35

Complications of Anterior Cruciate Ligament Reconstruction

*Matthew J. Matava, MD
Mark S. Muller, MD
Camille M. Clinton, MD
*Scott A. Rodeo, MD
Sam Akhavan, MD
Richard D. Parker, MD

Abstract

Anterior cruciate ligament reconstruction has become one of the most common arthroscopic knee procedures, and it has excellent success rates. Intraoperative technical complications are uncommon but can be devastating to knee function. Each of the multiple steps in the reconstruction has associated complications.

Instr Course Lect 2009;58:355-375.

Avoiding complications during reconstruction of the anterior cruciate ligament (ACL) begins with choosing a reconstructive graft. The most common grafts are bone-patellar tendon-bone (BPTB) autograft, BPTB allograft, and hamstring (semitendinosus-gracilis tendon) autograft. Less commonly used are Achilles or anterior tibial tendon allografts and quadriceps tendon or contralateral BPTB autografts. Most surgeons prefer using one type of graft, although they should become adept at harvesting and implanting at least one other graft because the preferred graft may be unavailable or dropped during the surgical procedure. It is imperative to confirm the availability of an appropriate-size allograft before surgery to avoid a size mismatch. For example, a BPTB allograft harvested from a very tall donor would not be suitable for use in a patient who is of less than average height. It is prudent to have more than one size of graft available.

Many factors influence the choice of graft, in addition to surgeon preference. The patient-related factors include age, occupation, athletic pursuits, and pain tolerance. The knee-specific factors include associated ligamentous injuries, earlier surgery or injury to the extensor mechanism, preexisting patellofemoral arthrosis, or surgical scars. A radiographic finding of patella alta, patella baja, or an open physis also may influence the graft choice. The presence of a free intratendinous ossicle, as is often seen with Osgood-Schlatter disease, may alter the method by which the graft is fashioned to prevent premature graft rupture.

Complications of Patellar Tendon Harvest

Patellar Fracture

The rate of fracture of the patella after harvest of a BPTB autograft is 0.23% to 2.3%.[1-3] Stein and associates[3] found that these fractures occur an average of 57 days after surgery (range, 24 to 121 days). Fractures occur during three distinct periods, each of which is related to a specific fracture configuration. Intraoperative fractures typically are

Matthew J. Matava, MD or the department with which he is affiliated has received research or institutional support from BREG, Inc and is a consultant for or an employee of ISTO Technologies. Scott A. Rodeo, MD or the department with which he is affiliated has received research or institutional support from Wyeth Research and Lifecall, Inc.

Figure 1 AP radiograph of the knee after ACL reconstruction with a BPTB graft, showing a stellate patellar fracture.

Figure 2 Lateral radiograph of the knee with a transverse fracture of the patella after ACL reconstruction with a BPTB graft.

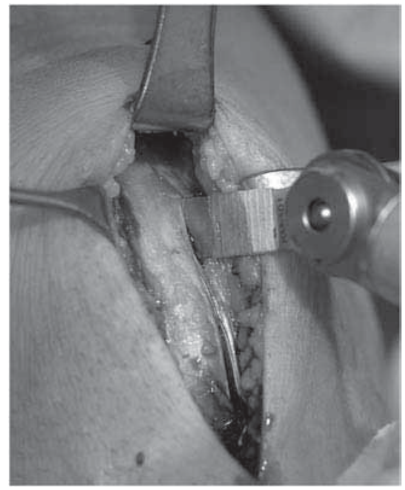

Figure 3 Sterile tape placed 8 mm from the end of the saw during patellar tendon harvest functions as a depth gauge to prevent overpenetration (a risk factor for patellar fracture).

Figure 4 AP radiograph showing stabilization of an oblique patellar fracture with screws, allowing early knee motion.

oriented longitudinally. They are caused by an imprecise bone cut, a dull saw blade, extension of the bone plug harvest proximal to the midpatella, or overly aggressive levering of the patellar bone plug out of the donor bone. These fractures can be avoided by precise, appropriately sized bone cuts and by rounding off the proximal corners of the bone cuts to decrease the stress-riser effect. Patellar fractures that occur during the early postoperative period usually are stellate in configuration (Figure 1). They arise from direct trauma to the knee or forced hyperflexion before complete healing of the donor site. Fractures that occur several months after surgery typically are transverse (Figure 2). Traverse fractures are caused by an eccentric quadriceps contraction of the flexed knee against resistance and are the most common pattern in unoperated patellae. Risk factors for postoperative patellar fracture include a hypoplastic patella, squared bone cuts, and a large bone plug harvested either proximal to the patellar equator or more deeply than one third of the patellar thickness. Using a precalibrated saw or placing sterile tape on the saw blade to indicate a depth of 8 mm can prevent cutting the bone too deeply (Figure 3). Late fractures can be prevented by bone grafting of the patellar defect. The patient should be instructed to avoid strenuous activities or direct patellar trauma before complete healing of the donor defect.

The standard principles of patellar fracture fixation should be followed. Longitudinal or oblique fractures occurring intraoperatively should be fixed with transverse, partially threaded 4.5-mm cortical screws to allow early knee motion (Figure 4). To avoid distraction of the articular surface, it is important to avoid placing these screws in a lag mode across the fracture. Nondisplaced postoperative fractures (less than 2 mm of fracture separation) can be treated nonsurgically if the extensor mechanisms are intact. Activity modification and protective bracing are recommended. Displaced transverse fractures that result in a loss of active knee extension can be repaired effectively with a tension band construct, using either cortical lag screws or Kirschner wires. Placing a tension band wire through a cannulated screw is likely to negate the tension band effect. The outcome of ACL reconstruction is not adversely affected by an intraoperative or early postoperative patellar fracture, provided that rigid fixation is achieved and early knee motion is established.[1]

Tibial Bone Plug Fracture

Fracture of the tibial bone plug usually occurs in patients who are nearing skeletal maturity. The bone typically splits in the coronal plane through the tibial tubercle apophysis if the saw cut is not deep enough and the superficial cortical bone is aggressively levered out. This complication is avoided by placing heavy, cerclage-type sutures through and around the bone plug to allow interference fixation (Figure 5). If the bone plug is insufficient for interference screw fixation, supplemental or alternative methods, such as a screw-and-post construct, should be considered.

The tibial bone plug also may fracture during harvest if it is attached or adjacent to an intratendinous ossicle, as occasionally occurs with Osgood-Schlatter disease. A shortened graft results if the ossicle is mistaken for the tibial tubercle during harvesting of the tibial plug. The ossicle can be left in place if it will fit into the tibial tunnel, or it can be excised from the tendinous portion and the tendon tubularized with a suture to facilitate tunnel passage. As long as a sturdy graft is fashioned, the presence of an Osgood-Schlatter ossicle portends neither a weakened graft nor increased risk of a poor clinical outcome after ACL reconstruction.[4]

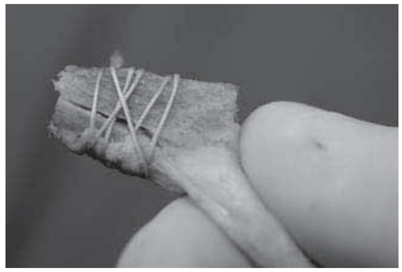

Figure 5 Repair of a coronal-plane fracture of a tibial bone plug using a circumferential suture to allow interference fixation.

Fat Pad Laceration

The fat pad can be lacerated because of overly aggressive excision during patellar tendon harvest or excessive arthroscopic débridement. Unrecognized excision of the fat pad during graft harvest can create a hole at the junction of the inferior pole of the patella and the fat pad, leading to fluid extravasation during the arthroscopic portion of the procedure. Laceration or excision of the fat pad is easily remedied with tendon approximation and temporary placement of bone wax in the patellar defect to form a watertight seal for the extensor mechanism (Figure 6). Aggressive fat pad débridement most commonly occurs during endoscopic ACL reconstruction, when visualization of the femoral screw placement is critical, and it can lead to fibrosis of the residual fat pad and patella baja, which has the potential to impair knee flexion postoperatively.

Figure 6 Bone wax placed in the patellar defect to prevent fluid extravasation through a rent in the retropatellar fat pad, which was caused by overly aggressive débridement.

Bone Plug Undersizing

Undersizing of the bone plug is best avoided by drilling the femoral and tibial tunnels to the correct size after the graft is harvested; the femoral tunnel can be intentionally undersized to fit a smaller plug. Alternatively, a coring reamer can be used to create the bone tunnels, with the resulting cylindrical bone plug sewn to an undersized plug to improve interference fixation. An undersized femoral bone plug can be secured with stacked interference screws, a cross-pin device, or a suspensory fixation device. An undersized tibial bone plug can be secured with stacked screws or a supplemental screw and post.

Complications of Hamstring Harvest

Premature Tendon Amputation

A premature transection of the semitendinosus or gracilis tendon can ultimately prevent the free passage of the tendon stripper over the tendon. Unrecognized adhesions between the tendon and the gastrocnemius or semimembranosus tendon are the most common cause of premature transection. An unrecognized accessory semitendinosus insertion also can lead to this complication if the accessory insertion slip is inadvertently stripped. These factors are compounded when an

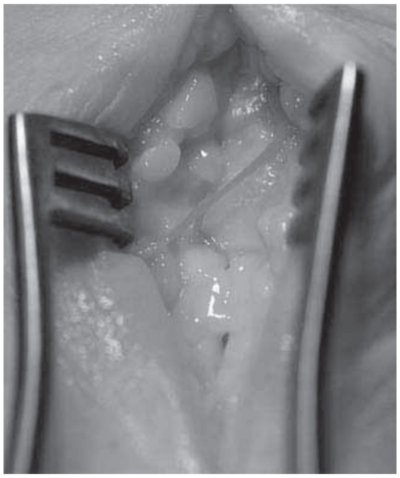

Figure 7 The infrapatellar branch of the saphenous nerve is at risk for injury during BPTB or hamstring graft harvesting.

overly rigid tendon stripper reduces the ability to sense a tethered tendon. A prematurely transected gracilis tendon can be used if the remaining tendon is at least 10 cm long; this single strand is sewed to the doubled semitendinosus tendon. The semitendinosus is the more robust of the two tendons, and its premature amputation often necessitates the use of an alternative graft.

Saphenous Nerve Injury

Nerve injury often is associated with hamstring graft harvest. Injury to the infrapatellar branch of the saphenous nerve during hamstring harvesting has been widely reported, with rates ranging from 22% to 74%[3,5-10] (Figure 7). Sanders and associates[11] reported a 74% incidence of sensory disturbance in the saphenous nerve distribution after autogenous hamstring ACL reconstruction. Unlike earlier researchers, they found that the rate of isolated injury was higher in the sartorial branch (23%) than in the infrapatellar branch (19%). Most frequently, however, symptoms occurred in both distributions (32%).

Nerve injury complications most often are associated with a vertical incision.[12,13] Typically the main nerve trunk is transected, resulting in a neurotmesis with permanent loss of sensation to the medial aspect of the leg. Nerve injury also can occur from direct contusion during the blunt release of adhesions or, more commonly, during tendon stripping where the nerve crosses the gracilis tendon. Nerve contusion typically causes a transient loss of sensation in the skin lateral to the tibial tubercle.

