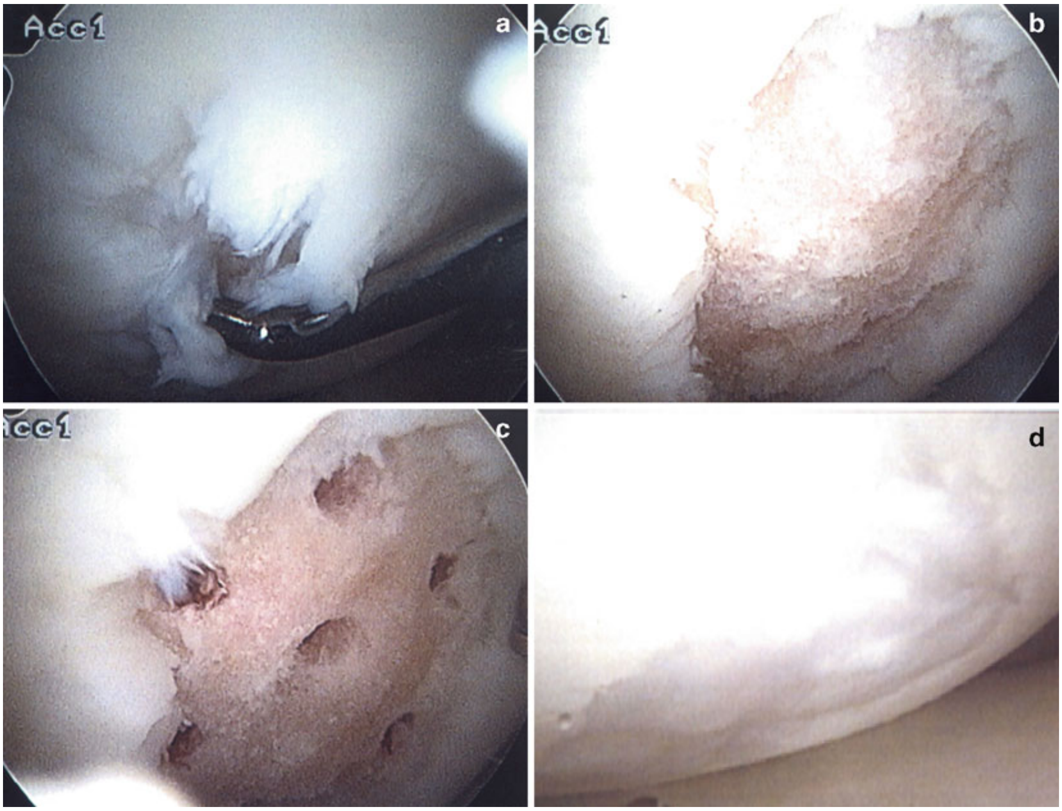


**Fig. 28.3** (**a**) Chondral lesion prior to debridement and microfracture. (**b**) Following debridement of unstable chondral flaps. (**c**) Lesion following microfracture. (**d**) Lesion filled with fibrocartilage repair tissue

In a high-grade (Outerbridge Grade 3 or 4) chondral lesion associated with a multiligament knee injury, microfracture can be a very good choice as a primary, and potentially final, treatment option [21]. Microfracture is technically straightforward, expeditious, cost-effective procedure with relatively minimal patient morbidity. These features make this option appealing as a first-line treatment for a full-thickness lesion associated with an acute multiligament knee injury which may not even be symptomatic. Multiligament reconstructive procedures can be quite long and wearying. Tourniquet time may also be an issue depending on surgeon preference. Treatment time and patient morbidity can be minimized when microfracture is used to address a concomitant high-grade articular cartilage injury. For full-thickness lesions, this has been the senior author's treatment of choice in the acute multiple ligament injured knee.

There have been no studies published specifically evaluating the results of microfracture combined with multiligament reconstruction. However, as stated in the literature, 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, 23, 33, 36–39]. Results have varied based on lesion size and location, activity levels, length of preoperative symptoms, follow-up intervals, patient age, and authors [36–40]. Negative prognostic factors include age >35 years, size of the defect >2 cm$^2$ [41], location in the patellofemoral compartment or tibial plateau, higher body mass index, and duration of symptoms >1 year [23, 36, 37, 40]. A recent systematic analysis revealed that microfracture provides effective short-term functional improvement, but insufficient data is available on its long-term results [36].

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, it is unknown if that is the case in this setting [39, 42–44]. It is currently controversial if microfracture may affect the results of a secondary ACI procedure [45, 46].

## 28.5 Osteochondral Autograft Transfer

Osteoarticular autograft transfer or mosaicplasty in the knee joint has been performed since the mid-1990s [47–49]. 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. 28.4). Contact stress studies have defined preferred donor sites

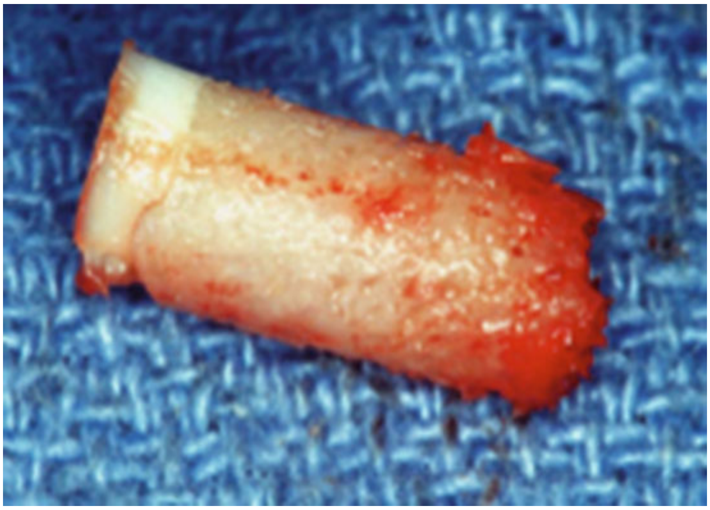


**Fig. 28.4** Autologous osteoarticular graft prior to transfer

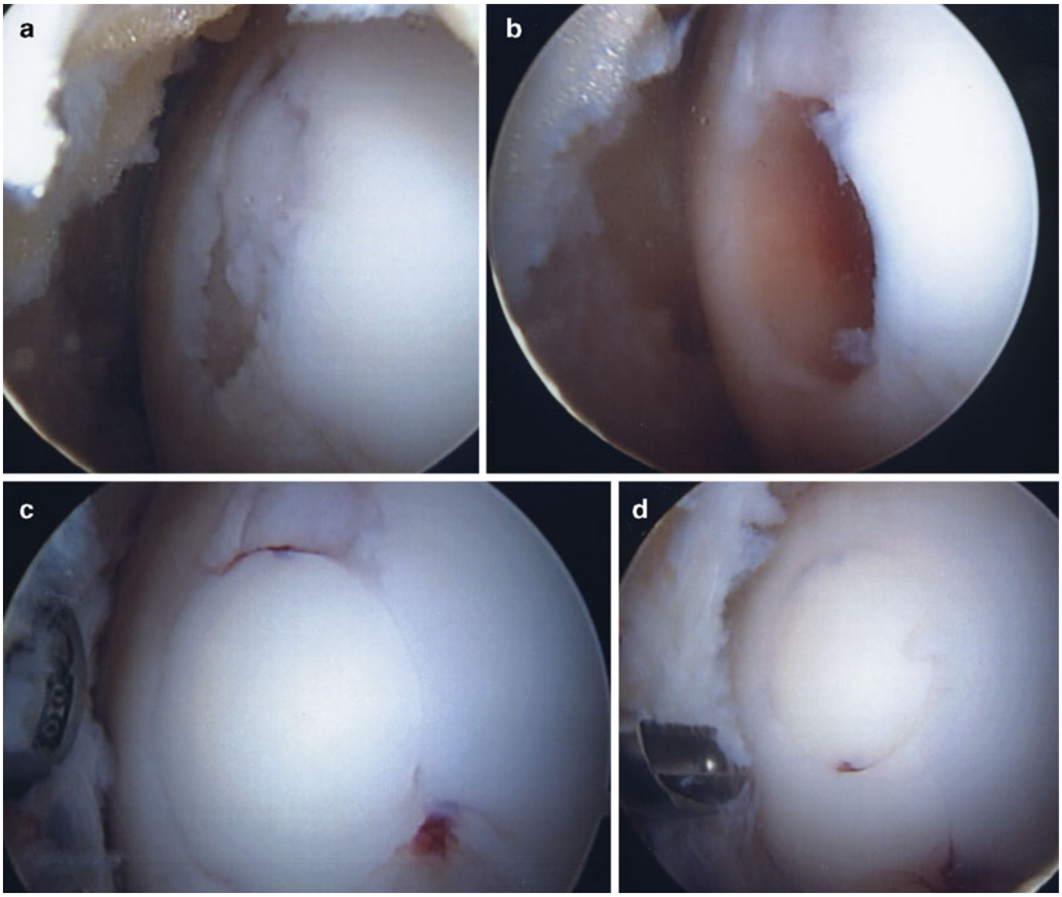


**Fig. 28.5** (**a**) Chondral lesion (<2 cm$^2$) on the medial femoral condyle accessible to an arthroscopic approach. (**b**) Recipient site prepared in the lower half of the lesion. (**c**) First autologous graft implanted into recipient site. (**d**) Following placement of the second graft just overlapping the first ("Mastercard" technique)

although there is some debate regarding the optimal donor harvest site [7–9]. This procedure has 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 (Fig. 28.5). Return to sports following treatment of a symptomatic smaller isolated defect with an osteochondral autograft may be highest relative to other cartilage treatment alternatives [43].

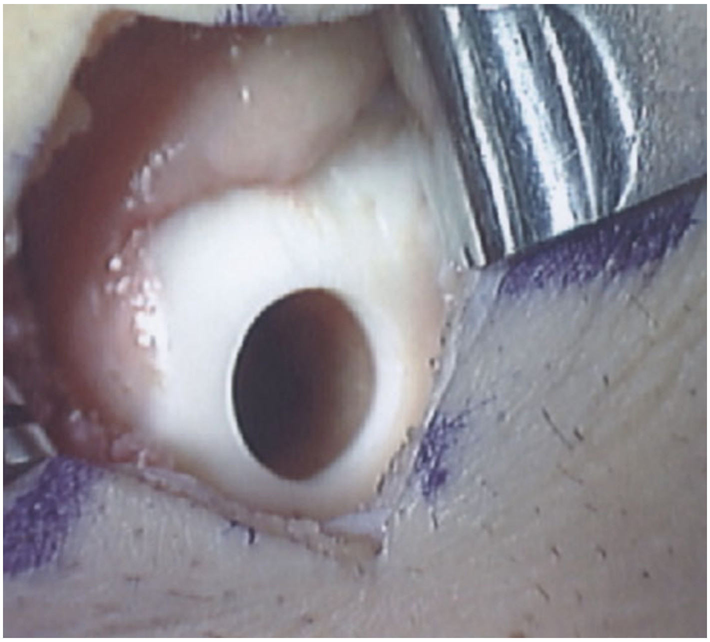


**Fig. 28.6** Donor plug harvest site visualized through a superolateral arthrotomy

There is some debate regarding donor site morbidity related to the harvest site (Fig. 28.6) [47, 50, 51]. Surgeons with the longest experience with osteochondral transfer have published relatively low rates of donor site problems [52]. 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 possibly be greater than previously suspected [51]. In an effort to decrease donor site morbidity, the donor sites may be backfilled with either bioabsorbable scaffolds or allograft plugs [47]. Backfilling donor sites may decrease the risk of postoperative hemarthrosis, but it is unknown if they will decrease donor site morbidity in the longer term. Recent data suggests that some synthetic grafts (Trufit; Smith & Nephew Endoscopy, Andover, MA) may not show evidence of bone ingrowth or osteoconductivity as intended [53]. Additionally, there are recently case reports revealing the potential for foreign body reactions to these same synthetic scaffolds used for the purpose of backfilling donor sites [54, 55]. Alternatively, donor sites may be left empty or backfilled with commercially prepared osteochondral allografts.

Even though the osteoarticular recipient sites may often be accessed arthroscopically, many authors still prefer to harvest the donor plugs through a small lateral arthrotomy to access the superolateral trochlea (see Fig. 28.6). 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 a microfracture procedure 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$^2$) especially in the setting of subchondral bone involvement. The question is whether or not the added morbidity and procedural time justify its use in the acute multiligament setting.

## 28.6 Fresh Osteochondral Allografts

Fresh osteochondral allografts are typically used for the treatment of larger symptomatic chondral or osteochondral lesions [56, 57]. Historically fresh allografts have not had much utility in the treatment of the acute chondral lesion associated with multiligament knee injury in part due to availability issues. Most acute multiligament knee injuries are currently being treated surgically within 3 weeks in most cases [3]. Even if a large chondral or osteochondral lesion is identified on a preoperative MRI, getting a fresh allograft at the proper time may be quite a logistic challenge. Certainly 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. However, most authors have typically utilized fresh allograft transplantations for the secondary treatment of persistently symptomatic lesions in this setting.

**Fig. 28.7** Cartilage biopsy may be obtained at the index procedure if the surgeon feels it may be required

## 28.7 Autologous Chondrocyte Implantation Biopsy

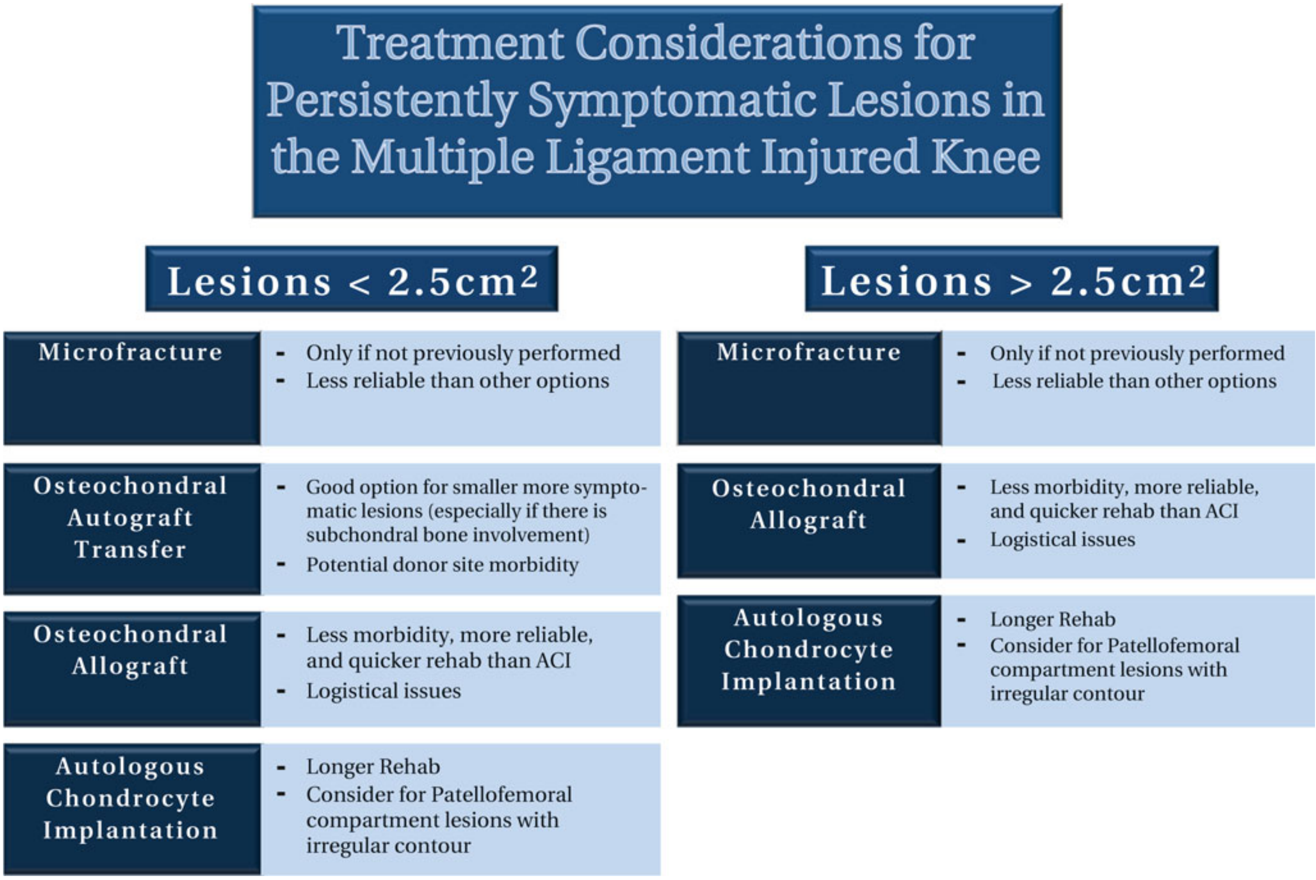
ACI (Carticel; Genzyme Corp, Cambridge, MA) is a two-staged procedure requiring at least 4–6 weeks between biopsy harvest and cell implantation [46, 58]. ACI is therefore not available as a first-line treatment for most patients in the multiligament setting. However, if a lesion is persistently symptomatic despite primary treatment, ACI may be a viable treatment option in the future [46, 58]. 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 an 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. Certainly 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. 28.7). The cartilage biopsy specimen is sent to Genzyme Corporation in Cambridge, MA, where the chondrocytes can be isolated from the specimen, cultured, and expanded in vitro if needed for a secondary procedure.

