Anterior Cruciate Ligament Insufficiency: Principles of Treatment

Robert L. Larson, MD, and Mario Taillon, MD, FRCS(C)

Abstract

Anterior cruciate ligament (ACL) injuries often result in functional disability, particularly in jumping, cutting, and deceleration activities. Some patients can accommodate to this functional loss, while others require surgical reconstruction of the ligament to provide stability and to protect the meniscus from further injury. Nonoperative management involves an intensive rehabilitation program, patient counseling about high-risk activities, and measures to prevent recurrent injuries. Surgical reconstruction of the ACL involves the technical factors of graft selection, positioning, fixation, and tensioning and the avoidance of stress risers. A supervised and intensive rehabilitation program is necessary to achieve optimal results.

J Am Acad Orthop Surg 1994;2:26-35

The anterior cruciate ligament (ACL) has been one of the most extensively studied ligaments in the body. Its importance in knee function has been emphasized, particularly for athletes who require knee stability in activities such as running, cutting, and kicking. Although an improvement in function can be achieved by present surgical techniques, the biologic and physiologic characteristics of the normal ACL are not fully restored. The normal ACL has proprioceptive senses that help protect the knee joint during use; it has a degree of viscoelasticity that allows it to stretch and return to its resting length without structural damage; it has a physical configuration with multiple bands and a multiaxial function that guides the knee through its complex helicoid motion, including both rotational and translational forces; and it has broad insertion sites, which allow the normal kinematics of knee motion to occur with stability in activities such as walking, running, jumping, and kicking.

Anatomy

The ACL is intracapsular but extrasynovial. Its predominant source of blood supply is the middle genicular artery, which arises from the popliteal artery and pierces the posterior capsule. The inferior medial and lateral genicular arteries also vascularize the ACL via the fat pad. The ACL has been shown to contain nerve fibers of the size most consistent with transmitting pain as well as mechanoreceptors that are postulated to function in proprioception.

The femoral origin of the ACL is on the lateral wall of the intercondylar notch at its posterior aspect and is oriented in the longitudinal axis of the femur. The tibial attachment is parallel to the anteroposterior axis of the tibia and is on the anterior aspect of the tibial plateau near the tibial spines. This produces a twist of the ACL fibers as the knee moves from extension to flexion. Traditionally, the ACL has been divided into an anteromedial band and a posterolateral band. The bands are actually a continuum of fascicles, different portions of which are taut throughout the range of motion, allowing the ligament to be functional in all degrees of flexion and extension. The anteromedial portion is tighter in flexion, and the posterolateral portion is tighter in extension.

Biomechanics and Function

The ACL functions as the primary restraint to limit anterior tibial displacement, as a secondary restraint to tibial rotation, and as a minor secondary restraint to varus-valgus angulation at full extension. It provides nearly 90% of anterior translational stability of the tibia. Greater anterior displacement occurs at 30 degrees of flexion. The contribution of the ACL in restraining rotation is greater in full extension than it is in early flexion. If a primary restraint has been torn but a secondary restraint remains intact, clinical testing may reveal only slight laxity.

Dr. Larson is Clinical Professor of Surgery, School of Medicine, Oregon Health Sciences University, Portland; and is in private practice in Eugene, Oregon. Dr. Taillon is in private practice in Calgary, Alberta, Canada.

Reprint requests: Dr. Larson, Orthopedic and Fracture Clinic of Eugene, 1200 Hilyard, Suite 600, Eugene, OR 97401.

Copyright 1994 by the American Academy of Orthopaedic Surgeons.

When both primary and secondary restraints are torn, marked laxity to clinical testing is evident.[1]

Six degrees of freedom are described to show the relationship of the tibia and the femur to each other (Fig. 1). These are broadly divided into rotational and translational. The three rotational degrees of freedom are flexion-extension, internal-external axial tibial rotation, and varus-valgus (adduction-abduction). The three translational degrees of freedom are anterior-posterior tibial displacement, medial-lateral tibial displacement, and proximal-distal (joint distraction-compression). Constraints to excessive degrees of motion in these freedoms are provided by ligamentous structures around the knee. Rupture or chronic deficiency of the ACL allows a combination of abnormal anterior translation and rotation of the tibia.

Noyes et al[2] performed a study on the tensile properties of the human ACL and reported that the ultimate load for the young ACL was 1,725 ± 269 N. Since that study, the criteria for the strength of autograft, allograft, and synthetic substitutes have been set at 1,730 N. However, factors other than ultimate strength will influence performance, such as biologic changes in graft materials over time and the effects of repetitive loading.