Blunt surgical dissection, careful identification of the nerve, and meticulous surgical closure all decrease the risk of injury to the infrapatellar branch of the saphenous nerve. The figure-of-4 position can be used during hamstring tendon harvest to improve surgical exposure and decrease tension on the medial soft tissues and saphenous nerve.[14] Several authors have recommended using an alternative surgical incision to prevent this complication.[11,15-18] Cadaver dissection has shown that the main branch of the saphenous nerve is intimately associated with the gracilis tendon in a 4.6-cm region between layers I and II of the medial knee. This close anatomic association is found where both structures run deep to the sartorial fascia between 11.8 cm and 7.2 cm proximal to the gracilis insertion.[7] A two-incision approach, as promoted by Kodkani and associates,[19] may lessen the risk of saphenous nerve injury.

Symptomatic neuromas are exceedingly rare and generally are not a significant complication for the patient. Saphenous nerve injury may be important from a medicolegal standpoint, however, and patients should be advised before surgery of the possibility of postoperative sensory disturbance.

Principles of Allograft Use

The patellar, Achilles, and anterior tibial tendons are the most commonly used allografts for ACL reconstruction. The surgeon must confirm that the selected type of graft is available before it is needed. The surgeon also must determine whether a specific available graft is appropriate for implantation in the intended recipient, based on the following criteria: donor age younger than 35 years, negative serologic tests for infectious diseases, and graft size. Inappropriate graft length can lead to graft-tunnel mismatch, especially in a smaller patient, but it may be difficult to avoid if the supply of grafts is limited.

The quality of any allograft tendon cannot be definitively determined until the graft is thawed and inspected. Aerobic and anaerobic cultures can be obtained intraoperatively. Although these cultures were positive in 9.7% to 13.3% of grafts, an infection did not develop in any of the affected patients.[20,21] Culturing the graft can apprise the surgeon of the rare, but documented, possibility of a potentially fatal infection with coliform bacteria.[22] The agents and processes that have been used to reduce the risk of bacterial, fungal, and viral infections include gamma irradiation, the Clearant process (Clearant, Los Angeles, CA), and the BioCleanse method (Regeneration Technologies, Alachua, FL). Few data are available to determine the biomechanical effects of these agents on the graft or the long-term clinical outcomes of their use. In lieu of solely relying on a secondary method of graft sterilization, several steps are recommended to reduce the risk of infection. The surgeon should know the tissue bank from which the graft was obtained and whether it is accredited by the American Association of Tissue Banks. The bank's donor selection criteria and tissue harvest practices should be investigated. The American Association of Tissue Banks specifies that harvest should occur within 15 hours after death, or within 24 hours if the body was refrigerated. Highly pathogenic contaminants are more commonly present after a traumatic death or a prolonged resuscitation attempt.

A whole patellar or Achilles tendon allograft can be split in half before the final graft is fashioned. The purpose is to provide a backup graft in case the first graft is dropped or cannot be used for technical reasons. A hemipatellar tendon allograft should be considered because it is less expensive than a whole patellar allograft.

Graft-Tunnel Mismatch

A mismatch between total tunnel length and the graft to be implanted can lead to inadequate fixation at the tibial tunnel. Graft-tunnel mismatch most frequently occurs in single-incision endoscopic ACL reconstructions, for which the total tunnel length is fixed.[23] It also can occur in patients with patella alta, resulting in external graft protrusion, or patella baja, resulting in internal graft protrusion. The use of a patellar tendon allograft can result in significant external protrusion of the tibial end of the graft, especially if the recipient is significantly shorter than the donor. The mismatch may not be predictable or preventable, and the surgeon should be ready to use an alternative means of tibial fixation whenever an allograft is considered.

Several formulae have been proposed for calculating the appropriate tunnel length and angle settings for the tibial drill guide[23-26] (Table 1). None of these methods is foolproof, but they are reasonable guidelines to help prevent a graft-tunnel mismatch.

Table 1
Methods for Calculating Tibial Tunnel Length and Angle*

Tibial Tunnel Length: The Graft – 50 Method

$G_{raft\ (actual)} = G_{raft\ (required)}$

$G_{raft\ (actual)} = T_{ibial\ tunnel} + X_{(assumed\ ACL\ length)} + 25\ mm$

$X = 25\ mm$

$G_{raft\ (actual)} = T_{ibial\ tunnel} + 50\ mm$

$T_{ibial\ tunnel} = G_{raft\ (actual)} - 50\ mm$

Tibial Tunnel Length: The N + 2 Method

$G_{raft\ (actual)} = G_{raft\ (required)}$

$G_{raft\ (actual)} = T_{ibial\ tunnel} + X_{(assumed\ ACL\ length)} + 25\ mm$

$X = 23\ mm$

$G_{raft\ (actual)} = T_{ibial\ tunnel} + 48\ mm$

$50\ mm + N_{(patellar\ tendon\ length)} = T_{ibial\ tunnel} + 48\ mm$

$T_{ibial\ tunnel} = N + 2\ mm$

Tibial Tunnel Angle: The N + 7 Method

$A_{ngle\ of\ drill} = N_{(patellar\ tendon\ length)} + 7°$

*Assuming femoral and tibial bone plugs of 25 mm each

Drilling the tibial tunnel at a relatively shallow angle (50° or less) can result in external graft protrusion and compromise interference screw fixation. A relatively high tibial tunnel angle (65° or greater) can lead to internal graft protrusion with the proximal end of the tibial bone plug proximal to the tunnel aperture, in a partially intra-articular position. This protrusion also can result in compromised interference fixation and bone plug impingement on the intercondylar notch when the knee is in extension. Drilling at a high tibial tunnel angle can cause difficulty in drilling an endoscopic femoral tunnel and necessitate placing a graft far up the tibial tunnel, requiring deep placement of the interference screw. If a revision reconstruction is necessary, retrieval of a deeply placed screw may be difficult.

A BPTB graft that is too long and protrudes from the tibial tunnel can be shortened by several methods: folding the tibial plug backward before interference fixation, twisting the graft, excising the tibial bone plug altogether and using soft-tissue fixation distally, or creating a trough in the tibial metaphysis and fixing the distal plug with a staple. If the graft is recognized as too long before it is inserted, as is possible with a BPTB allograft, it can be shortened relative to total tunnel length with a two-incision technique or an increase in the angle of the tibial drill guide to more than 60°.

At least 35 mm of patellar tendon length typically is required to ensure adequate graft length and fixation. Graft length can be predicted by determining the Insall-Salvati ratio (patellar tendon length divided by patellar length) using a preoperative lateral radiograph. If the graft is too short relative to the tibial tunnel, excising the tibial bone plug from the tendinous portion of the graft and using soft-tissue fixation distally can be considered. A hamstring graft also can be considered because it does not depend on a precise tunnel-graft length relationship.

The Dropped Graft

The surgeon is ultimately responsible when an ACL graft is dropped on the operating room floor. Izquierdo and associates[27] found that 25% of responding sports medicine specialists admitted to at least one dropped graft; 10% had two dropped grafts, and one surgeon admitted to having four dropped grafts. To prevent this embarrassing and sometimes costly complication, the arthroscopic fluid collection bag can be placed under the harvest site during graft removal, the graft can be placed into a basin or bag immediately after removal and before it is transferred to the back table, a BPTB graft can be secured with a towel clip during drilling of suture holes while the graft is in situ or during drilling on the back table, and the basin containing the graft can be placed in an instrument basket far from the table containing frequently used instruments.

Several studies examined the risk of graft contamination from the use of a dropped graft and the efficacy of commonly used sterilization methods. Goebel and associates[28] found 100% graft sterility after a 30-minute soak in 4% chlorhexidine gluconate followed by a 30-minute soak in a triple-antibiotic solution. Cooper and associates[29] found a 30% rate of patellar tendon graft contamination despite 15 minutes of soaking in bacitracin and polymyxin B. These grafts had spent 3 minutes on the floor. Forty percent of the untreated control grafts were found to remain sterile. Molina and associates[30] dropped 50 ACLs of patients undergoing total knee arthroplasty on the floor for 15 seconds. Although 96% of the floor-swab specimens were culture positive, only 58% of the ACLs were positive. Chlorhexidine provided the best sterilization; only 2% of the specimens soaked in chlorhexidine were positive for bacterial growth. These research models, although generally useful, have limited clinical applicability because of variables such as the duration of floor contact, the questionable bacterial colonization of operating room floors, and the efficacy of different antibiotic soaking regimens for different graft types. In addition, the effect of antibiotic regimens on graft strength is unknown.

The current medicolegal climate, the availability of alternative grafts, and the limited available research on the risk of bacterial contamination and graft sterilization all suggest that using an alternative graft should be strongly considered if the graft is dropped. A deep infection complicating an ACL reconstruction can have devastating consequences. The ipsilateral semitendinosus-gracilis tendon, the contralateral BPTB, or the quadriceps tendon (if the primary graft was the hamstring) can be used as an alternative autograft, or an allograft tendon can be used. The possibility that an allograft will be required should be discussed with the patient preoperatively. Alternatively, permission to use an allograft should be obtained intraoperatively from the patient's family, if they are available. Before the decision is made, the availability of the hardware necessary for fixation of the alternative graft must be determined.

Complications Associated With Tunnel Placement

Proper placement of the tibial and femoral tunnels is essential for a good outcome and for the long-term survival of an ACL graft. As understanding of the optimal ACL tunnel placement has evolved, the emphasis has shifted from controlling only AP laxity to controlling both AP laxity and rotation. The propensity for vertical graft placement to occur with standard transtibial tunnel drilling has been recognized. New techniques for ACL reconstruction, including double-bundle reconstruction, have the potential for use with specific complications.

The Tibial Tunnel

The ideal placement of the tibial tunnel in a standard, single-bundle reconstruction is the center of the ACL footprint, in line with the anterior horn of the lateral meniscus and between the tibial spines. A tunnel placed too anteriorly risks graft impingement in extension, which can be avoided by appropriately recognizing the intra-articular landmarks and performing an adequate notchplasty. An impingement rod can be used before graft passage to reveal impingement and allow adequate intercondylar bone resection before passage of the graft. Most commercially available reamers designed for the femoral tunnel have a head size larger than the shaft. These so-called acorn reamers should not be used for the tibial tunnel because when the reamer enters the joint from the tibial side, the guidewire and reamer may shift anteriorly to the path of least resistance. To avoid this complication, a reamer or drill with a larger shaft can be used, or the reamer can be passed several times over the intra-articular entrance of the tunnel with posteriorly directed force. Impingement can occur on the wall of the lateral femoral condyle if the tibial tunnel entrance is too far lateral. If lateral impingement is noted, a wallplasty should be done. Tunnel placement too far laterally also can disrupt the anterior horn of the lateral meniscus.

