CHAPTER 46

Revision Anterior Cruciate Ligament Surgery

Eric W. Carson and Charles H. Brown, Jr.

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Reconstruction of the anterior cruciate ligament (ACL) is one of the most commonly performed orthopedic operations. According to the National Center of Health Statistics, in 1991 approximately 63,000 ACL reconstructions were performed in the United States. Current industry estimates are that over 100,000 ACL reconstructions are performed annually in the United States. The importance of the ACL in the maintenance of normal knee function is now well accepted. An untreated ACL tear can lead to recurrent giving-way episodes and damage to the menisci and articular cartilage, with potential progression to osteoarthritis (1–7). Within the literature, because of the poor long-term results of nonoperative treatment, primary repair, and extraarticular reconstruction, intraarticular ACL reconstruction has become the surgical procedure of choice (8–25). The success rate of primary intraarticular ACL reconstruction has been reported to range from 75% to 93% good or excellent results with respect to relief of giving-way symptoms, restoration of functional stability, and return to normal or near-normal activity levels. Given the reported success rates, a significant number of patients are left with less than satisfactory clinical outcome (26–29). What qualifies as an unsatisfactory clinical result or "failure" after ACL reconstruction, however, has not been well defined or agreed upon. Johnson and Fu (30) have defined a failed ACL reconstruction as a knee that demonstrates recurrent pathologic laxity or a stable knee that has a range of motion of 10 to 120 degrees. This lack of motion is often painful and creates a functional deficit in activities of daily living. Failed ACL surgery can be classified into one of the following four categories, which may overlap in some cases:

- Loss of motion or arthrofibrosis
- Extensor mechanism dysfunction
- Arthritis
- Recurrent pathologic laxity

The next section provides the details with regard to the etiology of failed ACL reconstruction.

ETIOLOGY OF FAILED ANTERIOR CRUCIATE LIGAMENT SURGERY

Loss of Motion

Loss of motion is the most common complication after knee ligament surgery (31–33,154). The incidence of loss of motion after ACL surgery has been reported to range from 5.5% to 24% (33–35). In recent years, the incidence of loss of motion after ACL reconstruction has dramatically decreased. This can be directly attributed to the surgeon's choice of delaying ACL surgery and instituting immediate postoperative motion. Surgical intervention in the setting of an acutely injured knee that is highly inflamed further stimulates the inflammatory process and further compromises the range of motion. Delaying the ACL reconstruction allows the patient's knee to settle down and regain the full range of motion, and avoids such a disaster. Second, initiation of immediate postoperative motion with emphasis on full extension, patellar mobilization, early quadriceps exercises, and immediate weightbearing has been shown to reduce the incidence of loss of motion (22,33,34). Loss of motion can involve extension or flexion or both. Loss of flexion rarely causes functional problems unless the knee fails to flex to at least 120 degrees (34). Loss of flexion primarily interferes with activities such as running, stair climbing, squatting, kneeling, and sitting. Loss of extension is typically more disabling than loss of flexion. Patients with a loss of extension tend to ambulate with an abnormal bent-leg gait pattern. The sequelae of this abnormal gait pattern lead to and perpetuate anterior knee pain and quadriceps muscle weakness. Such a functional deficit can be very detrimental with regard to not only sporting activities but also activities of daily living. Prevention and early diagnosis are the mainstays in avoiding this pitfall of ACL surgery (33,36).

When revision ACL surgery is considered, correct identification of the cause of the loss of motion is critical so that a logical treatment plan can be formulated. The cause of the loss of motion is multifactorial and includes problems such as notch impingement (33,34,37,38), capsulitis (33), concomitant ligament surgery (39,40), and errors in surgical technique (41–46), immobilization (47,48), reflex sympathetic dystrophy, and infection. Obtaining a thorough history and performing a detailed physical examination often identifies the culprit to explain the loss of motion.

Impingement is the direct result of a physical block in the intercondylar notch that prevents full extension of the knee. Impingement can be caused by intercondylar notch scarring (the cause in approximately 50% of the cases), a "cyclops" lesion (49), an anteriorly placed ACL graft, or an inadequate notchplasty (27,34). In the early stages, treatment consists of serial extension casting or use of a dropout cast and quadriceps strengthening exercises (34,50). Surgical intervention is usually necessary in the later stages of the disease process and consists of arthroscopic débridement of the tissue impinging in the notch and revision notchplasty, followed by serial extension casting or use of a dropout cast before a revision ACL reconstruction (51,52) (Fig. 1).

