1 Posterior Cruciate Ligament Injuries and Reconstruction: What I Have Learned

Gregory C. Fanelli

Introduction

This chapter is a compilation of my experience treating posterior cruciate ligament (PCL) injuries and PCL-based multiple ligament knee injuries over the past 25 years. Departing from the style of most text books, this chapter is written in the first person, and is intended to be a conversation between the reader and myself about one of the most complex and interesting topics in orthopedic surgery—PCL injuries and the multiple ligament-injured knee. 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. 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 PCL and multiple ligament knee injury cases. Topics addressed include incidence of PCL injuries, three-zone arthroscopic evaluation of the PCL, diagnosis and classification of posterolateral and posteromedial instability, multiple knee ligament injury evaluation protocol, surgical timing, concepts of repair and/or reconstruction, graft preparation, arthroscopic or open surgical procedures, surgical technique highlights, mechanical graft tensioning, postoperative rehabilitation, PCL knee injuries in patients 18 years of age and younger, and results of treatment. Specific surgical procedures are discussed in various chapters throughout this text book.

Incidence

I live in rural central Pennsylvania in the USA. 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 PCL knee injuries occur with some frequency. PCL 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 PCL tears occur 3.5 % of the time in this population, while PCL tears combined with other ligaments (the PCL-based multiple ligament-injured knee) occur in 96.5 % of PCL injuries in our series. The combined PCL and anterior cruciate ligament (ACL) tears, 45.9 %, and the combined PCL posterolateral instability, 41.2 %, are the most common posterior cruciate-based combined injuries that have been seen in our series [2]. The purpose of reviewing these data is to emphasize the point that PCL 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 PCL injuries in high-energy sports are also at risk of being a combined ligament injury [1–3].

Arthroscopic Evaluation of the Posterior Cruciate Ligament

Arthroscopic evaluation of the PCL has been reported by Lysholm and Guillquist and by Fanelli et al. [4–6]. 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 PCL evaluation, and used this method in our treatment of PCL injuries [5, 6]. In this concept, the PCL is divided into three distinct zones. Zone 1 extends from the femoral insertion of the PCL to where the PCL disappears behind the ACL. Zone 2 of the PCL is where the PCL lies behind the ACL which is the middle section of the PCL. Zone 3 is the PCL tibial insertion site.

Arthroscopic PCL 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 PCL. The posterior medial portal is used to visualize zone 2 and zone

G. C. Fanelli (✉)
303 Kaseville Road, Danville, PA 17821, USA
e-mail: gregorycfanelli@gmail.com

G. C. Fanelli (ed.), *Posterior Cruciate Ligament Injuries*,
DOI 10.1007/978-3-319-12072-0_1,

3 also using the 25° or 30° arthroscope. These two portal-viewing combinations enable complete visualization of the PCL.

Arthroscopic findings in the PCL-injured knee are either direct or indirect [5, 6]. Direct findings include damage to the PCL itself such as midsubstance 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 PCL 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 ACL 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 ACL tension is restored. Altered contact points occur secondary to tibial drop back with the knee flexed 90°. Clinically, this is the posterior sag sign [7]. 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 [8, 9].

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 [10, 11]. Arthroscopic visualization is helpful to make the diagnosis by seeing the tibia rotates 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 PCL and related structures in the PCL-injured knee is a useful adjunct to the history, physical examination, arthrometer testing, and imaging studies. Arthroscopic PCL 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 PCL, and the posterolateral and posteromedial corners of the knee.

Correct Diagnosis

Isolated PCL injuries are uncommon in my experience. The patients that I see most commonly have PCL-based multiple ligament knee injuries. Identifying the multiple planes of instability in these complex knee ligament injuries is essential for successful treatment of the PCL-based multiple ligament-injured knee, and the ACL-based multiple ligament-injured knee. The posterior and ACL 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 instabilities is the key to successful posterior and ACL surgery.