A tibial tunnel placed too posteriorly results in a vertical graft, which can lead to a lack of rotational stability (even if there is satisfactory stability in the sagittal plane), increased graft force in extension, and the likelihood of eventual graft laxity and failure. Drilling the tunnel too far posterior can injure the posterior cruciate ligament, or it can be impinged by the ACL graft. Posterior tunnel placement is especially likely if there is anterior subluxation of the tibia.[31] Because the graft tends to sit posterior and lateral within the tunnel, erring on the anteromedial side may accommodate the eccentric position within the tunnel.[32] Computer navigation systems can be helpful in accurately placing the tibial tunnel, and their use has led to slightly more anterior placement of the tibial tunnel than is customary in single-incision endoscopic procedures.[33]

Placing the tibial guide relatively medially on the tibia allows a more oblique, less vertical graft placement, and it facilitates appropriate femoral tunnel placement if a single-incision transtibial technique is to be used for drilling the femoral tunnel. It is important to be medial on the tibia when a BPTB autograft is being used, to avoid breaking into the tibial bone plug harvest site. The ideal location is controversial. If a more medial starting point is desired, the medial collateral ligament can be split in line with its fibers. A starting point too far medial makes the transtibial technique difficult because the femoral guide will not fit into the over-the-top location; the result is a femoral tunnel too far down the lateral wall of the intercondylar notch.

Several options remain if improper placement of the tibial tunnel is not noticed until the tunnel has been reamed. If the tibial tunnel is significantly misplaced and adequate space is available, a new tunnel can be made in the correct location. If space is not available for a completely new tunnel, the existing tunnel can be enlarged by redrilling in a more appropriate position. After the tunnel is enlarged, interference screw fixation with a single screw usually is no longer feasible; an alternative means of fixation, such as a screw and post, a ligament button, or a staple, must be used. An interference screw can be positioned to compensate for a slight misplacement of the tibial tunnel. For example, a screw placed in a posterolateral location may move the graft slightly anterior and medial; the solution is to use bone graft for the tunnel, allow time for it to heal, and perform the ACL reconstruction as a staged procedure.

The Femoral Tunnel

A malpositioned femoral tunnel is the most common complication of ACL reconstruction and the most common cause of graft failure. The advent of double-bundle reconstruction raises the possibility of additional tunnel-related complications.[34] Beliefs about the ideal placement of the femoral tunnel for ACL reconstruction have evolved over time, as they have for the tibial tunnel. The femoral tunnel should be placed posteriorly, 1 to 2 mm from the posterior wall. Anterior graft placement has been correlated with poorer clinical outcome scores.[35] A tunnel position lower on the lateral wall of the intercondylar notch (at the 10-o'clock position rather than the 11-o'clock position) may provide more rotational stability and better knee kinematics.[36]

Placing the femoral tunnel too far anteriorly increases both the graft forces in flexion and the risk of early graft failure.[37] This common mistake can be avoided by identifying the anatomic landmarks and posterior wall. It may be necessary to perform a notchplasty adequate to allow viewing of the over-the-top position on the femur. However, an overly aggressive notchplasty can alter the knee kinematics and, ultimately, graft functioning.[38] An accessory central anteromedial portal, which is used for viewing in a double-bundle procedure, allows the wall of the lateral intercondylar notch to be seen without a notchplasty.[39] The lateral intercondylar ridge (the so-called resident's ridge), located approximately 1 cm anterior to the back wall and just anterior to the femoral ACL footprint, is a useful landmark indicating the anterior border of the femoral ACL attachment; the assumption that it actually is the back of the notch is incorrect. Fu and associates[40] described the lateral bifurcate ridge, which is a second femoral ridge separating the anteromedial and posterolateral bundles of the ACL attachment. To avoid placement of the femoral tunnel too far anteriorly, the posterior wall must be located using a curved curet or probe. Commercially available femoral tunnel offset guides allow specific placement of the guidewire with reference to the posterior edge of the wall. However, it is possible to hinge the guide on the resident's ridge rather than the posterior wall and place the femoral tunnel too anteriorly. Commercially available guides should be inspected to ensure they are not bent because a bend can cause the guidewire to be placed too far anteriorly.[41] If there is any uncertainty, fluoroscopy can be used to ensure correct

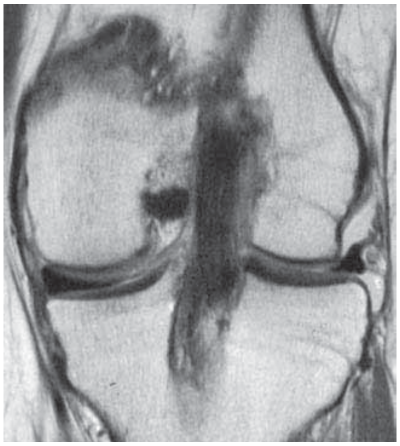

Figure 8 A coronal-plane MRI study of a vertical graft with a high femoral tunnel.

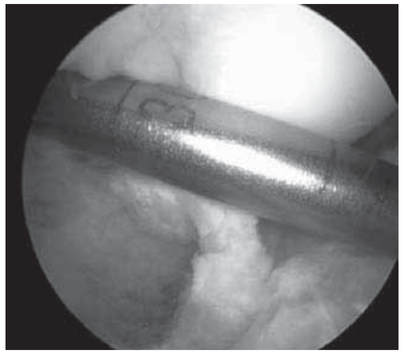

Figure 9 Arthroscopic view of the medial portal used for femoral tunnel drilling, which can be done if the transtibial technique does not allow appropriate placement.

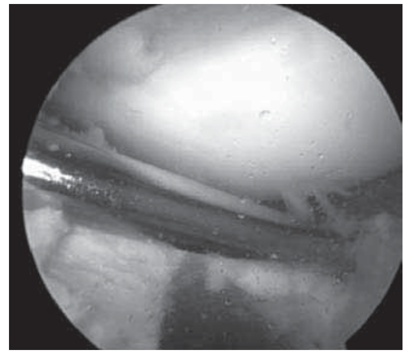

Figure 10 Arthroscopic view of a femoral guidewire placed through the medial portal in close proximity to the medial femoral condyle.

guidewire placement before tunnel placement.

Several options are available if too far anterior placement of the femoral tunnel is not recognized until after drilling. If there is space, the simplest solution is to drill an additional tunnel. If this is not possible, the tunnel can be redrilled convergent with the original tunnel to create a larger tunnel, which probably will require fixation in addition to or instead of an interference screw. A two-incision technique may allow a sufficient change in the trajectory of the tunnel to allow a second tunnel to be drilled. Alternatively, the tunnel can be filled with bone graft. The tunnel can be redrilled, and the ACL reconstruction can be completed as a staged procedure 3 to 6 months later.

A femoral tunnel placed too far posteriorly causes posterior wall blowout and prevents the use of interference screw fixation. To avoid this complication, proper verification of the location of the posterior wall is essential. A properly sized femoral offset guide 1 to 2 mm larger than the planned tunnel radius can be useful to ensure that the back wall is adequate. Placing the knee in hyperflexion (more than 90° to 100°) while the guidewire is placed and the tunnel is reamed also can help to avoid posterior wall blowout. Hand reaming may be helpful if the patient has poor bone quality. Reaming to a depth of 3 to 5 mm is advisable, with inspection of the planned tunnel location to ensure the posterior wall has not been violated.

If the posterior wall has been violated, the graft can be fixed in the blown-out tunnel using suspensory fixation on the lateral femur rather than interference fixation. Conversion to a two-incision approach can be done, with a lateral screw and post, a washer, or a staple used for fixation. If space allows, a second tunnel can be drilled; a two-incision technique may be useful to allow a change in the trajectory of the tunnel.

A femoral tunnel placed too high on the lateral wall results in a vertical graft and a lack of rotational stability (Figure 8). The appropriate position on the lateral wall is now believed to be no higher than the 10-o'clock position on the right knee or the 2-o'clock position on the left knee. To place the tunnel in the correct position, it is important to maintain proper orientation with the tibial plateau at neutral and parallel to the floor. A tibial tunnel that is placed more medially allows better femoral tunnel placement with transtibial drilling.

If the proper site on the lateral wall cannot be reached through the tibial tunnel, the medial portal can be used (Figure 9). However, it is important to recognize that drilling through the medial portal can place the medial femoral condyle at risk (Figure 10). Damage to the medial femoral condyle often can be avoided by placing the medial portal more centrally. Hyperflexion of the knee to 120° is necessary to avoid posterior wall violation when drilling through the medial portal. Observing the exit point of the guidewire anterior to the structures of the posterolateral corner also is useful in avoiding posterior wall violation. Using a low medial portal also helps avoid this complication. The femoral tunnel can be short (less than 2 cm) if the drilling is done through a far medial tunnel.[42] Viewing can be difficult, especially when the knee is kept in hyperflexion. Using a flexible reamer may improve viewing during drilling through the medial portal by avoiding the need for hyperflexion.

Drilling the guidewire from the outside in also can be used for femoral tunnel placement. In the traditional two-incision technique, an incision is made on the lateral thigh, the iliotibial band is split, and the periosteum is elevated from the distal lateral femur. The guide is placed at the appropriate position on the lateral wall and brought down to the lateral thigh. The guidewire can then be drilled into the knee and overreamed. The graft is fixed with an interference screw, a screw post, or a washer on the lateral femur.

The options for a too vertically placed femoral tunnel are similar to those for a too anteriorly placed tunnel. A second tunnel can be created in a more appropriate position, if space is available. If space is inadequate for a second tunnel, the existing tunnel can be redrilled to create a larger tunnel. The graft can then be fixed with lateral (suspensory) fixation rather than interference fixation. Alternatively, the tunnel can be filled with bone graft and allowed to heal before the ACL reconstruction is done as a staged procedure.

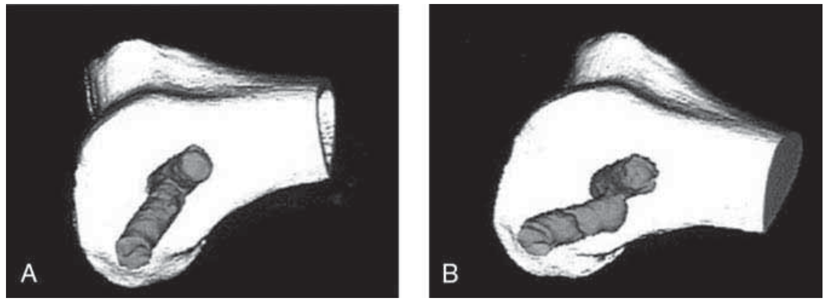

Figure 11 Schematic diagrams of a 20º **(A)** and 40º **(B)** coronal angulation of the lateral tunnel for posterolateral corner reconstruction. Such an angulation can cause convergence with the ACL tunnel. (Reproduced with permission from Shuler MS, Jasper LE, Rauh PB, Mulligan ME, Moorman CT III: Tunnel convergence in combined anterior cruciate ligament and posterolateral corner reconstruction. *Arthroscopy* 2006;22:193-198.)

Tunnel Convergence

Double-bundle ACL reconstruction has been gaining in popularity. A recent biomechanical study found that knee kinematics more closely resemble those of the native ACL after double-bundle reconstruction than after standard single-bundle reconstruction.[34] Because the double-bundle technique requires two graft bundles and tunnels instead of one, this procedure is technically more demanding than a standard single-bundle reconstruction.