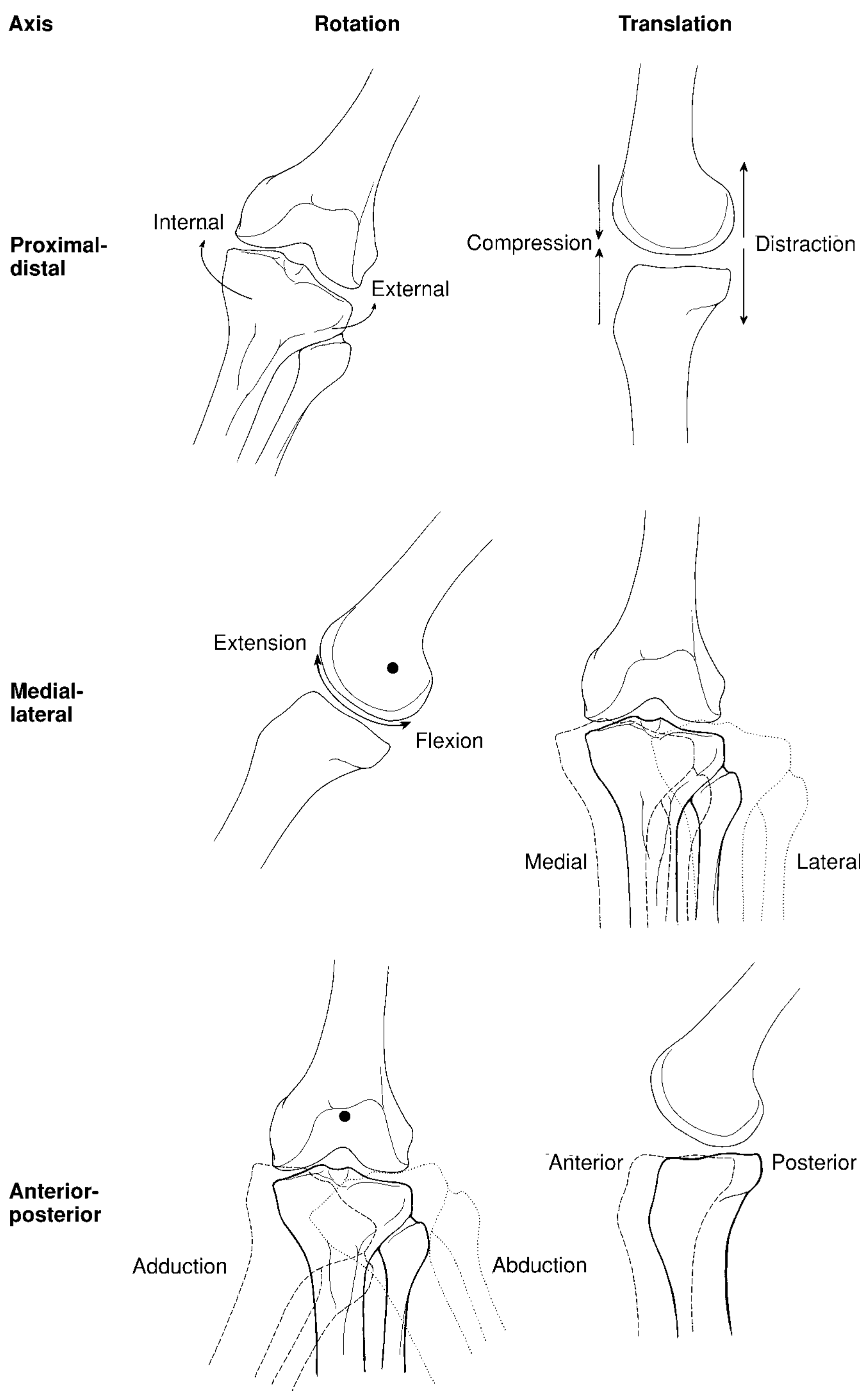

Fig. 1 Translation and rotation around each of the three axes provide the six degrees of freedom that allow knee motion.

Clinical Signs and Symptoms

The history of ACL injury is often a noncontact injury that occurred while changing direction or landing from a jump. The patient may state that a "pop" was felt or heard. Swelling (hemarthrosis) is noted within a few hours. The patient may say that his or her knee felt too unstable to continue playing and had difficulty bearing weight.

A careful physical examination will reveal most ligament disruptions if certain principles are followed. It is essential that the patient be relaxed and comfortable. The results of the physical examination of the injured knee must be compared with those of the normal knee.

A moderate to severe effusion is usually present, and this may limit range of motion. Range of motion may also be limited by pain, hamstring spasm, ACL stump impingement, and meniscal pathology.

If a tense effusion is accompanied by severe pain, aspiration under sterile conditions provides relief and allows the aspirate to be examined for the presence of blood. Injection of a mixture of saline and a local anesthetic may be used to provide additional relaxation and to aid in the clinical examination.

Lachman Test

This is an excellent test for ACL laxity. The knee is placed in a position of 20 to 30 degrees of flexion, the femur is stabilized, and an anteriorly directed force is applied to the proximal calf. The examiner should estimate the displacement (in millimeters) and assess the firmness of the endpoint (graded as firm [normal)], marginal, or soft). Any perceived side-to-side difference is usually significant.