There are three different types of instability patterns that I have observed in medial- and lateral-side knee injuries [10–12]. These are, type A (axial rotation instability only), type B (axial rotation instability combined with varus and/or valgus laxity with a firm end point), and type C (axial rotation instability combined with varus and/or valgus laxity with little or no end point). 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 aids in making 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 [5, 6, 13]. Once again, recognition and correction of the medial- and lateral-side instabilities is the key to successful posterior and ACL surgery.

Considerations in the PCL-Based Multiple Ligament-Injured Knee

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 patients 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.

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 [14–16]. 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 [17]. I have also seen posttraumatic deep venous thrombosis in these severe knee injuries.

Vascular Assessment

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 [18]. 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 that could potentially cause delayed vascular occlusion. Clinical examination suggesting deep venous thrombosis indicates the need for further vascular evaluation.

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 [19]. 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 [20]. 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 [21]. 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.

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 [22–31].

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 2–3 weeks has resulted in less motion loss and arthrofibrosis [22–35]. My preferred surgical approach is a single-stage arthroscopic posterior and ACL 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 [23, 24, 26].

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.

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.

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 [22–26]. Large PCL tibial bony avulsions are treated with reduction and fixation of the bony fragment. Small PCL tibial bony avulsions are evaluated with the arthroscopic three-zone PCL surgical technique to determine the condition of the PCL before proceeding with fixation of the small bony fragment [5]. Several studies have shown high rates of medial- and lateral-side surgical failures with primary repair alone [36–38]. We have had consistently successful results with combined primary repair and reconstruction with allograft or autograft tissue for medial- and lateral-side injuries [22–31, 39, 40]. 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.

Posterior Cruciate Ligament and Multiple Knee Ligament Reconstruction Surgical Technique

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.

Arthroscopic or Open Surgical Procedure

How do I decide to perform an open or arthroscopic combined posterior and ACL reconstruction in these multiple ligament-injured knees, and whether or not to do a single- or two-stage procedures? My preference is to perform a single-stage arthroscopic posterior and ACL 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 do 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 ACL 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.

Patient Positioning and Operating Room Preparation

The patient is positioned on the fully extended operating room table [28, 41–45]. 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 PCL 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 PCL, and a tibialis anterior allograft for the posteromedial bundle of the PCL reconstruction. The ACL 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 provide 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 Chaps. 9 and 15 of this text book. The following sections in this chapter will address specific points that contribute to the success of this complex surgical procedure.

Posteromedial Safety Incision

Three factors that contribute to PCL reconstruction surgical failures are failure to address associated ligamentous instabilities, varus osseous malalignment, and incorrect tunnel placement [5, 41–44]. My PCL reconstruction principles are to identify and treat all pathology, protect the neurovascular structures, accurately place tunnels to approximate the PCL 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 to use a slow and deliberate postoperative rehabilitation program.

My PCL reconstruction surgical technique since 1990 has been an arthroscopic transtibial tunnel PCL 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 [5, 41, 43, 44]. 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, 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 PCL reconstruction. The posteromedial safety incision is very important for the protection of these structures.

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 PCL 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 anteroposterior 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 PCL 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 extraarticular 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 PCL 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.

PCL Femoral Tunnel Creation

The PCL single- or double-bundle femoral tunnels are made from inside out using the double-bundle aimers, or using an endoscopic reamer 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 PCL anterior lateral bundle femoral tunnel. The double-bundle aimer or endoscopic reamer is positioned directly on the footprint of the femoral anterior lateral bundle PCL insertion site. The appropriately sized guide wire is drilled through the aimer or endoscopic reamer, through the bone, and out from 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 PCL 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 PCL 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 PCL femoral tunnels and the medial femoral condyle articular surface using the inside-to-outside method. Additionally, a more accurate placement of the PCL 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 PCL insertion sites under direct visualization.