## 28.8 Secondary Treatment for Persistently Symptomatic Articular Cartilage Lesions Associated with a Multiligament Knee Injury

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 [59, 60]. Patient age, lesion size and location, activity level, and mechanical environment of the involved compartment(s) are factors that will influence treatment for these patients [20, 26, 32]. 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 nonarthroplasty 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, 26, 32, 46]. 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



Treatment Considerations for Persistently Symptomatic Lesions in the Multiple Ligament Injured Knee

Lesions < 2.5cm²

| | |
|---|---|
| **Microfracture** | - Only if not previously performed<br>- Less reliable than other options |
| **Osteochondral Autograft Transfer** | - Good option for smaller more symptomatic lesions (especially if there is subchondral bone involvement)<br>- Potential donor site morbidity |
| **Osteochondral Allograft** | - Less morbidity, more reliable, and quicker rehab than ACI<br>- Logistical issues |
| **Autologous Chondrocyte Implantation** | - Longer Rehab<br>- Consider for Patellofemoral compartment lesions with irregular contour |

Lesions > 2.5cm²

| | |
|---|---|
| **Microfracture** | - Only if not previously performed<br>- Less reliable than other options |
| **Osteochondral Allograft** | - Less morbidity, more reliable, and quicker rehab than ACI<br>- Logistical issues |
| **Autologous Chondrocyte Implantation** | - Longer Rehab<br>- Consider for Patellofemoral compartment lesions with irregular contour |

**Fig. 28.8** Treatment options and considerations for persistently symptomatic lesions associated with a multiple-ligament knee injury

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 malalignment 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 tibiofemoral compartment versus other potential etiologies such as pain radiating from the patellofemoral compartment.

The following section of this chapter discusses potential treatment options for the treatment of persistently symptomatic defects associated with a previous multiligament injury. Special considerations for treatment of symptomatic chondral lesions in this patient population are highlighted in Fig. 28.8. This assumes that malalignment will be concomitantly corrected or was previously corrected. The more diffuse the chondrosis in the involved compartment, the more likely the senior author favors correcting the malalignment through an unloading osteotomy only. The more focal the defect, the more unloading the compartment and resurfacing the lesion at the same setting are favored. If meniscal deficiency is thought to be a contributing factor, this should also be addressed at the same setting of the chondral resurfacing [61].

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.

## 28.9 Microfracture

Microfracture may be considered as a viable treatment alternative if the lesion was initially untreated or simply debrided. The results of microfracture are generally considered to be worse with larger defects, especially in individuals over the age of 35 years old. Also the rate of return to sports when a symptomatic defect is treated may not be as high as with alternative treatment options [39, 42, 44]. In the setting of an individual who has persistent symptoms, thought to be localized to a chondral lesion, in a previous multiligament injured knee, we tend to opt for other resurfacing alternatives which may be more reliable or durable.

## 28.10 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 <2.5 cm$^2$.

## 28.11 Fresh Osteochondral Allografts

Fresh osteochondral allografts have a fairly extensive clinical history, extending over three decades [56, 62–67]. Allograft transplantation is currently gaining in popularity due to increasing appreciation that it reliably restores viable hyaline cartilage with normal architecture when compared to alternative treatment options for larger defects [56, 57]. 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 (Fig. 28.9). The technical aspects of the procedure have been well described elsewhere and will not be described here [57]. Fresh allografts are most useful in treating larger chondral or

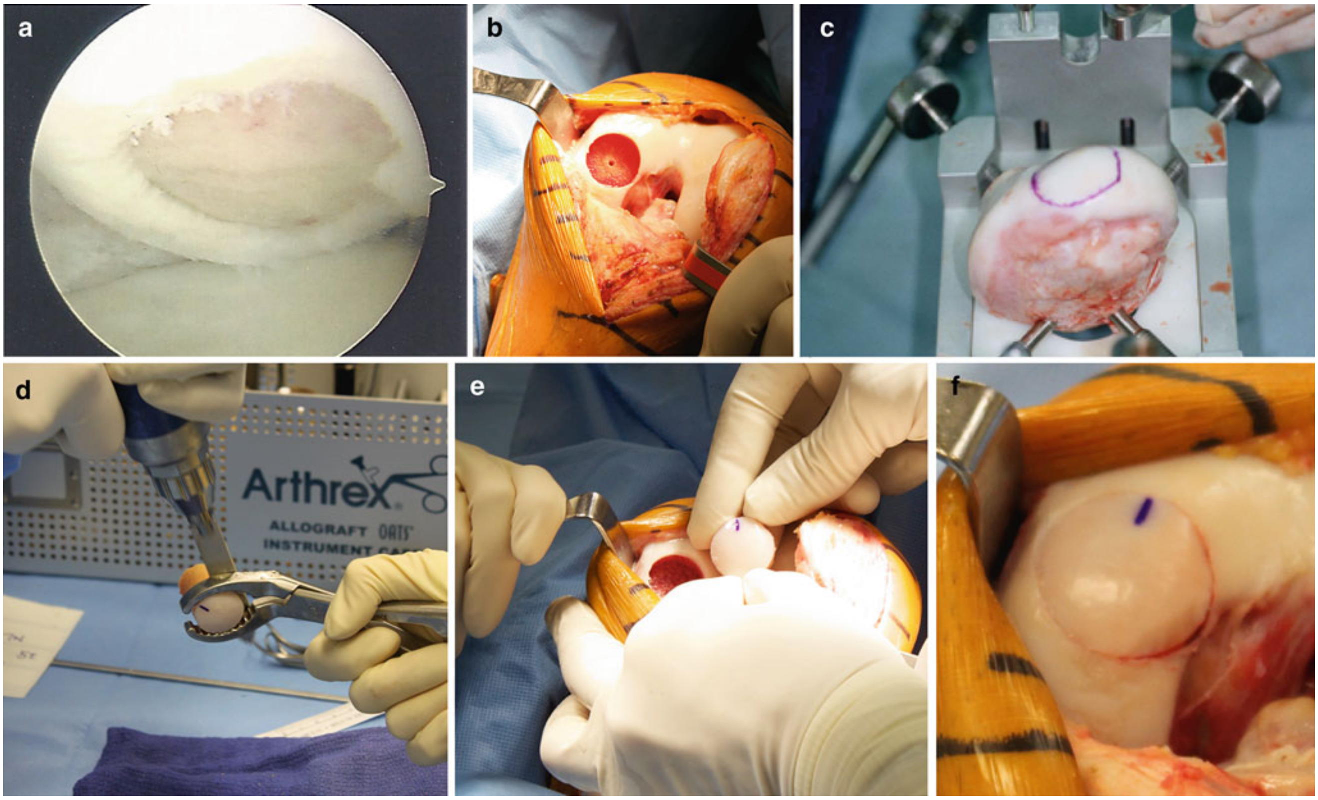


**Fig. 28.9** (**a**) Large chondral lesion which was treated with a microfracture at the initial ligament reconstruction. The patient had persistent symptoms medial despite a stable knee. (**b–f**) The lesion was revised to a fresh osteochondral allograft. The exposure was larger since the initial incision from a patellar tendon autograft was utilized

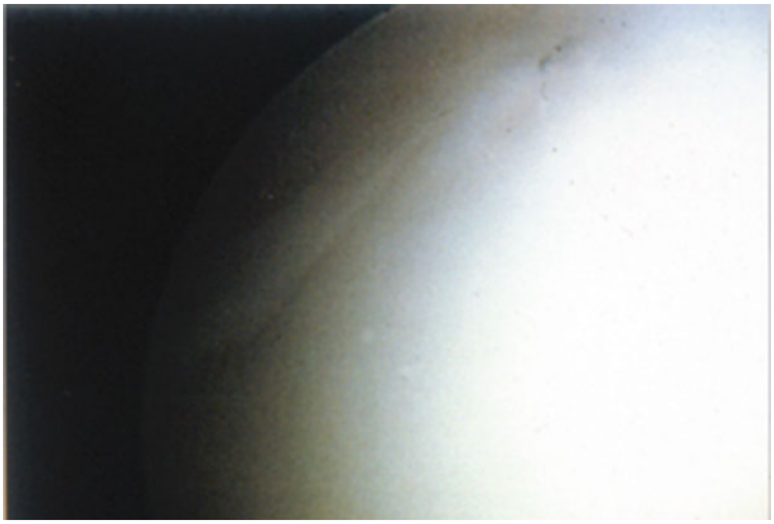


**Fig. 28.10** Arthroscopic appearance of a well-preserved articular surface following an osteochondral allograft 7 years earlier

osteochondral lesions (>2.5 $cm^2$) but can also be utilized for smaller defects in an effort to minimize morbidity. This is especially appealing in a multiligament 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 [56, 58]. Investigators have shown that 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 [59, 60]. Although nonviable cartilage will appear grossly normal for a period of time, it will not maintain normal histologic, biochemical, or biomechanical properties. As a result the cartilage will fibrillate, develop clefts, and erode over time [69, 70]. 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 [71].

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 [72–75]. Chondrocytes are surrounded by a matrix that isolates them from the host immune cells and makes them relatively “immunologically privileged” [64, 65]. Although donor cells within the osseous component are immunogenic, their immunogenicity is muted and probably not clinically significant in most patients [76, 77]. However, both the surgical trauma and the graft itself stimulate a local inflammatory response [78]. This response is primarily directed against the bone constituent of the graft that contains the marrow elements and other immunogenic elements [79]. 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 [80–83]. If the nonviable bone trabeculae cannot withstand mechanical stresses during the remodeling process, subchondral microfracture, collapse, and fragmentation may occur [56].

Long-term chondrocyte viability and clinical success following osteochondral allograft transplantation has been shown in multiple reports [62, 84–88]. Researchers have biopsied transplants at various time intervals following the index procedure with relatively high rates of chondrocyte viability [85, 88]. This potential for long-term survival supports the use of osteochondral allografts in an attempt to maintain extracellular matrix and thus prevent long-term articular degeneration within the graft (Fig. 28.10). Although no reports have focused on the multiligament patient, multiple authors have published on the outcomes of osteochondral allografts in younger patient populations with relatively good success [57, 82, 83, 85, 87]. Failures do occur with this technique and may increase with follow-up intervals as with any resurfacing procedure. Failures tend to be more related to the osseous component than the cartilage component and may include fragmentation and collapse [56]. Nonunion has not been a significant clinical problem especially with the dowel graft technique.

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: early vs late “failure” of typically the osseous component of the graft (as described above), supply issues, and the logistics of delivering an aseptic, size-matched graft with a high percentage of viable chondrocytes. Graft related infections are also a more significant concern when using fresh allografts compared to processed grafts although they are fortunately rare. Many clinical and basic scientific studies support the theoretical foundation and efficacy of osteochondral allografting [56].

## 28.12 Autologous Chondrocyte Implantation

ACI (Carticel; Genzyme Corp, Cambridge, MA) is a two-staged procedure requiring at least 4–6 weeks between biopsy harvest and cell implantation (Fig. 28.11) [46, 58]. Thus, ACI is impractical as a first-line treatment for most patients in the multiligament setting. However, if a lesion is persistently symptomatic despite primary treatment, ACI is a viable treatment option [46, 58]. 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, ACI is indicated for the treatment of femoral lesions. However, many authors feel that ACI may offer its best application in the patellofemoral compartment [89].

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), and controversy related to efficacy and histology of ultimate repair tissue for a costly procedure. There is certainly increasing evidence in the literature over the past 10 years related to the use of ACI and its efficacy [25, 34, 46]. Both single-site and multicenter reports have shown fairly good results for generally difficult patient populations [46, 89–92]. ACI seems to show more consistent defect fill when compared to microfracture, especially with larger lesions, although there may also be graft hypertrophy [34]. Durability of repair tissue and the ability to return to sports may be improved with ACI relative to marrow-stimulating techniques (Fig. 28.12) [43, 46].

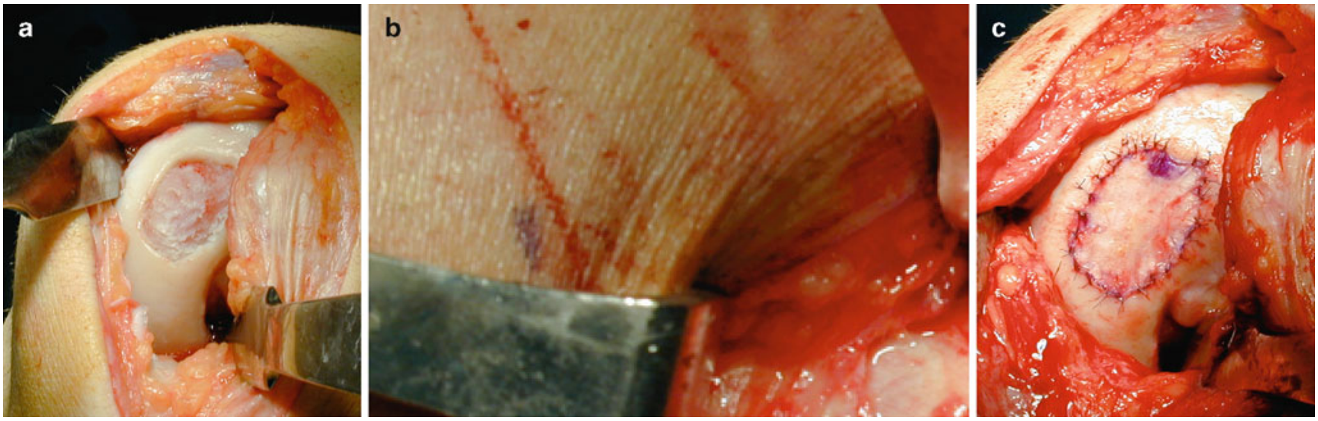


**Fig. 28.11** (**a**) Treatment of a large chondral lesion of the medial femoral condyle with autologous chondrocyte implantation. (**b**) Periosteum patch harvest site. (**c**) Periosteal patch sutured onto the defect (just prior to injection of the cells)

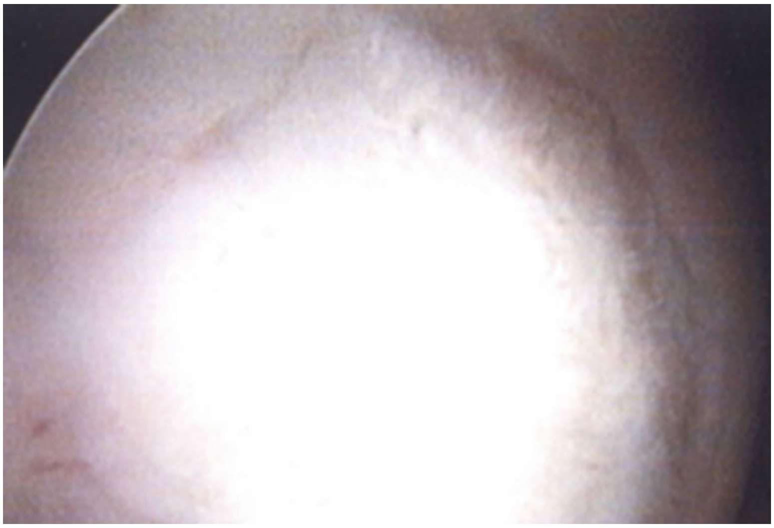


**Fig. 28.12** Arthroscopic visualization of repair tissue several years following autologous chondrocyte implantation

For symptomatic larger defects of the femoral condyles, ACI and osteochondral allografts are often considered more optimal choices compared to microfracture or autologous osteochondral transfer. ACI is a reasonable choice for this indication for a surgeon comfortable with the procedure and a patient willing to comply with the lengthy rehabilitation. One major benefit of ACI 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 as follows: it eliminates 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. ACI may be more optimal for patellofemoral lesions due to the technical difficulty associated with restoring the patients surface topography at these sites with a large osteochondral allograft. However, approval for isolated patellar lesions can be an issue since ACI was FDA approved for the femoral condyle only.

## 28.13 Unloading Osteotomies in Articular Cartilage Resurfacing

One would be remiss to discuss the treatment of articular cartilage resurfacing in younger individuals without discussing 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 malalignment is felt to be important for the long-term success of the resurfacing procedure [25]. 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.

Younger patients who are undergoing a cartilage restoration procedure for a symptomatic cartilage defect of the femoral condyle who also has a mechanical axis that falls outside the neutral zone, bordered by the tibial spines, should be strongly considered to have an osteotomy as part of the cartilage repair treatment [25]. Physicians who treat cartilage lesions should be comfortable with performing osteotomies but at the same time respect their added morbidity and potential complications [93]. Clearly, the greater the malalignment, 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 postcorrection goal of neutral in most cases. As a result, the correction is typically smaller in many cases.