Pivot Shift Test

There are many variations to the pivot shift test, including the classic test, the Losee test, the side-lying test, and the flexion-rotation drawer test. They are all based on the fact that in very early flexion there is anterior subluxation of the tibia and that with further flexion (20 to 40 degrees) the posterior pull of the iliotibial tract reduces the tibia. It is the relocation event that the clinician usually grades subjectively as 0 (absent), 1+ (pivot glide), 2+ (pivot shift), or 3+ (momentary locking).

Anterior Drawer Test

This test is performed at 90 degrees of flexion. This position may be difficult to achieve in the acutely injured knee since hamstring spasm influences test results. Many normal knees have significant excursion in this position. For these reasons, it is the least reliable test.

Imaging the ACL-Injured Knee

Plain Radiography

Plain radiography should be the first imaging study ordered. This is important to rule out other abnormalities and associated injuries. An avulsion of the insertion of the ACL may be seen on the lateral or the tunnel view. A vertically oriented Segond fracture is often associated with an ACL injury. This results from excessive tension on the lateral capsular ligament of the knee. The fracture is located posterior to Gerdy's tubercle and superior and anterior to the fibular head. The anteroposterior standing radiograph can be used to evaluate any joint-space narrowing, as well as the presence of a varus deformity.

Usually, clinical examination and plain radiographs are sufficient. Occasionally, special tests may be necessary to evaluate the integrity of the ACL or the meniscus. These additional tests include arthrography, magnetic resonance (MR) imaging, instrumented measurement of knee motion, examination under anesthesia, and arthroscopy.

Arthrography

The role of arthrography is mainly to evaluate the status of the menisci. Interpretation of the arthrographic appearance of the ACL is operator-dependent and may be misleading in the case of an intact synovial sheath surrounding the ACL. The cost of arthrography is significantly less than that of MR imaging, but the procedure may be uncomfortable for the patient. It does have a role for the patient who is claustrophobic or who has other contraindications to MR imaging.

MR Imaging

Although the overall accuracy of MR imaging in assessing the ACL is approximately 95%, MR imaging of the knee with a suspected ACL deficiency should not be used routinely. The normal ACL appears as a smooth, well-defined structure of low signal intensity on a sagittal image through the intercondylar notch. The abnormal ACL shows discontinuity of the ligament in the sagittal plane (Fig. 2). If there is an acute injury, the T2-weighted sequences will demon-

A B

Fig. 2 Magnetic resonance images of a normal (**A**) and an abnormal (**B**) ACL (arrow).

strate high signal intensity within the ligamentous substance secondary to edema and local hemorrhage. Another finding may be a wavy irregular contour of the anterior margin of the ACL, indicating loss of tautness. Acute kinking or anterior bowing of the posterior cruciate ligament may also indicate an ACL tear. Magnetic resonance imaging also allows detection of bone abnormalities not seen on conventional radiographs. Approximately 60% of ACL injuries have accompanying bone abnormalities often referred to as “bone bruises”[3] (Fig. 3). The significance and the long-term sequelae of these lesions have yet to be determined.

Instrumented Ligament Testing

Instrumented ligament testing devices such as the KT-1000 arthrometer have been used to measure anteroposterior displacement. These devices may be used preoperatively, intraoperatively, and postoperatively. In a unilaterally injured patient, a right-left difference of less than 3 mm is classified as normal motion and a right-left difference on any test of 3 mm or greater is classified as pathologic.[4] The reliability of the test may be influenced by the tester’s experience and proficiency.

Fig. 3 Magnetic resonance image showing a bone bruise (arrow).

Examination Under Anesthesia and Arthroscopy

When the status of the ACL and menisci remains in doubt, examination under anesthesia with the patient completely relaxed gives a more reliable index of ligamentous laxity. This is followed by arthroscopic inspection of the ACL, menisci, and other joint structures. Such an evaluation is usually not necessary in the chronic case when the functional status of the knee has been tested. It is more often used in the acute or subacute situation when a definitive diagnosis is imperative.

Treatment Selection

Physicians who treat acute torn ACLs must understand that there is still no ideal method that ensures restoration of normal function. The final decision between operative and nonoperative treatment must be based on many variables that are unique to each individual. Among factors to be considered are the presence or absence of other lesions involving the knee, the age and level of activity of the patient, the degree of instability, the type of injury to the ACL, and the ability of the patient to comply with the rehabilitation program. The type of sporting activity in which the patient wishes to participate is also important. Jumping, cutting, and pivoting sports place the ACL-disrupted patient at risk of injury, and many patients treated nonoperatively are unable to return to these types of activities.

Patients with a chronic ACL deficiency must be evaluated to determine whether their instability is producing a functional disability and whether their activity level combined with their instability may cause meniscal damage. The incidence of meniscus tear in an acute ACL disruption is greater than 50% in most studies. There are a greater number of lateral meniscal tears than medial tears.[4] If judged to be stable, lateral meniscal tears posterior to the popliteal tendon may be left alone; they will either heal or be asymptomatic. The decision as to whether to evaluate the status of the menisci must be individualized to each patient and to his or her progress in the rehabilitation program. The menisci should be evaluated by repeat clinical examination. Arthrography, arthroscopy, or MR imaging may also be utilized. Arthroscopy still appears to be the most accurate method of diagnosing a meniscal tear in a patient with persisting symptoms.

