Posterior Cruciate Ligament Reconstruction in Patients 18 Years of Age and Younger

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Introduction

The purpose of this chapter is to present the senior author's Gregory C. Fanelli (GCF) experience in treating posterior cruciate ligament (PCL) injuries and PCL-based multiple ligament knee injuries in patients who are 18 years of age and younger. This chapter discusses patient age at the time of surgery, mechanisms of injury, surgical techniques, considerations in patients with open growth plates, a review of the literature, and the author's surgical outcomes in PCL and PCL-based multiple knee ligament reconstructions in patients 18 years of age and younger.

Patient Population

PCL reconstructions in patients 18 years of age and younger represent approximately 14% of our total PCL reconstruction experience at a rural tertiary care medical center. This 14% consists of 58 patients in the combined PCL-collateral ligament group, and 25 patients in the combined PCL–anterior cruciate ligament (ACL)-collateral ligament group for a total of 83 patients. Mechanisms of injury in the PCL-collateral ligament group are sports related in 72%, motor vehicle accident related in 25%, and trampoline accidents in 3%. Mechanisms of injury in the PCL–ACL-collateral ligament group are sports related in 39%, motor vehicle accident related in 57%, and trampoline-related accidents in 4%.

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

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

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

Preoperative Planning: Special Considerations

The concern in the pediatric and adolescent patient population with open growth plates is the potential for growth arrest and resultant angular deformity about the knee after

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surgical intervention. This risk can be decreased by insuring that no fixation devices or bone blocks cross or damage the physis during ligament reconstruction. Growth remaining and physiologic stage of development of the patient is very important, and is considered in the preoperative planning for the treatment of these complex knee ligament injuries [1, 2]. Adults with PCL injuries will often have mid-substance disruptions of the PCL, while children may have an increased incidence of PCL avulsion-type injuries, both cartilaginous and bony in nature leading to the consideration of primary repair, primary repair with augmentation, and reconstruction of the injured ligaments [3]. Additionally, an understanding of the relationships of the PCL and collateral ligaments to the physis is important when planning the surgical procedure [4].

Surgical Techniques and Outcomes in the Literature

Many surgeons have described successful surgical techniques to treat PCL and multiple knee ligament injuries in patients' with open growth plates. These studies are presented for a broad view of the treatment of these complex knee ligament injuries. Kocher et al. reviewed two separate patient groups with adolescent and pediatric PCL injuries: those managed nonoperatively and those treated surgically with ligament reconstruction or direct repair [3]. The group reviewed 26 PCL (1 bilateral) injuries in patients under age 18 over a 16-year period with a mean follow-up time of 27.8 months. Fourteen patients (15 knees) were treated operatively, and the other 11 patients had nonoperative treatment. All patients were evaluated using Tegner, Lysholm, and Pediatric International Knee Documentation Committee (Pedi-IKDC) scores. The group determined that patient outcomes for nonoperative treatment of nondisplaced avulsion injuries or partial PCL tears are viable in pediatric populations. They also concluded that PCL reconstruction or repair is a suitable treatment option for young patients with multiligament injuries or isolated PCL injuries who fail conservative treatment.

Warme and Mickelson present a case report of a 10-year-old boy who sustained an avulsion of the PCL from the insertion site on the tibia [5]. The boy required a PCL reconstruction after failing conservative treatment and a primary repair attempt. The team completed physeal sparing reconstruction using a modified femoral tunnel placement method combined with tibial inlay technique. The presented method prevented transphyseal drilling and also attained favorable anatomic graft placement. This technique also avoided the "killer" turn often associated with a transtibial approach. The boy had complete return to the pre-injury level of activity.

Solayar and Kapoor present a case report of a pediatric patient with a PCL avulsion off the insertion site of the tibia with an accompanying posterior horn medial meniscal tear from the posterior capsule [6]. The boy was treated with an open reduction and internal fixation of the detached fragment and suture repair for the meniscal tear. Solayar and Kapoor stress the importance of managing associated intra-articular injuries when treating pediatric PCL tibial avulsions.

Kwon et al. present a case of a 13-year-old girl with tibial detachment of the PCL that was surgically treated with arthroscopic reduction and pullout suture [7]. The procedure left the epiphyseal plate intact by using a posterior trans-septal portal. The Kwon group suggests that this alternative treatment to PCL detachment injuries in pediatric patients will avoid injury to the physeal and maintain ligament tension during healing. However, this is yet to be proven in terms of biomechanical benefit.

The Anderson group reports the case of a pediatric patient with posterolateral knee and posterior instability [8]. The patient failed nonoperative treatment and was successfully treated with physeal-saving intra-articular PCL reconstruction and extra-articular posterolateral structure reconstruction.