In a recent report of multiligament injuries in athletes, 8% of the 26 patients underwent an osteotomy by 8 years for symptomatic diffuse degenerative changes. Arthritis, and not focal cartilage defects, was the clinical issue in this group at follow-up. Unfortunately, this is often the outcome in the multiligament 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. Postoperative alignment goals would be similar to the classic technique.

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# Chapter 29
# Meniscus Transplant in the Multiple Ligament Injured Knee

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## 29.1 History of Meniscal Allograft Transplant

The critical function of the meniscus in cartilage preservation of the knee was first discussed by Fairbanks in 1948 when he described the classic radiographic changes of osteoarthritis after complete meniscectomy [1, 2]. Consequently, the chondroprotective significance of the meniscus has influenced the current treatment of meniscal injuries with the primary goal to maintain meniscal integrity by attempting to preserve as much meniscal tissue as possible. In a select patient population with prior complete meniscectomy and symptoms localized to the affected compartment, meniscal allograft transplant (MAT) surgery has become a viable surgical option.

The concept of meniscus replacement surgery can be dated back to 1916 and 1933 when fat interposition arthroplasty was utilized to substitute for the function of the meniscus [3]. In 1908, the first MAT surgery was reported in the literature in the setting of limb salvage surgery via complete knee transplantation [4]. More recently, Locht et al. reported on utilizing massive proximal tibial osteochondral allografts with meniscus allograft to treat late tibial plateau fractures [5]. The short-term success of MAT was demonstrated in animal studies in the 1980s [6, 7]. The first meniscal allograft transplantation was performed in 1984 [3]. Since the procedure was first described over 25 years ago, there have been no randomized controlled studies or long-term outcome studies for the procedure, which would be beneficial for clinical guidelines, indications, patient selection, and expected outcomes for MAT.

## 29.2 Patient Demographics

It has been estimated that there are over 850,000 meniscal procedures performed annually in the United States [8–11]. Males tend to be affected two to four times as commonly as females and typically sustain injuries in the third decade of life [12]. The medial meniscus is more commonly torn in all age groups [1, 13]. MAT is a relatively newer procedure with no prospective randomized controlled trials (RCTs) and mostly a large number of retrospective case series with different techniques and inherent biases. As such, there is limited data on the patient demographics as it pertains to MAT.

The first systematic review of the literature on MAT attempted to establish clinical guidelines for surgeons to better understand four very important clinical guidelines: (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 [14]. As a result, this study provides information on the demographics of patients who underwent MAT between 1989 and 2005. The review included 15 studies (3 level III evidence and 12 level IV evidence) and included 516 patients with

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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% of the time compared to 32% in females. Mean follow-up time for this series was 55 months (range: 6 months to 14.5 years).

A more recent systematic review of 14 articles (1 level III and 13 level IV) published between 2000 and 2007 included 7 articles from the aforementioned systematic review and looked at 352 MAT procedures in 323 patients [15]. The 7 studies 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). Height, weight, and sex were not addressed in the review of these studies.

It can be inferred from these systematic reviews that 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.

## 29.3 Meniscus Structure and Function

The menisci are fibrocartilaginous structures of the knee with the primary function for load transmission, shock absorption, increasing joint congruity, reducing joint contact stresses, and joint lubrication and nutrition [1, 9, 10, 16–22]. 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 [23, 24]. 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 force across the articular cartilage. Collagen fibers within the meniscus are arranged in a circumferential pattern and are held together by radially oriented collagen fibers which create hoop stresses, helping to prevent displacement of the menisci during loading [25].

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 to the medial meniscus, which is more oval shaped and covers only 30% of the 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 [26]. 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 role in knee stability [12, 27].

## 29.4 Effects of Meniscectomy

Biomechanical studies investigating the effects of partial and complete meniscectomy have emphasized the importance of maintaining meniscal integrity. Partial meniscectomy attempts to reduce stress to the cartilage compared to complete meniscectomy, but there still is increased contact stress compared to an uninjured knee, and earlier degenerative osteoarthritis results from this condition [28, 29]. Several important points should be made when considering meniscectomy. First, meniscectomy of the lateral meniscus has been shown to increase peak joint contact pressures when compared to medial meniscectomy and increase the incidence of osteoarthritis [30]. 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 [31]. Finally, resection of 75% or more of the posterior horns of the menisci biomechanically functions as a complete meniscectomy [31, 32]. Consequently, not every meniscal tear is amenable to partial meniscectomy, and some tears functionally behave like complete meniscectomies when debrided which may make that patient a candidate for MAT.

Patient subjective outcomes following complete meniscectomy are fair to poor in long-term outcome studies [16, 33–36]. Studies have demonstrated the correlation of clinical and radiographic osteoarthritis in patients with a history of previous meniscectomy [1, 37]. A recent 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) [36]. As a result of the poor outcomes following total meniscectomy, MAT has been an acceptable alternative to a meniscal deficient knee.

## 29.5 Indications for Meniscal Transplant

The relative indications for meniscal transplantation are the following: 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, asymptomatic, young, athletic patients with a complete lateral meniscectomy present a clinical challenge with rapid progression of osteoarthritis commonly. In this highly selected population, an early MAT procedure may be a reasonable consideration.

There has been clinical evidence that the success and rate of healing of the allograft is improved in patients with mild degenerative changes or less in the involved joint [38]. Noyes et al. demonstrated that knees with less than Outerbridge grade 4 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 [39].

The success of MAT depends on a ligamentously stable knee. Commonly, MAT is performed with concomitant anterior cruciate ligament (ACL) reconstruction due to the increased incidence of medial meniscus tears in the chronic ACL-deficient knee. 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 [40]. There is a lack of 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 [41]. Ligamentous instability should be restored with reconstruction prior to or at the time of MAT.

Normal mechanical alignment is critical to the success of MAT. Garrett and Stevenson were the first to address the high failure rate of MAT in extremity malalignment [42]. 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 up to 85% of the time after MAT have been demonstrated when performed at the same time as a realignment osteotomy [43]. There are no prospective comparison outcome studies that compare osteotomy alone or osteotomy with MAT. Therefore, a corrective osteotomy, whether for valgus or varus, should be performed prior to or concomitantly with MAT. In cases of valgus alignment, a varus-producing distal femoral osteotomy should be considered, and for a varus-aligned knee, a valgus-producing high tibial osteotomy should be considered.

Some additional contraindications to allograft transplantation are obesity, infection, inflammatory arthritis, and skeletal immaturity. 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 good patient selection and preoperative counseling are paramount to the success of the surgery and patient satisfaction. Further research needs to provide prospective data on the expected return to high-level sports and long-term outcomes of this procedure to help guide surgeon recommendation to return to activity.

Patients who may be candidates for MAT tend to have a complex past surgical history of the knee [38, 43]. Additionally, the patient may have concomitant chondral, ligamentous, or alignment abnormalities of the knee that need to be considered in their surgical planning. As a result, there are many factors that can affect the long-term success of MAT. Due to the lack of RCTs and long-term clinical outcomes, it is difficult to predict the ideal candidate for MAT.

## 29.6 Graft-Specific Factors

Method of preservation, secondary sterilization, and method of graft sizing are graft-specific factors that are critical to 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. High cell viability has been theorized to better maintain the mechanical integrity of allograft tissue [44]. 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 also 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 [45, 46].

Allograft tissue has the small potential to transmit bacterial, viral, or fungal infection, and secondary sterilization is the process to eliminate infection. 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 [47, 48]. Ethylene oxide has also been used for sterilization, but its use was discontinued due to its tendency to cause a synovitic reaction 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 recreate 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 utilize plain radiographs, MRI, or CT and may utilize the either the injured or uninjured extremity for measurements [49, 50]. A lack of clinical studies comparing one measuring technique to another exists. 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 >10% size mismatch can alter the biomechanics of the joint and place increased stress on the meniscus allograft [51]. The most commonly utilized protocol has been described by Pollard et al. which utilizes bony landmarks on AP and lateral plain radiographs [52]. 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 [49].

## 29.7 Graft Implantation

MAT can be performed open or arthroscopically using several different methods. Two systematic reviews of MAT support that there is no one ideal method of surgical approach or fixation [14, 15]. There have been cadaveric and clinical studies that 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 [14, 15, 53].

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 [54–56]. The importance of rigid graft fixation outweighs the small theoretical increased risk of disease transmission from the allogenic bone. Secure fixation of bone plugs is commonly used for medial MAT to avoid disrupting the native footprint of the ACL, which inserts medial on the tibia between the two horns. Lateral MAT can also be performed with bone plugs, but 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 by its advocates. 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 [57, 58].

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 pull-out strength [53]. Biodegradable implants have been utilized but less frequently than suture fixation due to the decreased tensile strength of these implants.

## 29.8 Perioperative Considerations

The most critical factor in performing meniscal allograft transplantation is proper patient selection. While knee compartments that are meniscal deficient will see abnormal contact stresses and may experience advanced degenerative changes, meniscal allograft transplantation is a technically challenging procedure and patients with relative contraindications should not be offered this treatment. Factors such as high BMI and tobacco use may be "modifiable" but may suggest that meniscal allograft transplantation may not appropriate.

Ensuring that the lower limb is mechanically aligned in the coronal plane is paramount. If an osteotomy is required, this has considerable ramifications on the potential for concomitant procedures and staged future procedures, especially in the case of the MLIK. As is typically recommended for ligamentous procedures in malaligned knees, it is the authors' preferred approach to perform osteotomies as the initial procedure. This is usually performed with a concomitant knee arthroscopy to assess the meniscal status and condition of the articular cartilage. Clearly, in acute cases with MLIKs, collateral and/or cruciate repairs/reconstructions may be performed early in order to allow for rehabilitation. In chronic cases, we prefer to first ensure proper alignment, as well as perform any needed collateral reconstructions. Then we typically allow for a 3–6-month period prior to performing the staged meniscal allograft transplantation in conjunction with any necessary cruciate reconstructions. This allows adequate time for the procurement of size-matched meniscus allograft in addition to any chondral grafts as well as to allow for adequate healing of the osteotomy site to allow for screw removal as needed in case of tunnel obstruction. The cruciate work is usually performed in conjunction with the meniscus transplantation as an empty notch significantly facilitates this technically challenging procedure.

Clearly, the treatment of an acute MLIK does not involve planning for meniscus transplantation. As discussed in previous chapters, it is critical to have a high index of suspicion for a vascular injury and evaluate thoroughly. After emergent reduction and confirmation of vascular status, the most important determination is to define the injury. The presence of fractures may alter the surgical approach, as well as the extent of ligamentous involvement. The presence of meniscal injury has been noted in 50% of knee dislocations [59]. It is important to repair peripheral tears as well as meniscocapsular injuries. These repairs are typically performed during initial open repair or arthroscopic evaluation. While a total or subtotal meniscectomy should be rarely necessary, these patients should have thorough documentation of compartment status as meniscus allograft transplantation may be possible in the future. As these grafts need to be size-matched, staged transplantation is the approach usually taken and is most appropriate in MLIK cases as ligamentous stability is the primary goal. Given the additional stability provided by the menisci, concomitant meniscal transplantation may be considered in cases of total meniscectomy and cruciate deficiency. However, in our experience, meniscal allograft transplantation is usually performed in a delayed fashion following initial ligamentous reconstruction. A recent review of our institution's experience with meniscal allograft transplantation revealed that very few meniscal transplantations have been performed in patients having sustained true knee dislocations. However, of a total of 84 meniscal allograft transplants performed at our institution from 2005 to 2010, only 3 were multiligamentous knees, with 2 undergoing concomitant ACL/PLC reconstructions and another having a PCL/PLC reconstruction. In fact we are aware of only one report of a MLIK undergoing combined cruciate reconstructions and MAT in the literature [60].

## 29.9 Authors' Surgical Technique

As previously mentioned, it is recommended to ensure both ligamentous stability and proper mechanical alignment prior to considering meniscal allograft transplantation. While ligament reconstruction may be performed in conjunction with meniscus transplantation, surgeons should consider performing high tibial osteotomy or distal femoral osteotomy in a staged fashion (ideally 6 months prior to transplant to allow for hardware removal as needed). The performance of arthroscopy at the time of osteotomy allows for optimal assessment of meniscal and chondral lesions. In cases with neutral alignment confirmed by standing alignment radiographs, ligamentous deficiencies are confirmed by physical examination and stress radiographs as necessary.

As discussed previously in this chapter, there are many described techniques of meniscal allograft transplantation. We prefer to use a bone plug technique for both lateral and medial transplantations [61]. This is an arthroscopic technique in which the bone plugs are fixed into recipient sockets on the tibial plateau.

The surgical technique begins with the graft preparation, which is initiated while the patient is being set up in order to minimize operative time. A free meniscus graft is fashioned from the donor meniscus and hemi-plateau allograft (Fig. 29.1), with 8×10 mm bone plugs attached to both the anterior and posterior meniscal roots (Fig. 29.2). A number 2 permanent suture is placed up through a central vertical hole in each cylindrical plug, transversely through the root, and back through the central hole. A second suture is placed in a simple fashion vertically through the meniscal allograft 1 cm from the posterior horn bone plug—this is the posterior horn stitch. A third suture is placed 1 cm from the second in a similar fashion—this is the mid-body stitch (Fig. 29.3). With this, the graft is maintained in a moist sponge on the back table until the knee is ready for graft passage.

After a thorough diagnostic arthroscopy, the notch is prepared for any cruciate reconstructions needed. In cases of cruciate intact knees, space is cleared in order to pass the posterior bone plug through the notch. A small amount of the PCL is debrided

**Fig. 29.1** 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. 29.2** 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

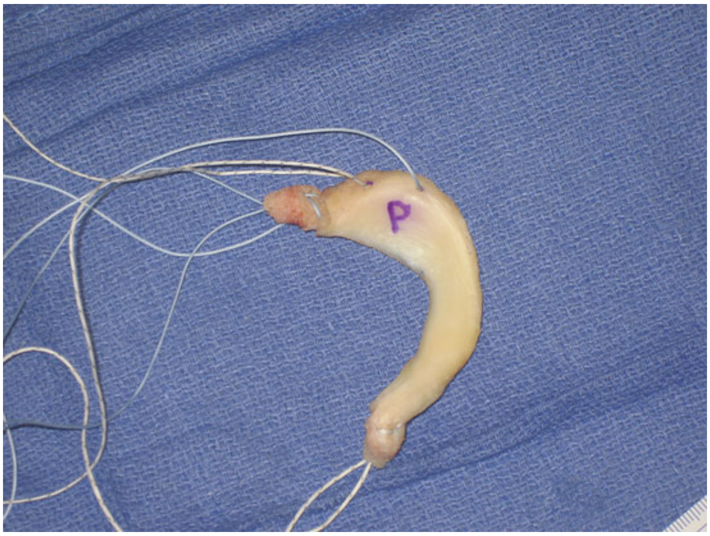

**Fig. 29.3** Completed bone plug meniscal allograft with number 2 permanent sutures passed up central vertical holes in the bone plugs, passed transversely across the root, and back down through the bone plug. Two additional number 2 sutures are placed in the meniscus in the posterior horn and mid-body of the meniscus

**Fig. 29.4** For medial meniscus transplants, a small amount of the PCL is debrided along with the extreme lateral aspect of the medial femoral condyle and the medial tibial eminence to facilitate bone plug passage

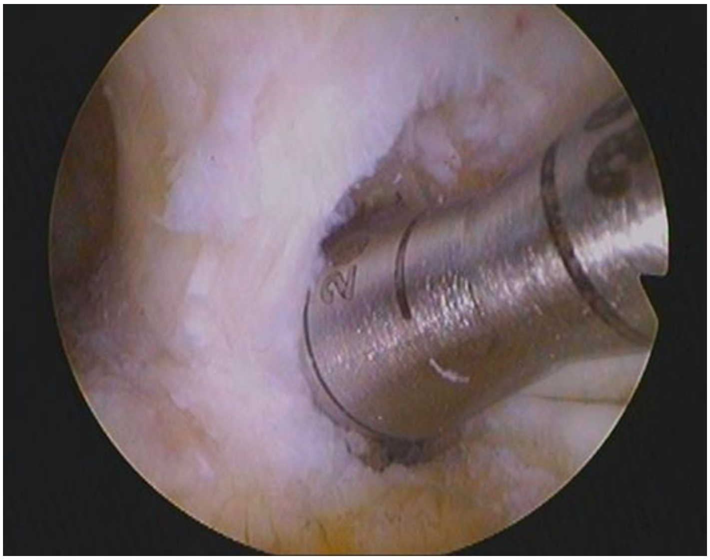

**Fig. 29.5** For lateral meniscus transplants, a minimal recession of the ACL posterolateral bundle and debridement of the medial aspect of the lateral femoral condyle and lateral tibial eminence is performed to facilitate bone plug passage. Successful passage of an 8-mm tunnel dilator confirms that adequate space exists to pass the posterior bone plug

along with the extreme lateral aspect of the MFC and the medial eminence for a medial meniscus transplant (Fig. 29.4). Lateral transplants require a minimal recession of the ACL PL bundle and debridement of the medial aspect of the LFC and lateral eminence. Once an 8-mm smooth dilator can be easily passed (Fig. 29.5), the preparation is adequate.