ACL Reconstruction

With the knee in approximately 90° of flexion, the ACL tibial tunnel is created using a drill guide. My preferred method of ACL 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 ACL tibial tunnel, the graft will approximate the tibial anatomic insertion site of the ACL. 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 ACL. The ACL 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 endoscopic transtibial femoral tunnel ACL reconstruction surgical technique enables reliable tunnel creation which allows the ACL graft tissue to approximate the tibial and femoral anatomic insertion sites of the ACL. Proper tunnel position increases the probability of successful results.

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 ACL grafts [44, 45]. During this surgical technique, the posterior and/or ACL 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 ACL fixation. In combined PCL–ACL reconstructions, the PCL graft is tensioned first, followed by final PCL graft(s) tibial fixation. The ACL 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 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 ACL graft is performed using the Biomet graft-tensioning boot (Biomet Sports Medicine, Warsaw, Indiana) after tensioning and final fixation of the PCL graft(s) have been performed. Traction is placed on the ACL 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 ACL 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 ACL 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 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.

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 [28, 41, 43, 44].

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 aforementioned 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, 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 2 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 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 2 braided nonabsorbable sutures 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 2 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 [22–25, 40]. 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 [24, 26].

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 [28, 41, 43, 44]. 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 (MCL) 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 MCL. 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 2 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 MCL using three number 2 permanent braided ethibond sutures in horizontal mattress fashion, and that suture line is reinforced using a running number 2 ethibond suture.

When superficial MCL 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 MCL 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 2 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.

Postoperative Rehabilitation

The knee is maintained in full extension for 3–5 weeks nonweight 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 11. The long leg range of motion brace is discontinued after the 10th 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 9th–12th postoperative month when sufficient strength, range of motion, and proprioceptive skills have returned [46–49]. It is very important to carefully observe these complex knee ligament injury patients, and get a feel for the "personality of the knee." The surgeon may need to make adjustments and individualize the postoperative rehabilitation program as necessary. Careful and gentle range of motion under general anesthesia is a very useful tool in the treatment of these complex cases, and is utilized as necessary. Our postoperative rehabilitation program is discussed in more detail in Chap. 25 of this book.

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 6 to 18 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 PCL-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 [27, 28, 41, 43–45, 49–55]. 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 PCL reconstruction in patients with open growth plates, while single- or double-bundle PCL reconstructions 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 PCL-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.

Outcomes and Results of Treatment

Combined PCL Posterolateral Reconstruction

Fanelli and Edson, in 2004, published the 2–10-year (24–120 months) results of 41 chronic arthroscopically assisted combined PCL–posterolateral reconstructions evaluated pre- and postoperatively using Lysholm, Tegner, and Hospital for Special Surgery (HSS) knee ligament rating scales, KT 1000 arthrometer testing, stress radiography, and physical examination [25]. PCL reconstructions were performed using the arthroscopically assisted single femoral tunnelsingle-bundle transtibial tunnel PCL 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. Thirty degrees 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 HSS 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 PCL 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 the 2–10-year follow-up using objective parameters of knee ligament rating scales, arthrometer testing, stress radiography, and physical examination.

Combined PCL–ACL Reconstruction Without Mechanical Graft Tensioning

Our results of multiple ligament-injured knee treatment without mechanical graft tensioning are outlined below [24]. This study presented the 2–10-year (24–120 months) results of 35 arthroscopically assisted combined ACL–PCL reconstructions evaluated pre- and postoperatively using Lysholm, Tegner, and HSS 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, three different knee ligament rating scales, stress radiography, and physical examination. Arthroscopically assisted combined ACL–PCL reconstructions was 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, 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. Thirty degrees varus stress testing was normal in 22/25 (88 %) of knees, and grade 1 laxity in 3/25 (12 %) of knees. Thirty degrees 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), 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 the 2–10-year follow-up using objective parameters of knee ligament rating scales, arthrometer testing, stress radiography, and physical examination.