The Bovid group presents the case of an 11-year-old boy with a high-grade intrasubstance PCL injury [9]. The injury was operatively treated and reconstructed using the all-arthroscopic tibial inlay technique with a modification to minimize physeal injury risk. The patient returned to pre-injury level of activity by 17 months follow-up with no posterior sag and a grade 1 posterior drawer. Radiographs did not indicate degenerative changes. Both the distal femoral and proximal tibial physes were widely patent and showed no angular deformity. The operative limb was longer following surgery with a 1-cm leg-length discrepancy.

Accadbled et al. present a case report of an 11-year-old boy with a PCL rupture [10]. He was operatively treated with an arthroscopic PCL reconstruction employing a single-bundle four-strand hamstring autograft. At 24 months follow-up, the patient had resumed the pre-injury level of activity with no growth disturbance indicators and a normal clinical examination.

Stadelmaier et al. studied the inhibitive effects of soft tissue grafts on the formation of a bony bridge within drill tunnels across open tibial and femoral growth plates for a canine model [11]. A fascia lata autograft was positioned in tunnels drilled across the proximal tibial and distal femoral physes in four skeletally immature canines. A control group of four additional canines had a similar procedure, but all drill holes were left unfilled. All growth plates were evaluated at either 2 weeks or 4 months following the procedure with high-resolution radiography and histologic study. This study indicates that a soft tissue graft of fascia lata inserted in drill holes across an open growth plate prevents bony bridge formation. These findings support other clinical studies that report no apparent changes to growth plate function following pediatric intra-articular ACL reconstruction.

MacDonald et al. present a case report of a 6-year-old boy with a partial radial tear of the medial meniscus and a chronic PCL tear [12]. He was treated nonoperatively and at 5 years post injury presented with a looseness sensation in the knee and occasional anterior knee pain. The group concluded that additional follow-up will be necessary to determine whether instability will develop into arthritic changes.

Shen et al. present a case report of a 5-year-old boy with posterolateral rotatory instability and PCL injury [13]. The patient was surgically treated and returned to the pre-injury level of activity by 4-year follow-up. The findings of the Shen group suggest that operative treatment of acute PCL/PLC injuries can be successful in this patient population.

Author's Surgical Technique

Graft Selection

Our preferred graft for the PCL reconstruction is the Achilles tendon allograft without bone plug for single-bundle PCL reconstructions and Achilles tendon allograft without bone plug and tibialis anterior allografts for double-bundle PCL reconstructions. Achilles tendon allograft without bone plug or other all soft tissue allograft are the preferred grafts for the ACL reconstruction when combined PCL–ACL reconstruction is indicated. The preferred graft material for the lateral posterolateral reconstruction is all soft tissue (no bone plugs) allograft tissue combined with a primary repair, and posterolateral capsular shift procedure. Our preferred method for medial-side injuries is a primary repair of all injured structures combined with posteromedial capsular shift and all soft tissue allograft (no bone plugs) supplementation–augmentation as needed. All soft tissue grafts adhere to the principles of Stadelmaier [11].

General Concepts

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 [14–26]. The concern in the patient population of 18 years of age and younger 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 reconstruction have both been successful in patients with closed or nearly closed growth plates. We have had no patients with growth arrest and resultant angular deformity about the knee after surgical intervention.

PCL Reconstruction

The patient is placed on the operating room table in the supine position, and after satisfactory induction of anesthesia, the operative and nonoperative lower extremities are carefully examined [23–26]. A tourniquet is applied to the upper thigh of the operative extremity, and that extremity is prepped and draped in a sterile fashion. The well leg is supported by the fully extended operating room table which also supports the surgical leg during medial- and lateral-side surgery. A lateral post is used to control the surgical extremity. An arthroscopic leg holder is not used. Preoperative and postoperative antibiotics are given, and antibiotics are routinely used to help prevent infection in these time-consuming, difficult, and complex cases. Allograft tissue is prepared prior to bringing the patient into the operating room to minimize general anesthesia time for the patient, and to facilitate the flow of the surgical procedure. The reader is referred to Chaps. 9 and 15 for additional information regarding the principles and techniques of surgical reconstruction in the PCL-injured knee and the multiple-ligament-injured knee.

The arthroscopic instruments are inserted with the gravity inflow through the superolateral patellar portal. Arthroscopic fluid pumps are not used. Instrumentation and visualization are positioned through inferomedial and inferolateral patellar portals, and can be interchanged as necessary. Additional portals are established as needed. Exploration of the joint consists of an evaluation of the patellofemoral joint, the medial and lateral compartments, medial and lateral menisci, and the intercondylar notch. The residual stumps of the PCL are debrided; however, the PCL anatomic insertion sites are preserved to serve as tunnel reference points. When a combined PCL–ACL reconstruction is performed, the same principles apply to preparing for the ACL reconstruction, and the notchplasty for the anterior cruciate ligament portion of the procedure is performed at this time. Care is taken throughout the procedure to protect the proximal tibial and distal femoral growth plates.