Because absence of the meniscus enhances joint deterioration, the goal should be to preserve as much meniscal tissue as possible with every attempt to restore meniscal function to as near normal as possible.

Patient Selection

The primary candidates for ACL surgery are those patients with an active lifestyle who have an acute ACL deficiency and those with a chronic ACL deficiency that results in functional instability that endangers the menisci.

Daniel et al[5] did outcome studies on 292 patients who had acute ACL injuries over a 12-year period. Nineteen percent underwent surgery within the first 3 months. Another 19% requested surgery over the next 5 years. Sixty-two percent were able to function satisfactorily without an ACL.

Two factors were found to be most predictive of who would need later surgery. The first was the number of hours per year of level I or II sports (jumping, pivoting, lateral-motion sports) in which the patient participated prior to injury. The second factor was the maximum manual displacement difference between the affected and unaffected knees as measured by ligament testing. Those patients who had less than 5 mm of side-to-side difference and who participated for 50 hours or less in level I or II sports had a low risk of needing further surgery. Those patients with a 7-mm or greater side-to-side difference with more than 50 hours of level I or II sports activity were in the high-risk group.

Nonoperative Management

The initial nonoperative treatment of the acutely injured ACL is splinting and use of crutches for comfort and early active range of motion. The goal is to obtain full range of motion as compared with the normal knee. Strengthening is achieved by using closed-chain weight-bearing exercises. The goal is to return the function of the hamstring and quadriceps muscles to within 90% of that of the contralateral limb as determined by isokinetic testing or functional testing, such as the hop test. Patients should also receive counseling concerning high-risk activities and measures to prevent recurrent injuries.

The role of functional knee bracing remains controversial. The proposed mechanisms of protection are mechanical constraint of joint motion and improvement of joint-position sense. It has been shown that functional knee braces decrease anterior joint subluxation at low loads, but not at physiologic loads. The concept that braces function to enhance joint proprioception has been investigated, without definitive results. Others have evaluated brace use by performing functional tests in brace users in and out of their braces. The fact remains that some patients believe they have better function in a brace, allowing them to participate in an increased level of sporting activity. The use of braces cannot be substituted for exercise to achieve and maintain quadriceps or hamstring strength. The use of a brace is an individual and optional decision.

Patients with grade III instability who participate in vigorous activities, especially those producing rotational stress to the knee, cannot be assured that bracing will provide adequate protection from further injury. A modification of activity level will be required if a nonoperative course is to be pursued.

Operative Management

Surgical techniques for intra-articular and extra-articular reconstruction of the ACL have included the use of the iliotibial band, the semitendinosus and gracilis tendons, the patellar tendon, the meniscus, allograft tissue, and various synthetic materials.

Graft Selection

Factors considered in the selection of autogenous graft to replace the deficient ACL include the biomechanical properties of the graft, including initial strength; the ease of graft harvest; the security of graft fixation; potential donor-site morbidity; and individual patient considerations.[4] Noyes et al[2] examined the biomechanical properties of nine different autograft tissues. Their results showed that a bone–patellar tendon–bone complex (14-mm-wide graft) was approximately 1.6 times as strong as normal human ACL. The semitendinosus displayed only 70% of the strength of the normal human ACL; the gracilis, 50%; the distal iliotibial tract, 50%; and the quadriceps–patellar retinaculum–patellar tendon complex, only 14% to 21%. Other studies have shown that multiple strands of semitendinosus or semitendinosus-gracilis composites are stronger than a normal ACL.

Autogenous tissue used as a graft merely provides a collagen lattice, not a structural support, in the early stages of graft resorption, revascularization, and restructuring with new collagen. Histologic and electron microscopy studies have shown that the collagen tissue produced after ACL reconstruction does not match the size or density of normal ACL collagen fibers.[6]

Surgeons vary in preference of autogenous tissue. The patellar tendon that has the greater initial tensile strength, provides greater bulk, and allows more secure bone-to-bone fixation is preferred by some. The tensile strength of a patellar-tendon graft has been shown to increase by 30% when the tendon is twisted 90 degrees. Others prefer the semitendinosus tendon, which is often double-looped, used with the gracilis tendon, or quadruple-looped when endoscopic fixation is used. The semitendinosus also provides greater elasticity, requires smaller drill holes for insertion, is easier to harvest, and carries less risk of later patellofemoral pain.

A review of the literature published between 1981 and 1986 showed that the percentage of patients with a 0-1 Lachman test and a 0-1 pivot shift test was the same 2 years after surgery no matter what autogenous tissue was used initially.[7]

Graft Fixation

The weak link in the reconstructed knee in the early postoperative period is the point of ligament or graft fixation. Kurosaka et al[8] performed fixation studies on bone–patellar tendon–bone fixation, and Robertson et al[9] studied soft-tissue fixation to bone; their results are shown in Tables 1 and 2, respectively.