Nonanatomic graft placement is often accompanied by a loss of motion. In these cases a maximal painless range of motion should be restored before considering revision ligament surgery. Therefore, a staged approach is required in most cases, in which the nonanatomic graft may require arthroscopic débridement followed by manipulation to obtain full range of motion. Postoperatively the emphasis is on obtaining a painless functional range of motion. In many cases, revision ligament surgery is not necessary, for residual instability is minimal. If instability is present after a full rehabilitation program has been completed and full painless range of motion has been regained, then and only then should a revision ACL be performed (Fig. 2).

Capsulitis is defined as periarticular inflammation and swelling, and results in the development of adhesions and intraarticular scar formation. Capsulitis typically causes a loss of both flexion and extension, and also results in a restriction of patellar mobility. The loss of extension and decrease in patellar mobility can lead to quadriceps weakness with loss of pull through the extensor mechanism. If unrecognized and untreated, the loss in pull through the extensor mechanism may lead to an adaptive shortening of the patellar tendon, patella baja, and the development of an infrapatellar contracture syndrome.

Capsulitis can be either primary or secondary. Primary capsulitis is defined as an exaggeration of the normal inflammatory process caused by surgery or trauma. Primary capsulitis is a diagnosis of exclusion after secondary causes have been eliminated. Secondary causes of capsulitis include surgery performed during the acute inflammatory stage after injury, improper surgical technique, and postoperative immobilization or restriction of motion. Secondary capsulitis can be prevented by appropriate timing of surgery, proper surgical technique, immediate initiation of motion, early use of quadriceps muscle exercises, patellar mobilization, and early weightbearing after surgery (33). Patients with capsulitis usually complain of constant pain and stiffness. Examination generally demonstrates an actively inflamed and diffusely swollen knee, a quadriceps lag, a loss of more than 10 degrees of extension and 25 degrees of flexion, and limited patella mobility.

Treatment of capsulitis depends on the stage of the process. In the early stages of the disease process, the goals of treatment are to reduce pain and inflammation, and to restore motion and quadriceps strength. Aggressive forceful manipulations should be avoided during this stage, as they may further stimulate the inflammatory process. Cryotherapy, antiinflammatory medications, gentle stretching exercises, and overnight splinting in extension are prescribed. Once the inflammation of the knee has receded and the patient has entered the fibrotic phase of the disease process, arthroscopic débridement and lateral release should be considered. A more advanced phase of capsulitis is the infrapatellar contracture syndrome (32,38,50,51). If the disease progresses to this stage, arthroscopic débridement is not adequate, and open débridement and open capsular releases are usually required to restore a functional range of motion (50,51).

Extensor Mechanism Dysfunction

Dysfunction of the extensor mechanism in an otherwise stable knee can also lead to failure of the original ACL reconstruction. Extensor mechanism dysfunction includes anterior knee pain, quadriceps muscle weakness, patellar tendinitis, problems secondary to graft harvesting (patellar fracture, extensor mechanism rupture, donor site pain), and the infrapatellar contracture syndrome (39,41,44,45,47,48,53–61). As mentioned earlier, there is often an overlap between loss of motion and extensor mechanism dysfunction (Fig. 3).

Anterior knee pain is one of the most common complications after ACL reconstruction (35,53). The incidence of anterior

