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

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1.1 Introduction

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

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

1.2 Respect the Anatomy

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

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

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

1.3 Vascular Assessment

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

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

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

1.4 Peroneal Nerve Injury

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

1.5 Correct Diagnosis

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

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

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

1.6 Arthroscopic Evaluation of the Posterior Cruciate Ligament

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

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

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

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

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

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

1.7 External Fixation

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

1.8 Surgical Treatment

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

1.9 Surgical Timing

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

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

1.10 The Chronic Multiple Ligament Injured Knee

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

1.10.1 Repair or Reconstruction

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

1.10.2 Multiple Knee Ligament Reconstruction Surgery

1.10.2.1 Graft Preparation

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

1.10.2.2 Arthroscopic or Open Surgical Procedure

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

1.10.2.3 Surgical Technique

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

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

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

1.11 Posteromedial Safety Incision

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

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

1.12 PCL Tibial Tunnel Creation

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

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

1.13 PCL Femoral Tunnel Creation

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

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

1.14 ACL Reconstruction

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

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

1.15 Mechanical Graft Tensioning and Fixation

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

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

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

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

1.16 Posterolateral Reconstruction

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

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

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

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

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

1.17 Posteromedial Reconstruction

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

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

1.18 Postoperative Rehabilitation

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

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

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

1.20 Outcomes and Results of Treatment

1.20.1 Combined PCL Posterolateral Reconstruction

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

1.20.2 Combined PCL ACL Reconstruction Without Mechanical Graft Tensioning

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

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

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

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

1.20.3 Combined PCL ACL Reconstruction with Mechanical Graft Tensioning

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

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

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

1.20.4 Double Bundle Compared to Single Bundle PCL Reconstruction

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

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

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

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

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

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

1.20.5 Combined PCL, ACL, Medial Posteromedial Reconstruction

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

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

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

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

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

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

1.20.7 Knee Dislocations with 5–22 Year Postoperative Results

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

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

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

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

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

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

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

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

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

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

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

1.20.8.1 PCL + Collateral Ligament Group

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

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

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

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

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

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

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

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

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

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

1.20.9 Revision PCL Based Multiple Knee Ligament Reconstruction

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

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

1.21 Summary

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

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