Tunnel convergence can occur when two tunnels are drilled into each bone. This complication can be avoided by paying careful attention to guidewire placement before drilling. Drilling from the outside in also can be helpful. The tunnels should not be larger than 9 mm in diameter. There also is a risk of subchondral bone injury or penetration during tunnel drilling, especially for the posterolateral bundle. Zantop and associates[34] reported that in a cadaver study, the drilling of the posterolateral femoral tunnel from a high medial portal with knee flexion of 70° damaged the lateral femoral subchondral bone in every specimen. Drilling from a low medial portal with knee flexion of only 70° created a tunnel only 2 mm (±0.5 mm) from the chondral surface, with subchondral bone damage in 40% of specimens. To avoid this complication, a low medial portal and a high knee flexion angle are required. Using a low medial portal with knee flexion of 110° resulted in a tunnel 10.8 mm (±0.4 mm) from the chondral surface, with no subchondral bone injury.

Tunnel convergence and eventual ACL graft failure can occur during combined ACL and posterolateral corner reconstruction. Shuler and associates[43] found that this complication can be avoided by limiting ACL femoral tunnel depth to 25 mm and avoiding proximal or sagittal plane femoral tunnel angulation (especially of more than 20°) for posterolateral corner reconstruction. Anterior angulation of the femoral tunnel for posterolateral corner reconstruction was found to increase the distance between the ACL and the lateral ligament tunnels (Figure 11).

Complications Associated With Graft Fixation

The quality of graft fixation is the most important factor determining graft stability during the early postoperative period. The strength and stiffness of ACL graft fixation depends on the patient's bone quality and the type of implant used. Interference screws provide compressive fixation within a bone tunnel and have been considered the gold standard for bone plug fixation.[44,45] Bioabsorbable interference screws also have been used successfully; clinical and biomechanical study results have been equivalent to those of metal screws.[46,47] Interference screws can be used for the fixation of soft-tissue grafts, but their inferior biomechanical properties have led to the introduction of alternative forms of graft fixation that vary widely in the mechanism of fixation (suspension, expansion), surgical technique, instrumentation, and inherent complications. The surgeon must be familiar with all characteristics of the device selected for graft fixation.

Interference Screw Divergence

Interference screw divergence is a well-known complication that can weaken graft fixation. This complication became increasingly frequent in the femoral tunnel with the transition to endoscopic, single-incision, transtibial ACL reconstruction.[48] A biomechanical study found significantly higher holding strength when screw-bone plug divergence angles of less than 15° were used.[45] Although the clinical significance of these study findings is unknown, the goal of interference screw fixation should be to produce a more parallel path between the graft and screw.[48] Using a cannulated screw after placing a guidewire parallel to the graft can help to properly orient the interference screw. Knee flexion of 30° to 40° beyond the angle used for femoral tunnel reaming also can help ensure parallel placement.[48] Bioabsorbable screws have a fixation strength comparable to that of metal interference screws, but obtaining initial screw purchase inside the tunnel can be more difficult with bioabsorbable screws. An initial starting notch at the tunnel edge can improve the passage of the screw along the correct path.

Graft Laceration

Graft laceration is generally associated with interference screw fixation in the femoral tunnel. Adequate visualization is essential to ensure that the interference screw is placed parallel to the bone plug, with compression of the bone and not the soft-tissue portion of a BPTB graft. Placing the interference screw against the cancellous surface of the bone plug keeps the screw farther away from the tendinous portion of the graft and helps prevent the screw threads from damaging the soft tissue. A graft-protector sheath can be placed between the screw and the tendon while the interference screw is inserted into the femoral tunnel.[49]

Graft laceration also can be caused by the shaver or burr used for notchplasty. If a notchplasty is necessary, ideally it should be done before graft passage. Use of a shaver or burr between the ACL graft and an impinging lateral wall or roof puts the graft at unnecessary risk. It is safer to use an osteotome to remove bone from the lateral wall for any additional notchplasty required after graft passage.

Bone Quality

Interference screw fixation of ACL grafts has less strength and stiffness in osteopenic cancellous bone, which is encountered more commonly on the tibial than the femoral side (the tibial metaphysis has a lower bone mineral density). Tunnel dilators can be used to compact bone in the tibial tunnel, rather than remove it, to increase the density of the bone at the tunnel wall and improve the quality of interference screw fixation. Another method of addressing poor bone quality is to use a fixation method that relies on cortical fixation. Some suspensory devices rely exclusively on suspension from the cortical bone at the tunnel edge, and other such devices provide suspension over a device anchored within the cortical and cancellous bone. Corticocancellous suspensory devices were found to be the strongest and stiffest devices for soft-tissue graft fixation.[50] Secondary fixation can be used with poor interference screw fixation. Sutures can be tied around a post or tied over a button, or a graft with extra length can be stapled to the cortex outside the tunnel or fixed with a spiked washer and screw.

Suture Laceration or Bone Plug Fracture

Interference screw threads can lacerate the sutures placed for graft passage. Rupture of the tension sutures almost always occurs on the tibial side of a BPTB graft and is caused by proximal advancement of the cannulated screw over the sutures. This complication can occur on the femoral side with the two-incision reconstruction method. Suture rupture rarely occurs with hamstring grafts secured with interference screws. Unrecognized graft advancement up the tibial tunnel, or down the femoral tunnel with the two-incision method, leads to graft laxity, which can be prevented by using two No. 2 or No. 5 braided nonabsorbable sutures plus a 24-gauge wire through the at-risk plug to increase resistance to damage from the cannulated screw (Figure 12). Sutures should be placed so they do not exit directly from the bone surface to be fixed by the interference screw. In addition, a suture should be placed 5 mm from the end of the femoral bone plug to ensure that at least one suture is intact during final seating of the interference screw.

If the sutures in the femoral bone plug are cut before the plug is adequately fixed, the screw should be backed out, and the graft removed from the knee. Sutures should be placed back through the graft, and graft passage and fixation should be repeated. A larger interference screw may be required for adequate fixation. Other forms of fixation, including sutures tied over a button or around a post, can be considered. If tibial bone plug sutures are lacerated after fixation on the femoral side, the graft can be retrieved by opening the fat pad, retrieving the bone plug, directly resuturing the bone, and passing the sutures back down the tibial tunnel. Alternatively, a drill-in suture anchor can be placed directly into the distal end of the advanced plug while it is still in the tunnel, with tension placed on the attached sutures to retrieve the graft so that interference fixation is again possible.

Bone plug fracture can occur during graft harvest or through a hole drilled in the plug for the passing suture. A fractured bone plug may not provide an adequate surface for interference screw fixation. This complication can be treated by placing a running, locking stitch in the end of the graft with the fractured bone plug and fixing the graft by tying the sutures over a post or through a button.

Improperly Seated Button

Button devices are popular for the fixation of soft-tissue grafts on the femoral side. Button fixation depends on proper deployment, with the button resting against cortical bone outside the femoral tunnel. Buttons have been reported to flip prematurely within the femoral tunnel or too far beyond the lateral femoral cortex, into the thigh musculature.[51-53] Soft-tissue interposition could lead to postoperative pain and limited function as well as compromised graft fixation. Pressure necrosis of the interposed soft tissue before graft healing also could lead to graft laxity. Overdrilling the femoral tunnel only 5 to 6 mm does not provide enough clearance for flipping the button. The button can partially flip within the tunnel, giving the false impression that it is seated on the lateral femoral cortex. The cancellous bone of the tunnel wall may provide an intraoperative sensation of adequate fixation, but the fixation may not withstand the forces placed on it during postoperative rehabilitation. Careful attention should be given to tunnel length when using button fixation to ensure that the device is properly deployed and that 20 to 30 mm of graft remains in the tunnel. Intraoperative fluoroscopy is used to confirm that the button rests on the lateral femoral cortex. If the device is deployed into the soft tissue, the graft and button-passing sutures can be alternately pulled to attempt to reposition the button. If the device remains in the soft tissue, a lateral incision can be used to approach the device and seat it properly on the cortex. If the device deploys within the femoral tunnel and cannot be repositioned, a bioabsorbable interference screw can be used as secondary fixation.

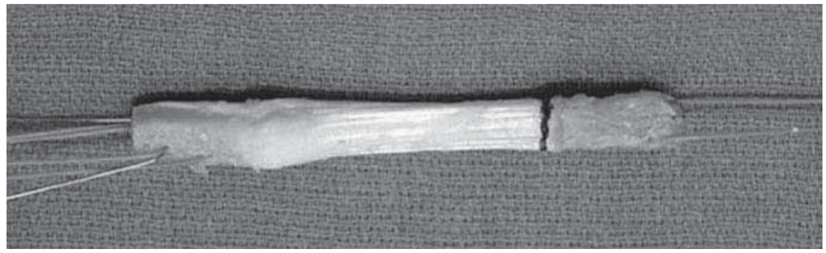

Figure 12 A prepared BPTB graft with nonabsorbable sutures in the bone plugs (two sutures in the tibial plug and one in the femoral plug) and a 24-gauge wire through the tibial plug.

Malpositioned Transfixation Device

Femoral transfixation devices allow corticocancellous suspensory fixation of hamstring grafts closer to the femoral tunnel aperture than traditional suspensory devices. These devices have biomechanical characteristics superior to those of most other forms of soft-tissue graft fixation. The targeting guides must be fully seated in the femoral tunnel to ensure that the graft is properly positioned in the tunnel and the device is not placed too distally. The targeting guide should be oriented directly lateral to medial in the coronal plane. Improper orientation can result in intra-articular protrusion of the tip of the crossing pin.[54] The guidewire should be held taut during insertion of the crossing pin. If the guidewire is bent or twisted, the cannulated crossing pin may not advance or may lacerate the graft as it crosses the femoral tunnel. Fixation depends on the crossing pin engaging the medial wall of the femoral tunnel, thus adequate pin length is critical.

Neurologic Injury

Motor deficits are quite uncommon after ACL reconstruction; most reports of nerve injury with persistent motor deficit after ACL reconstruction are isolated. Pressure on the lateral knee at the fibular head should be minimized intraoperatively to avoid compression of the peroneal nerve. In addition, tourniquet pressure and time should be minimized. The nonsurgical leg should be carefully positioned, and the bony prominences should be padded before surgical draping to prevent nerve compression. Vardi[55] reported a sciatic nerve injury during a hamstring harvest, which immediately after surgery caused a complete foot drop and loss of sensation distal to the knee. Nerve conduction velocity studies 2 and 4 weeks postoperatively revealed injury to the nerve proximal to its bifurcation into the common peroneal and tibial nerves. Although significant symptoms persisted 10 weeks postoperatively, the patient had an almost full recovery at 1-year follow-up.