The meniscal remnant is next removed. This is most efficiently performed using a radiofrequency probe or meniscal scissors to cut along the meniscal periphery; however, a piecemeal debridement with a biter is often necessary. The goal is to remove all meniscal tissue, leaving a rim of 1–2 mm, while preserving the chondral surfaces (Fig. 29.6). The footprint of the posterior horn insertion is cleared of soft tissue and marked with the radiofrequency device (Fig. 29.7). A posterior horn bone tunnel or socket is created. While a traditional tunnel can be created, a reverse-drilled socket is preferable to minimize tunnel compromise, which is a concern in MLIK cases that also require ACL and PCL tunnels. We prefer the use of an 8-mm FlipCutter (Arthrex, Naples, FL) to create an 8 × 10 mm socket at the site of the posterior horn attachment, placed using a tibial ACL aiming guide (Fig. 29.8). A passing suture is placed through this hole.

A medial or lateral skin incision is made for the inside-out meniscal repair. The medial or lateral gastrocnemius fascia is elevated and a retractor placed. A second passing suture is placed 1 cm from the posterior root socket using a suture shuttle passed through the capsule and out into the medial or lateral wound—this is the posterior horn suture (Fig. 29.9). A third suture is placed 1 cm from the last in a similar fashion—this is the mid-body suture. At this point, the knee is prepared for graft passage. With the camera in the anterior portal opposite the compartment being transplanted, an enlarged portal is created—enough to allow a finger to freely enter the joint. Once the 3 passing sutures are identified and organized, the respective passing sutures are used to pass the graft sutures. This suture organization is critical to successful graft passage

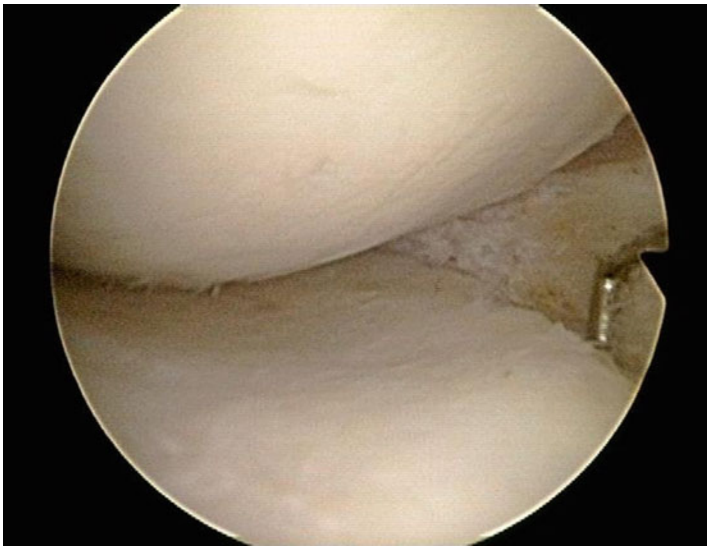

**Fig. 29.6** A 1–2-mm residual rim of native meniscus is preserved in order to allow secure fixation of the donor meniscus with meniscocapsular suture passage. Extreme care is taken to protect the chondral surfaces during this preparation

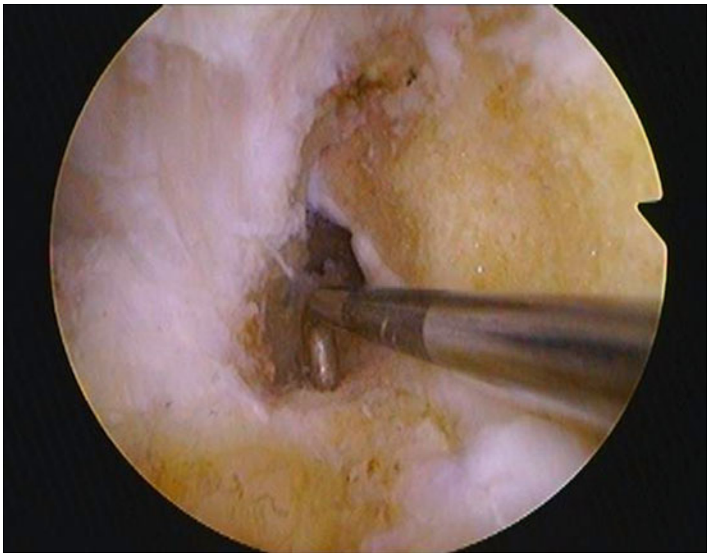

**Fig. 29.7** The posterior horn insertion site is cleared of all soft tissue and marked with a radiofrequency device

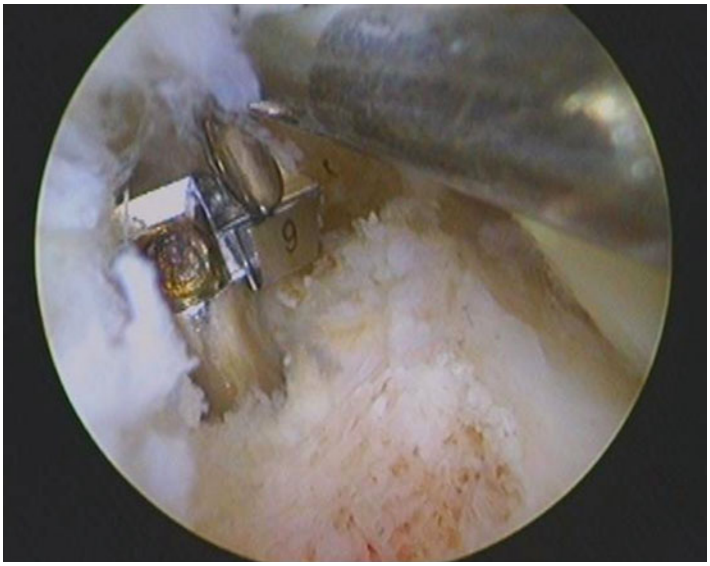

**Fig. 29.8** An 8-mm-diameter FlipCutter (Arthrex, Naples, FL) is used to create an 8 mm diameter by 10 mm deep socket in the anatomic posterior horn footprint using a tibial ACL aiming guide. A passing suture will be placed through this hole and socket for passage of the posterior horn bone plug

**Fig. 29.9** 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

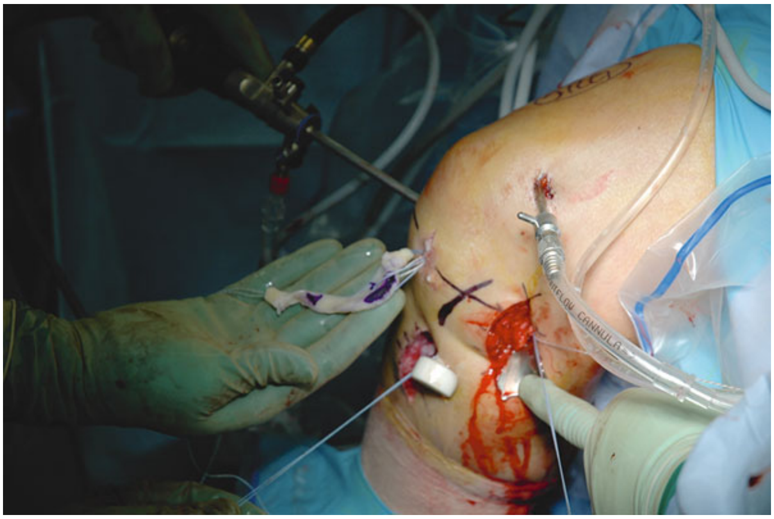

**Fig. 29.10** The graft is passed into the knee through the enlarged portal and facilitated by first securing the posterior bone plug into its socket

and should reflect the following "bottom-to-top" organization: posterior bone plug stitch closest to the tibial surface, followed by the posterior horn passing stitch in the middle position, and finally the mid-body passing stitch furthest from the tibial surface. Using a ring grasper, it should be confirmed that all three of these passing sutures exit the arthrotomy without any tissue bridges between them. The graft is passed into the knee (Fig. 29.10)—first securing the posterior bone plug into its receptive socket—then passing the posterior horn under the femoral condyle by pulling on the horn and mid-body stitches (Fig. 29.11). The passage of the posterior horn can be assisted by varus or valgus loading of the knee to open the compartment and by judicious use of a blunt outflow trocar to gently direct the meniscus beneath the condyle. The posterior root bone plug is secured by tying onto the cortex with a button or post. The posterior horn and mid-body stitches are tied together over the capsule. At this point a standard inside-out meniscal repair is performed, working from posterior to anterior (Fig. 29.12). When arriving at the anterior horn, the anterior root bone plug is assessed for where it lays in relation to the anterior tibia. An 8×10-mm socket is placed through the enlarged portal at this position. A guide pin is placed from the anterior tibial cortex into this socket, and bent suture passer is used to pass the bone plug sutures out the tibial cortex. The bone plug is secured into its socket, and sutures are tied to either the posterior bone plug sutures or over the cortex with a button or post.

When performing concomitant cruciate ligament reconstruction, we prefer to pass the meniscus graft and secure the posterior bone plug, followed by the mid-body repair. Before we complete the repair and anterior bone plug fixation, we typically pass the cruciate grafts and secure them on the femoral side. After completing our meniscal transplantation, we secure the cruciate and collateral grafts sequentially as covered in other chapters.

**Fig. 29.11** 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. 29.12** Zone-specific cannulas are used to perform a standard inside-out meniscal repair from posterior to anterior

## 29.10 Rehabilitation After Meniscal Allograft

Rehabilitation after meniscal allograft transplantation should allow for meniscal healing without exceeding the load to failure of the meniscocapsular sutures or meniscal horn fixation. Basic science studies have reported on the meniscal motion and loading patterns associated with muscle activation and various knee flexion angles. Motion of the meniscus is significant during knee flexion and extension [62]. Specifically, knee flexion >90° results in significant meniscal motion and displacement of the posterior horn from the capsule [26, 63]. In contrast, knee extension reduces the meniscus to the capsule and there is minimal meniscal motion with less than 60° of flexion [62]. Anatomically, the semimembranosus attaches on the medial meniscus and the popliteus on the lateral meniscus [64]. As a result, active knee flexion and passive knee flexion >60–90° may stress the meniscocapsular and meniscal horn fixation during early healing phases. On the other hand, case series have shown favorable outcomes with early range of motion protocols [65, 66]. Clinical trials comparing rehabilitation protocols to determine the clinical effect of these biomechanical studies and case series are unavailable. In the absence of compelling evidence for specific rehabilitation protocols after meniscal transplantation, postoperative restrictions are often determined by concomitant cartilage, ligament, or limb realignment procedures [65].

The authors follow a three-phase rehabilitation protocol (Table 29.1). The first phase is a protective phase and extends 6 weeks after surgery. The patient is instructed to wear a brace at all times and ambulate with brace locked in full extension. The patient is partial weight-bearing and able to passively range the knee from full extension to 90° of flexion. The second

**Table 29.1** 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 at 0–25% body weight |
| | • Wks 3–4: partial weight-bearing at 25–50% body weight |
| | • Wks 5–6: partial weight-bearing at 50–75% body weight |
| Brace: | Locked at 0° extension for 6 weeks |
| Rehabilitation: | Begin patellar mobilizations and scar massage after suture removal |
| | Calf pumping with tubing |
| ~Weeks 1–2 | Heel slides—assisted as needed: within the limits of 0–90° |
| | Static quad sets, SLRs (in brace) |
| | Supine passive extension with towel under heel, gentle HS stretching |
| ~Weeks 3–4 | Short arc quads—may add light weights as tolerated |
| | Seated bilateral calf raises—progress to standing bilateral calf raises |
| ~Weeks 5–6 | Hamstring curls—light weight 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 | Stationary bike, gait training, progressive strengthening |
| 9–10 Weeks | Standing balance exercises, progressive strengthening |
| 11–12 Weeks | 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 | Progressive functional training, strengthening, and balance training |
| 17–26 Weeks | 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 at ~9 months post-op |

phase generally extends from weeks 7 to 12 postoperatively. This phase is aimed at returning full knee range of motion and achieving a normal gait pattern. The brace is worn but unlocked to allow full range of motion. The patient is instructed to progress to full weight-bearing during weeks 7 and 8, and crutches are discontinued when the patient can demonstrate a normal gait. The third phase is aimed at a return to activity and extends between 4 and 6 months postoperatively. 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. The patient can return to full activity after 9 months.

Meniscal allografts have a limited life span with deteriorating outcomes over time despite revascularization of the allograft tissue [67, 68]. As a result, we currently do not recommend a return to high-load activities involving cutting, pivoting, or jumping. While >60% of meniscal allograft patients return to some level of sports activities, the goal of the procedure should be a painless knee during activities of daily living [15, 69].

## 29.11 Outcomes

Meniscal allograft transplantation is a successful procedure in reducing pain, decreasing effusions, and improving knee function. These clinical improvements are presumably due to the load transmission characteristics of a meniscal allograft compared to a meniscectomized knee [70]. Despite improvements in biomechanical function, there is minimal clinical evidence that meniscal allograft transplantation slows progression of cartilage degeneration. As a result, the goals of this salvage procedure should be to reduce pain and improve knee function in the short term during activities of daily living.

Despite a high incidence of meniscal injuries after multiligament knee injuries, very few studies have been reported on the outcomes of MATs with multiligamentous knee reconstructions [71]. The literature on multiligamentous knee injuries treated with reconstruction and meniscal allograft are limited to individual case reports [50, 60].

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 multiple ligament injury presumably has cartilage damage and altered mechanics that may hasten the development of arthritis. The goals of meniscal allograft transplantation in this setting is to provide the meniscectomized knee with tissue that replicates the improved contact mechanics, reduced peak contact pressures, stabilizing, and chondroprotective effects of the meniscus intact knee.

## 29.12 Prevention of Osteoarthritis

Chondroprotective effects of meniscal allograft transplants have been evaluated in multiple animal and cadaveric models. Cadaveric models have utilized pressure sensitive film to evaluate tibiofemoral contact pressures of meniscectomy compared to allograft transplantation. Lateral meniscal allograft decreases peak local contact pressures by 55–65% compared to meniscectomy, but contact pressures remain higher than the intact state [70]. Maximum and mean contact pressures are reduced 75% after medial meniscal transplantation, and the contact pressure reduction is closely related to the accuracy of size-matched graft tissue [56]. McDermott et al. found peak pressures to be restored to near normal after lateral allograft transplantation and noted a slight advantage of bone plug fixation compared to sutures alone [72]. The cadaveric models suggest a chondroprotective effect of meniscal allograft transplantation through reduction in contact pressures.

Szomor et al. utilized a sheep model to evaluate in vivo chondroprotective effects of meniscal transplantation [73]. The area of damaged articular cartilage was reduced by 50% with meniscal allograft or autograft compared to the meniscectomized animals 4 months after surgery. Similarly, Kelly et al. used a sheep model to compare meniscectomized animals with lateral meniscal allograft transplantation [74]. The cartilage was evaluated at 2, 4, and 12 months with gross inspection, magnetic resonance imaging, T2 mapping, biomechanical testing, and histological analysis. The model showed significant chondroprotective effects of meniscal allograft compared to meniscectomy, but the meniscal allograft animals had more cartilage damage compared to the meniscal intact control group. The authors concluded that meniscal allografts provide significant but incomplete protection in short-term follow-up against cartilage degradation after meniscectomy.

In contrast, Rijk et al. utilized a rabbit model to compare radiographic and cartilage cellular activity changes 1 year after meniscectomy or meniscal allograft [75]. The authors noted no differences in radiographic changes or functional changes in articular cartilage between the meniscectomized animals and the meniscal allograft animals concluding transplantation does not prevent degenerative changes with longer follow-up [75, 76].

The evaluation of chondroprotective effects of meniscal allografts in human subjects is limited to case series. Ha et al. noted no progression in arthrosis grade in 77.8% of knees evaluated with magnetic resonance imaging or 64% of second-look arthroscopies evaluated at 31 months [77]. In a clinical series evaluating radiologic outcomes, Verdonk et al. reported that 41% of fresh meniscal allografts had no further decrease in tibiofemoral joint space at a minimum of 10 years postoperatively [78]. The authors concluded that the operation had a potentially chondroprotective effect based on the absence of additional joint space narrowing. 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.

## 29.13 Healing of Meniscal Allograft

Several animal studies have reported healing of meniscal allografts with host cellular replacement of peripheral meniscal tissue. Cryopreserved menisci were shown in a dog model to heal the capsular tissues by fibrovascular scar tissue [79]. The allograft cells had a decrease in the number of metabolically active cells but had a normal cellular distribution. A goat model revealed fresh and cryopreserved menisci showed peripheral healing and revascularization but noted biochemical changes in the extracellular matrix at 6 months after transplantation [80].