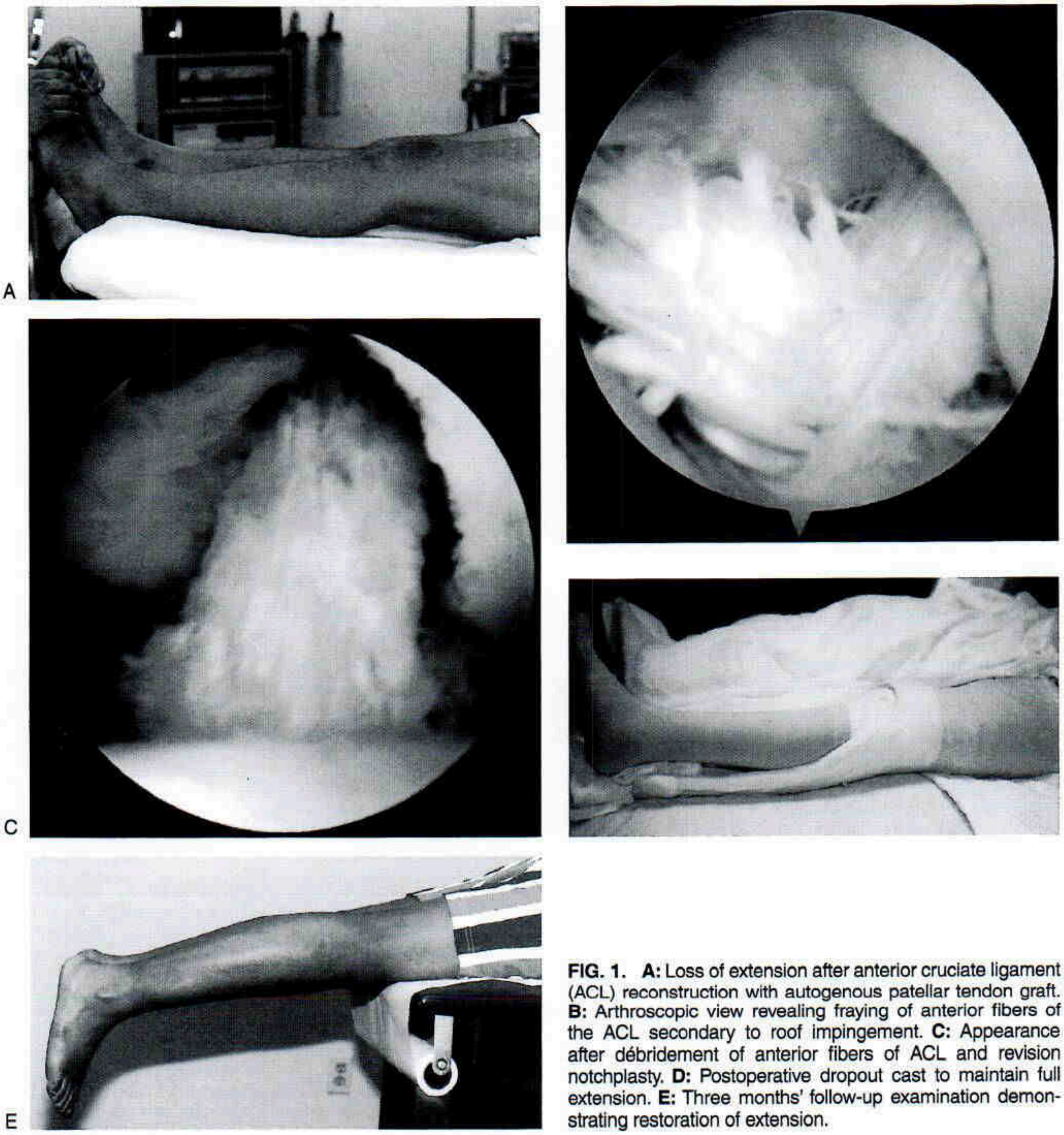


FIG. 1. **A:** Loss of extension after anterior cruciate ligament (ACL) reconstruction with autogenous patellar tendon graft. **B:** Arthroscopic view revealing fraying of anterior fibers of the ACL secondary to roof impingement. **C:** Appearance after débridement of anterior fibers of ACL and revision notchplasty. **D:** Postoperative dropout cast to maintain full extension. **E:** Three months' follow-up examination demonstrating restoration of extension.

knee pain after ACL reconstruction has been reported to range from 3% to 47% (9,11,12,19,21,35,52,53,61). The large variations in incidence reported in various clinical studies reflect differences in the preoperative status of the patellofemoral joint, ACL graft source, surgical technique, postoperative rehabilitation, and the criteria used to define the problem. The cause of anterior knee pain after ACL reconstruction is multifactorial. Reported risk factors include a history of preoperative anterior knee pain, preexisting articular cartilage injury to the patellofemoral joint, ACL graft source (patellar tendon), improper surgical technique, graft impingement, flexion contracture, and aggressive use of open-chain exercises (35,53,61,62). Improvements in surgical technique and preoperative and postoperative rehabilitation have significantly reduced the incidence of anterior knee pain after ACL reconstruction.

Extensor mechanism dysfunction associated with sequelae of the harvest of the bone–patellar tendon–bone autograft, such as patellar fracture, extensor mechanism rupture, patellar tendinitis, and anterior knee pain secondary to abnormalities of patellar tracking or contracture of the extensor mechanism, are usually manifested during the first year after surgery (9,19,63–65). Fortunately, many of these complications can be prevented by