An extracapsular extra-articular posteromedial safety incision is made by creating an incision approximately 1.5–2 cm long starting at the posteromedial border of the tibia approximately 1 in. below the level of the joint line and extending distally. Dissection is carried down to the crural fascia, which is incised longitudinally. An interval is developed between the medial head of the gastrocnemius muscle and the nerves and vessels posterior to the surgeon's finger, and the capsule of the knee joint anterior to the surgeon's finger. The posteromedial safety incision enables the surgeon to protect the neurovascular structures, confirm the accuracy of the PCL tibial tunnel, and to facilitate the flow of the surgical procedure. There is no subperiosteal stripping or elevation from the proximal tibia or distal femur.

The curved over-the-top PCL instruments (Biomet Sports Medicine, Warsaw, IN, USA) are used to sequentially lyse adhesions in the posterior aspect of the knee, and elevate the capsule from the posterior tibial ridge. This will allow accurate placement of the PCL/ACL drill guide, and correct placement of the tibial tunnel. Care is taken to gently elevate the posterior capsule only, and not to strip or elevate the periosteum or damage the posterior proximal tibial growth plate.

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

The appropriately sized standard cannulated reamer is used to create the tibial tunnel. The surgeon's finger through the extracapsular extra-articular posteromedial incision monitors the position of the guide wire. When the drill is engaged in bone, the guide wire is reversed, blunt end pointing posterior, for additional patient safety. The drill is advanced until it comes to the posterior cortex of the tibia. The chuck is disengaged from the drill, and completion of the tibial tunnel is performed by hand.

Our preference is to perform single-bundle PCL reconstruction in patients with open growth plates in order to protect the distal femoral growth plate, while single- or double-bundle PCL reconstruction have both been successful in patients with closed or nearly closed growth plates. This is a decision the surgeon will need to make on each case based on the anatomy at the time of surgery, the patient's development, and expected potential growth remaining. The PCL single- or double-bundle femoral tunnels are made from inside out using the double-bundle aimers, or an endoscopic reamer can be used as an aiming device (Biomet Sports Medicine, Warsaw, IN, USA). 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 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. Once again, care is taken throughout the procedure to protect the proximal tibial and distal femoral growth plates.

The surgical technique of PCL femoral tunnel creation from inside to outside is preferred for two reasons. First, there is a greater distance and margin of safety between the PCL femoral tunnel or tunnels and the medial femoral condyle articular surface using the inside-to-outside method. Second, a more accurate placement of the PCL femoral tunnels is possible, in the senior author's opinion, because the double-bundle aimer or endoscopic reamer can be placed on the anatomic footprint of the anterior lateral or posterior medial PCL insertion site under direct visualization.

A Magellan suture retriever (Biomet Sports Medicine, Warsaw, IN, USA) is introduced through the tibial tunnel into the joint, and retrieved through the femoral tunnel. The traction sutures of the graft material are attached to the loop of the Magellan suture retriever, and the graft is pulled into position. The graft material is secured on the femoral side using a bioabsorbable interference screw for primary aperture-opening fixation, and a polyethylene ligament fixation button for backup fixation.

The cyclic dynamic method of graft tensioning using the Biomet graft-tensioning boot (Biomet Sports Medicine, Warsaw, IN, USA) is used to tension the posterior and anterior cruciate ligament grafts [24]. This tensioning method is discussed in Chap. 21 of this book. Tension is placed on the PCL graft distally using the Biomet graft-tensioning boot (Biomet Sports Medicine, Warsaw, IN, USA). Tension is gradually applied with the knee in 0° of flexion (full extension) reducing the tibia on the femur. This restores the anatomic tibial step-off. The knee is cycled through a full range of motion multiple times to allow pretensioning and settling of the graft. The process is repeated until there is no further change in the torque setting on the graft tensioner. The knee is placed in 70–90° of flexion, and fixation is achieved on the tibial side of the PCL graft with a bioabsorbable interference screw placed just inside the cortex of the tibia, and backup fixation with a bicortical screw and spiked ligament washer or polyethylene ligament fixation button. No fixation devices or bone plugs cross or violate the growth plates.

Anterior Cruciate Ligament Reconstruction

When combined posterior and anterior cruciate ligament reconstructions are performed, the PCL reconstruction is performed first followed by the ACL reconstruction. With the knee in approximately 90° of flexion, the anterior cruciate ligament tibial tunnel is created using a drill guide. The senior author's preferred method of anterior cruciate ligament reconstruction is the transtibial femoral tunnel endoscopic surgical technique. The arm of the drill guide enters the knee joint through the inferior medial patellar portal. The bullet of the drill guide contacts the anterior medial proximal tibia externally at a point midway between the posterior medial border of the tibia, and the anterior tibial crest just above the level of the tibial tubercle away from the proximal tibial physis. An approximate 1-cm bone bridge exists between the PCL and ACL tibial tunnel starting points on the proximal tibia. The guide wire is drilled through the guide and positioned so that after creating the anterior cruciate ligament tibial tunnel, the graft will approximate the tibial anatomic insertion site of the anterior cruciate ligament. A standard cannulated reamer is used to create the tibial tunnel.