Vascular Injury

Vascular complications of ACL reconstruction are rare, but they can be catastrophic. A literature review reported a 0.01% overall rate of arterial injury.[56] Aldridge and associates[57] reported an avulsion of the middle genicular branch off the popliteal artery, which probably occurred during débridement of the femoral remnant of the native ACL. Evans and associates[58] reported a pseudoaneurysm of the medial inferior genicular artery, which was related to periosteal elevation off the medial tibia during exposure for the tibial tunnel. Roth and Bray[59] reported occlusion of the proximal popliteal artery under a graft fixed on the femoral side with a staple. The delay in diagnosing each of these intraoperative injuries highlights the need for a careful intraoperative and postoperative vascular examination whenever there is concern about possible injury. Identifying vascular injury intraoperatively allows inflation of the tourniquet and a vascular surgery consultation. Early clinical assessment, angiography, and prompt surgical intervention are the primary means of preventing a catastrophic result.

Two patients with popliteal artery pseudoaneurysm and thrombosis related to the use of a bicortical screw for tibial fixation in ACL reconstruction have been described.[60,61] These patients required surgical intervention with vascular repair and venous bypass grafts. Post and King[62] evaluated the neurovascular structures at risk during bicortical proximal tibial drilling in ACL reconstruction. They created a 4.5-mm bicortical drill hole 1 cm distal to the tibial tunnel and found the nearest structure posteriorly to be the bifurcation of the popliteal vessels (11.4 mm away). It was concluded that bicortical fixation is relatively safe. The reports of vascular injury nonetheless suggest that care should be taken with this method of proximal tibial fixation. Knee flexion during drilling may relax the posterior neurovascular structures and increase the safe distance for transtibial drilling, but ACL fixation in knee flexion may capture the knee and lead to postoperative flexion contracture. Unicortical drilling eliminates the risk of this potentially devastating complication; other forms of graft fixation on the tibial side, including interference screws, staples, and buttons, also avoid the risks of transtibial drilling.

Compartment Syndrome

Compartment syndrome can occur during knee arthroscopy. The likelihood of significant fluid extravasation from the intra-articular space into the soft tissues is increased by capsular injury or the use of an infusion pump at a high-pressure setting. Tourniquet use can be a contributing factor. The combination of an acutely injured knee with persistent capsular injury, arthroscopic surgery, and the use of an infusion pump or tourniquet creates a potentially dangerous situation.[63-65] Intermittent assessment of compartment swelling is required during ACL reconstruction, with measurement of compartment pressures as needed. After an intraoperative diagnosis of elevated compartment pressure, close observation with serial examinations may be appropriate; however, persistent elevation of compartment pressures requires an urgent decompressive fasciotomy. Permanent neurologic injury may occur after 6 to 8 hours of warm ischemia.

Periarticular Fractures

Femoral and tibial periarticular fractures have been described after ACL reconstruction. These fractures are rare and typically result from the stress-riser effect associated with multiple passes of a Beath pin, thermal necrosis from drilling, bone tunnels filled with soft-tissue graft, and hardware (typically diaphyseal) used for graft fixation.

Fractures of the lateral femoral condyle that extend into the femoral tunnel have been reported after both BPTB and hamstring ACL reconstructions.[66,67] Supracondylar femoral fracture occurred after a reconstruction using a Gore-Tex (WL Gore, Flagstaff, AZ) ACL graft and through the tenodesis screw site after a BPTB reconstruction augmented with an iliotibial band tenodesis.[26,68] A fracture of the proximal tibia was reported to originate just distal to the tibial tunnel.[69]

The treatment of these fractures is determined by their location, stability, and timing as well as the extent to which they compromise graft fixation. Fractures involving the distal femur generally warrant surgical fixation. Fractures of the proximal tibia often can be treated with a cast, brace, or cast-brace device if the fracture is extra-articular, is acceptably aligned, and does not compromise distal graft fixation. Standard principles of fracture fixation should be followed if surgical stabilization is warranted. Prolonged knee immobilization should be discouraged during the early postoperative period because of its negative influence on the outcome of the ACL reconstruction.

Superficial Infection and Septic Arthritis

Superficial infection is uncommon after ACL reconstruction. It can range in severity from a superficial cellulitis resulting from a retained suture to a deep infection. Typically, the erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) level are normal or slightly elevated. The patient is not systemically ill but has a low-grade fever (< 100°F) and drainage from the incision, with redness and pain. Gram staining and cultures should be obtained for aerobic, anaerobic, and fungal etiologies. The knee joint should be aspirated to rule out a deep joint infection.

Septic arthritis after ACL reconstruction is rare but potentially devastating. Studies have reported rates ranging from 0.14% to 1.7%.[70-78] A recent systematic review of nine randomized, controlled studies of autograft reconstruction found an incidence of 0.8%; the outcomes of the affected patients were not analyzed separately.[79] The possibility of septic arthritis when autograft is used should be discussed preoperatively with all patients. Synthetic materials have a higher infection rate but are rarely used today.

The risk factors for septic arthritis after ACL reconstruction include a history of knee surgery and a concomitant procedure such as a meniscal repair.[74,78] Neither tourniquet use nor the choice of a one- or two-incision technique appears to influence the incidence of septic arthritis.[74] One study found an increased frequency of septic arthritis with the use of hamstring autografts and attributed this finding to the presence of an extra-articular infection with septic arthritis at the site of hamstring harvest and tibial tunnel fixation (in 8 of 11 patients).[72] To decrease the risk of septic arthritis, preoperative prophylaxis with antibiotics is recommended. Schurman and associates[80] reported that preoperative antibiotics protected rabbit joints from a low-dose bacterial challenge.

A patient with septic arthritis after ACL reconstruction typically has a sudden increase in pain, an elevated temperature (higher than 100°F), warmth, a painful range of motion, and knee effusion. Occasionally, there is drainage from the surgical wounds. If the cause is a relatively low virulence organism, such as a coagulase-negative staphylococcus, the clinical presentation may be indolent.[75] Septic arthritis should be suspected, and the patient should be evaluated whenever there is a change in the postoperative course, such as a significant decrease in motion during physical therapy or a sudden increase in pain. Most infections appear within 20 days after the primary reconstruction, although the time from the procedure to the onset of symptoms varies from a few days to months.

Joint aspiration and laboratory studies should be done immediately if septic arthritis is suspected. The synovial fluid often is turbid and yellow. The synovial fluid white blood cell (WBC) count typically is more than 50,000/mm³, although the range is wide.[81] The WBC count differential typically reveals more than 90% polymorphonuclear cells. Fluid cultures often reveal the offending organism, typically *Staphylococcus aureus* or *Staphylococcus epidermidis,* although other bacteria and fungi have been reported.[82,83] Bacterial sensitivities are useful for guiding the antibiotic regimen. The length of treatment has not been clearly defined, and consultation with an infectious disease specialist is recommended. The ESR and the CRP level have the highest negative predictive value for septic arthritis, although it is important to remember that these values may be elevated during the first week after surgery. The CRP level usually is the first value to return to normal; the ESR may remain elevated for several weeks. The ESR and the CRP level can be used to monitor the course of treatment. The absolute peripheral WBC count is notoriously unreliable for monitoring treatment, although a so-called left shift resulting in a preponderance of neutrophils is commonly observed.

When septic arthritis has been diagnosed, irrigation and débridement of the joint should be promptly carried out. Open arthrotomy can be used for débridement of septic arthritis, but arthroscopic débridement is widely accepted and has less risk of morbidity[77] (Figure 13). A partial or total synovectomy is done, using additional portals if necessary to débride the posterior compartments. All surgical wounds are opened and débrided to reduce the

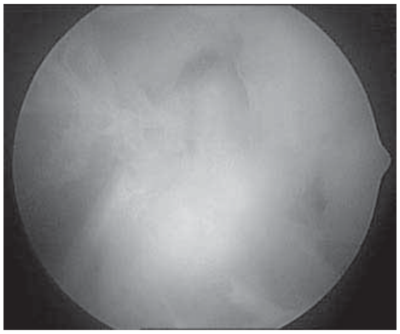

Figure 13 An initial arthroscopic view of the intercondylar notch of an ACL reconstruction with septic arthritis. Infected fibrinous tissue covers the articular cartilage and ACL graft.

possibility that an extra-articular infection could reinoculate the joint. The wound can be left open or loosely closed over packing or drains. Foreign materials, such as sutures and hardware, should be removed if they are no longer required to secure the fixation, especially if the graft has been incorporated into the tunnels.

Whether to preserve or remove the ACL graft is controversial. Authors who favor graft removal argue that until the graft is incorporated and revascularizes, it acts as a nonviable foreign body capable of harboring bacteria, sterile microbial fragments, and inflammatory mediators that may increase the risk of chondrolysis.[78,84] Graft removal has been successfully used to treat septic arthritis after ACL reconstruction,[84] but eventually a second reconstruction is required.

Although infection can be eradicated with a graft in place, some authors have reported inferior outcomes compared with those of uncomplicated ACL reconstruction.[74,75] The inferior results, however, may reflect articular cartilage damage resulting from the infection rather than graft retention. The graft was retained after irrigation and débridement in 11 of 12 patients with septic arthritis; 5 patients had a fair or poor result, mostly because of pain and stiffness.[72] Viola and associates[77] studied 13 patients who initially received only joint aspiration and antibiotics; irrigation and débridement were done only in patients who did not respond to this treatment. The outcomes were similar to those of uncomplicated ACL reconstruction, although long-term follow-up was not reported.

Our current protocol for treating suspected septic arthritis after ACL reconstruction is based on experience and the few available case studies. Joint aspiration and laboratory analysis (CRP level, ESR, and WBC count with differential) are done as soon as the patient exhibits signs and symptoms of infection, and empiric broad-spectrum antibiotics are administered until the culture results are known. Arthroscopic irrigation and débridement with synovectomy are done immediately after the diagnosis is confirmed. All wounds are opened and débrided, along with the removal of any foreign material.

Graft retention is considered if the diagnosis was not delayed, the joint appears benign, and the graft appears viable and competent. Graft and hardware removal is strongly considered if the infection appears to be well established or the diagnosis was delayed. We do not use antibiotic beads or cement spacers, although some authors have reported success with their use, especially for chronic infections.[85,86] The joint and associated wounds are drained postoperatively, and empiric intravenous antibiotics are continued until an organism is identified. If the response to treatment is poor after graft retention, repeat irrigation and débridement are warranted, with hardware and graft removal. The highest priority is to maintain the articular joint surface. Antibiotic treatment should be based on the patient's response and the recommendation of an infectious disease specialist. Four to 6 weeks of antibiotic therapy typically are necessary; the route and length of treatment depend on the identified organism. Postoperative rehabilitation should begin with range-of-motion maintenance but no weight bearing. A continuous passive motion device can be used but is not necessary. The development of arthrofibrosis requiring active management is not uncommon after the infection is resolved.

Burks and associates[84] reported excellent results in four patients with reimplantation of an ACL graft after graft removal. The reconstruction was successfully revised within 6 weeks of eradicating the infection, using an ipsilateral hamstring or BPTB graft. The preferred prophylactic antibiotic was the antibiotic that had been used to eradicate the infection.

Arthrofibrosis

Loss of motion after ACL reconstruction has been reported in as many as 59% of patients.[87-91] Loss of extension is most common, although loss of flexion and limited patellar mobility also occur. Even a 5° loss of extension can result in abnormal gait, patellofemoral pain, and quadriceps weakness.[92] When evaluating a patient with loss of motion after ACL reconstruction, it is imperative to rule out the presence of an intra-articular infection.