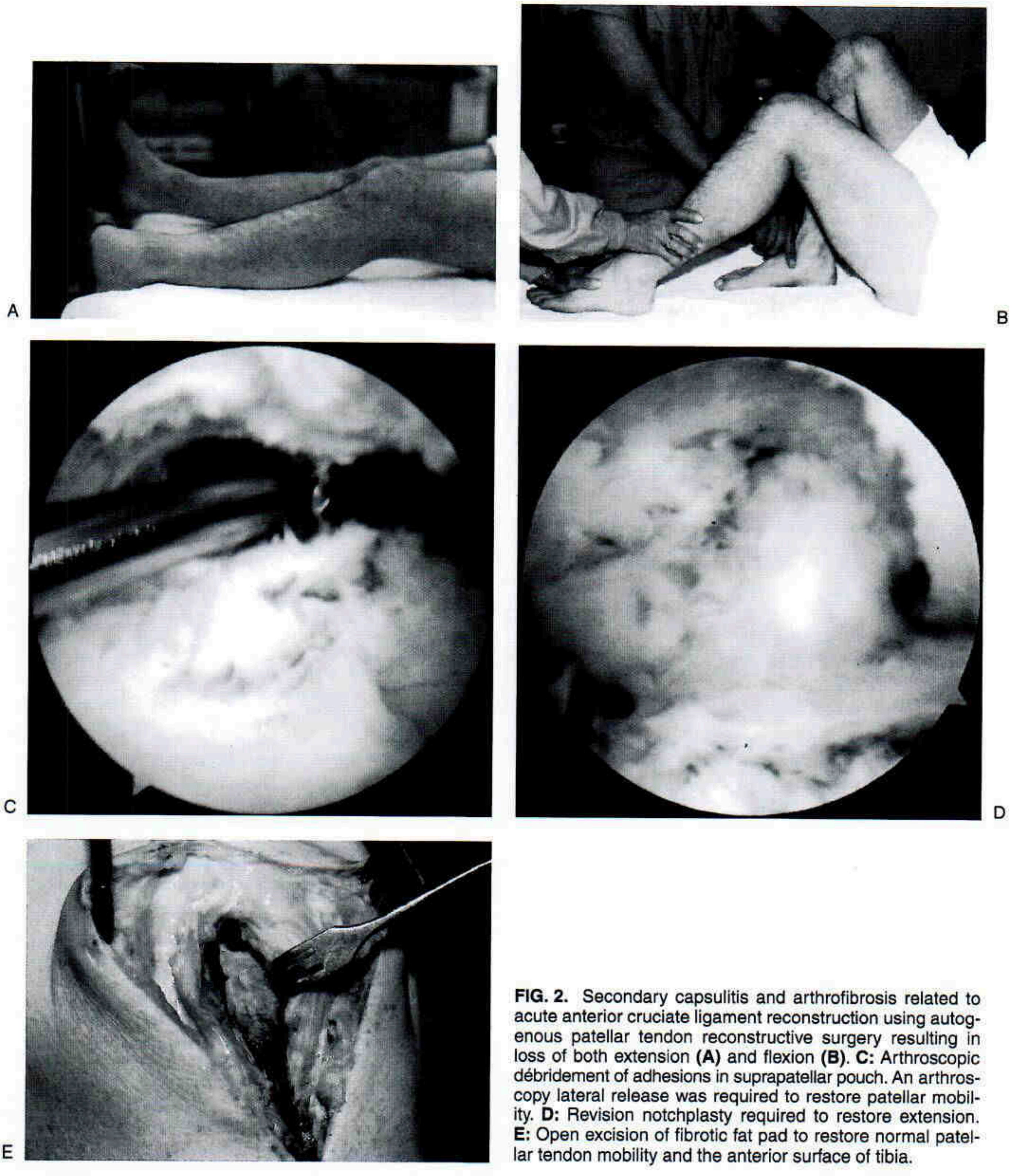


FIG. 2. Secondary capsulitis and arthrofibrosis related to acute anterior cruciate ligament reconstruction using autogenous patellar tendon reconstructive surgery resulting in loss of both extension **(A)** and flexion **(B)**. **C:** Arthroscopic débridement of adhesions in suprapatellar pouch. An arthroscopy lateral release was required to restore patellar mobility. **D:** Revision notchplasty required to restore extension. **E:** Open excision of fibrotic fat pad to restore normal patellar tendon mobility and the anterior surface of tibia.

proper surgical technique, bone grafting of the patella defect and protection of the patellar harvest site, emphasis on immediate full knee extension, patellar mobilization, prevention of quadriceps muscle shutdown, and avoidance of early open-chain exercises (22,35,66,67). In light of all of the information regarding the use of autogenous patellar tendon grafts, selection of an alternative ACL graft such as an allograft (patellar tendon, Achilles tendon, and tibialis anterior tendon) or autogenous hamstring tendon graft in high-risk patients may decrease the incidence of complications.