With the knee in approximately 90–100° of flexion, an over-the-top femoral aimer is introduced through the tibial tunnel, and used to position a guide wire on the medial wall of the lateral femoral condyle to create a femoral tunnel approximating the anatomic insertion site of the anterior cruciate ligament. The anterior cruciate ligament graft is positioned, and fixation achieved on the femoral side using cortical suspensory fixation with a polyethylene ligament fixation button. No fixation devices or bone plugs cross or violate the growth plates.

The cyclic dynamic method of tensioning of the anterior cruciate ligament graft is performed using the Biomet graft-tensioning boot [24] (Biomet Sports Medicine, Warsaw, IN, USA). Traction is placed on the anterior cruciate ligament graft sutures with the knee in 0° of flexion, and tension is gradually applied reducing the tibia on the femur. The knee is then cycled through multiple full flexion and extension cycles to allow settling of the graft. The process is repeated until there is no further change in the torque setting on the graft tensioner, and the Lachman and pivot shift tests are negative. The knee is placed in approximately 30° of flexion, and fixation is achieved on the tibial side of the anterior cruciate ligament graft with a bioabsorbable interference screw placed just inside the cortex of the tibia, and backup fixation with a polyethylene ligament fixation button. No fixation devices or bone plugs cross or violate the growth plates.

Posterolateral Reconstruction

Our most commonly utilized surgical technique for posterolateral reconstruction is the fibular-head-based figure-of-eight free-graft 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, once again protecting the proximal tibial and distal femoral growth plates.

In acute cases, primary repair of all lateral-side-injured structures is performed with suture anchors, and permanent sutures through drill holes as indicated. The primary repair is then augmented with an allograft tissue reconstruction. No fixation devices or bone plugs cross or violate the growth plates. Posterolateral reconstruction with the free-graft figure-of-eight technique utilizes semitendinosus or other soft tissue allograft. A lateral curvilinear incision is made. Dissection is carried down to the layer 1 fascia level. The peroneal nerve is identified, peroneal nerve neurolysis is performed, and the peroneal nerve is protected throughout the entire procedure. When the distal femoral growth plates are open, no hardware or drill holes are made on the lateral aspect of the knee. The common biceps tendon at its insertion into the fibular head is identified. A semitendinosus or other all soft tissue allograft is looped around the common biceps tendon insertion at the head of the fibula, and sewn with number 2 permanent braided sutures where the common biceps tendon inserts into the fibular head. Care is taken to not damage the fibular physis.

The iliotibial band is incised in line with its fibers. Dissection is carried down to the anatomic insertion site of the fibular collateral ligament and the popliteus tendon. A longitudinal incision is made posterior and parallel to the fibular collateral ligament. This incision provides access to the posterolateral compartment of the knee to assess capsular insertion sites for primary repair, and to enable the posterolateral capsular shift. Primary repair is performed as indicated. Posterolateral capsular shift is performed with permanent number 2 ethibond suture.

The semitendinosus allograft limb positioned lateral to the common biceps femoris tendon is passed medial to the iliotibial band and parallel to the fibular collateral ligament. This represents the fibular collateral ligament arm of the fibular head-common biceps femoris-tendon-based figure-of-eight posterolateral reconstruction. The semitendinosus allograft limb positioned medial to the common biceps femoris tendon is passed medial to the iliotibial band and medial to the fibular collateral ligament, and parallel to the popliteus tendon. This limb represents the force vector of the popliteus tendon and popliteal fibular ligament. The two limbs of the semitendinosus allograft are crossed in a figure-of-eight fashion, and sewn into the respective anatomic insertion sites of the fibular collateral ligament and popliteus tendon on the distal lateral aspect of the femur using number 2 permanent braided suture. The posterolateral capsule that had been previously incised is then shifted and sewn into the strut of figure-of-eight graft tissue material using number 2 ethibond permanent braided suture. The allograft tissue used for the posterolateral reconstruction is also sewn into the underlying fibular collateral ligament, popliteus tendon, and popliteofibular ligament also using number 2 permanent braided suture. Throughout the procedure, there is protection of both the fibula and the distal femoral physes, and the peroneal nerve. At the completion of the lateral-side procedure, the wound is thoroughly irrigated and closed in layers. When the growth plates of the proximal tibia and distal femur are functionally closed, the posterolateral reconstruction is carried out as described in Chap. 15.