Shelbourne and associates[93] classified arthrofibrosis based on the severity and pattern of stiffness. Type I arthrofibrosis is defined as normal flexion and an extension loss of less than 10°, with normal patellar mobility; type II is normal flexion and more than 10° of extension loss, with or without loss of patellar mobility; type III is more than 25° of flexion loss and more than 10° of extension loss, with loss of patellar mobility; and type IV is more than 25° of flexion loss, more than 10° of extension loss, and infrapatellar contraction syndrome, which occurs when the fat pad becomes fibrotic with inferior translation of the patella and limited mobility.

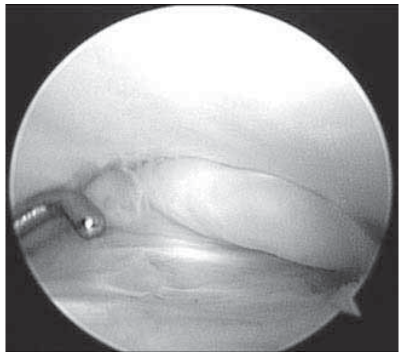

Figure 14 Arthroscopic view of a cyclops lesion secondary to fraying of the graft and a slightly anterior tibial tunnel placement.

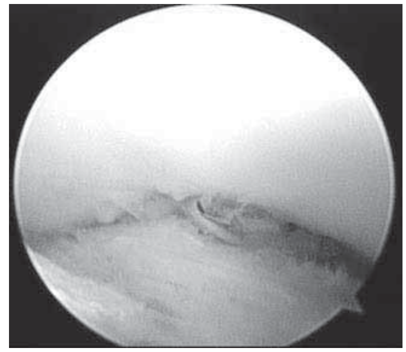

Figure 15 Arthroscopic view after débridement of a cyclops lesion. Full extension was achieved.

Etiology

The etiology of arthrofibrosis often is multifactorial. Rates as high as 35% were reported in older studies, and especially high rates were reported after reconstruction of acute injury without preoperative motion restoration or decreased knee effusion.[94] Postoperative rehabilitation with cast immobilization also was a factor. Robins and associates[95] reported a higher incidence of motion loss if there was an associated rupture of the medial collateral ligament from its proximal insertion on the medial femoral condyle. Distal rupture was not associated with loss of motion. As the understanding of ACL reconstruction and postoperative rehabilitation has evolved, rates of arthrofibrosis after ACL reconstruction have declined and now approach 4%.[96]

Primary Block to Extension

Terminal loss of extension most commonly is caused by the development of a nodule of scar tissue anterior to the graft, which impinges on the intercondylar notch as the knee comes into extension. Several theories have been proposed regarding the cause of these lesions. Delince and associates[97] attributed the presence of hypertrophic scar tissue to the presence of the native ACL stump and debris from tibial tunnel reaming. In some patients, only hypertrophic scar tissue surrounds the graft and the notch, and it may be secondary to repeated impingement of the graft against the roof of the notch from an inadequate notchplasty. This so-called cyclops lesion was first described by Jackson and Schaeffer[89] in 13 patients (Figure 14). Patients typically had loss of terminal extension, and bringing the knee into extension usually produced a palpable and audible clunk. In all patients, arthroscopic examination revealed an anterior nodule of scar tissue composed of granulation tissue. Five patients also had bone fragments and cartilage. Arthroscopic débridement of the tissue led to an average postoperative gain of 10° of extension (Figure 15). Other authors found similar lesions during second-look arthroscopy in patients with terminal loss of extension.[88,98]

A cyclops lesion should be treated with arthroscopic débridement. Although most patients regain extension, a permanent flexion contracture can result. Preventive measures include a thorough débridement of the ACL stump at its tibial attachment; if the stump is scarred to the infrapatellar fat pad, it should be properly freed and débrided. The joint should be thoroughly irrigated, and all bony debris should be carefully removed after the tibial and femoral tunnels are drilled. Proper tunnel placement can minimize impingement of the graft and prevent scar tissue formation. After placement, the graft should be checked in full extension to ensure it does not impinge on the roof of the intercondylar notch. If necessary, a proper notchplasty should be performed.

Graft Placement Errors

The traditional practice of nonanatomic, extra-articular graft placement has largely been abandoned because of high rates of early failure; current ACL reconstruction techniques rely on anatomic graft placement. Arthroscopic techniques and improved understanding of the ACL anatomy have greatly increased the success of ACL reconstruction. Improper tunnel placement is responsible for 70% to 80% of ACL reconstruction failures.[99-101]

An improper anterior graft placement commonly results from poor visualization during drilling of the femoral tunnel; anterior placement can cause the graft to be overly tight when the knee comes into flexion, leading to loss of flexion or early failure from excessive stress on the graft and subsequent laxity. The graft also can be placed anteriorly as a result of improper drilling of the tibial tunnel. In a review of 21 patients with loss of extension, Marzo and associates[102] found that improper placement of the tibial tunnel led to anterior placement of the graft, which caused roof impingement to develop at the notch with knee extension and formation of a cyclops nodule. Other authors also found that an anterior tibial tunnel can cause graft impingement and loss of extension.[103-105] MRI studies revealed that the optimal position of the tibial tunnel is approximately 3 mm posterior to the central insertion of the native ACL. If this criterion is used, little or no notchplasty is necessary.[104,105] When the graft is found to impinge, a portion of the roof of the intercondylar notch can be removed to minimize impingement. If excessive removal of bone is necessary, the surgeon should be aware that the bone may grow back and eventually cause loss of motion or failure of the graft.

Timing of Surgery

Most patients with an acute ACL rupture have a swollen, painful knee with limited range of motion. Acute ACL reconstruction or repair traditionally was done within the first 2 weeks after injury, but acute reconstruction is now known to be a significant risk factor for the development of arthrofibrosis. Strum and associates[94] evaluated 156 ACL ruptures after reconstruction or repair. Among patients who had surgery within 3 weeks of injury, arthrofibrosis developed in 35%, compared with 12% of patients who had surgery more than 3 weeks after injury. The findings of Shelbourne and associates[91] were similar; patients treated after 3 weeks had more flexion and were more likely to have almost full extension.

The extent of inflammation, pain, and motion limitation should be noted when evaluating a patient with an acute ACL tear. For a patient with decreased motion and a large effusion, the risk of arthrofibrosis can be minimized by a short course of preoperative physical therapy to regain full motion. Cosgarea and associates[106] correlated preoperative and postoperative range of motion, finding that arthrofibrosis occurred less frequently in patients with less than 10° preoperative extension loss who had reconstruction more than 3 weeks after injury.

Postoperative Rehabilitation

Current postoperative treatment protocols stress the importance of early motion after ACL reconstruction to prevent a later loss of motion. The former practice of postoperative immobilization in flexion resulted in loss of flexion. Dandy and Edwards[87] reported that loss of motion in patients immobilized in flexion postoperatively led to a 59% revision rate. Cosgarea and associates[106] found a 23% rate of arthrofibrosis when patients were immobilized for 1 week at 45° of flexion; the rate was 3% when patients were immobilized in extension.

Evaluation and Treatment

A full patient history, physical examination, and evaluation of the rehabilitation protocol may help elucidate the etiology of a loss of motion after ACL reconstruction. Early stiffness suggests that the graft was improperly positioned, whereas late stiffness may indicate the development of arthrofibrosis. It is important to rule out the presence of infection, remembering that an indolent infection with a low-virulence organism may have subtle signs and symptoms. The radiographic evaluation should include weight-bearing AP, lateral in full extension, Merchant, and long-leg alignment views. Tunnel placement should be evaluated on radiographs, and any heterotopic ossification or patella infera should be identified. MRI can be useful for detecting anterior scar tissue and evaluating the competency of the graft.

Any necessary surgery usually can be done arthroscopically. In type I arthrofibrosis, scar tissue or a cyclops lesion may anteriorly impinge on full extension. After the lesion is removed, the knee should be brought to full extension. Graft impingement in the roof of the intercondylar notch should be treated. In more advanced types of arthrofibrosis, a systematic release of adhesions typically is required. Careful attention should be given to releasing the suprapatellar pouch and both the medial and lateral gutters. The infrapatellar fat pad should be released and débrided to reestablish the prepatellar recess and decrease patellofemoral contact pressure. The area surrounding the graft should be carefully evaluated to ensure there is no impingement of the graft throughout motion. Roof notchplasty can be done as necessary. It is important to remember that loss of extension usually is attributable to scarring of the intercondylar notch, whereas loss of flexion usually results from scarring of the fat pad, suprapatellar pouch, and gutters. Hemostasis must be achieved because a hemarthrosis can result in postoperative loss of motion.

An aggressive physical therapy regimen is initiated postoperatively, with an emphasis on maintaining extension. Bracing and nighttime splinting may be used. Early range-of-motion exercises and weight bearing are initiated. Good patellar mobility must be maintained, in conjunction with physical therapy. Continuous passive motion, an indwelling epidural catheter for perioperative pain control, anti-inflammatory medication, and analgesics also can be helpful in maintaining patellar motion.

Outcomes

Arthrofibrosis is a prolonged and frustrating complication of ACL reconstruction. Six to 9 months of treatment may be required to regain maximal function. Mayr and associates[107] noted an improvement in overall range of motion from 94° to 130° in 56 patients, with an overall 1.7° loss of extension. The initial average loss of extension was more than 10°, but only 5 patients had such a severe deficit after surgery.

Harner and associates[108] found loss of motion of more than 10° of extension, with flexion of 125° or less, in 11% of 244 patients who had ACL reconstruction. The risk factors for loss of motion included acute reconstruction and concomitant collateral ligament repair or posterior oblique ligament reefing. On average, patients regained 10° of extension after surgery.

The treatment of arthrofibrosis typically leads to improved range of motion, but the treatment course often is prolonged and may be frustrating to both the physician and the patient. It is important for patients to have a realistic expectation about the outcome of a loss of motion.

Summary

Reconstruction of the ACL is typically associated with excellent outcomes and a low risk of complications. Attention to detail is mandatory when treating a patient with this type of injury. Treatment involves creating and placing a strong, well-fixed graft in an anatomically correct location and early resumption of knee motion. As in any surgical procedure, recognizing potential complications is the first step in their prevention.