Table 1
Strength After Bone–Patellar Tendon–Bone Fixation[8]

Device	Maximum Tensile Strength, N
Kurosaka 9.0 screw	475.8
AO 6.5 screw	214.8
Sutures over buttons	248.2
Staples	128.5

Graft-Site Morbidity

Bone–patellar tendon–bone harvest has resulted in rare cases of patellar fracture and patellar-tendon rupture. Some animal studies have shown significantly decreased patellar-tendon strength at 6 months after harvesting of the middle third of the patellar tendon. The clinical significance in humans remains to be shown.

Several studies have compared the incidence of anterior knee pain following ACL reconstruction using hamstring tendons and autograft or allograft patellar tendon.[10] Even with modern rehabilitation protocols, there is an increased incidence of anterior knee pain in patients receiving bone–patellar tendon–bone autografts. Whether this anterior knee pain is functionally significant has not been shown.

Table 2
Strength After Soft-Tissue Fixation to Bone[9]

Device	Maximum Tensile Strength, lb
Screw with washer	14
Barbed staple	11
Stone staple	8
Screw with plate	5

Variables that occur in individual patients may influence which autogenous graft source is appropriate. A history of patellar tendinitis or patellofemoral pain or the finding of a short, narrow patellar tendon may necessitate the use of another autogenous graft source. A previous pes anserinus transplant or inadequate size of the hamstring tendons may negate this source of graft material.

Surgical Technique

Appropriate surgical technique is very important in ensuring the proper function of the reconstructed ACL, as well as in decreasing wear and increasing its longevity. These factors are much more important than the type of graft tissue or whether an open or endoscopic technique is used for reconstruction.

It is clear that the normal anatomy of the ACL cannot be completely reproduced. It is of utmost importance that the graft be positioned in as near an anatomic position as possible that will permit a full range of motion, provide stability, and allow no impingement. This goal can be achieved through various means, either endoscopically or through an open technique (Fig. 4).

Femoral position can be achieved by routing the graft “over the top” or through a bony tunnel. If the over-the-top method is used, it is necessary to provide a 4- to 5-mm deepened groove to approximate the posterior attachment site of the ACL. Tunnel orientation and contour are important to avoid stress risers that may lead to increased wear and graft failure. Avoidance of impingement can be achieved by appropriate positioning of the graft on the tibial side and performing adequate notchplasty to avoid femoral impingement of the graft throughout a full range of motion. So-called isometric placement of the graft does not necessarily ensure that impingement will not occur.

Graft tensioning is important in achieving a successful ACL reconstruction. A graft that is too tight may lead to poor range of motion, and a graft that is too loose may lead to instability. It appears that a 5- to 8-lb pull is adequate to provide proper tensioning. Graft tension should be checked in different positions of knee flexion and extension intraoperatively.

Extra-articular Reconstruction

Wide variability exists in the reported results of extra-articular procedures to control ACL instability due to the multiplicity of indications and techniques. The consensus is that in the active individual, an extra-articular reconstruction will stretch out, especially if its purpose is to hold the tibia in external rotation.

Extra-articular reconstructions are used by some surgeons in the less active or older individual whose instability produces functional limitations in his or her normal activities. To be effective, the reconstruction must be anchored near the isometric point on the femoral condyle in relation to Gerdy’s tubercle. This point is just posterior to the superior attachment of the lateral collateral ligament. Proper attachment may allow the normal coupling of the anterior force on the tibia and the rotational forces to reduce abnormal subluxation of the lateral tibial plateau.

Most reports suggest that extra-articular procedures provide no benefit to augment intra-articular reconstructions.

Autografts and Allografts

Both experimental and clinical observations have shown that autografts undergo biologic and bioma-