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 and below the proximal tibial physis. 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 are protected. The tibialis anterior or other soft tissue allograft is secured with a suture anchor, and multiple number 2 braided nonabsorbable ethibond sutures at the popliteus tendon anatomic femoral insertion site, and there is no violation of the distal femoral physis. 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 that does not violate the growth plate, and polyethylene ligament fixation button. The fibular-head-based reconstruction and posterolateral capsular shift procedures are then carried out as described above. Number 2 permanent braided ethibond suture is used to sew the allograft to the deep capsular layers for additional reinforcement. When the growth plates of the proximal tibia and distal femur are functionally closed, the posterolateral reconstruction is carried out as described in Chap. 15.

Posteromedial Reconstruction

The surgical leg positioned on the extended operating room table in a supported flexed knee position. Posteromedial and medial reconstructions are performed through a medial curved incision taking care to maintain adequate skin bridges between incisions. In acute cases, primary repair of all medial-side-injured structures is performed with suture anchors and permanent sutures as indicated. The primary repair is then augmented with an allograft tissue reconstruction. Care is taken to make sure that there is no compromise or violation of the proximal tibia or distal femoral growth plates.

In chronic cases of posteromedial reconstruction, the Sartorius fascia is incised and retracted exposing the superficial medial collateral ligament and the posterior medial capsule. Nerves, blood vessels, and the growth plates are protected throughout the procedure. A longitudinal incision is made just posterior to the posterior border of the superficial medial collateral ligament. Care is taken not to damage the medial meniscus during the capsular incision. Avulsed capsular structures are primarily repaired using suture anchors and number 2 permanent braided sutures. The interval between the posteromedial capsule and medial meniscus is developed. The posteromedial capsule is shifted in an anterior and superior direction. The medial meniscus is repaired to the new capsular position, and the shifted capsule is sewn into the medial collateral ligament using three number 2 ethibond permanent braided sutures in a horizontal mattress fashion, and that suture line is reinforced using a running number 2 ethibond permanent braided suture.

When superficial medial collateral ligament reconstruction is indicated, this is performed using allograft tissue after completion of the primary capsular repair, and posteromedial capsular shift procedures are performed as outlined above. This graft material is attached at the anatomic insertion sites of the superficial medial collateral ligament on the tibia using a screw and spiked ligament washer, or suture anchors. Care is taken to make sure that there is no compromise or violation of the proximal tibia or distal femoral growth plates. The graft is looped around the adductor magnus tendon, tensioned, and sewn back to itself using number 2 ethibond permanent braided sutures. 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 permanent braided sutures are used to sew the allograft to the deep capsular layers for additional reinforcement. In patients with closed growth plates, screw and washer fixation may be used if desired on both the tibia and femur to secure the allograft tissue.

Postoperative Rehabilitation Program

The knee is maintained in full extension for 3–5 weeks non-weight bearing. Progressive range of motion begins during postoperative week 3–5. Progressive weight bearing occurs at the beginning of postoperative weeks 3 through 5. Progressive closed kinetic chain strength training, proprioceptive training, and continued motion exercises are initiated very slowly beginning at postoperative week 12. The long leg range of motion brace is discontinued after the 10th week. Return to sports and heavy labor occurs after the 9th to 12th postoperative month when sufficient strength, range of motion, and proprioceptive skills have returned [27–30]. 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.

Authors' Results

We present the senior author's results of PCL reconstructions in patients 18 years of age and younger representing approximately 14 % of our total PCL reconstruction experience at a rural tertiary care medical center. This 14 % consists of 58 patients in the combined PCL-collateral ligament group, and 25 patients in the combined PCL–ACL-collateral ligament group for a total of 83 patients. Mechanisms of injury in the PCL-collateral ligament group are sports related in 72 %, motor vehicle accident related in 25 %, and trampoline accidents in 3%. Mechanisms of injury in the PCL–ACL-collateral ligament group are sports related in 39 %, motor vehicle accident related in 57 %, and trampoline-related accidents in 4%.

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

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

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

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 stage of development of the growth plate at the time of surgery as described in the surgical technique section of this chapter. The concern in the patient population of 18 years of age and younger 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; however, single- and double-bundle PCL reconstruction have both been successful in patients with closed or nearly closed growth plates. Thus far, we have had no patients with growth arrest and resultant angular deformity about the knee after surgical intervention in any age group.

Postoperatively, the patients were evaluated with the range of knee motion, KT 1000 arthrometer, 90° knee flexion stress radiography, Lysholm, Tegner, and Hospital for Special Surgery knee ligament rating scales, X-ray, and physical examination [31–33]. Each evaluation criterion compared the postoperative surgical knee to the uninjured nonsurgical normal knee.

PCL + Collateral Ligament Group

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

Tibiofemoral displacement measurements were performed using the KT 1000 knee arthrometer (Medmetric Corporation, San Diego, CA, USA) and the Telos stress radiography device (Austin Associates, Baltimore, MD, 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-pound anterior displacement 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 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 pre-injury 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 pre-injury Tegner level of function, respectively.