References

1. Berg EE: Management of patellar fractures associated with central third bone-patellar tendon-bone autograft ACL reconstructions: Technical note. *Arthroscopy* 1996;12:756-759.
2. Papageorgiou CD, Kkostopoulos VK, Moebius UG, Petropoulou KA, Georgoulis AD, Soucacos PN: Patellar fractures associated with medial-third bone-patellar tendon-bone autograft ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2001;9:151-154.
3. Stein DA, Hunt SA, Rosen JE, Sherman OH: The incidence and outcome of patella fractures after anterior cruciate ligament reconstruction. *Arthroscopy* 2002;18:578-583.
4. McCarroll JR, Shelbourne KD, Patel DV: Anterior cruciate ligament reconstruction in athletes with an ossicle associated with Osgood-Schlatter's disease. *Arthroscopy* 1996;12:556-560.
5. Ebraheim NA, Mekhail AO: The infrapatellar branch of the saphenous nerve: An anatomic study. *J Orthop Trauma* 1997;11:195-199.
6. Mochida H, Kikuchi S: Injury to infrapatellar branch of saphenous nerve in arthroscopic knee surgery. *Clin Orthop Relat Res* 1995;320:88-94.
7. Olszewski AD, Miller MD, Ritchie JR: Ideal tibial tunnel length for endoscopic anterior cruciate ligament reconstruction. *Arthroscopy* 1998;14:9-14.
8. Poehling GG, Pollock FE Jr, Koman LA: Reflex sympathetic dystrophy of the knee after sensory nerve injury. *Arthroscopy* 1988;4:31-35.
9. Solman CG Jr , Pagnani MJ: Hamstring tendon harvesting: Reviewing anatomic relationships and avoiding pitfalls. *Orthop Clin North Am* 2003;34:1-8.
10. Swanson AJ: The incidence of prepatellar neuropathy following medial meniscectomy. *Clin Orthop Relat Res* 1983;181:151-153.
11. Sanders B, Rolf R, McClelland W, Xerogeanes J: Prevalence of saphenous nerve injury after autogenous hamstring harvest: An anatomic and clinical study of sartorial branch injury. *Arthroscopy*2007;23:956-963.
12. Luo H, Yu JK, Ao YF, et al: Relationship between different skin incisions and the injury of the infrapatellar branch of the saphenous nerve during anterior cruciate ligament reconstruction. *Chin Med J (Engl)* 2007;120:1127-1130.
13. Portland GH, Martin D, Keene G, Menz T: Injury to the infrapatellar branch of the saphenous nerve in anterior cruciate ligament reconstruction: Comparison of horizontal versus vertical harvest site incisions. *Arthroscopy* 2005;21:281-285.
14. Pagnani MJ, Warner JJ, O'Brien SJ, Warren RF: Anatomic considerations in harvesting the semitendinosus and gracilis tendons and a technique of harvest. *Am J Sports Med* 1993;21:565-571.
15. Boon JM, Van Wyk MJ, Jordaan D: A safe area and angle for harvesting autogenous tendons for anterior cruciate ligament reconstruction. *Surg Radiol Anat* 2004;26:167-171.
16. Mochizuki T, Akita K, Muneta T, Sato T: Anatomical bases for minimizing sensory disturbance after arthroscopically-assisted anterior cruciate ligament reconstruction using medial hamstring tendons. *Surg Radiol Anat* 2003;25:192-199.
17. Tifford CD, Spero L, Luke T, Plancher KD: The relationship of

the infrapatellar branches of the saphenous nerve to arthroscopy portals and incisions for anterior cruciate ligament surgery: An anatomic study. *Am J Sports Med* 2000;28:562-567.

18. Tillett E, Madsen R, Rogers R, Nyland J: Localization of the semitendinosus-gracilis bifurcation point relative to the tibial tuberosity: An aid to hamstring tendon harvest. *Arthroscopy* 2004;20:51-54.
19. Kodkani PS, Govekar DP, Patankar KS: A new technique of graft harvest for anterior cruciate ligament reconstruction with quadruple semitendinosus tendon autograft. *Arthroscopy* 2004;20:e101-e104.
20. Diaz-de-Rada P, Barriga A, Barroso JL, García-Barrecheguren E, Alfonso M, Valentí JR: Positive culture in allograft ACL-reconstruction: What to do? *Knee Surg Sports Traumatol Arthrosc* 2003;11:219-222.
21. Guelich DR, Lowe WR, Wilson B: The routine culture of allograft tissue in anterior cruciate ligament reconstruction. *Am J Sports Med* 2007;35: 1495-1499.
22. Centers for Disease Control and Prevention: Update: Allograft-associated bacterial infections. United States, 2002. *MMWR* 2002;51:207-210.
23. Kenna B, Simon T, Jackson D, Kurzweil P: Endoscopic ACL reconstruction: A technical note on tunnel length for interference fixation. *Arthroscopy* 1993;9:228-230.
24. Miller MD, Olszewski AD: Cruciate ligament graft intraarticular distances. *Arthroscopy* 1997;13:291-295.
25. Miller MD, Hinkin DT: The "N + 7 Rule" for tibial tunnel placement in endoscopic anterior cruciate ligament reconstruction. *Arthroscopy* 1996;12: 124-126.
26. Noah J, Sherman O, Roberts C: Fracture of the supracondylar femur after anterior cruciate ligament reconstruction using patellar tendon and iliotibial band tenodesis. *Am J Sports Med* 1992;20:615-618.
27. Izquierdo R Jr, Cadet ER, Bauer R, et al: A survey of sports medicine specialists investigating the preferred management of contaminated anterior cruciate ligament grafts. *Arthroscopy* 2005;21:1348-1353.
28. Goebel ME, Drez D, Heck SB, Stoma MK: Contaminated rabbit patellar tendon grafts: In vivo analysis of disinfecting methods. *Am J Sports Med* 1994;22:387-391.
29. Cooper DE, Arnoczky SP, Warren RF: Contaminated patellar tendon grafts: Incidence of positive cultures and efficacy of an antibiotic solution soak. An in vitro study. *Arthroscopy* 1991;7:272-274.
30. Molina ME, Nonweiller DE, Evans JA, DeLee JC: Contaminated anterior cruciate ligament grafts: The efficacy of 3 sterilization agents. *Arthroscopy* 2000;16:373-378.
31. Almekinders LC, Chiavetta JB: Tibial subluxation in anterior cruciate ligament-deficient knees: Implications for tibial tunnel placement. *Arthroscopy* 2001;17:960-962.
32. Clancy WG Jr, Nelson DA, Reider B, Narechania RG: Anterior cruciate ligament reconstruction using one third of the patellar ligament augmented by extra-articular tendon transfers. *J Bone Joint Surg Am* 1982; 64:352-359.
33. Mauch F, Apic G, Becker U, Bauer G: Differences in the placement of the tibial tunnel during reconstruction of the anterior cruciate ligament with and without computer-assisted navigation. *Am J Sports Med* 2007;35:1824-1832.
34. Zantop T, Haase AK, Fu FH, Petersen W: Potential risk of cartilage damage in double bundle ACL reconstruction: Impact of knee flexion angle and portal location on the femoral PL bundle tunnel. *Arch Orthop Trauma Surg* 2008;128:509-513.
35. Behrend H, Stutz G, Kessler MA, Rukavina A, Giesinger K, Kuster MS: Tunnel placement in anterior cruciate ligament (ACL) reconstruction: Quality control in a teaching hospital. *Knee Surg Sports Traumatol Arthrosc* 2006;14:1159-1165.
36. Loh JC, Fukuda Y, Tsuda E, Steadman RJ, Fu FH, Woo SL: Knee stability and graft function following anterior cruciate ligament reconstruction. Comparison between 11 o'clock and 10 o'clock femoral tunnel placement. *Arthroscopy* 2003;19:297-304.
37. Markolf KL, Hame S, Hunter DM, et al: Effects of femoral tunnel placement on knee laxity and forces in anterior cruciate ligament graft. *J Orthop Res* 2002;20:1016-1024.
38. Hame SL, Markolf KL, Hunter DM, Oakes DA, Zoric B: Effects of notchplasty and femoral tunnel position on excursion patterns of an anterior cruciate ligament graft. *Arthroscopy* 2003; 19:340-345.
39. Cohen SB, Fu FH: Three-portal technique for anterior cruciate ligament reconstruction: Use of a central medial portal. *Arthroscopy* 2007;23: 325.e1-325.e5.
40. Fu FH, Jordan SS: The lateral intercondylar ridge: A key to anatomic anterior cruciate ligament reconstruction. *J Bone Joint Surg Am* 2007;89: 2103-2104.
41. Bach BR Jr, Sellards RA: Femoral aimer deformation: Potential cause for altered femoral tunnel placement in anterior cruciate ligament surgery. *Arthroscopy* 2003;19:e7.
42. Golish SR, Baumfeld JA, Schoderbek RJ, Miller MD: The effect of femoral tunnel starting position on tunnel length in anterior cruciate ligament reconstruction: A cadaveric study. *Arthroscopy* 2007;23:1187-1192.
43. Shuler MS, Jasper LE, Rauh PB, Mulligan ME, Moorman CT III: Tunnel convergence in combined anterior cruciate ligament and posterolateral corner reconstruction. *Arthroscopy* 2006;22:193-198.
44. Kurosaka M, Yoshiya S, Andrish JT: A biomechanical comparison of different surgical techniques of graft fixation in anterior cruciate ligament reconstruction. *Am J Sports Med* 1987; 15:225-229.
45. Pierz K, Baltz M, Fulkerson J: The effect of Kurosaka screw divergence on

the holding strength of bone-tendon-bone grafts. *Am J Sports Med* 1995;23: 332-335.