A

B

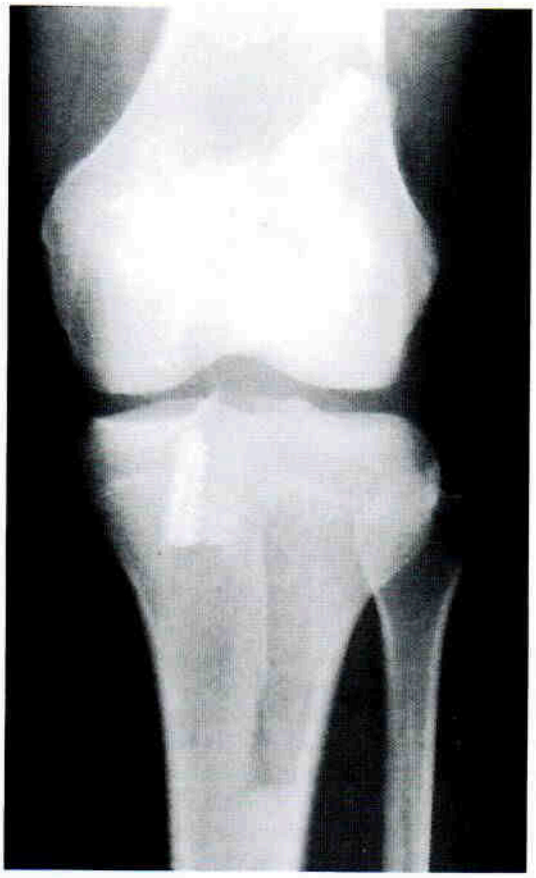


FIG. 3. A, B: Intraoperative patellar fracture treated with internal fixation.

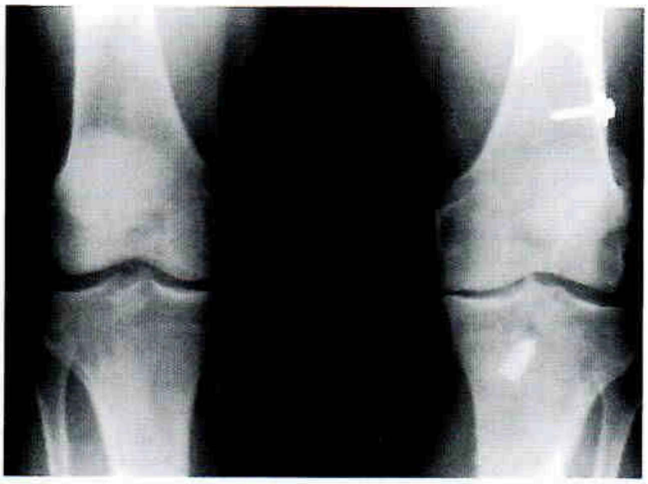


FIG. 4. Subtotal meniscectomy was performed before anterior cruciate ligament reconstruction. After anterior cruciate ligament reconstruction, the patient had full range of motion, showed normal anteroposterior laxity, and no longer complained of instability; however, the patient was unable to return to the pre-injury sports level because of recurrent swelling and medial compartment pain.

Arthritis

One of the goals of ACL reconstruction is to prevent or delay the development of osteoarthritis. The development of osteoarthritis after ACL reconstruction is related to many factors, including injury to the articular cartilage (156) and meniscal injury (153) sustained at the time of the initial traumatic event or instability secondary to previous meniscectomy; damage to secondary restraints from repeated giving-way episodes before surgery all lead to abnormal knee biomechanics (2) (Fig. 4).

At the time of the initial traumatic injury to the ACL, other structures are often damaged. In approximately 80% of acute ACL injuries, bone bruises are present (68,69). These injuries typically occur at the anterior aspect of the lateral femoral condyle and the posterolateral aspect of the lateral tibial plateau. Bone bruises are thought to represent trabecular microfractures from blunt trauma and may result not only in injury to the bone marrow but also injury to the overlying articular cartilage. Although the articular cartilage may not appear to be visibly damaged, a bone bruise may lead to changes to the articular cartilage at the biochemical, histologic, and ultrastructural level. These changes may result in future cartilage degeneration even after a successful ACL reconstruction.

Whether the onset or progression of osteoarthritis after an otherwise successful ACL reconstruction should result in classification of the ACL reconstruction as a failure is controversial. Many of the preexisting conditions that may contribute to the development of osteoarthritis cannot be expected to be corrected by an ACL reconstruction, and therefore the final knee rating may not reflect the actual result of the ACL reconstruction (52,70). In a patient with recurrent instability and pain secondary to articular cartilage damage, it is important to determine which of these two symptoms is the primary complaint. The treatment algorithms for these two specific symptoms are very different though some overlap exists. Performing revision ligament surgery in a patient whose primary complaint is pain will likely result in continued symptoms and an unsatisfactory outcome. For such a patient, consideration of a high tibial osteotomy (HTO) as a separate procedure or in conjunction (staged or simultaneously) with revision ACL may be indicated. Recent papers by Williams et al. (74) attempt to address these difficult situations.