Physical examination tests used to evaluate the postoperative outcomes of the combined PCL collateral ligament group included the posterior drawer, Lachman, pivot shift, varus stress, valgus stress, and the axial rotation dial tests. All physical examination tests compared the postoperative surgical knee to the normal uninjured nonsurgical knee. The posterior drawer test was normal in 63% (34/54), grade 1/2 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 and resultant angular deformity about the knee after surgical intervention in any age group.

PCL + ACL + Collateral Ligament Group

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

Tibiofemoral displacement measurements were performed using the KT 1000 knee arthrometer (Medmetric Corporation, San Diego, CA, USA) and the Telos stress radiography device (Austin Associates, Baltimore, MD, 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-pound anterior displacement 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 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 pre-injury 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 pre-injury Tegner level of function, respectively.

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

Case Presentation

The patient is a 12-year-old boy referred to me 3 weeks after a right knee injury sustained playing baseball. The patient slid into base and collided with another player and the fixed base with his knee in 90° of flexion. Initial evaluation by another physician revealed a bloody effusion upon aspiration, posterior tibial translation at 90° of flexion, and a magnetic resonance imaging (MRI) study of the right knee demonstrating a PCL tear. The patient was referred to me for evaluation and treatment.

Physical examination comparing the injured right knee to the uninvolved left knee revealed the skin and neurovascular status to be intact. Range of knee motion was symmetrical to the uninvolved left knee. There was no pain or restriction of motion at the hip or ankle on the involved or normal side. The tibial step-offs were decreased, and the posterior drawer test was positive. There were positive posterolateral and posteromedial drawer tests, and the dial test was positive at both 30° and 90° of knee flexion. The knee was stable to valgus stress at 0° and 30° of knee flexion, and there was varus laxity at both 0° and 90° of knee flexion with a soft end point. The hyperextension external rotation recurvatum test was negative, and the heel liftoff test was symmetrical on the injured and noninjured side. The Lachman test and pivot shift tests were both negative.

Initial radiographs taken in the orthopedic clinic demonstrated open growth plates on the distal femur and the proximal tibia with no fractures (Fig. 19.1). There was no physeal injury noted on stress radiography, or MRI imaging. MRI showed a tear of the PCL, and bone marrow edema without fracture in the anterior tibial epiphysis in the midline. There were no articular cartilage injuries or meniscus tears.

KT 1000 arthrometer testing revealed the following side-to-side difference measurements: PCL screen at 90° of knee flexion 6 mm, corrected posterior measurement at 70° of knee flexion 6 mm, corrected anterior measurement at 70° of knee flexion 4 mm, and the 30-pound anterior displacement measurement at 30° of knee flexion was 1 mm. Side-to-side difference on stress radiography at 90° of knee flexion with a posterior displacement force applied to the tibial tubercle area of the proximal tibia using the Telos device comparing the involved to the normal knee was 10 mm (Fig. 19.2).

Preoperative testing with three knee ligament rating scales revealed the following: Hospital for Special Surgery score was 42/100, Lysholm score was 44/100, and the Tegner activity score was 3 (pre-injury, the patient was level 7).

The diagnosis in this patient is a right knee subacute PCL-based multiple-ligament-injured knee with PCL tear, posteromedial instability type A, and posterolateral instability type B in a patient with open growth plates. The decision was made to proceed with arthroscopic single-bundle transtibial PCL reconstruction using fresh-frozen Achilles tendon allograft without bone plug combined with a fibular-head-based figure-of-eight posterolateral reconstruction using fresh-frozen semitendinosus allograft. The PCL reconstruction femoral tunnel crossed the distal femoral physis, and the PCL tibial tunnel was positioned distal to the tibial physis. Cortical suspensory fixation with two stacked polyethylene ligament fixation buttons were used on the femoral side, and a bioabsorbable interference screw and bicortical screw and spiked ligament washer were used on the tibial side fixation. No fixation device crossed the growth plates, and there were no bone plugs on the Achilles tendon allograft tissue, so no bone plug crossed the growth plate (Fig. 19.3).

The posterolateral reconstruction was a fibular-head-based figure-of-eight reconstruction using a fresh-frozen semitendinosus allograft. The allograft was looped around the common biceps tendon at the fibular head and sewn there

Fig. 19.1 Preoperative radiographs in a 12-year-old boy. The diagnosis in this patient is a right knee posterior-cruciate-ligament-based multiple-ligament-injured knee with posterior cruciate ligament tear, posteromedial instability type A, and posterolateral instability type B in a patient with open growth plates