The 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

[81]. Debeer confirmed host repopulation in a patient with DNA analysis of meniscal allograft tissue retrieved 1 year after transplantation [46]. Rodeo et al. evaluated meniscal allograft biopsies 16 months after implantation and noted that the meniscus is repopulated with cells derived from the synovial membrane with characteristics similar to synovial cells and fibroblasts [82]. The authors noted cells indicative of an immune response directed at the meniscal allograft, but it did not affect the clinical outcome.

## 29.14 Clinical Outcomes

The preponderance of clinical evidence for meniscal allograft transplants are derived from case series. Unfortunately, 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 are not uniformly described that may affect outcome include method of size matching, concomitant chondral and ligamentous injury, and limb alignment. With these limitations in mind comparing clinical outcomes of meniscal transplantation, a recent systematic review reported patient satisfaction ranges from 62.5 to 100% and early failure rates range from 7 to 35% [15, 83–85]. Excluding older patients with preexisting osteoarthritis, the early failure rate averaged 10% [15].

Meniscal allograft transplantation was first reported by Milachowski in 1989. The authors reported an 86% success rate with 22 meniscal allografts at 14 months after surgery [3]. In one of the largest series published to date, Noyes et al. reported on 96 fresh-frozen, gamma-irradiated meniscal allografts. The authors noted a 58% failure rate which has been largely attributed to the gamma irradiation [38]. Wirth et al. noted inferior results in lyophilized meniscus transplants with outcomes similar to a meniscectomy control group [68].

Recent series with improve sterilization and preservation methods have shown improved outcomes. In a prospective case series, Cole et al. reported on a series of 40 meniscal allografts with anterior and posterior bone plug fixation. Cryopreservation was the most common graft preparation type. The authors noted an 86% success rate and IKDC scores in the normal or near normal range at 2 years [84]. Similarly, a recent case series of 40 patients treated with frozen, nonirradiated 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 [86].

## 29.15 Long-Term Follow-Up

While early results of allograft transplantation have been successful with objective and patient-reported outcome measures, the long-term results remain the most important. Van der Wal evaluated 63 cryopreserved meniscal allografts with soft tissue fixation at 13.8 years after surgery [67]. He reported a 29% failure rate and deterioration in patient outcome over time. Lysholm scores significantly declined from 79 at 3 years after surgery to 61 at final follow-up. Interestingly, there was no difference in Lysholm scores between allograft survivors and those that failed requiring a knee arthroplasty. Similarly, Wirth et al. reported a decline in Lysholm scores from 84 at 3 years to 75 at 14-year follow-up [68]. A recent case series of 22 cryopreserved meniscal allografts had up to a 55% failure rate at 11.8 years. The authors noted improvements in pain and function but only fair results at longer-term follow-up [87]. In contrast, a series of 50 cryopreserved meniscal allografts implanted with soft tissue-only fixation had a 10% failure rate [88].

## 29.16 Medial Versus Lateral

Survival and outcomes of medial versus lateral meniscal allograft transplantation have been different in several series [78, 87, 89, 90]. In a study with long-term follow-up, lateral meniscal allografts had a 76.5% survival rate at 10 years, while medial allografts had a 50.6% survival at 9 years [89]. In contrast, a second series evaluated at 11.8 years after surgery had a 25% medial allograft failure rate compared to a 50% lateral failure rate [87]. Finally, several authors showed no significant differences in outcomes between medial and lateral meniscal allografts [66, 91, 92]. This disparity in outcomes may be attributed to differences in ligamentous stability or mechanical alignment that predisposes the medial or lateral side to failure. A recent systematic review of meniscal allograft transplantation detected no difference in outcomes between medial and lateral allograft transplants [93].

## 29.17 Preexisting Osteoarthritis

Preexisting osteoarthritis portends a worse prognosis after meniscal allograft transplantation. In an early study of 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 [38, 94]. Stollsteimer reported improved postoperative Lysholm and Tegner scores in patients with Outerbridge scores of less than 2, and patients with Outerbridge scores >3 in any area did not improve with surgery [66]. Evaluation of 29 meniscal allografts with magnetic resonance imaging revealed that allograft degeneration was associated with moderate and severe chondral wear, and the authors recommended preoperative assessment to identify patients at risk for failure [95].

Defining the optimal time to offer a meniscal allograft transplantation remains difficult. Total meniscectomy results in long-term degradation of the articular cartilage [1]. While 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. Authors have considered prophylactic meniscal allografts before the onset of symptoms in an attempt to prevent degenerative changes [96]. However, 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. As a compromise to 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 imaging or laboratory studies may enable earlier detection of cartilage degradation to help define the appropriate indications for meniscal allograft transplantation. Little evidence exists supporting the routine use of MRI or bone scanning at intervals in such patients and the cost over time obtaining such studies may be prohibitive.

## 29.18 Extrusion

Meniscal allograft extrusion is reported in 40–100% of patients after transplantation [78, 97, 98]. While studies have shown inferior clinical outcomes associated with meniscal extrusion, many studies have failed to show meniscal extrusion to be associated with clinical outcomes [95]. Lee evaluated 43 patients treated with a variety of fixation techniques and reported that 40% of grafts extruded an average of 3 mm at 1 year after surgery, but the extrusion did not progress at the 5-year evaluation [98]. He also noted that the presence of graft extrusion did not correlate with joint space narrowing or clinical outcomes at 5 years.

Ha et al. evaluated 36 patients 31 months after meniscal allograft transplantation and noted average meniscal extrusion to be 3.9 mm [98]. The authors also noted no correlation with clinical, radiologic, or arthroscopic outcomes and meniscal extrusion. Finally, 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 [97].

## 29.19 Allograft Tear Rate

The meniscal allograft symptomatic tear rate ranges in case series from 10 to 36% and is the most common reason for revision surgery after transplantation [43, 86, 87, 93, 97, 99]. Magnetic resonance imaging of meniscal allografts has been shown to correlate with arthroscopic findings regarding capsular incorporation and allograft tears [95]. 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 based on tear pattern, size, and quality of the remaining allograft tissue.

## 29.20 Outcomes Related to Graft Morphology

The 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 are returned most closely to the native state with appropriately size-matched graft tissue [56].

Meniscal grafts larger than the native meniscus led to increased forces across the articular cartilage, while smaller grafts resulted in increased forces across the menisci [51].

Pollard performed a cadaveric study and showed that meniscal sizing could be accomplished with standard anteroposterior and lateral radiographs [52]. Medial and lateral width could be estimated from the peak of the tibial eminence to the periphery of the tibial metaphysis on anteroposterior films. Medial and lateral meniscal length was reported to be 80 and 70%, respectively, of the tibial plateau on the lateral radiograph. Shaffer compared radiographic and magnetic resonance imaging to actual meniscus dimensions and found that both modalities were more than 2-mm different than actual dimensions [49]. A recent report found that meniscal sizing based on height, weight, and gender may be more accurate than radiographic measurements [100]. 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.

## 29.21 Fixation Method

Numerous techniques have been described for medial and lateral meniscal allograft transplantation, but studies have drawn a distinction between techniques that employ osseous versus soft tissue fixation of the meniscal horns. Stable fixation of the meniscal horns is critical to successful function of the meniscus. Loss of horn fixation has been shown biomechanically to be equivalent to a total meniscectomy [70]. Cadaveric studies have shown that stable fixation of the anterior and posterior horns are critical to restoration of the load-sharing properties of the meniscus [54, 56]. While a clinical study has not 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 [55, 72]. In contrast to the models, clinical series have shown successful results with soft tissue only fixation of the meniscal horns [97, 101]. The authors of the series note an unknown effect of 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.

## 29.22 Meniscal Allograft with Ligament Reconstruction

In addition to improving contact mechanics, medial meniscal allograft transplantation can provide secondary stabilization. A cadaveric model showed that medial meniscectomy allowed significant displacement of the tibia in ACL-deficient knees, which was restored to normal with meniscal allograft transplantation [102]. 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 a multiligamentous knee reconstruction with a meniscal allograft transplant [50, 60].

Wirth et al. reported the first series of ACL reconstructions with concomitant meniscal allograft transplantation [68]. The authors noted Lysholm knee scores of 75 at 14-year follow-up. Sekiya et al. reported 86% normal or near normal IKDC scores 3 years after combined ACL and meniscal allograft transplantation [103]. 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 [90, 104]. A case-controlled trial of 16 ACL reconstructions with meniscal pathology matched medial meniscus transplantations with meniscal repair or partial meniscectomy [105]. At 5-year follow-up, the groups had similar IKDC and Lysholm scores with only the meniscal allograft group having more swelling. A recent systematic review of the literature revealed no difference in outcomes between isolated meniscal allograft transplantation and those with concomitant procedures [93].

## 29.23 Meniscal Allograft with Osteotomy

The long-term survival of meniscal transplantation relies on appropriate mechanical alignment. Prior reports have documented the importance of normal joint alignment in patient outcomes and survivability of meniscal allografts [39, 101]. A high tibial or distal femoral osteotomy is useful to unload a damaged compartment and to protect the transplanted allograft. In contrast to overcorrection osteotomy for osteoarthritis, mechanical alignment is adjusted to align with the opposite tibial spine of the transplanted meniscus [106]. A case series of meniscal allograft with concomitant procedures revealed a survival rate to be longer when performed with a high tibial osteotomy [101]. Mean survival time in combination with osteotomy was 13 years, and the 10-year survival rate was 83%. Cameron and Saha [43] 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, off-load damaged articular cartilage, and protect a transplanted allograft.

## 29.24 Conclusions

Meniscal allograft transplantation is a technically challenging procedure that is useful to improve patient satisfaction after total or subtotal meniscectomy. While not yet shown to be chondroprotective, it reliably improves patient subjective outcome measures over the short- to midterm follow-up period. Its use in conjunction with the treatment of the multiple ligament injured knee is limited to very specific cases, and little clinical evidence outside of case reports has been published to guide decision-making in this challenging treatment environment associated with such major knee injuries.

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# Chapter 30
# Extensor Mechanism Injury in Multiple Ligament Injured Knee

**Laura Scordino and Thomas M. DeBerardino**

## 30.1 Background

The first extensor mechanism injury was reported by Galen, who described a young man injured in a wrestling match. Despite a long period of healing, the patient remained unable to extend his leg and had difficulty walking on inclined surfaces. McBurney, in 1887, was the first to account an extensor mechanism rupture in the American literature. He described a 50-year-old man who bumped his leg just above his patella on a box, sustaining an inability to extend his leg [1].

Extensor mechanism injury refers to disruption of the patellar tendon, quadriceps tendon, or patellar retinaculum. It is a relatively infrequent injury, but requires prompt diagnosis and treatment to afford better outcomes. Patellar and quadriceps tendon ruptures occur in different age groups. Greater than 80% of patellar tendon tears are reported to occur in patients less than 40 years old, while greater than 80% of quadriceps tendon tears are reported to occur in patients greater than 40 years [1].

Isolated patellar tendon or quadriceps tendon ruptures occur as a result of eccentric quadriceps contraction, as the muscle lengthens, against the full weight of the body. This may occur as a person tries to catch themselves from slipping by firing their quadriceps while the knee is flexed. Rupture occurs in eccentric contraction as this is the position in which the quadriceps tendon is under the most stress. Patellar tendon ruptures occur most commonly at the proximal insertion site rather than midsubstance. This is thought to occur not only because this area is relatively avascular but also because there is a decrease in collagen fiber stiffness at the insertion site resulting in greater strain at that insertion area than in the midsubstance fibers [2].

Ruptures that occur due to indirect trauma are thought to be the final stage of chronic degeneration of the tendon [3]. In a study by Kannus and Jozsa in which 891 ruptured tendons were biopsied, including 53 patellar tendons, 97% of the ruptured tendons showed degenerative pathological changes such as hypoxic tendinopathy, mucoid degeneration, tendolipomatosis, and calcifying tendinopathy [4]. It is felt that healthy patellar or quadriceps tendons do not rupture and that the weak point in the extensor mechanism is, in fact, the patella itself. Thus a tension overload in a patient with a healthy patellar and quadriceps tendon would result in a transverse fracture of the patella, not a tendon rupture [5].

Systemic diseases that have an effect on the vascular or innate tissue quality of the extensor mechanism have been associated with nontraumatic, bilateral, and midsubstance quadriceps and patellar tendon ruptures. In fact, approximately 20% of those with unilateral and one third of those with bilateral spontaneous rupture of the extensor mechanism have systemic diseases that may contribute to the degradation of healthy tendon. Diabetes mellitus, hyperparathyroidism, systemic lupus erythematosus, osteomalacia, and the use of steroids have all been shown to cause microvascular changes within the tendons making them more susceptible to rupture [6–12]. Rheumatoid arthritis causes chronic inflammatory changes and results in synovitis and diffuse fibrosis. Gout can lead to tophaceous synovitis and fibrinoid necrosis of the tendon, while chronic renal failure and uremia actually degrade the collagen structure itself [8, 9, 11, 12]. Rupture has also been reported after injection of cortisone near the patellar tendon for treatment of jumper's knee [5], as a rare complication following total knee arthroplasty [13], and following anterior cruciate ligament reconstruction when the central third is harvested for the reconstructive graft [14].

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## 30.2 Anatomy

The extensor mechanism is composed of the quadriceps tendon proximally, the patellar tendon distally, and the patella as the large sesamoid bone in between. As the largest muscle in the body, the quadriceps femoris is made up of four muscular heads that coalesce distally to become the quadriceps tendon. The musculotendinous junction occurs approximately 3 cm above the superior pole of the patella. The rectus femoris is the superficial most muscle and originates from both the anteroinferior iliac spine and the hip capsule just superior to the acetabulum. It is the sole muscle of the quadriceps that originates from above the hip. Deep to the rectus femoris is the vastus intermedius which originates from the anterior portion of the femur and like the rectus femoris inserts on the superior pole of the patella. Laterally, the vastus lateralis originates from the linea aspera just below the greater trochanter. While medially, the vastus medialis originates from the medial aspect of the femur just below the lesser trochanter. The vastus lateralis and vastus medialis insert onto the superomedial and superolateral patella creating the medial and lateral retinacula, respectively. In some patients an anatomical variant, the articularis genu muscle, lies deep to the vastus intermedius originating off the distal anterior femur and inserting onto the joint capsule.

The quadriceps tendon is confluent with the patellar tendon distally. From the distal portion of the patella the patellar tendon is approximately the width of the patella or about 30 mm. Distally the tendon actually broadens as it inserts onto the tibial tubercle. Throughout its length the tendon is approximately 4–7 mm thick [15].

Blood supply of the patellar tendon is primarily from the infrapatellar fat pad, as well as the retinacular structures. This is an important anatomical consideration when fixing the patellar tendon. Furthermore, the infrapatellar fat pad, with contribution from the inferior medial and lateral geniculate arteries, supplies the posterior portion of the tendon, while the retinacula and the recurrent tibial artery supply the anterior portion of the tendon. Both the proximal and distal insertion points of the tendon are relatively avascular and thus put these areas at a high risk for rupture [16]. The quadriceps tendon is innervated by the femoral nerve (L2–L4).

The composition of tendon is 60–70% water by wet weight and approximately 70–80% collagen by dry weight. The collagen is 90% type I and 10% type III collagen. This high portion of collagen explains why systemic diseases which affect soft tissue can lead to increased rates of rupture [13].

## 30.3 Diagnosis

The diagnosis of a rupture of the extensor mechanism is reached by the compilation of information gained from the patient history and age, physical exam, radiographs, and chronically from additional imaging such as an ultrasound or MRI.

The triad of acute knee pain, inability to actively extend the knee, and a suprapatellar gap is pathognomonic for quadriceps tendon rupture [14, 17].

## 30.4 Physical Exam

Patients often present with inability to bear weight secondary to pain along with a hemarthrosis. Because of the mechanism of injury with associated hemarthrosis, patellar dislocation and ACL tear must be ruled out on exam. A basic knee exam, including distal neurovascular status, along with knee ligamentous exam should be performed.

The primary action of the extensor mechanism is to actively extend the knee against gravity. With complete disruption of the extensor mechanism the patient will demonstrate inability to extend the knee or inability to maintain a passively extended knee. This is the most important finding to diagnose complete disruption. The flexor mechanism will be intact. If the patient cannot extend against gravity, the patient should be rolled on their side, and the patient should attempt to extend the knee with gravity removed. Also, an intra-articular anesthetic may provide pain relief necessary to test the extensor mechanism. If a partial tear of the quadriceps or patella tendon occurs, or if a complete rupture occurs (but the retinaculum has remained intact), active extension may be possible, but it will be weak, and an extension lag will be present.