Recurrent Pathologic Laxity (Graft Failure)

The incidence of graft failure after primary ACL reconstruction has been reported to range from 0.7% to 8% (16,28,63, 71,72). The patient with recurrent pathologic laxity usually presents with instability symptoms similar to those experienced before the primary reconstruction. The University of Pittsburgh has developed a classification system in an attempt to define factors that can lead to recurrent pathologic laxity after primary ACL reconstruction (29,70). In this classification system, the three general categories responsible for graft failure are

FIG. 5. A: Loss of flexion secondary to nonanatomic graft placement. **B:** Anterior placement of the femoral tunnel.

1. Surgical technical errors
2. Failure of graft incorporation
3. Traumatic reinjury

To maximize the chances for success and to avoid repeating errors that led to failure of the primary ACL reconstruction, it is important to identity the cause of graft failure before undertaking revision ACL surgery.

MECHANISMS OF GRAFT FAILURE

Errors in Surgical Technique

Nonanatomic graft placement is the most common surgical error responsible for failure of the primary ACL graft (28,29,73,74). An improperly positioned femoral or tibial tunnel will result in excessive length changes of the ACL graft as the knee moves through a range of motion. Because biologic ACL grafts can accommodate only small changes in length before plastically deforming, improper graft placement results in the graft's stretching and becoming lax with time, which leads to recurrent pathologic laxity and instability (4,5). Alternatively, the graft functions as a check rein and captures the knee, which results in a loss of motion. Either one of these situations may result in failure of the ACL reconstruction.

Small changes in the position of the femoral tunnel compared to the tibial tunnel have a profound effect on graft length-tension relationships because the femoral attachment site is close to the axis of rotation of the knee (75,76). Anterior placement of the femoral tunnel is the most common error in surgical technique (29,74,77) (Fig. 5A, B). Incorrect anterior placement of the femoral tunnel is most often caused by the surgeon's failure to adequately visualize the "over-the-top" position and referencing off "resident's ridge." Anterior placement of the femoral tunnel and fixation of the graft between 0 and 30 degrees of extension results in the graft's lengthening and developing increased tension as the knee is flexed (78). This leads to one of two scenarios: (a) eventual stretching of the ACL graft with the development of recurrent pathologic laxity, or (b) loss of flexion with increased stress on the articular surfaces and pain on range-of-motion movements.

Placement of the tibial tunnel was originally thought to be of less importance to the success of ACL surgery; however, it has subsequently been shown to have a profound effect on the clinical results of ACL reconstruction (17,26,27,79). Placement of the tibial tunnel in the eccentric anteromedial position as described by Clancy et al. (15) has been shown to cause impingement of the ACL graft against the roof of the intercondylar notch as the knee is extended (Fig. 6). The clinical manifestations of graft impingement include an effusion, loss of extension, and progressive graft failure (17,26,27,79). A lateral radiograph taken with the knee in maximum hyperextension or a magnetic resonance imaging (MRI) scan through the sagittal plane of the ACL graft or both can be helpful in demonstrating the presence of graft impingement (26,27). Graft impingement can be avoided by positioning the tibial tunnel posterior to the slope of the intercondylar roof with the knee in maximum hyperextension (26,42,43,79). In most knees, an impingement-free tibial tunnel can be produced by positioning the center of the tunnel at the junction of the middle and posterior third of the ACL footprint (77). Knees that have a vertical intercondylar roof or significant hyperextension require placement of the tibial tunnel in a more posterior location or