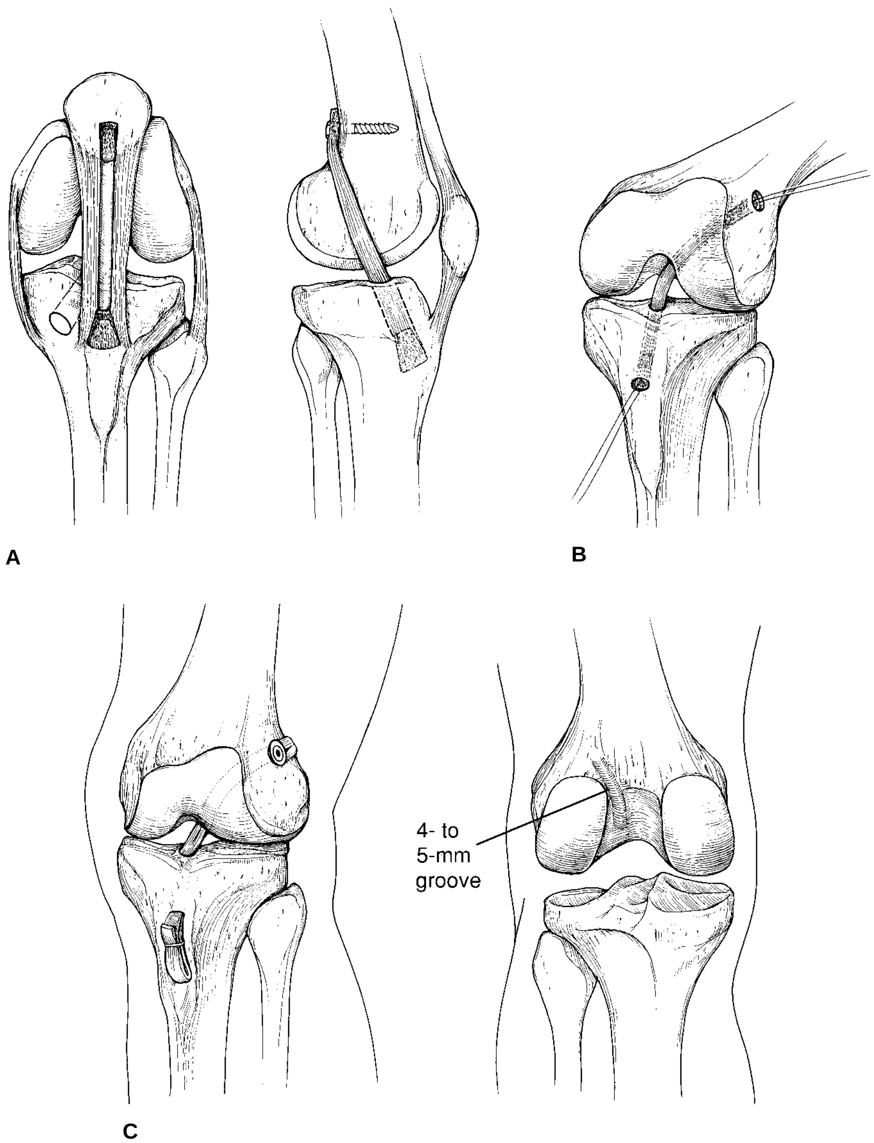

Fig. 4 Methods of reconstruction of the ACL. **A,** The patellar tendon is harvested and taken through a tibial drill hole and "over the top." **B,** Dual drill holes through the tibia and femur with interference-screw fixation of the bone plugs. **C,** A double loop of semitendinosus tendon is used as the graft and taken over the top of the femoral condyle laterally. Note the deepening of the groove to provide a near-"isometric" placement.

terial remodeling.[6] The biologic remodeling involves a process of tissue ischemia and cell death, revascularization, cellular proliferation, and eventual tissue remodeling. This is a gradual process, which may take 6 months or more. The biomaterial-remodeling process never yields a tissue that is as strong as it was originally. Allografts have been shown to undergo a similar, albeit slower, remodeling process. Both autografts and allografts are weakest at 6 to 12 weeks.

Deep-freezing and freeze-drying have been shown to be effective methods for rendering allografts less antigenic, probably by killing cells and denaturing the histocompatibility antigens on their surface. This process does not appear to alter the biomaterial properties of the graft.

Secondary methods of sterilization, such as the use of ethylene oxide and gamma radiation, have been used to treat the graft for bacterial and viral contamination. These procedures have been associated with alterations in graft properties and a marked inflammatory response when ethylene oxide was used.

The advantage of an early decrease in morbidity when using an allograft may be attractive to some, but there is little evidence that the long-term results are better than those associated with the use of autogenous tissues. Therefore, this advantage must be weighed against the possible risks of using an allograft.

Prosthetic Ligaments

Augmentation of autogenous tissue has been proposed as a method of increasing the initial tensile strength of the graft, as an enhancement to fixation, and as a means of providing increased length when necessary.[11] The hypothesis is that with a composite graft of autogenous and synthetic material, the stiffer material will carry most of the load. During the early phases of postoperative healing, the tensile strength of the autogenous tissue is markedly compromised as it revascularizes and new collagen is being formed. The synthetic material assumes a load-sharing function with the autogenous tissue during this time period. Fixation of the synthetic material at one end only prevents the autogenous tissue from being stress shielded, which would diminish its later capacity to develop tensile strength. The cost of the synthetic devices used for augmentation and the reported results suggest that their use should be limited to specific indications, such as the presence of weak tissue or the need for enhancement of length or fixation.

The use of a synthetic material as a true prosthetic device for ACL replacement has certain limitations that must be recognized. First and foremost is that the device is ultimately going to fail. Fatigue, fraying, and wear have resulted in an unacceptably high rate of failure. Thus, it is our opinion that prosthetic replacement of the ACL has limited applications (e.g., as a salvage procedure in a patient who has undergone multiple attempts at ACL reconstruction).