Another diagnostic clue to an extensor mechanism disruption is a palpable gap in the tendon itself. For a quadriceps rupture the gap will be felt approximately 3 cm proximal to the patella, at the area of the myotendinous junction, while a patellar

**Table 30.1** Characteristics of patellar versus quadriceps tendon injury

| Injury | Mechanism of injury | Deficit | Physical exam | Imaging | Age | Management |
|---|---|---|---|---|---|---|
| Patellar tendon rupture | Eccentric quadriceps contracture versus body weight | Inability to extend knee | Infrapatellar gap | Patella alta, patellar tendon shadow interrupted | <40 | Acute surgical repair |
| Quadriceps tendon rupture | Same | Same | Suprapatellar gap | Patella baja, quadriceps tendon shadow interrupted | >40 | Same |

Comparing the most common findings on history, physical exam, imaging, and management for patellar versus quadriceps tendon rupture

**Fig. 30.1** Radiograph of patellar tendon rupture demonstrating patella alta, or displacement of the patella proximally, superior to Blumensaat's line

tendon rupture will present with a palpable gap distal to the patella. These areas will be tender to palpation. Hematoma in the area of acute injury, hemarthrosis, and scar tissue in the chronic injury can sometimes make a gap difficult to appreciate and can lead to misdiagnosis. Diagnostic failure rates of 10–50% have been reported with delays from days to months [17, 18].

Once again the key to diagnosis based on physical exam is the inability to actively extend the knee (Table 30.1).

## 30.5 Imaging

Standard anteroposterior and lateral radiographs of the knee should be obtained anytime a patient presents with new-onset knee pain, especially if associated with a trauma, and the inability to bear weight. They can provide several consistent findings with disruption of the extensor mechanism. Patellar tendon rupture may result in patella alta or the presence of the patella superior to Blumensaat's line as seen on a lateral radiograph (Fig. 30.1).

On the other hand, quadriceps tendon rupture may result in patella baja on lateral radiograph, defined as inferiorly displaced patella. In a study of 18 patients, radiographs revealed a disruption of quadriceps soft tissue shadow in all 18 patients; a suprapatellar mass representing the retracted tendon in 12 patients; suprapatellar calcific densities, either avulsions or chronic findings, in 12 patients; and patella baja in 10 patients [17]. Ultrasound has been identified as a quick, less expensive way to identify patellar tendon ruptures. The location of the rupture can be delineated by an area of hypo- or anechoic area representing tendon rupture filled in will hematoma. Because ultrasound is a dynamic test, partial tendon tears can be differentiated from full tendon ruptures by flexing the knee which will distract the gap in complete tendon ruptures only. The negative of ultrasound is that it is operator dependant [19, 20].

MRI is the most effective tool to diagnose chronic or questionable patellar tendon tears and to rule out other intra-articular lesions. A recent study has suggested that injuries to the extensor mechanism are often associated with intra-articular knee damage. Thirty-three patients with patellar tendon ruptures and 31 patients with quadriceps tendon ruptures which occurred over the course of 10 years were reviewed. Patellar tendon rupture was associated with an intra-articular injury 1/3 of the time, while 10% of quadriceps ruptures were associated with intra-articular injury. Anterior cruciate ligament tear (18%) and medial meniscus tears (18%) were the most common injury to be associated with patellar tendon rupture [21]. Although MRI is both sensitive and specific, because of its expense, it should only be used if other diagnostic methods have failed or if additional information is needed for preoperative planning [19, 20].

## 30.6 Treatment

Indications for operative fixation of extensor mechanism include complete rupture. The natural history of unrepaired extensor mechanism rupture is that of disability, weak leg extension, and difficulty raising from chairs or walking up inclined surfaces [1].

There are few contraindications to repair of the extensor mechanism. Medical comorbidities such as recent MI, heart failure, or other conditions that predispose the patient to an unusually high risk of complication are a few of the specific contraindications. Also local factors posing increased risk for infection or potential wound complications such as contaminated wounds or poor soft tissue coverage should be addressed prior to an expedited trip to the operating room. Once the soft tissue around the knee joint appears adequate for closure postoperatively without an increased risk of infection, attention can be directed to extensor mechanism repair.

While medical comorbidities and the soft tissue envelope surrounding the knee must be optimized before proceeding with extensor mechanism repair, many studies have suggested that repair within the first few days of injury results in favorable outcomes as opposed to delayed treatment. Delay in diagnosis or treatment results in contraction of the quadriceps tendon, resulting in a gap and making mobilization of the distal and proximal extent of the extensor mechanism difficult. While acceptable results after delayed treatment have been reported in some studies, a more complex reconstructive technique often requiring allograft may be necessary.

## 30.7 Surgical Technique

Standard orthopaedic instrumentation should be set up on the operative field, with fluoroscopy available in the room to check patellar height against preoperative radiographs of the nonoperative leg before tendon tightening. The patient should be positioned supine with the well leg adequately protected and padded and preoperative antibiotics administered. A sterile tourniquet should be available but usually is not inflated because its direct pressure on the quadriceps will limit mobility of the proximal extent of the extensor mechanism. A standard extremity drape is applied as proximal as possible on the thigh.

The incision for both patellar and quadriceps repair is centered longitudinally and should be positioned distally over the tibial tubercle and directed proximally through the midportion of the patella. Full skin flaps are elevated medially and laterally to expose the tendon along with the medial and lateral retinaculum which are likely also torn and in need of repair. Often a large hematoma is present which can be removed with irrigation. The area of tendon rupture should be debrided of hematoma and fibrinous tissue down to healthy tissue adequate for repair. Specific surgical techniques differ for acute versus chronic rupture and for avulsion versus midsubstance tear.

Acute repair of a quadriceps tendon avulsion from the proximal pole of the patella involves obtaining strong suture investment within the quadriceps followed by solid fixation of the suture into the patella. First, the quadriceps is freed from any investing scar or soft tissue adhesions. A trial reduction is preformed in which the quadriceps is held with an atraumatic clamp and pulled distally to the patella to confirm closure of the gap. The patella is then prepared by placing three equally spaced longitudinally directed drill holes made either with a 2.5-mm AO drill or with a Beath pin (see Fig. 30.2). These figures are stepwise intraoperative fixation of a patella avulsion off of the inferior pole of the patella, but the same principles apply to a quadriceps avulsion off the superior pole of the patella. Our preferred technique involves the use of No. 2 or No. 5 nonabsorbable double-armed braided suture applied in a locking Krackow fashion with a deep and superficial, lateral, and medial row. Each row, one double-armed medial and lateral row, starts from posteriorly approximately 3 cm proximal to the torn edge and is carried down the tendon exiting in the posterior half of the free edge. The outermost sutures are passed through the outermost longitudinal holes in the patella, and the innermost two sutures are combined to pass through the central hole. We have found the use of the Hewson suture passer from a distal to proximal direction to be the easiest technique to pass the suture. The soft tissue on the proximal pole of the patella is freed so that the suture is approximated as

**Fig. 30.2** Intraoperative stepwise fixation of patellar tendon avulsion off inferior pole of the patella. (**a**) Inferior pole of the patella is isolated and prepared for tendon apposition. (**b**) Two double-armed No. 2 or No. 5 nonabsorbable sutures are applied in a Krackow technique starting 2–3 cm distal to the free edge and exit the free edge proximally. (**c**) and (**d**) Three equally spaced drill holes are made in the inferior pole of the patella directed superiorly. As the drill is removed, the Hewson suture passer is held ready to follow through the hole to pass the Krackow sutures. (**e**) The sutures are secured at the superior pole of the patella laying closely against bone. The lateral suture arm is tied to one of the central arms, while the medial suture arm is tied to the other central arm

close to bone as possible when tied. One suture from the center hole is brought laterally and one medially to tie to sutures from the outermost holes. A second row of more superficial Krackow sutures is next applied again from approximately 2–3 cm proximal to the free edge of the patella tendon. A double-armed lateral and medial row proceed distally to their exit point in the anterior half of the free edge of the quadriceps tendon. These four superficial Krackow suture strands are either fixed into the patella with suture anchors or invested in the strong tissue over the patella. This technique allows a double-row approach similar to that done for rotator cuffs so that an anatomical fixation respecting the anterior broad insertion of the quadriceps as well as the more stout posterior portion. The Scuderi technique has also been described if the quadriceps repair seems tenuous or if a small gap is present. In this technique an inverted "V" is created in the quadriceps tendon just proximal to the myotendinous junction. The proximal pole is then flipped over distally so that it covers the gap or tenuous area of tendon repair [22].

Our technique for acute repair of a patellar tendon avulsion from the distal pole of the patella is similar to the above quadriceps avulsion, except we do not employ a double-row, superficial and deep, technique to fixation. Absorbable suture repair of the retinaculum is performed medially and laterally after patellar tendon repair. If the patellar tendon repair appears tenuous, a cerclage wire or additional No. 2 nonabsorbable suture should be passed through transverse drill hole tunnels through the distal pole of the patella as well as 1 cm deep to the tibial tubercle (Fig. 30.2).

Repair of patellar tendon avulsions off of the tibial tubercle can be challenging to manage. Once again an anatomic repair is the basis of this technique. The patellar tendon insertion into the tibial tubercle is actually broader based than its origin off the inferior pole of the patella. To replicate this anatomy, the footprint on the tibial tubercle is first prepared with a rongeur to allow good bleeding and potential for osseous ingrowth (Fig. 30.3).

Four nonabsorbable No. 2 or No. 5 sutures are applied in a Krackow fashion in the free edge of the patellar tendon. One double-armed suture is placed to control and grasp each of four virtual tendon quadrants as viewed when looking directly at the avulsed end of the tendon: deep medial, superficial medial, deep lateral, and superficial lateral. The deep medial arms are combined and passed with the aid of a prepassed suture passer through an oblique drill hole made from distal lateral to proximal medial. Similarly, the deep lateral arms are combined and passed through an oblique drill hole

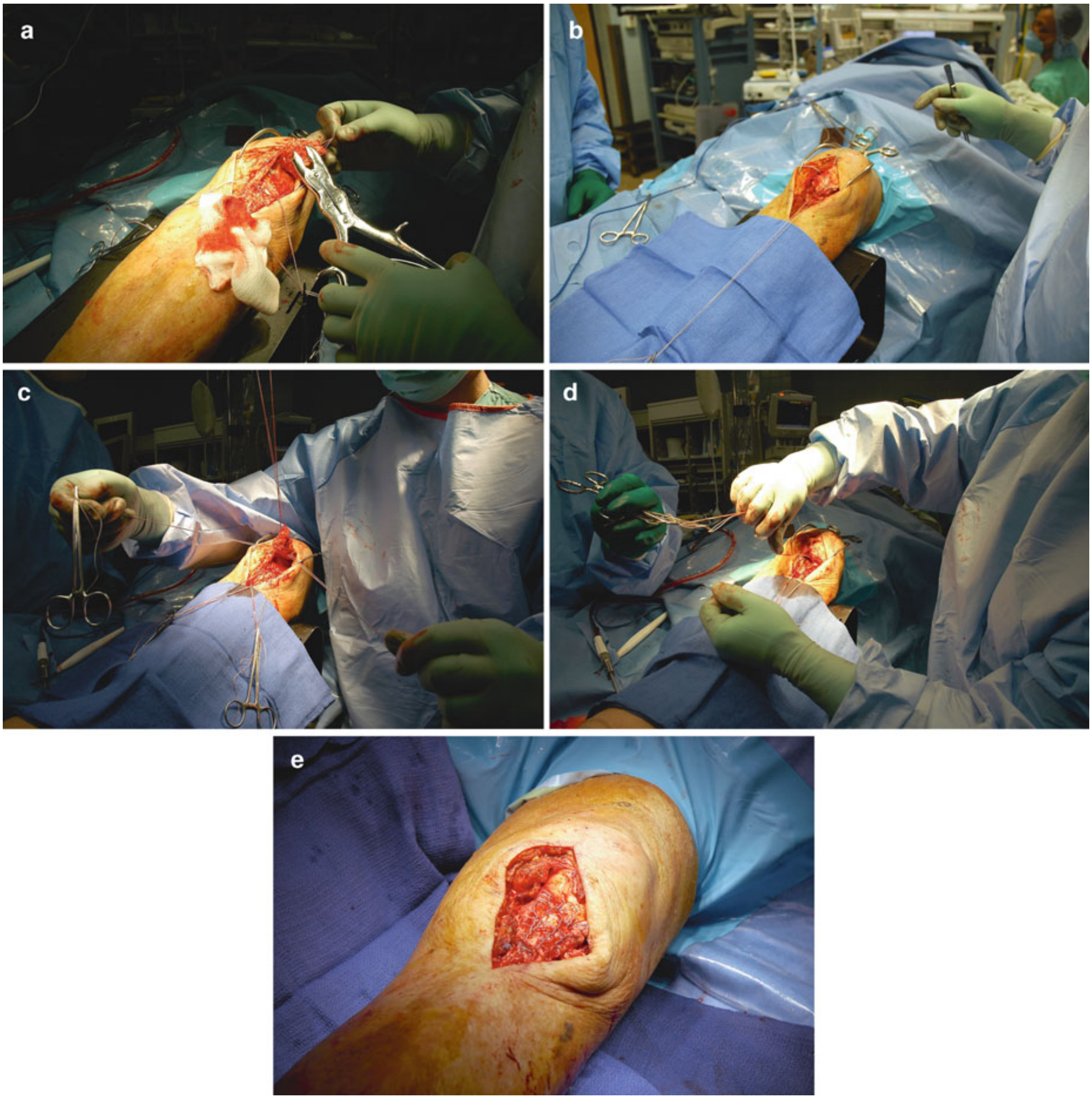

**Fig. 30.3** Intraoperative stepwise fixation of patellar tendon avulsion off the tibial tubercle. (**a**) A rongeur is used to prepare the tibial tubercle as well as the torn edge of the patellar tendon. (**b**) Once the Krackow sutures are placed, a trial reduction is preformed. (**c**) One Krackow suture is placed to control each quadrant, two superficial and two deep. (**d**) Two holes are drilled obliquely in the tibia. The two deep sutures are passed through these holes and tied distally so that they crisscross. The two superficial sutures are used to broaden the patellar tendon insertion into the tibia. Fixation is achieved with anchors. (**e**) The final anatomically based double-row repair

oriented distal medial to proximal lateral. In this way the two sets of suture arms cross and are fixed distally to the tibia with suture anchors. The superficial medial and lateral suture limb combinations are separately secured via suture anchors into the more distal and portion of the anatomic footprint on the tibial tubercle. This allows for recreation of the broad insertion of the patella on the tibia.

Chronic repairs of the extensor mechanism often require augmentation of allograft tissue. Achilles tendon allograft is a versatile graft. The bone plug can either be inserted distally in the tibial tubercle and used for a patellar tendon rupture or inserted distally in the patella and used for a quadriceps tendon rupture.

Wounds are closed over a closed system suction drain for the first 1–2 postoperative days if warranted as hemarthrosis is common.

## 30.8 Postoperative Protocol

The most common complications following extensor mechanism repair are decreased knee flexion as well as quadriceps weakness. Patients are made weight bearing as tolerated with crutches for the first 3 weeks and can wean from crutches thereafter as quadriceps muscle strength increases. Patients are kept in a knee immobilizer for the first 6 weeks, locked for ambulation, and unlocked for rehabilitation to allow early range of motion from 0° to 45° for the first 3 weeks. This is increased to 0–90° after 3 weeks postoperatively. Early straight-leg raises (in the locked brace initially until and extensor lag is absent) are encouraged to strengthen the quadriceps and to attempt to prevent quadriceps atrophy commonly seen postoperatively. Strengthening exercise can begin at week 7, while resisted strengthening should not be allowed until 10–12 weeks postoperatively. Return to sports can be resumed gradually after 3 months. With a strong rehab program stressing early range of motion and quadriceps strengthening, full strength recovery with no extensor leg can be expected.

In addition to standard postoperative pain medications, muscle relaxants are frequently given in the short term. This is most applicable for chronic ruptures since upon repair the quadriceps is suddenly under increased tension which can be painful and cause spasm.

## 30.9 Outcome

Clinical outcome appears to most closely correlate with the interval between rupture and fixation. In a study by Siwek and Rao based on 72 patellar tendon repairs, 80% excellent and 60% good outcomes were reported for patients treated within 7 days of injury. Whereas those treated greater than 2 weeks after surgery only resulted in 33% excellent and 50% good results [1]. Other studies including those by Larsen and Lund, as well as Hsu and colleagues, suggest that acute fixation results in excellent and good outcomes on a regular basis [23].

A review of studies which were appropriately divided into studies that focused on quadriceps tendon rupture or patellar tendon rupture suggests that in general patient age, sex, mechanism of injury, site of rupture, and type of repair did not affect the outcome of treatment [21, 24–26].

## 30.10 Complications

The most common postoperative complications following repair of the extensor mechanism in a multiligament injured knee are stiffness, specifically a lack of knee flexion, as well as quadriceps weakness. This once again underscores the importance of a well-executed postoperative rehabilitation program stressing early range-of-motion exercises and quadriceps strengthening. Closed manipulation under anesthesia may be considered if at least 120° of flexion is not obtained by 6–8 weeks postoperatively [27]. Quadriceps atrophy, up to 2–3 cm, has been noted in past studies, but by objective and subjective studies does not seem to compromise final return to strength if adequate rehabilitation is performed [1].

Other complications include postoperative hematoma. As such, the use of a closed suction drain at the time of closure is recommended by many.

Wound complications and infections are risks that can be reduced by placing the distal patellar tendon incision slightly lateral from the tibial tubercle to allow better soft tissue coverage as well as vascular supply from the underlying anterior compartment [22, 27].