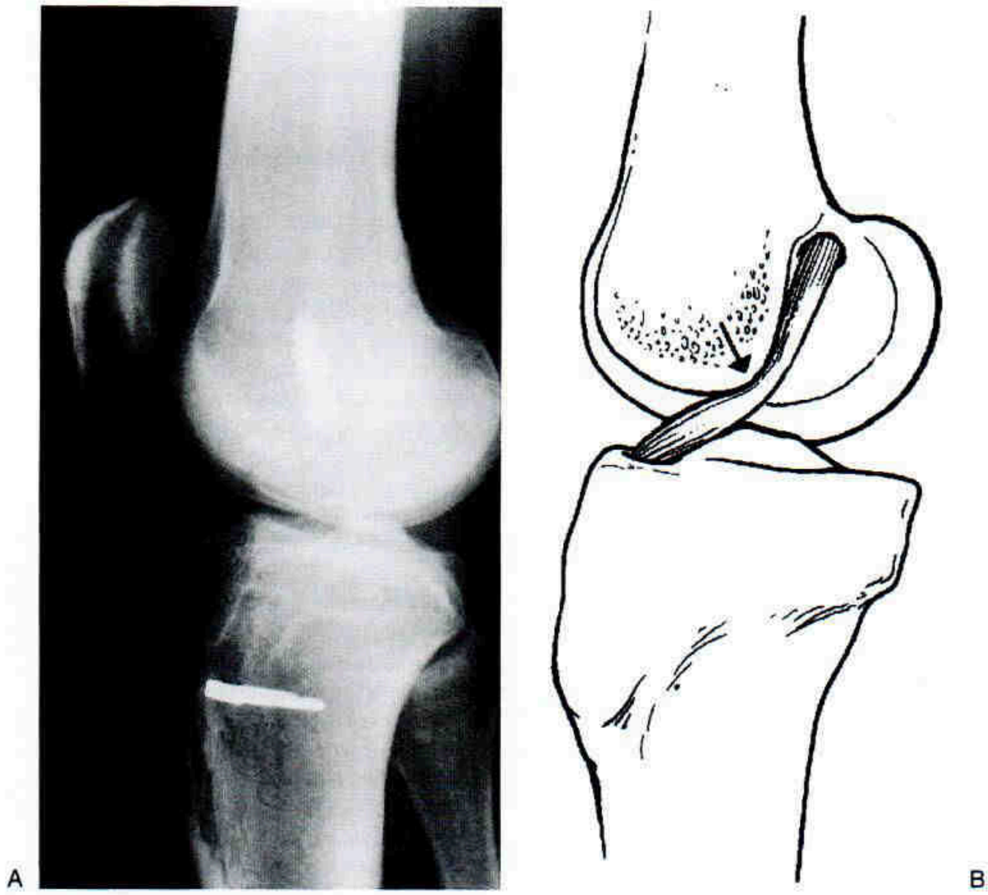


FIG. 6. A, B: Anterior placement of the tibial tunnel results in premature contact of the anterior cruciate ligament graft with the intercondylar notch as the knee extends. This results in a loss of extension or anterior cruciate ligament graft failure.

removal of bone from the roof of the intercondylar notch, or both, to avoid graft impingement in extension (17,42,43). Too posterior a placement of the tibial tunnel, however, can result in excessive laxity of the ACL graft in flexion or a vertically oriented graft that will experience higher tensile forces and is biomechanically less effective in resisting anterior translation of the tibia. Other situations, which occur less frequently, include malposition of the tibial tunnel in the medial and lateral planes. Too medial a placement of the tibial tunnel can result in damage to the articular cartilage of the medial tibial plateau and impingement of the graft against the posterior cruciate ligament (Fig. 7). Too lateral a placement can result in impingement of the graft against the medial aspect of the lateral femoral condyle (Fig. 8).

Inadequate Notchplasty

The amount of intercondylar notchplasty that should be performed continues to be debated. Thought processes have evolved with regard to the size of the notchplasty. In the past, aggressive notchplasty was performed to visualize the over-the-top position (80,139). Some surgeons now are advocating minimal to no notchplasty (17,26,27,79). Follow-up studies have shown the notch to grow back over an 18- to 24-month period (80). Most ACL replacement grafts are larger than the size of the original ACL. When a large graft is placed in a small notch, the graft will impinge against the roof of the intercondylar notch or the inner wall of the lateral femoral condyle or both. Impingement has been shown to lead to gradual attrition of the ACL graft and eventual graft failure (27). Impingement can also compromise the biologic incorporation of the graft (81).

Incorrect Graft Tension

The optimal intraoperative tension that should be applied to the ACL graft is unknown (1,78,82–84). Optimal graft tension depends on a number of factors, including the amount of preoperative native laxity, the type of graft used, graft placement, the type of graft fixation used, and the knee flexion angle at the time of graft fixation (78). Because ACL grafts do not tighten with time, undertensioning of the graft will result in residual pathologic laxity. Therefore, it is important that the ACL graft be fixed under adequate tension at the time of implantation. Overtensioning of the graft, however, has been associated with delayed graft incorporation, myxoid degeneration, decreased graft strength, and overconstraint of the joint (83). Overconstraint of the joint may result in a loss of joint motion or increased joint contact pressures or both, which may accelerate joint wear and lead to osteoarthritis (83,84).

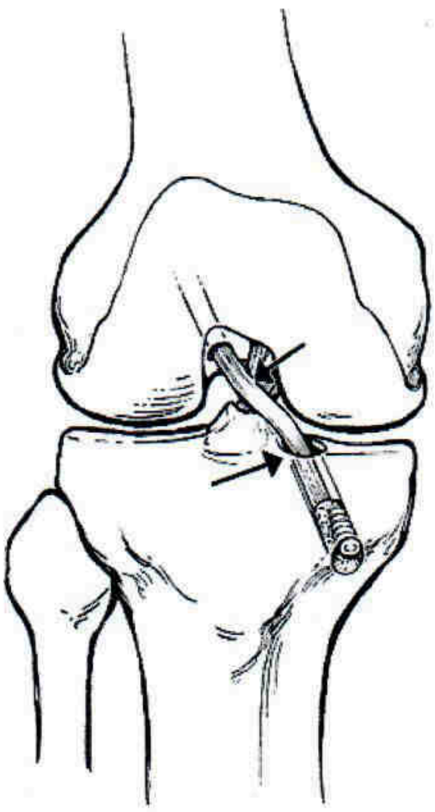


FIG. 7. Too medial a placement of the tibial tunnel can result in damage to the articular cartilage of the medial tibial plateau and impingement of the anterior cruciate ligament graft against the posterior cruciate ligament.