Combined PCL–ACL Reconstruction with Mechanical Graft Tensioning

Our results of multiple ligament-injured knee treatment using mechanical graft tensioning are outlined below [26]. These data present the 2-year follow-up of 15 arthroscopic-assisted ACL–PCL reconstructions using the Biomet graft-tensioning boot (Biomet Sports Medicine, Warsaw, Indiana). This study group consists of 11 chronic and 4 acute injuries. These injury patterns included six ACL–PCL–PLC injuries, four ACL–PCL–MCL injuries, and five ACL–PCL–PLC–MCL injuries. The Biomet graft-tensioning boot was used during the procedures as in the surgical technique described above. All knees had grade III preoperative ACL–PCL laxity, and were assessed pre- and postoperatively using Lysholm, Tegner, and HSS knee ligament rating scales, KT 1000 arthrometer testing, stress radiography, and physical examination.

Arthroscopically assisted combined ACL–PCL reconstructions was performed using the single-incision endoscopic ACL technique, and the single femoral tunnelsingle-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.

Postreconstruction physical examination results revealed normal posterior drawer/tibial step off in 13/15 (86.6 %) of knees. Normal Lackman test in 13/15 (86.6 %) knees, and normal pivot shift tests in 14/15 (93.3 %) knees. Posterolateral stability was restored to normal in all knees with posterolateral instability when evaluated with the external rotation thigh foot angle test (nine knees equal to the normal knee, and two knees tighter than the normal knee). Thirty degrees varus stress testing was restored to normal in all 11 knees with posterolateral lateral instability. Thirty degrees and 0° valgus stress testing was restored to normal in all nine knees with medial-side laxity. Postoperative KT-1000 arthrometer testing mean side-to-side difference measurements were 1.6 mm (range 3–7 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 %), 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 ACL reconstruction procedures.

Double-Bundle Compared to Single-Bundle PCL Reconstruction

Our comparison of single- and double-bundle PCL reconstruction in the PCL based multiple ligament-injured knee using allograft tissue revealed the following [29]. Ninety consecutive arthroscopic transtibial PCL reconstructions were performed by a single surgeon (GCF). Forty-five single- and 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- and double-bundle PCL collateral; and single- and double-bundle PCL–ACL collateral.

Mean postoperative side-to-side difference values for Telos, KT PCL screen, and 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, and 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 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 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, and 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, and 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 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 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, and 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, and 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 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 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- and the double-bundle PCL reconstruction in any of the groups compared ($p > 0.05$).

Return to preinjury level of activity was evaluated between the single- and double-bundle PCL 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- and double-bundle group in the PCL-based multiple ligament-injured knee. Both single- and double-bundle arthroscopic transtibial tunnel PCL reconstructions provide excellent results in these complex multiple ligament-injured knee instability patterns. Our results did not indicate that one PCL reconstruction surgical procedure was clearly superior to the other.

PCL Reconstruction in Knees with Global Laxity 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 [30]. Forty combined PCL–ACL-lateral–medial-side (global laxity reconstructions were performed by a single surgeon (GCF). Twenty-eight of 40 were available for the 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: HSS 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 posttraumatic 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.

Summary

The goals leading to successful PCL reconstruction surgery include 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 approximate the PCL insertion sites, and minimization of graft bending also enhances the probability of PCL reconstruction success. In addition, mechanical graft tensioning, primary and back-up PCL graft fixation, and the appropriate postoperative rehabilitation program are also necessary ingredients for the PCL reconstruction success. Both single- and double-bundle PCL reconstruction surgical techniques are successful when evaluated with stress radiography, KT 1000 arthrometer measurements, and knee ligament rating scales. Indications for double-bundle PCL reconstruction as of this writing include severe hyperextension of the knee and revision PCL reconstruction.

The multiple ligament-injured knee is a severe injury subgroup of PCL injuries 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. 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 MCL 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. A slow, deliberately progressive postoperative rehabilitation program is utilized to avoid overloading healing tissues.

PCL and multiple knee ligament injuries also occur in children with open growth plates. Surgical reconstruction of the PCL-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.