Rehabilitation

Postoperative rehabilitation has emerged as an extremely important aspect of the care of the ACL-deficient patient. Previously, rehabilitation of the ACL-reconstructed knee focused on protection of the new ligament, with blocking of full extension and avoidance of active quadriceps function in the terminal degrees of extension. These precautions led to stiffness, weakness, and patellofemoral problems.

Recently, Shelbourne and Nitz[12] advocated an accelerated rehabilitation protocol. The objective of their protocol remains early and long-term maintenance of full knee extension as measured by the ability of the ACL-reconstructed knee to extend as much as the opposite normal knee. This protocol was based on the use of a central-third bone–patellar tendon–bone graft. The exact method of attaining the different goals of rehabilitation may vary depending on the graft used and the type of fixation, but the principles are similar. Shelbourne and Nitz divided their accelerated rehabilitation program into four phases:

Phase I: Preoperative Period

The goal is to obtain full range of motion compared with the normal knee. At this time, the patient may be educated about the details of the operative procedure and the postoperative rehabilitation program.

Phase II: 0 to 2 Weeks After Surgery

The goals are to achieve full extension, allow wound healing, maintain adequate quadriceps control, minimize swelling, and achieve flexion of 90 degrees. Full extension must be achieved early, or the notch may fill in with scar tissue and cause a permanent block to extension.

Phase III: 3 to 5 Weeks After Surgery

The goals in this phase are to maintain full extension and increase flexion up to full range of motion. Exercises such as knee bends, StairMaster use, and bicycling may be performed.

Phase IV: 6 Weeks After Surgery

The goal is to maintain motion and gradually increase strength and agility depending on the patient's progress and desire to return to sports activities. Increased strength and agility are best achieved by using closed-chain weight-bearing exercises.

ACL Injury in the Immature Athlete

Traditionally, ACL injuries in the immature athlete have been thought to be predominantly tibial-eminence avulsion fractures. Treatment of these injuries has been well understood. Nondisplaced and minimally displaced fractures are treated with closed reduction, and displaced fractures are treated with open reduction and internal fixation that does not violate the growth plate.

Recently, there appear to be an increasing number of midsubstance ACL tears in immature athletes. This may be due to improved diagnostic testing or increasing participation in competitive athletics by skeletally immature athletes.

McCarroll et al[13] studied adolescent athletes with open or closing epiphyses who sustained an ACL injury. Forty-two percent were able to return to their original sport, but all complained of "giving way" in spite of bracing and a rehabilitation program. At follow-up, 50% were found to have meniscal tears. Reconstruction of the ACL was done at the age of 13 to 16 years, and 92% of patients were able to return to their original sport. No abnormal growth as a result of damage to the growth plate from the intra-articular reconstruction was reported.

Preservation of the menisci is the primary goal in treatment of these patients. For the prepubescent child with wide-open physes, an initial course of rehabilitation with avoidance of activities that would cause meniscal damage is the initial goal. This would allow passage through the growth spurt and closing of the physis, at which time ACL reconstruction could be done safely.

Complications of ACL Surgery

General complications such as anesthetic mortality must always be kept in mind, but are rare in this usually young, healthy population. The surgeon should be ever mindful of the possibility of fluid extravasation and compartment syndrome when performing endoscopic techniques. As with other surgery on the knee, deep venous thrombosis and infection are also possible.

Reflex sympathetic dystrophy has been reported to be associated with knee trauma and ACL surgery. The incidence has generally been less than 1%.

Nerve and vascular injury can occur with ligamentous surgery, although the incidence is less than 1%. A careful neurovascular examination performed at the initial evaluation would obviate suspicion of its having been surgically incurred.

Flexion contracture, quadriceps weakness, and patellar irritability are the most frequent problems after ACL reconstruction.

Joint Stiffness

Proper surgical techniques and rehabilitation help reduce the incidence of joint stiffness. A knee with a significant flexion contracture represents a greater impairment than an ACL-deficient knee. The term "arthrofibrosis" has been used to describe the knee stiffness that develops following ACL reconstruction. The pathophysiology has been shown to be inflammation of the fat pad and synovium followed by thickening of the capsule, which obliterates the suprapatellar pouches and medial and lateral gutters. The patellar tendon becomes shortened and may produce patella baja and articular damage.

The patient presents with the inability to regain motion, quadriceps weakness, marked decreased patellar mobility, and some skin and soft-tissue changes. Paulos et al[14] have defined three stages: stage 1 (early stage [2 to 6 weeks]), with findings of decreased extension, quadriceps lag, swelling, failure to progress in physiotherapy, and decreased patellar mobility; stage 2 (active stage [6 to 30 weeks]), with findings of marked decrease in range of motion, quadriceps atrophy, decreased patellar motion, osteopenia, skin changes, and significant limp; and stage 3 (residual stage [more than 8 months]), with findings of rigid patella, markedly decreased range of motion, osteopenia, quadriceps atrophy, patella baja, and possible arthrosis.