46. Barber FA, Elrod BF, McGuire DA, Paulos LE: Preliminary results of an absorbable interference screw. *Arthroscopy* 1995;11:537-548.
47. Caborn DN, Urban WP Jr, Johnson DL, Nyland J, Pienkowski D: Biomechanical comparison between BioScrew and titanium alloy interference screws for bone-patellar tendon-bone graft fixation in anterior cruciate ligament reconstruction. *Arthroscopy* 1997;13:229-232.
48. Hackl W, Benedetto KP, Hoser C, Kunzel KH, Fink C: Is screw divergence in femoral bone-tendon-bone graft fixation avoidable in anterior cruciate ligament reconstruction using a single-incision technique? A radiographically controlled cadaver study. *Arthroscopy* 2000;16:640-647.
49. Milankov M, Stankovic M, Miljkovic N: Protection of the bone-tendon-bone graft during anterior cruciate ligament reconstruction. *Arch Orthop Trauma Surg* 2005;125: 288-290.
50. Milano G, Mulas PD, Ziranu F, Piras S, Manunta A, Fabbriciani C: Comparison between different femoral fixation devices for ACL reconstruction with doubled hamstring tendon graft: A biomechanical analysis. *Arthroscopy* 2006;22: 660-668.
51. Almazan A, Miguel A, Odor A, Ibarra JC: Intraoperative incidents and complications in primary arthroscopic anterior cruciate ligament reconstruction. *Arthroscopy* 2006;22: 1211-1217.
52. Karaoglu S, Halici M, Baktir A: An unidentified pitfall of Endobutton use: Case report. *Knee Surg Sports Traumatol Arthrosc* 2002;10:247-249.
53. Simonian PT, Sussmann PS, Baldini TH, Crockett HC, Wickiewicz TL: Interference screw position and hamstring graft location for anterior cruciate ligament reconstruction. *Arthroscopy* 1998;14:459-464.
54. Misra R, Strover A, El-Shazly M: Intra-articular protrusion of malpositioned Transfix implant following anterior cruciate ligament reconstruction. *Arthroscopy* 2006;22:226.
55. Vardi G: Sciatic nerve injury following hamstring harvest. *Knee* 2004;11: 37-39.
56. Sachs RA, Reznik A, Daniel DM, et al: Complications of knee surgery, in Daniel DM, Akeson WH, O'Connor JJ (eds): *Knee Ligaments: Structure, Function, Injury, and Repair*. New York, NY, Raven Press, 1990, pp 505-520.
57. Aldridge JM III, Weaver JP, Mallon WJ: Avulsion of the middle genicular artery: A previously unreported complication of anterior cruciate ligament repair. A case report. *Am J Sports Med* 2002;30:748-750.
58. Evans JD, de Boer MT, Mayor P, Rees D, Guy AJ: Pseudoaneurysm of the medial inferior genicular artery following cruciate ligament reconstruction. *Ann R Coll Surg Engl* 2000; 82:182-184.
59. Roth JH, Bray RC: Popliteal artery injury during anterior cruciate ligament reconstruction: Brief report. *J Bone Joint Surg Br* 1988;70:840.
60. Janssen RP, Sala HA: Embolism of the popliteal artery after anterior cruciate ligament reconstruction: A case report and literature review. *Knee Surg Sports Traumatol Arthrosc* 2007;15: 1449-1451.
61. Janssen RP, Scheltinga MR, Sala HA: Pseudoaneurysm of the popliteal artery after anterior cruciate ligament reconstruction with bicortical tibial screw fixation. *Arthroscopy* 2004;20: e4-e6.
62. Post WR, King SS: Neurovascular risk of bicortical drilling for screw and spiked washer fixation of soft-tissue anterior cruciate ligament graft. *Arthroscopy* 2001;17:244-247.
63. Hirvensalo E, Tuominen H, Lapinsuo M, Helio H: Compartment syndrome of the lower limb caused by a tourniquet: A report of two cases. *J Orthop Trauma* 1992;6:469-472.
64. Luk KD, Pun WK: Unrecognized compartment syndrome in a patient with tourniquet palsy. *J Bone Joint Surg Br* 1987;69:97-99.
65. Seybold EA, Busconi BB: Anterior thigh compartment syndrome following prolonged tourniquet use and lateral decubitus position: Case report and review of the literature. *Am J Orthop* 1996;25:493-496.
66. Berg EE: Lateral femoral condyle fracture after endoscopic anterior cruciate ligament reconstruction: Case report. *Arthroscopy* 1994;10:693-695.
67. Manktelow AR, Haddad FS, Goddard NJ: Late lateral femoral condyle fracture after anterior cruciate ligament reconstruction: A case report. *Am J Sports Med* 1998;26:587-590.
68. Ternes JP, Blasier RB, Alexander AH: Fracture of the femur after anterior cruciate ligament reconstruction with a Gore-Tex prosthetic graft. *Am J Sports Med* 1993;21:147-149.
69. Moen KY, Boynton MD, Raasch WG: Fracture of the proximal tibia after anterior cruciate ligament reconstruction: A case report. *Am J Orthop* 1998;27:629-630.
70. Fong SY, Tan JL: Septic arthritis after arthroscopic anterior cruciate ligament reconstruction. *Ann Acad Med Singapore* 2004;33:228-234.
71. Indelli PF, Dillingham M, Fanton G, Schurman DJ: Septic arthritis in postoperative anterior cruciate ligament reconstruction. *Clin Orthop Relat Res* 2002;398:182-188.
72. Judd D, Bottoni C, Kim D, Burke M, Hooker S: Infections following arthroscopic anterior cruciate ligament reconstruction. *Arthroscopy* 2006;22: 375-384.
73. Matava MJ, Evans TA, Wright RW, Shively RA: Septic arthritis of the knee following anterior cruciate ligament reconstruction: Results of a survey of sports medicine fellowship directors. *Arthroscopy* 1998;14:717-725.
74. McAllister DR, Parker RD, Cooper AE, Recht MP, Abate J: Outcomes of postoperative septic arthritis after anterior cruciate ligament recon-

struction. *Am J Sports Med* 1999;27: 562-570.

75. Schollin-Borg M, Michaelsson K, Rahme H: Presentation, outcome, and cause of septic arthritis after anterior cruciate ligament reconstruction: A case control study. *Arthroscopy* 2003; 19:941-947.

76. Van Tongel A, Stuyck J, Bellemans J, Vandenneucker H: Septic arthritis after arthroscopic anterior cruciate ligament reconstruction: A retrospective analysis of incidence, management and outcome. *Am J Sports Med* 2007; 35:1059-1063.

77. Viola R, Marzano N, Vianello R: An unusual epidemic of Staphylococcus-negative infections involving anterior cruciate ligament reconstruction with salvage of the graft and function. *Arthroscopy* 2000;16:173-177.

78. Williams RJ III, Laurencin CT, Warren RF, Speciale AC, Brause BD, O'Brien S: Septic arthritis after arthroscopic anterior cruciate ligament reconstruction: Diagnosis and management. *Am J Sports Med* 1997;25: 261-267.

79. Spindler KP, Kuhn JE, Freedman KB, Matthews CE, Dittus RS, Harrell FE Jr: Anterior cruciate ligament reconstruction autograft choice: Bone-tendon-bone versus hamstring. Does it really matter? A systematic review. *Am J Sports Med* 2004;32:1986-1995.

80. Schurman DJ, Johnson BL Jr, Amstutz HC: Knee joint infections with Staphylococcus aureus and Micrococcus species. *J Bone Joint Surg Am* 1975;57:40-49.

81. Centeno JM, Woolf S, Reid JB III, Lubowitz JH: Do anterior cruciate ligament allograft culture results correlate with clinical infections? *Arthroscopy* 2007;23:1100-1103.

82. Burke WV, Zych GA: Fungal infection following replacement of the anterior cruciate ligament: A case report. *J Bone Joint Surg Am* 2002;84:449-532.

83. Farooq AH, Dabke HV, Majeed MA, Carbarns NJ, Mackie IG: Clostridial wound infection following reconstruction of the anterior cruciate ligament using bone-patella-bone autograft. *J Coll Physicians Surg Pak* 2007;17:369-370.

84. Burks RT, Friederichs MG, Fink B, Luker MG, West HS, Greis PE: Treatment of postoperative anterior cruciate ligament infections with graft removal and early reimplantation. *Am J Sports Med* 2003;31:414-418.

85. Jung KA, Lee SC, Song MB, Lee CK: Treatment of persistent extraarticular infection using a temporary cement spacer on the tibia after ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2008;16:37-39.

86. Schulz AP, Gotze S, Schmidt HG, Jurgens C, Faschingbauer M: Septic arthritis of the knee after anterior cruciate ligament surgery: A stage-adapted treatment regimen. *Am J Sports Med* 2007;35:1064-1069.

87. Dandy DJ, Edwards DJ: Problems in regaining full extension of the knee after anterior cruciate ligament reconstruction: Does arthrofibrosis exist? *Knee Surg Sports Traumatol Arthrosc* 1994;2:76-79.

88. Fisher SE, Shelbourne KD: Arthroscopic treatment of symptomatic extension block complicating anterior cruciate ligament reconstruction. *Am J Sports Med* 1993;21:558-564.

89. Jackson DW, Schaefer RK: Cyclops syndrome: Loss of extension following intra-articular anterior cruciate ligament reconstruction. *Arthroscopy* 1990;6:171-178.

90. Nabors ED, Richmond JC, Vannah WM, McConville OR: Anterior cruciate ligament graft tensioning in full extension. *Am J Sports Med* 1995; 23:488-492.

91. Shelbourne KD, Wilckens JH, Mollabashy A, DeCarlo M: Arthrofibrosis in acute anterior cruciate ligament reconstruction: The effect of timing of reconstruction and rehabilitation. *Am J Sports Med* 1991;19:332-336.

92. Sachs RA, Daniel DM, Stone ML, Garfein RF: Patellofemoral problems after anterior cruciate ligament reconstruction. *Am J Sports Med* 1989;17: 760-765.

93. Shelbourne KD, Patel DV, Martini DJ: Classification and management of arthrofibrosis of the knee after anterior cruciate ligament reconstruction. *Am J Sports Med* 1996; 24:857-862.

94. Strum GM, Friedman MJ, Fox JM, et al: Acute anterior cruciate ligament reconstruction: Analysis of complications. *Clin Orthop Relat Res* 1990;253: 184-189.

95. Robins AJ, Newman AP, Burks RT: Postoperative return of motion in anterior cruciate ligament and medial collateral ligament injuries: The effect of medial collateral ligament rupture location. *Am J Sports Med* 1993;21: 20-25.

96. Tonino P, Risinger RJ, Garcia M, Bach BR Jr: Arthrofibrosis following ACL reconstruction, in Freedman KB (ed): *Complications in Orthopaedics: Anterior Cruciate Ligament Surgery*. Rosemont, IL, American Academy of Orthopaedic Surgeons, 2005, pp 35-48.

97. Delince P, Krallis P, Descamps PY, Fabeck L, Hardy D: Different aspects of the cyclops lesion following anterior cruciate ligament reconstruction: A multifactorial etiopathogenesis. *Arthroscopy* 1998;14:869-876.

98. Shelbourne KD, Johnson G: Evaluation of knee extension following anterior cruciate ligament reconstruction. *Orthopedics* 1994;17:205-206.

99. Greis PE, Johnson DL, Fu FH: Revision anterior cruciate ligament surgery: Causes of graft failure and technical considerations of revision surgery. *Clin Sports Med* 1993;12: 839-852.

100. Johnson DL, Fu FH: Anterior cruciate ligament reconstruction: Why do failures occur? *Instr Course Lect* 1995; 44:391-406.

101. Johnson DL, Swenson TM, Irrgang JJ, Fu FH, Harner CD: Revision anterior cruciate ligament surgery: Experience from Pittsburgh. *Clin Orthop Relat Res* 1996;325:100-109.

102. Marzo JM, Bowen MK, Warren RF, Wickiewicz TL, Altchek DW: Intraarticular fibrous nodule as a cause of loss of extension following anterior cruciate ligament reconstruction. *Arthroscopy* 1992;8:10-18.

103. Howell SM, Clark JA: Tibial tunnel placement in anterior cruciate ligament reconstructions and graft impingement. *Clin Orthop Relat Res* 1992;283:187-195.

104. Howell SM, Clark JA, Farley TE: A rationale for predicting anterior cruciate graft impingement by the intercondylar roof: A magnetic resonance imaging study. *Am J Sports Med* 1991;19:276-282.

105. Howell SM, Clark JA, Farley TE: Serial magnetic resonance study assessing the effects of impingement on the MR image of the patellar tendon graft. *Arthroscopy* 1992;8:350-358.

106. Cosgarea AJ, Sebastianelli WJ, DeHaven KE: Prevention of arthrofibrosis after anterior cruciate ligament reconstruction using the central third patellar tendon autograft. *Am J Sports Med* 1995;23:87-92.

107. Mayr HO, Weig TG, Plitz W: Arthrofibrosis following ACL reconstruction: Reasons and outcome. *Arch Orthop Trauma Surg* 2004;124:518-522.

108. Harner CD, Irrgang JJ, Paul J, Dearwater S, Fu FH: Loss of motion after anterior cruciate ligament reconstruction. *Am J Sports Med* 1992;20:499-506.