References

1. Fanelli GC. PCL injuries in trauma patients. Arthroscopy. 1993;9:291–4.
2. Fanelli GC, Edson CJ. PCL injuries in trauma patients, part II. Arthroscopy. 1995;11:526–9.
3. Fanelli GC. The multiple ligament injured knee: what I have learned. In: Fanelli GC, editor. The multiple ligament injured knee. A practical guide to management. 2nd ed. New York: Springer; 2013. pp. 3–14.
4. Lysholm J, Gillquist J. Arthroscopic examination of the posterior cruciate ligament. J Bone Joint Surg. 1981;63A:363–6.
5. Fanelli GC, Giannotti B, Edson CJ. Current concepts review. The posterior cruciate ligament: arthroscopic evaluation and treatment. Arthroscopy. 1994 Dec;10(6):673–88.
6. Fanelli GC. Arthroscopic evaluation of the PCL. In: Fanelli GC, editor. Posterior cruciate ligament injuries. A practical guide to management. New York: Springer; 2001. pp. 95–105.
7. Hughston JC, Baker CL, Norwood LA. Acute combined posterior cruciate and posterolateral instability of the knee. Am J Sports Med. 1983;12:204–8.
8. Clancy WG, Shelbourne KD, Zoellner GB, Keene JS, Reider B, Rosenberg TD. Treatment of knee joint instability secondary to rupture of the posterior cruciate ligament. Report of a new procedure. J Bone Joint Surg. 1983;65A:310–22.
9. Clancy WG. Repair and reconstruction of the posterior cruciate ligament. In: Chapman M, editor. Operative orthopaedics. Philadelphia: JB Lippincott; 1988. pp. 1651–65.
10. Fanelli GC, Feldman DD. Management of combined anterior cruciate ligament/posterior cruciate ligament/posterolateral complex injuries of the knee. Oper Tech Sports Med. 1999;7(3):143–9.
11. Fanelli GC, Harris JD. Late MCL (medial collateral ligament) reconstruction. Tech Knee Surg. 2007;6(2):99–105.
12. Fanelli GC, Harris JD. Surgical treatment of acute medial collateral ligament and posteromedial corner injuries of the knee. Sports Med Arthrosc Rev. 2006 May;14(2):78–83.
13. LaPrade RF. Arthroscopic evaluation of the lateral compartment of knees with grade 3 posterolateral knee complex injuries. Am J Sports Med. 1997;25(5):596–602.
14. Green NE, Allen BL. Vascular injuries associated with dislocation of the knee. J Bone Joint Surg. 1977;59A:236–9.
15. Welling RE, Kakkasseril J, Cranley JJ. Complete dislocations of the knee with popliteal vascular injury. J Trauma. 1981;21(6):450–3.
16. Wascher DC, Dvirnik PC, Decoster TA. Knee dislocation: Initial assessment and implications for treatment. J Orthop Trauma. 1997;11:525–9.
17. Kennedy JC. Complete dislocations of the knee joint. J Bone Joint Surg. 1963;45:889–904.