Also, ensuring that the repair sutures are not directly in line with the incision can decrease the likelihood of wound complications.

In the past when wires had been used to augment the fixation, wire failure and pullout and the necessity to return to the operating room to remove the wire fragments were concerns. Today, nonabsorbable sutures are often used instead of wires to reduce the potential additional surgical procedure to remove wires as a second procedure.

Patella baja or alta has been reported and may lead to subsequent patellofemoral degeneration. This is a technical consideration during tensioning of the tendon repairs, and appropriate patellar height should be confirmed on lateral radiograph intraoperatively to avoid this complication [22, 27]. Draping out both lower extremities is an easy way to use the normal limb as a template for reestablishing the appropriate patellar height during surgery.

Finally, although uncommon, tendon repairs can re-rupture requiring additional surgical fixation with possible augmentation.

## 30.11 Pearls

*Making the initial longitudinal incision slightly lateral to the tibial tubercle can allow for a less tensioned soft tissue closure, along with more vascular supply from the muscular anterior compartment.

*Before completing the tensioning and the repair, a lateral radiograph or fluoroscan image is obtained to ensure proper patellar height to avoid patella baja or alta. Also, if undertaking a chronic extensor mechanism, it is suggested to prep both the operative and well leg into the field so that patellar height may be directly compared.

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# Chapter 31
# Brace Considerations in PCL Instability and the Multiple Ligament Injured Knee

**Andrew A.R. Lehman and Bruce Williams**

## 31.1 Brace Treatment

Knee braces, used both in operative and nonoperative treatment, play an integral role in the management of ligamentous knee injuries. Numerous knee braces are available, varying by design and intention of use. In their 1994 review article on knee bracing, France and Paulos described four categories of bracing: prophylactic, rehabilitative, functional, and patellofemoral braces. Prophylactic braces are used to prevent or reduce the severity of injuries on native tissues of the knee. Rehabilitative braces allow protected motion of either newly injured or postoperative knees. Functional braces control normal and abnormal motions caused by a failure of native soft-tissue restraints of the knee. Patellofemoral braces are used to alleviate pain associated with abnormal patellar tracking [1]. This chapter reviews the use of rehabilitative and functional knee bracing in the multiple ligament injured knee.

## 31.2 Rehabilitative Braces

Although multiple ligament knee injuries can be managed nonoperatively—particularly in those who are elderly, sedentary, or medically unsuitable for operative intervention—operative treatment has resulted in better outcomes overall and is recommended by most authors. Therefore, rehabilitative braces are used less commonly for nonoperative treatment and more commonly for postoperative management.

Rehabilitative braces are used in the initial postoperative or post-injury state during healing stages when patients have limited control of muscular function and are susceptible to unintentional loading of the extremity which may result in excessive strains on the various ligament complexes. During this period, patients are usually non-weight bearing or partial weight bearing with assistive devices. The principal goal of these braces is to provide range of motion control, either rigid immobilization or controlled flexion and extension at a predetermined arc. Aiding with pain management as well as control of varus and valgus stress at the knee is also accomplished with such braces. Shearing loads in the sagittal plane are relatively low during this period, and therefore, the neutralization of anterior and posterior translation is of secondary importance with these braces. During this period, patients have considerable swelling, and their muscles undergo atrophy, resulting in significant changes in the circumference of the leg. A common example of a rehabilitative brace is shown in Fig. 31.1.

Rehabilitative braces have three elemental components: a foam shell, hinge arms, and straps. The foam shell, optimally, will adjust to accommodate changes in swelling and soft-tissue contours as the patient progresses through the early phases of treatment. Shells are constructed out of a comfortable material that will enable usage 24 h a day for several weeks. Full-length arms or paddles with hinges help control range of motion. Their increased length compared to functional braces gives them a biomechanical advantage due to an increased lever arm.

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**Fig. 31.1** Rehabilitative knee brace. (Courtesy of Bledsoe Brace Systems, Grand Prairie, TX)

**Fig. 31.2** Rehabilitative knee brace hinge. (Courtesy of Bledsoe Brace Systems, Grand Prairie, TX)

Single-axis hinges are found on most postoperative braces; this design does not allow physiologic motion at the extremes of flexion. As the knee reaches flexion much greater than 90°, the motion arc of the brace deviates from the motion arc of the native knee. As shown in Fig. 31.2, control of the hinges is usually obtained through user-friendly adjustment dials that can be locked into the desired arcs of motion. Cawley et al. in their biomechanical investigation of rehabilitative knee braces concluded that joint line contact was the principal key in controlling varus and valgus stresses. They also found that overall brace stiffness, dependent on the integration of the brace into a single unit, was also a key component to effective functioning of the brace [2]. Essential to the brace functioning as a single unit are the straps which help interface the shell and hinge arms.

Increasing surface contact in areas with significant soft tissues overlying the bone is needed for control due to the increased propensity for the brace to compress, rotate, and translate in these areas. The leverage application point of most braces is centered over the tibial tuberosity; here the brace may gain increased purchase on a subcutaneous bone. Off-the-shelf braces tend to be less expensive and are more practical in this period when soft-tissue contour is changing and treatment is only for a limited time period. Obviously, patient size has significant implications on the effectiveness of these external devices. Thinner patients with less subcutaneous tissues gain more effective control, while patients with a significant amount of redundant soft tissues are virtually impossible to adequately control with bracing.

Postoperatively, patients are placed in a rehabilitative brace that is initially locked in full extension. This position has been shown to decrease the forces on the posterior cruciate ligament (PCL) and helps avoid early flexion contractures [3]. Patients are kept in the brace 24 h a day, being allowed to remove the brace to shower and bathe only. To help with swelling, patients are encouraged to apply ice routinely.

During the initial 5 weeks postoperatively, patients remain relatively non-weight bearing. There has been some support for early range of motion following multiple ligament reconstruction [4, 5]; however, several of the patients in these studies still required further intervention for motion loss. Fanelli et al. reported that restricting range of motion limited deleterious effects on the healing grafts, and in a small percentage of patients, the loss of knee flexion resulted in a need for further intervention [6]. Beginning with week 6, patients begin progressive weight bearing. They are instructed to start bearing 20% of their body weight, increasing by 20% weekly until full weight bearing is achieved at week 10.

At week 6, the rehabilitative brace is unlocked to full flexion, and patients are encouraged to begin passive flexion of the knee. Patients are encouraged to attain 90–100° of knee flexion by week 10. Once they attain full-weight-bearing status at week 10, crutches are discontinued along with the rehabilitative brace, and the patient is fitted for a functional brace.

## 31.3 Functional Bracing

Functional braces are designed to control normal motions while resisting any abnormal motion that may be caused by a failure of native soft-tissue restraints of the knee [1]. Cawley et al. pointed out that functional braces frequently serve more as prophylactic braces, used after ligament reconstruction to protect a stable reconstructed knee [7].

By the end of postoperative week 10, patients should be full weight bearing, and at this point, they may be fitted for a functional brace. The brace should be a combined instability brace to protect the cruciate ligament reconstructions while also supporting the medial and lateral structures. Patients are encouraged to continue brace usage during sports participation or other activities that could place the knee at risk. At 18 months after reconstruction, brace usage becomes optional.

These braces can be either passive or dynamic in design. Passive functional braces provide resistance only to abnormal movements, while dynamic functional braces provide an active resistance during all movements to help counteract or augment knee deficiencies.

Functional braces have the same basic components of rehabilitative braces; there are, however, some important differences in the design and intent of the brace. Functional braces are usually designed to last longer than rehabilitative braces and to withstand the higher forces encountered during active rehabilitation as well as the return to sporting activities. They are designed to be worn for shorter periods of the day, and materials are usually more resistant to wear and less accommodative to the patient's soft tissues to enable prolonged life of the brace. The hinge arms of functional braces are shorter; therefore, the materials need to be stiffer to compensate for the shortened lever arms. The hinges are polycentric or eccentric cam type hinges to allow for greater range of motion and to more closely follow the native motion arc of the knee.

Braces are available as off-the-shelf or custom-made. Custom braces have been found to be more consistent in their effectiveness to control anterior tibial displacement [8, 9]. They do tend, however, to be more expensive and may require refitting if the patient is still undergoing soft-tissue contour changes with postoperative swelling.

Functional braces are usually double upright braces that use a four-point leverage system to control motion. Braces are engineered to address specific or combined injuries. Anterior cruciate ligament (ACL) dynamic braces use a posterior-directed tibial preload that is applied by the brace in knee extension to counteract forces placed on the ACL-deficient or reconstructed knee. PCL dynamic braces use a similar tibial preload force, but the force is anteriorly directed on the calf and is applied by the brace when the knee is in flexion. Combined instability (CI) braces are designed without any tibial preload

**Fig. 31.3** Full-force, ACL functional knee brace. (Courtesy of DJO Global, Vista, CA)

**Fig. 31.4** Defiance, PCL functional knee brace. (Courtesy of DJO Global, Vista, CA)

but counteract abnormal forces in a passive function to protect combined ACL and PCL injuries. An example of each of these braces is shown in Figs. 31.3, 31.4, and 31.5.

Load-shifting braces use a three-point leverage system to deliver a dynamic coronal-plane-directed force to unload the medial or lateral side of the knee. These braces can be used for isolated medial- or lateral-sided injuries, or when combined with a four-point leverage system, protection of ACL, PCL, and medial- or lateral-sided injuries may be obtained. Passive protection of medial and lateral injuries may also be obtained through use of a four-point leverage system without the load-shifting feature.

In 2003, Marx et al. published an article on the beliefs and attitudes of members of the American Academy of Orthopaedic Surgeons regarding the treatment of ACL injuries. In their article, they state a significant variation in opinion regarding

**Fig. 31.5** Full-force, CI functional knee brace. (Courtesy of DJO Global, Vista, CA)

postoperative brace usage in ACL reconstructed knees. Use of a brace for the first 6 weeks postoperatively was suggested by only 60% of surgeons while use of a brace with sports participation was suggested by a slightly higher 62.9% of surgeons [10]. An American Orthopaedic Society for Sports Medicine survey found that 31% of surgeons recommend functional bracing for 81–100% of patients after ACL reconstruction [11]. This variability in bracing practice may very well represent an uncertainty in their effectiveness.

The vast majority of literature on functional bracing after reconstructive surgery of the knee pertains to ACL reconstruction. Sterett et al. evaluated the effect of functional bracing on knee injuries in skiers 2 years after ACL reconstruction. They found nonbraced skiers to be 2.74 times more likely to sustain subsequent injury when compared to braced skiers. The author recommends functional bracing for skiers after ACL reconstruction but was unsure if the protective effect seen in their study could be extrapolated to other high-demand patients [12].

A biomechanical analysis of ACL-strain response in braced and nonbraced knees showed that functional knee bracing can protect the ACL during anterior-posterior shear loading [13]. Cook et al. evaluated running and cutting maneuvers in ACL-deficient individuals with and without their custom-molded functional braces and witnessed significantly better performances by those wearing the brace. They also found even greater improvement for those individuals who had not yet achieved 80% of their quadriceps strength [14].

Though there seems to be some literature pointing toward bracing effectiveness, there are articles that have refuted any clinical significance in the use of functional bracing after ACL reconstruction. McDevitt et al. randomized 100 US service members with ACL reconstructions into two treatment groups—those with bracing and those without. Their results did not show statistically significant differences between the groups in regard to knee stability, functional testing, knee range of motion, isokinetic scoring, or other outcome measures. No conclusion was able to be drawn on the influence of bracing on reinjury rates due to their low occurrence rate in the study [15].

Another prospective randomized study evaluated 150 patients after ACL reconstruction and compared differences between the use of a functional brace and neoprene sleeve. There were no statistically significant differences seen at 1–2 years for any of the outcomes measured. Bracing did appear to have a positive psychological effect on individuals; there was a higher subjective rating observed in the brace group for confidence in the knee provided by the brace at 6 and 12 months postoperatively [16].

There is a paucity of literature on the effectiveness of functional bracing after multiple ligament reconstructions, and one may have a difficult time extrapolating the literature on bracing and ACL reconstruction to multiple ligament reconstructions. Therefore, the use of functional bracing in multiple ligament reconstructions is still recommended by many authors [17–19].

**Table 31.1** Brace indications

| | | Indicated brace | |
|---|---|---|---|
| Ligament injury | Treatment | Postoperative | Functional |
| ACL | Nonsurgical | Rehabilitative brace | 4-Point ACL |
| | Surgical | | 4-Point ACL |
| MCL—grade I/II | Nonsurgical | | Hinged neoprene brace (optional varus moment) |
| MCL—grade III | Nonsurgical | Rehabilitative brace | Rehabilitative brace (locked in ext×6 weeks) |
| | Surgical | | Combined instability |
| PCL | Nonsurgical | Rehabilitative brace | 4-Point PCL |
| | Surgical | | 4-Point PCL |
| ACL/MCL | Nonsurgical | Rehabilitative brace | 4-Point PCL |
| | Surgical | | 4-Point PCL (optional varus moment) |
| ACL/lateral side | Nonsurgical | Rehabilitative brace | 4-Point ACL |
| | Surgical | | 4-Point ACL (optional valgus moment) |
| PCL/lateral side | Nonsurgical | Rehabilitative brace | 4-Point PCL |
| | Surgical | | 4-Point PCL (optional valgus moment) |
| ACL/PCL | Nonsurgical | Rehabilitative brace | Combined instability |
| | Surgical | | Combined instability |
| ACL/PCL/lateral side | Nonsurgical | Rehabilitative brace | Combined instability |
| | Surgical | | Combined instability (optional valgus moment) |
| ACL/PCL/lateral and medial side | Nonsurgical | Rehabilitative brace | Combined instability |
| | Surgical | | Combined instability |

*ACL* anterior cruciate ligament, *MCL* medial collateral ligament, *PCL* posterior cruciate ligament

## 31.4 Conclusions

Knee braces, used in both operative and nonoperative treatments, play an integral role in the treatment of multiple ligament knee injuries. Due to the large variety and multiple designs of knee braces, an integral knowledge of the ligamentous knee injury and engineering of the braces are needed to effectively manage these injuries. Please refer to Table 31.1 for a summary of brace indications for the various ligament injuries. Whether or not knee braces have a beneficial effect on postoperative management of the multiple ligament knee injury is currently unclear and should be a focus for future research. Currently, it is still recommended that use of knee bracing—both in the acute postoperative phase with a rehabilitative brace and the active rehabilitative phase with a functional knee brace—continue until evidence suggests otherwise.

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# Chapter 32
# Postoperative Rehabilitation of the Multiple Ligament Injured Knee

**Craig J. Edson and Gregory C. Fanelli**

## 32.1 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 reconstruction 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.

## 32.2 Postoperative Program Rationale

The determination of the optimum rehabilitative approach following multiple knee ligament reconstruction 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 repair or reconstruction, 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

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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.

## 32.3 Postoperative Rehabilitation Program

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), the strength and motion achievement phase (postoperative weeks 11 through 26), and the preparation for return to activity phase (postoperative weeks 27 through 52).

## 32.4 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 reconstruction involves 5 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 immobilizer is applied locked in extension and continues through postoperative week 5. The patient wears this brace 24 h per day. When ambulating, the surgical extremity is strictly non-weight-bearing. This eliminates compression 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 five 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.

## 32.5 Moderate Protection Phase

The moderate protection phase begins with postoperative week number 6 and continues through postoperative week number 10. 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 6. 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 20% of their body weight on the involved extremity; however, we do not expect this to be a precise amount. The 20% 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 20% each week so that they have attained full weight-bearing by the end of postoperative week 10 when the crutches and the long leg brace are discontinued.

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 and hamstring 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 10.

## 32.6 Strength and Motion Achievement Phase

The strength and motion achievement phase occurs during postoperative weeks 11 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 in 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 11 through 26, the strength and motion achievement phase, include 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 range of motion greater than 90° of knee flexion is not achieved by the end of postoperative month number 4.

## 32.7 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 postop 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. A patient should be within 10% of the uninvolved leg with all functional tests to be considered for return to physically demanding activities.

Prophylactic bracing is a controversial issue and one that will not be analyzed within this chapter. We recommend that the patient 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.

## 32.8 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, 22–30]. 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.

## 32.9 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 reconstruction. 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 reinjury. 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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# Chapter 33
# Complications Associated with the Treatment of the Multiple Ligament Injured Knee

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## 33.1 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% [2–5]. 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 [6, 7]. 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, ABI, or repeated physician documented physical exam over a minimum 24-h observation period [8, 9]. Nerve injury is also common in knee dislocation and can result in significant morbidity. The common peroneal nerve is the most frequent injured peripheral nerve. Most studies have reported the incidence of peroneal nerve injury in conjunction with knee dislocations to range from 25% to 35% [10–13]. The tibial nerve is less commonly involved, and few case reports resulting from knee dislocation have been reported [14–16]. Five cases of tibial nerve injury associated with knee dislocation have been reported, and in each patient, a peroneal nerve injury was also observed [1]. 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 perform a thorough examination of the whole patient with a particular emphasis on the neurovascular structures in the injured extremity in order to avoid complications associated with missed injuries. 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. Historically there has been a paucity of good-quality evidence to formulate the optimal treatment. Early literature presented varied intervention from immobilization [17] to surgical repair [18]. Currently the advancement in operative techniques has demonstrated good mid- to long-term outcomes with open [19] as well as with modern arthroscopic techniques which are becoming the standard of care [20–24].