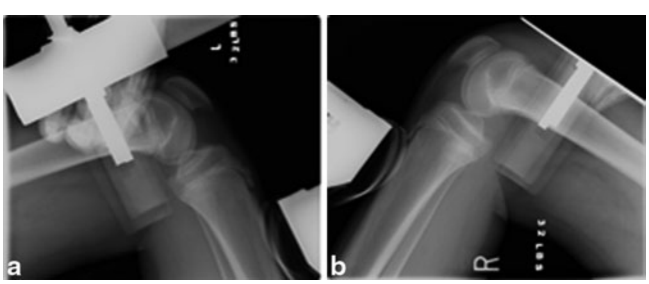

Fig. 19.2 Preoperative stress radiography with a posterior directed force applied to the proximal tibia of the normal uninjured knee (**a**) and the PCL, posterolateral, posteromedial injured knee (**b**). These stress radiographs demonstrate increased posterior translation at approximately 90° of knee flexion in the injured knee compared to the normal knee. Side-to-side difference on stress radiography at 90° of knee flexion with a posterior displacement force applied to the tibial tubercle area of the proximal tibia using the Telos device comparing the involved to the normal knee was 10 mm increased posterior tibial translation compared to the normal knee. PCL posterior cruciate ligament

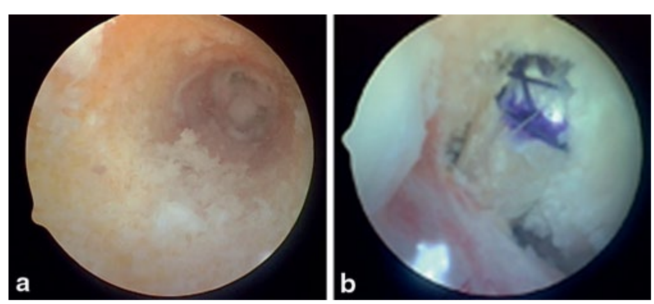

Fig. 19.3 The posterior cruciate ligament reconstruction femoral tunnel crossed the distal femoral physis (**a**), and the PCL tibial tunnel was positioned distal to the tibial physis. Cortical suspensory fixation with two stacked polyethylene ligament fixation buttons were used on the femoral side, and a bioabsorbable interference screw and bicortical screw and spiked ligament washer were used on the tibial side fixation. No fixation device crossed the growth plates, and there were no bone plugs on the Achilles tendon allograft tissue, so no bone plug crossed the growth plate (**b**). PCL posterior cruciate ligament

using permanent braided suture. The fibular collateral ligament component was passed medial to the iliotibial band, and the popliteofibular popliteus tendon component passed medial to the common biceps tendon and the iliotibial band. The allograft limbs were crossed in a figure-of-eight fashion with the fibular collateral component being lateral to the popliteus tendon component. The graft limbs were sewn into their respective anatomic femoral insertion sites with number 2 braided permanent sutures with a slight valgus applied to the knee to close the lateral compartment with the knee in approximately 90° of flexion. The allograft was then sewn to the deep capsular layers for additional reinforcement, and a posterolateral capsular shift was also performed. There were no drill holes through or around the lateral-side growth plates (Fig. 19.4).

The posteromedial reconstruction was performed using the posteromedial capsular shift technique (Fig. 19.5). This was an all suture posteromedial capsular advancement procedure performed with the knee in approximately 45° of flexion as described in Chap. 15. The PCL reconstruction, the posterolateral reconstruction, and the posteromedial reconstruction procedures were all protective of the growth plates. Postoperatively, the surgical knee was immobilized in a long leg brace locked in full extension, and was non-weight bearing with crutches. Prophylactic preoperative and postoperative antibiotics were utilized. Progressive weight bearing and the range of knee motion were gradually initiated according to our postoperative rehabilitation program detailed in Chap. 25.

Six-year follow-up postoperative examination of the patient at the age of 19 reveals equal leg lengths, normal and symmetrical carrying angles, and normal gait during ambulation. Radiographs reveal closed distal femoral and proximal tibial physes that are symmetrical to the normal knee with no malalignment, no evidence of growth arrest, and no degenerative changes (Fig. 19.6). Physical examination of the surgical right knee compared to the normal left knee reveals the posterior drawer is negative, posteromedial and posterolateral drawer tests are negative, and the dial test is symmetrical at 30° and 90° of knee flexion. The Lachman test is negative, the pivot shift test is negative, and the surgical knee is stable to varus and valgus stress throughout the flexion extension arc. The hyperextension external rotation recurvatum and heel liftoff tests are symmetrical compared to the normal knee.

Three-year postoperative KT 1000, stress radiography, and knee ligament rating scale measurements reveal the following. Range of motion is 0–125° on the surgical right knee, and 0–130° on the uninvolved left knee. Side-to-side difference on KT 1000 measurements on the PCL screen, corrected posterior, and corrected anterior measurements are 2.0, 2.5, and −2.0 mm respectively. Side-to-side difference on the KT 1000 anterior displacement measurement at 30° of knee flexion is 2.0 mm. Stress X-rays at 90° of knee flexion using the Telos device comparing the surgical to the knee normal knee reveal a 1.8 mm side-to-side difference (Fig. 19.7). The Hospital for Special Surgery, Lysholm, and Tegner knee ligament rating scale scores are 98/100, 99/100, and 7. The patient's pre-injury Tegner score was 7 indicating a return to pre injury level of function.