18. Mills WJ, Barei DP, McNair P. The value of the ankle-brachial index for diagnosing arterial injury after knee dislocation: a prospective study. J Trauma. 2004;56(6):1261–5.
19. Stuart MJ. Evaluation and treatment principles of knee dislocations. Oper Tech Sports Med. 2001;9(2):91–5.
20. Levy B, Fanelli GC, Whalen D, Stannard J, MacDonald P, Boyd J, Marx R, Stuart M. Modern perspectives for the treatment of knee dislocations and multiligament reconstruction. J Am Acad Orthop Surg. 2009 April;17(4):197–206.
21. Stannard JP. Stabilization of knee dislocations using a hinged external fixator: a prospective randomized study. In: Proceedings of the 73rd annual meeting of the American Academy of Orthopaedic Surgeons; 2006. Chicago, IL.
22. Fanelli GC, Gianotti BF, Edson CJ. Arthroscopically assisted combined posterior cruciate ligament/posterior lateral complex reconstruction. Arthroscopy. 1996;12(5):521–30.
23. Fanelli GC, Gianotti BF, Edson CJ. Arthroscopically assisted combined anterior and posterior cruciate ligament reconstruction. Arthroscopy. 1996;12(1):5–14.
24. Fanelli GC, Edson CJ. Arthroscopically assisted combined ACL/PCL reconstruction. 2–10 year follow-up. Arthroscopy. 2002;18(7):703–14.
25. Fanelli GC, Edson CJ. Combined posterior cruciate ligament–posterolateral reconstruction with Achilles tendon allograft and biceps femoris tendon tenodesis: 2–10 year follow-up. Arthroscopy. 2004;20(4):339–45.
26. Fanelli GC, et al. Treatment of combined anterior cruciate-posterior cruciate ligament-medial-lateral side knee injuries. J Knee Surg. 2005;18(3):240–8.
27. Fanelli GC, Beck JD, Edson CJ. Double bundle posterior cruciate ligament reconstruction. Surgical technique and results. Sports Med Arthrosc Rev. 2010;18(4):242–8.
28. Fanelli GC, Beck JD, Edson CJ. Combined PCL ACL lateral and medial side injuries: treatment and results. Sports Med Arthrosc Rev. 2011;19(2):120–30.
29. Fanelli GC, Beck JD, Edson CJ. Single compared to double bundle PCL reconstruction using allograft tissue. J Knee Surg. 2012;25(1):59–64.
30. Fanelli GC, Edson CJ. Surgical treatment of combined PCL, ACL, medial, and lateral side injuries (global laxity): surgical technique and 2–18 year results. J Knee Surg. 2012;25(4):307–16.
31. Fanelli GC, Sousa P, Edson CJ. Long term follow-up of surgically treated knee dislocations: stability restored, but arthritis is common. Clin Orthop Relat Res. 2014;472(9):2712–7.
32. Fanelli GC, Orcutt DR, Edson CJ. The multiple-ligament injured knee: evaluation, treatment, and results. Arthroscopy. 2005;21(4):471–86.