## 33.2 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

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subsequent arterial injuries [25]. 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 with observation [1, 5, 10, 26–28]. When ligament reconstruction is performed, it has been our practice to inject a bolus of 5,000 U of heparin IV prior to inflating the tourniquet. The orthopedic 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.

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 [24]. 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 the revascularization [29]. 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 [30]. 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 [31–33]. A recent 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 [34]. 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 and allows adequate exposure to the popliteal artery through a posteromedial approach and protects the repair. While the fixator is being applied, the vascular surgeon can harvest the contralateral saphenous vein in order to save time.

Tourniquet use during ligamentous surgery 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 [35]. 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 pulses remained diminished 6 weeks after revascularization, we have performed the ligament reconstruction without the use of a tourniquet or injected a bolus of 5,000 U of heparin IV prior to inflating the tourniquet.

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 passage of a guide pin or when drilling the tibial tunnel [36]. 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° [37]. 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.

## 33.3 Nerve Injury

Nerve injuries can occur at the time of injury and can also result from treatment of a 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. The peroneal nerve injuries occur most commonly when the posterolateral corner structures are injured [38]. 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 [15]. Some authors have advocated early exploration of an injured peroneal nerve and performing a nerve repair or neurolysis [39, 40]. Full return of peroneal nerve function is uncommon, regardless of treatment [41–43].

Nerve injury can also result from treatment of the dislocated knee [44]. 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. 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 [45]. As the nerve courses toward the fibular head, there are numerous fascial bands encompassing both the biceps femoris tendon and peroneal nerve [46]. 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 never be used with the vessel loop as the weight of the hemostat can cause 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.

The effects of tourniquet use on a patient with concomitant peroneal nerve injury have not been well documented [35]. 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 [47]. 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 [35]. 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 [35]. 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/reconstruction. If the sartorial branch is cut, the patient will experience numbness over the anteromedial aspect of the calf. A painful neuroma can also 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.

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 [48–50].

## 33.4 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.

A study showed the efficacy of low molecular weight heparin (LMWH) in preventing DVT in patients with spanning external fixator for high-energy lower extremity injuries [51]. One hundred forty-three external fixators were applied to 136 patients with a total of 151 injuries; ten of these were knee dislocations. All patients were started on either enoxaparin 40 mg daily or dalteparin 5,000 units per day within 24 h of presentation. Duplex ultrasounds were performed just prior to fixator removal at a mean of 17.9 days (range 4–45). Only three of the patients (2.2%) were found to have DVT. The authors concluded that LMWH was effective in minimizing the risk of DVT in patients with a spanning external fixator for lower extremity trauma.

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 should be utilized in these patients. Prior to any surgical intervention, the anticoagulants need to be stopped and a careful examination performed to identify any venous thrombosis. Following surgical reconstruction of the knee ligaments, the patient's anticoagulation is restarted and maintained until the patients is full weight bearing. Any DVT detected in the postoperative period will need longer-term anticoagulation.

## 33.5 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 [52–56]. 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 for 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.

## 33.6 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 posteromedial 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, the presence of systemic illnesses, corticosteroid use, previous scars, etc.) can also negatively impact wound healing [46, 57].

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 and the use of surgical drains are critical to prevent hematoma formation; postoperative hematoma is a leading cause of skin necrosis and infection [57]. 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.

## 33.7 Arthrofibrosis

Arthrofibrosis is a common complication of 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 [17]. 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%) [58]. 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 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) [59].

Some authors have suggested that multiligament reconstructions should be avoided for 3 weeks after injury because of a high risk of arthrofibrosis with early intervention [60–63]. Other authors have found improved outcome measures in patients who underwent reconstruction within 3 weeks of injury [19, 64–66]. A systematic review by Levy et al. [67] identified five studies that compared early versus delayed surgery [19, 46, 64–66]. 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 [67]. 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 [23]. 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.

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 [68]. Paulos coined the term infrapatellar contraction syndrome (IPCS) for knees in which there is decreased flexion and extension in combination with decreased patellar mobilization [69]. 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, the graft choices, and the fixation of the ligaments. However, if aggressive motion exercises are begun too early, there is a risk of stretching out the healing grafts. After multiligament reconstructions, the surgeon must balance the risk of recurrent laxity with that of arthrofibrosis. An individualized rehabilitation protocol needs to developed for every patient and communicated to the therapist. Our general practice has been to immobilize the knee in 30° flexion for 2–3 weeks before initiating range of motion exercises. Hyperextension, flexion >90°, and weight bearing are avoided for 6 weeks.

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 [68]. 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; 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 [69]. These authors make it clear that arthrofibrosis is best treated with prevention or early intervention.

## 33.8 Recurrent Instability

Recurrent or persistent instability is also a common complication of treatment of multiligament knee injuries. Factors that will affect the stability of the knee joint include the severity of the initial injury, the type of treatment selected, how well that treatment is performed, the rehabilitation program, and additional traumatic events. Knees with chronic instability are predisposed to further injury to the menisci and articular cartilage. In a series by Noyes [70], 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 [59]. Repair versus reconstruction of the involved structures in a multiligament injured knee 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 [67]. 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 [71]. Our approach is to attempt 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 [60]. 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 tendon, semitendinosus, gracilis, tibialis anterior, or Achilles tendon. The surgeon must have available a variety of fixation techniques. Technical errors that can result in residual pathologic laxity are 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 much 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 [72]. The major factors that contribute to the risk of graft failure in the early postoperative period are the need to utilize allografts and the damage to the secondary stabilizers. Hyperextension, varus-valgus loads, and rotational forces can place high loads on the 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 for 3 months in our patients with multiligament reconstructions. Running is not initiated until the patient has full range of motion, no effusion, and good muscle control; this usually takes at least 4 months. 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.

## 33.9 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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# Part IX

# Outcomes Data

# Chapter 34
# Results of Treatment of the Multiple-Ligament-Injured Knee

**Sommer Hammoud, Moira McCarthy, and Robert G. Marx**

## 34.1 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 vs. delayed reconstruction, repair vs. reconstruction of the posterolateral corner (PLC), and preferred treatment of the medial side or medial collateral ligament (MCL) in the multi-ligament-injured knee.

## 34.2 Operative vs. 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 operative management of the multiple-ligament-injured knee.

A meta-analysis of operative vs. 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

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**Table 34.1** 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 (1995) | 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. (1999) | 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. (2008) | 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. (2005)[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

(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 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.

## 34.3 Allograft Use in the Treatment of the Multiple-Ligament-Injured Knee

Allograft tissues have 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 [8]. 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 34.1) [9–12].

## 34.4 Results of Early vs. Delayed Reconstruction

The optimal surgical timing for the multiple-ligament-injured knees remains controversial. Specific factors to be taken into account that could change 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 [13–15]. Others recommend immobilization followed by delayed surgery [16, 17]. 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 were more commonly encountered with delayed reconstruction [13, 17]. Although there seems to be more recent evidence supporting acute reconstruction of knee dislocations, the specific structures injured dictate whether acute or chronic reconstruction is preferred.

Shelbourne et al. [17] 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 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 treatment of low-velocity knee dislocations in sports injuries, Shelbourne and Klootwyk [18] 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. [19] 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 vs. 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. [16] 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. [13] reported on their results for 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. [14] 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. [20] 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. [10] 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. [15] 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. [21] 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) ($p < 0.001$).

Overall, the data is somewhat controversial regarding the optimal timing of surgical management for knee dislocations. The data suggests that both delayed and acute reconstructions can have good outcomes. There is some data to support better outcomes and improved return to sport with acute reconstructions. That is balanced by the potential for residual instability and increased possibility for joint stiffness following an acute reconstruction vs. a delayed reconstruction. MCL injury is one indication for which delayed reconstruction may be appropriate.

## 34.5 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 [22] 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 [22] (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. [12] 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. [10] reviewed the results in 13 patients who underwent simultaneous allograft ACL/PCL reconstruction after knee dislocation. At a mean 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 [20] evaluated 11 patients with ACL/PCL reconstructions and immediate 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, 9 knees had <3 mm of increased displacement and 2 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. [23] 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. [24] 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. [25] 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.

## 34.6 Return to Pre-injury Activity Level

Return to pre-injury level of activity is not reliable following reconstruction for knee dislocations. Mariani et al. [26] 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 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. [16] 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 [22] 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. [25] 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. [27] 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. [10] 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 unrestricted sport was 46% while return to modified sport was 31%. Tzurbakis et al. [15] 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.

Overall, the return to activity following knee dislocation and reconstruction, whether acute or chronic, is unpredictable. There is not much data, but the available literature suggests that single-stage reconstructions using autografts of ACL and PCL tears yield an approximately 50% chance of return to pre-injury activity. Additionally, the return to activity when both cruciate ligaments are injured is less successful than when one cruciate ligament and one collateral ligament are injured.

## 34.7 Repair vs. 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 [28–31]. 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 [28].

Shelbourne et al. [32], 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 [33, 34]. Stannard et al. [34] reported on the results of repair vs. 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. [33] reported on a cohort of 45 patients with minimum 2-year follow-up who underwent repair vs. 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.

## 34.8 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 [22] 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. [16] 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. [35] 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. [21] 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 [36–39] or when found with concomitant cruciate ligament injury [40]. 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 [16, 22, 41].

Bicruciate ligament injuries associated with high-grade MCL injuries have less clear results. Several authors [20, 42, 43] 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 [44–46].

## 34.9 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. Several controversies exist with regard to operative vs. nonoperative treatment, timing of surgery, repair vs. 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 a few conclusions may be made. Acute and delayed reconstructions are both associated with favorable outcomes, although arthrofibrosis remains an issue following acute reconstruction. Low-grade MCL injuries in the multi-ligament-injured knee can be treated with brace treatment allowing for MCL healing followed by delayed bicruciate ligament reconstruction. Return to pre-injury level of activity is unpredictable following knee dislocations.

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# Part X

# Clinical Case Studies

# Chapter 35
# Selected Case Studies in the Treatment of the Multiple-Ligament-Injured Knee

**Gregory C. Fanelli**

## 35.1 Introduction

This chapter in *The Multiple Ligament Injured Knee*: *A Practical Guide to Management*, *Second Edition*, presents selected cases in treatment of the multiple-ligament-injured knee that are representative of my practice. I have written this chapter in the 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 chapter since the surgical technique was performed as I have described in Chaps. 1, 20, and 22 in this textbook. 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.

## 35.2 Case Study 1: Acute ACL–PCL and 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 valgus, external rotation, and flexion forces were applied to the patient's knee resulting in a posterior tibiofemoral 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 1/2 compared to 2/2 in the normal left lower extremity. Posterior tibial pulses were intact and symmetrical. Peroneal and tibial nerve functions 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 was stable to examination with varus stress at 30° and 0° of knee flexion, and the posterolateral drawer test was negative. The patient was able to perform a 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. Postreduction X-rays revealed the tibia still 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.

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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 tibiofemoral joint by removing the entrapped medial capsule, thereby protecting the skin, and reduce the risk of arthrofibrosis and heterotopic ossification by doing a two-stage surgical procedure.

The patient was taken to surgery 2 days postinjury for stage 1 surgical procedure where open reduction of the tibiofemoral 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. Stage 2 surgical procedure was performed 5 weeks after the stage 1 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 5 weeks. The postoperative rehabilitation program that was followed is described in detail in Chap. 32 of this textbook.

This patient's postoperative Tegner, Lysholm, and Hospital for Special Surgery knee ligament rating scale scores 2 years post reconstruction were 5, 94/100, and 80/100, respectively. KT1000 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 KT1000 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 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.

## 35.3 Case Study 2: Acute PCL, ACL, Medial and Lateral Side Injuries and 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 functions were intact with respect to sensory and motor functions. 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 tibiofemoral joint and a patella displaced in a superior direction. There were no fractures. MRI demonstrated complete tears of the anterior and posterior cruciate ligaments and 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. 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 five 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 4–5 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 2, the patient's involved left knee range of motion is 0–102° compared to 0–140° on the uninvolved right knee. The Hospital for Special Surgery, Lysholm, and Tegner knee ligament rating scale scores are 89/100, 93/100, and 3, respectively. The patient's preinjury Tegner score was also 3 indicating a return to preinjury level of function. KT1000 arthrometer side-to-side difference values for the PCL screen, corrected posterior, and corrected anterior measurements were 1.0, 1.0, and 0.0 mm, respectively. The KT1000 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 2.5 mm. The Lachman test was negative, pivot shift negative, tibial step-off equal to the uninvolved side, posterior drawer negative, and valgus and varus stress tests 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 no indication of heterotopic ossification or degenerative joint disease.

## 35.4 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 6 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 that the injured left knee, compared to the normal right knee, has negative tibial step-offs, a grade three posterior drawer, positive posterolateral drawer, negative posteromedial drawer, no valgus laxity at 0° and 30° of knee flexion, and varus laxity at 0° and 30° of knee flexion of approximately 10 mm of increased lateral joint line opening. The dial test was positive, with the left thigh–foot angle greater than 10° at 30° of knee flexion and increased at 90° 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 is 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 was passed medial to the common biceps tendon and the iliotibial band. The allograft limbs were crossed in a 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 two 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.

At follow-up after five and one half years, 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 KT1000 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 KT1000 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 knee to the 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 that 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, respectively. The patient's preinjury Tegner score was 7 indicating a return to nearly preinjury level of function.

## 35.5 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 postinjury day number 1. 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 and 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 9 months postinjury 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 5 weeks. The postoperative rehabilitation program that was followed is described in detail in Chap. 32 of this textbook.

This patient's postoperative Tegner, Lysholm, and Hospital for Special Surgery knee ligament rating scale scores 3 years post reconstruction were 3, 70/100, and 75/100, respectively. KT1000 arthrometer side-to-side difference values for the PCL screen, corrected posterior, and corrected anterior measurements were 0.0, 0.5, and −0.5 mm, respectively. The KT1000 side-to-side difference measurement at 30° of knee flexion was 2.0 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 −1.0 mm indicating that the surgical knee was tighter than the nonsurgical knee. 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 tests symmetrical to the nonsurgical knee at 0° and 30° of knee flexion, and range of motion 0–122° of knee flexion (nonsurgical side range of motion 0–130°), 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 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.

## 35.6 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 6-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 postinjury day 22 and the left knee surgery approximately 10 weeks postinjury 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 5 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 both Chaps. 20 and 32 of this textbook.

Eight years post right and left knee multiple knee ligament reconstructions, this patient’s postoperative Tegner score was level 4 (preinjury level 6). Postoperative Lysholm score was 90/100, and the Hospital for Special Surgery knee ligament rating scale score was 96/100 on the left and 94/100 on the right. KT1000 arthrometer side-to-side difference values for the PCL screen, corrected posterior, and corrected anterior measurements were 2.0, 2.0, and 0.5 mm, respectively. The KT1000 side-to-side difference measurement at 30° of knee flexion was 0.0 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 2.3 mm. The Lachman test was 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 stable and symmetrical at 0° and 30° of knee flexion, and range of motion 0–126° of knee flexion on the right and 0–132° 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; however, she does have some exertional pain and some impairment with stair climbing and squatting.

## 35.7 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 planted left foot 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 4 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 KT1000 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 KT1000 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 5 weeks. The postoperative rehabilitation program is described in detail in Chap. 32 of this textbook.

This patient's postoperative Tegner, Lysholm, and Hospital for Special Surgery knee ligament rating scale scores 1 year post reconstruction were 5, 94/100, and 86/100, respectively. The IKDC score is 77. KT1000 arthrometer side-to-side difference values for the PCL screen, corrected posterior, and corrected anterior measurements were 2.0, 4.5, and −1.5 mm, respectively. The KT1000 side-to-side difference measurement at 30° of knee flexion was −6.0 mm (the patient had a prior ACL reconstruction on the right knee). 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 3.0 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 tests negative and symmetrical to the nonsurgical knee at 0° and 30° of knee flexion, and range of motion 0–121° of knee flexion (nonsurgical side range of motion 0–140°), with a stable extensor mechanism. Follow-up radiographs show no indication of heterotopic ossification or degenerative joint disease. The patient has achieved his non-competitive sports preinjury level of function with respect to work and recreational sports; however, he has chosen not to return to competitive wrestling.

## 35.8 Case Study 7: 17-Year Follow-Up of 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 functions 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 10 weeks postinjury. Postoperatively, the patient was immobilized in a long leg brace locked in full extension and non-weight-bearing for approximately 5 weeks followed by progressive range of motion and weight-bearing. The postoperative rehabilitation program that was followed is described in detail in Chap. 32 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. The IKDC score is 64. KT1000 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 KT1000 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 tests 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 are 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.

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