Fig. 19.4 The posterolateral reconstruction was a fibular-head-based figure-of-eight reconstruction using a fresh-frozen semitendinosus allograft. The allograft was looped around the common biceps tendon at the fibular head and sewn there using permanent braided suture. The fibular collateral ligament component was passed medial to the iliotibial band, and the popliteofibular popliteus tendon component passed medial to the common biceps tendon and the iliotibial band. The allograft limbs were crossed in a figure-of-eight fashion with the fibular collateral component being lateral to the popliteus tendon component. The graft limbs were sewn into their respective anatomic femoral insertion sites with number 2 braided permanent sutures with a slight valgus applied to the knee to close the lateral compartment with the knee in approximately 90° of flexion. The allograft was then sewn to the deep capsular layers for additional reinforcement, and a posterolateral capsular shift was also performed. There were no drill holes through or around the lateral-side growth plates

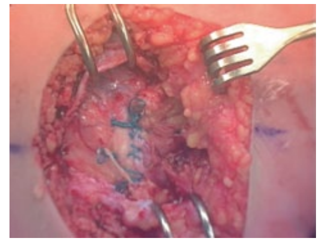

Fig. 19.5 The posteromedial reconstruction was performed using the posteromedial capsular shift technique. This was an all suture posteromedial capsular advancement procedure performed with the knee in approximately 45° of flexion. A longitudinal incision is made just posterior to the posterior border of the superficial medial collateral ligament. Care is taken not to damage the medial meniscus during the capsular incision. Avulsed capsular structures are primarily repaired using suture anchors and number 2 permanent braided sutures. The interval between the posteromedial capsule and medial meniscus is developed. The posteromedial capsule is shifted in an anterior and superior direction. The medial meniscus is repaired to the new capsular position, and the shifted capsule is sewn into the medial collateral ligament using three number 2 ethibond permanent braided sutures in horizontal mattress fashion, and that suture line is reinforced using a running number 2 ethibond permanent braided suture

Fig. 19.6 Six-year follow-up postoperative examination of the patient at the age of 19 reveals equal leg lengths, normal and symmetrical carrying angles, and normal gait during ambulation. Radiographs reveal closed distal femoral and proximal tibial physes that are symmetrical to the normal knee with no malalignment, no evidence of growth arrest, and no degenerative changes

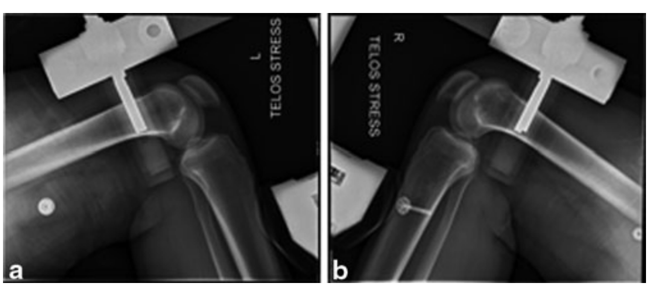

Fig. 19.7 Six -year postoperative stress X-rays at 90° of knee flexion using the Telos device comparing the normal knee (**a**) to the surgical knee (**b**) reveal a 1.8 mm side-to-side difference

Summary

The concern in the pediatric and adolescent patient population with open growth plates is the potential for growth arrest and resultant angular deformity about the knee after surgical intervention. This risk can be decreased by insuring that no fixation devices or bone blocks cross or damage the physis during ligament reconstruction. Growth remaining and physiologic stage of development of the patient is very important, and is considered in the preoperative planning for the treatment of these complex knee ligament injuries. Adults with PCL injuries will often have mid-substance disruptions of the PCL, while children may have an increased incidence of PCL avulsion-type injuries, both cartilaginous and bony in nature, leading to the consideration of primary repair, primary repair with augmentation, and reconstruction of the injured ligaments. Additionally, an understanding of the relationships of the PCL and collateral ligaments to the physis is important when planning the surgical procedure.

The majority of patients in our experience are in the 15–18-year-old age group, and our surgical technique was adjusted to accommodate to the stage of development of the growth plate at the time of surgery as described in the surgical technique section of this chapter. Many surgeons have described successful surgical techniques to treat PCL and multiple knee ligament injuries in patients' with open growth plates, and these concepts should be incorporated into the surgical planning in patients with open growth plates. Patients with closed or nearly closed growth plates may be treated with the same surgical techniques as adults, while skeletally immature patients require modified surgical techniques outlined in this chapter. Our preference is to perform single-bundle PCL reconstruction in patients with open growth plates, while single- or double-bundle PCL reconstruction have both been successful in patients with growth plates that are closed or nearly closed. Anterior cruciate ligament and collateral ligament surgery must also respect the stage of development of the physis. Thus far, in the senior author's experience, there have been no patients with growth arrest and resultant angular deformity about the knee after surgical intervention in any age group.

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