33. Fanelli GC, Beck JD, Edson CJ. How I manage the multiple ligament injured (dislocated) knee. Oper Tech Sports Med. 2010 Dec;18(4):198–210.
34. Wascher DC. High-velocity knee dislocation with vascular injury. Treatment principles. Clin Sports Med. 2000;19(3):457–77.
35. Mook WR, Miller MD, Diduch DR, Hertel J, Boachie-Adjei Y, Hart JM. Multiple-ligament knee injuries: a systematic review of the timing of operative intervention and postoperative rehabilitation. J Bone Joint Surg. 2009;91(12):2946–57.
36. Stannard JP, et al. The posterolateral corner of the knee: repair versus reconstruction. Am J Sports Med. 2005;33(6):881–8.
37. Levy BA, Dajani KA, Morgan JA, Shah JP, Dahm DL, Stuart MJ. Repair versus reconstruction of the fibular collateral ligament and posterolateral corner in the multiligament-injured knee. Am J Sports Med. 2010;38(4):804–9.
38. Levy BA, Dahm DL, Herrera DA, MacDonald PB, Dajani KA, Stuart MJ. Acute repair of posteromedial and posterolateral corners in multiligament knee injury is not indicated. Presented at the 27th Annual Meeting of the Arthroscopy Association of North America, Washington, DC, April 24–27; 2008.
39. Fanelli GC, Fanelli DG, Edson CJ, Fanelli MG. Combined anterior cruciate ligament and posterolateral reconstruction of the knee using allograft tissue in chronic knee injuries. J Knee Surg. 2014;27(5):353–8.
40. Fanelli GC, Fanelli DG. Fibular head based posterolateral reconstruction of the knee combined with capsular shift procedure. Sports Med Arthrosc Rev. In press.
41. Fanelli GC. Rationale and surgical technique for PCL and multiple knee ligament reconstruction. 3rd ed. Warsaw: Biomet Sports Medicine; 2012.
42. Noyes FR, Barber-Westin SD. Posterior cruciate ligament revision reconstruction, part 1. Causes of surgical failure in 52 consecutive operations. Am J Sports Med. 2005;33(5):646–54.
43. Fanelli GC. The multiple ligament injured knee: what I have learned. In: Fanelli GC, editor. The multiple ligament injured knee. A practical guide to management. 2nd ed. New York: Springer; 2013. pp. 3–14.
44. Fanelli GC. Surgical treatment of combined PCL ACL medial and lateral side injuries (global laxity): acute and chronic. In: Fanelli GC, editor. The multiple ligament injured knee. A practical guide to management. 2nd ed. New York: Springer; 2013. pp. 281–301.
45. Fanelli GC. Mechanical graft tensioning in multiple ligament knee surgery. In: Fanelli GC, editor. The multiple ligament injured knee. A practical guide to management. 2nd ed. New York: Springer; 2013. pp. 323–30.
46. Edson CJ, Fanelli GC, Beck JD. Postoperative rehabilitation of the posterior cruciate ligament. Sports Med Arthrosc Rev. 2010;18(4):275–9.
47. Edson CJ, Fanelli GC, Beck JD. Rehabilitation after multiple ligament reconstruction of the knee. Sports Med Arthrosc Rev. 2011;19(2):162–6.
48. Edson CJ, Fanelli GC. Postoperative rehabilitation of the multiple ligament injured knee. In: Fanelli GC, editor. The multiple ligament injured knee. A practical guide to management. 2nd ed. New York: Springer; 2013. pp. 437–42.
49. Fanelli GC, Feldmann DD. Arthroscopically assisted combined anterior cruciate ligament/posterior cruciate ligament reconstruction. In: Fanelli GC, editor. Posterior cruciate ligament injuries: a practical guide to management. New York: Springer; 2001. pp. 215–36.
50. Fanelli GC. Arthroscopic PCL reconstruction: transtibial technique. In: Fanelli GC, editor. Posterior cruciate ligament injuries. A guide to practical management. New York: Springer; 2001. pp. 141–56.
51. Fanelli GC. Combined ACL PCL medial lateral side injuries of the knee. In: Fanelli GC, editor. The multiple ligament injured knee. A practical guide to management. New York: Springer; 2004. pp. 111–31.
52. Fanelli GC, Edson CJ, Reinheimer KN. Evaluation and treatment of the multiple ligament injured knee. Am Acad Orthop Surg Instr Course Lect. 2009;58:389–95.
53. Levy B, Dajani KA, Whalen DB, Stannard JP, Fanelli GC, Stuart MJ, Boyd JL, MacDonald PA, Marx RG. Decision making in the multiple ligament injured knee: an evidence based systematic review. Arthroscopy. 2009 April;25(4):430–8.
54. Levy B, Fanelli GC, Whalen D, Stannard J, MacDonald P, Boyd J, Marx R, Stuart M. Modern perspectives for the treatment of knee dislocations and multiligament reconstruction. J Am Acad Orthop Surg. 2009 April;17(4):197–206.
55. Fanelli GC, Stannard JP, Stuart MJ, MacDonald PB, Marx RG, Whelan DB, Boyd JL, Levy BA. Management of complex knee ligament injuries. J Bone Joint Surg. 2010 Sept 15;92-A(12):2235–46.

Recommended Reading

56. Fanelli GC, editor. Posterior cruciate ligament injuries: a practical guide to management. New York: Springer; 2001.
57. Fanelli GC, editor. The multiple ligament injured knee. A practical guide to management. New York: Springer; 2004.
58. Fanelli GC, editor. The multiple ligament injured knee. A practical guide to management. 2nd ed. New York: Springer; 2013.