The initial treatment for all stages includes aggressive physiotherapy, anti-inflammatory agents, and patellar mobilization. In stage 2, arthroscopic debridement and dynamic splinting may be beneficial. Stage 3 usually requires open debridement. This consists of medial and lateral capsular incisions with freeing of the suprapatellar adhesions as well as those in the medial and lateral gutters. The patellar tendon is identified, and all scar tissue posterior to it is excised. If the ACL graft is placed too far anteriorly and is preventing full extension, this too must be excised. It is extremely unlikely that the arthrofibrotic knee will ever again be unstable. Adequate pain control and aggressive rehabilitation must be employed postoperatively.

Graft impingement has been shown to block full extension and is related to inadequate notchplasty and incorrect placement of the tibial tunnel too far anteriorly.[15] The position of the graft in full extension should always be checked intraoperatively to avoid impingement.

Graft Donor-Site Complications

Late patellar fracture has been reported, and it is postulated that this is a stress fracture due to decreased vascularity to the patella. Intraoperative patellar fracture may also occur during harvesting of the patellar graft. Avulsion of the inferior pole of the patella has also occurred rarely.

Patellofemoral morbidity occurs more frequently with bone–patellar tendon–bone grafts than with hamstring autografts.

Summary

It is clear that the management of ACL injuries is complex and continues to evolve. Surgical techniques of ACL reconstruction require proper placement and tensioning, avoidance of impingement and stress risers on the implanted tissue, and adequate fixation. Biochemical and enzymatic changes occur in a knee joint after injury and with the alteration of normal mechanics. These changes alter articular cartilage function and may affect the success of knee ligament surgery. Degenerative changes in an injured knee are not necessarily prevented by restoration of ligament stability. The presence or absence of the menisci seems to have the greatest effect in protecting the knee from wear changes. The answers to many questions remain to be shown in carefully designed prospective, randomized, long-term outcome studies comparing techniques of treatment.

References

1. Grood ES, Noyes FR: Diagnosis of knee ligament injuries: Biomechanical precepts, in Feagin JA Jr (ed): *The Crucial Ligaments: Diagnosis and Treatment of Ligamentous Injuries About the Knee.* New York: Churchill Livingstone, 1988, pp 245-260.
2. Noyes FR, Butler DL, Grood ES, et al: Biomechanical analysis of human ligament grafts used in knee-ligament repairs and reconstruction. *J Bone Joint Surg Am* 1984;66:344-352.
3. Graf BK, Cook DA, De Smet AA, et al: "Bone bruises" on magnetic resonance imaging evaluation of anterior cruciate ligament injuries. *Am J Sports Med* 1993;21:220-223.
4. Daniel DM: Principles of knee ligament surgery, in Daniel DM, Akeson WH, O'Connor J (eds): *Knee Ligaments: Structure, Function, Injury, and Repair.* New York: Raven Press, 1990, pp 11-29.
5. Daniel DM, Stone ML, Dobson BC, et al: Fate of the ACL injured patient: A prospective outcome study. Presented at the Annual Meeting of the American Orthopaedic Society of Sports Medicine, Sun Valley, Idaho, July 12, 1993.
6. Amiel D, Kuiper S: Experimental studies on anterior cruciate ligament grafts:

Histology and biochemistry, in Daniel DM, Akeson WH, O'Connor J (eds): *Knee Ligaments: Structure, Function, Injury, and Repair.* New York: Raven Press, 1990, pp 379-388.

7. Burger RS, Larson RL: Acute ligamentous injury, in Larson RL, Grana WA (eds): *The Knee: Form, Function, Pathology, and Treatment.* Philadelphia: WB Saunders, 1993, pp 514-598.
8. 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.
9. Robertson DB, Daniel DM, Biden E: Soft tissue fixation to bone. *Am J Sports Med* 1986;14:398-403.
10. Sachs RA, Daniel DM, Stone ML, et al: Patellofemoral problems after anterior cruciate ligament reconstruction. *Am J Sports Med* 1989;17:760-765.
11. Larson RL: Prosthetic replacement of knee ligaments: Overview, in Feagin JA Jr (ed): *The Crucial Ligaments: Diagnosis and Treatment of Ligamentous Injuries About the Knee.* New York: Churchill Livingstone, 1988, pp 495-506.
12. Shelbourne KD, Nitz P: Accelerated rehabilitation after anterior cruciate ligament reconstruction. *Am J Sports Med* 1990;18:292-299.
13. McCarroll JR, Rettig AC, Shelbourne KD: Anterior cruciate ligament injuries in the young athlete with open physes. *Am J Sports Med* 1988;16:44-47.
14. Paulos LE, Rosenberg TD, Drawbert J, et al: Infrapatellar contracture syndrome: An unrecognized cause of knee stiffness with patella entrapment and patella infera. *Am J Sports Med* 1987;15:331-341.
15. Howell SM, Taylor MA: Failure of reconstruction of the anterior cruciate ligament due to impingement by the intercondylar roof. *J Bone Joint Surg Am* 1993;75:1044-1055.