Inadequate Graft Fixation

Graft fixation strength depends on the type of graft, the type of fixation device used, and bone quality at the fixation sites. The initial graft fixation must be secure enough to prevent graft elongation at the graft fixation sites until the fixation sites are healed (85). Interference screw fixation has been demonstrated to be the strongest and stiffest fixation method for patellar tendon grafts (85). Potential pitfalls of interference screw fixation, however, include graft-tunnel mismatch, nonparallel or divergent screw placement, bone block fracture, graft laceration, laceration of the tensioning sutures, and loss of fixation in osteopenic bone (14,31,86,133). If unrecognized at the time of the primary ACL reconstruction, any of the aforementioned conditions could compromise graft fixation strength and lead to an early failure of the ACL reconstruction.

Fixation techniques for hamstring tendon grafts have continued to evolve with their increased usage. The biomechanical strength of these newer fixation methods is reported to equal or exceed that of patellar tendon grafts fixation with interference screws (87). The basic science of soft tissue fixation and long-term clinical results for newer hamstring techniques are yet to be substantiated. Aggressive rehabilitation of a hamstring ACL reconstruction in which a more compliant type of fixation has been used (sutures tied around a post or biologic interference screw) could result in excessive graft elongation and early graft failure. Regardless of the type of graft and the method of fixation used, the graft fixation device must be properly inserted and must prevent loss of the graft tension initially applied until the fixation sites heal.

Failure to Recognize or Address Associated Instabilities

Failure to recognize or surgically treat secondary restraints to anterior tibial translation can subject the newly reconstructed ACL to increased tensile forces, which may result in graft failure. In studies by Johnson et al. (29,30,70), failure to diagnose and address associated ligamentous instability at the time of the primary ACL reconstruction was the cause of failure in 15% of the failed ACL reconstructions.

Posterolateral instability [lateral collateral ligament (LCL), posterolateral capsule, arcuate ligament complex, and popliteus] is probably the most common unrecognized and untreated associated pathologic laxity. Gersoff and Clancy (55) have estimated that associated posterolateral laxity is present in 10% to 15% of chronically ACL-deficient knees. Untreated posterolateral instability may result in continued complaints of the knee's "giving way backwards" due to increased hyperextension and varus recurvatum (88). Increased external tibial rotation at 30 degrees of flexion or an increase in external tibial rotation of more than 10 degrees compared to the opposite side has been shown to be the most sensitive test for injury to the posterolateral structures (88). Findings on clinical examination of posterolateral instability in the ACL-deficient knee must be addressed at the time of ACL reconstruction. Posterolateral instability may result in failure of the ACL reconstruction secondary to the excessive tensile forces placed on the ACL graft as a result of the tendency for the knee to go into hyperextension and lateral joint opening (15,88).

Unrecognized or untreated injury to the medial ligamentous structures may also result in failure of the primary ACL reconstruction. The superficial medial collateral ligament (MCL), posterior oblique ligament (POL), and posterior horn of the medial meniscus are secondary restraints to anterior tibial translation on the medial side of the knee (51,89). The popularity and ease of arthroscopy-assisted ACL reconstruction, along with the high incidence of stiffness reported after combined ACL reconstruction and repair of the medial structures, has led to a deemphasis on surgical repair of the medial structures (40). Although good clinical results have been reported with no operative treatment of grade III MCL tears in knees with combined ACL and MCL injuries, it should be recognized that not all grade III medial-sided injuries have such a favorable result (39,40). A grade III MCL tear associated with a complete tear of the POL and the meniscofemoral and meniscotibial ligaments results in the loss of the important "brake-stop" effect of the posterior horn of the medial meniscus (40). Failure to surgically restore this important brake-stop mechanism by repair of the posteromedial structures may subject the ACL graft to increased forces and result in graft failure.

Nonoptimal Graft Material

The type of graft used to perform the primary ACL reconstruction may also play a possible role in the failure of the reconstruction. At the present time, the central-third bone–patellar tendon–bone graft is the most widely used autograft to replace a torn ACL. One advantage of the patellar tendon is the ability to obtain

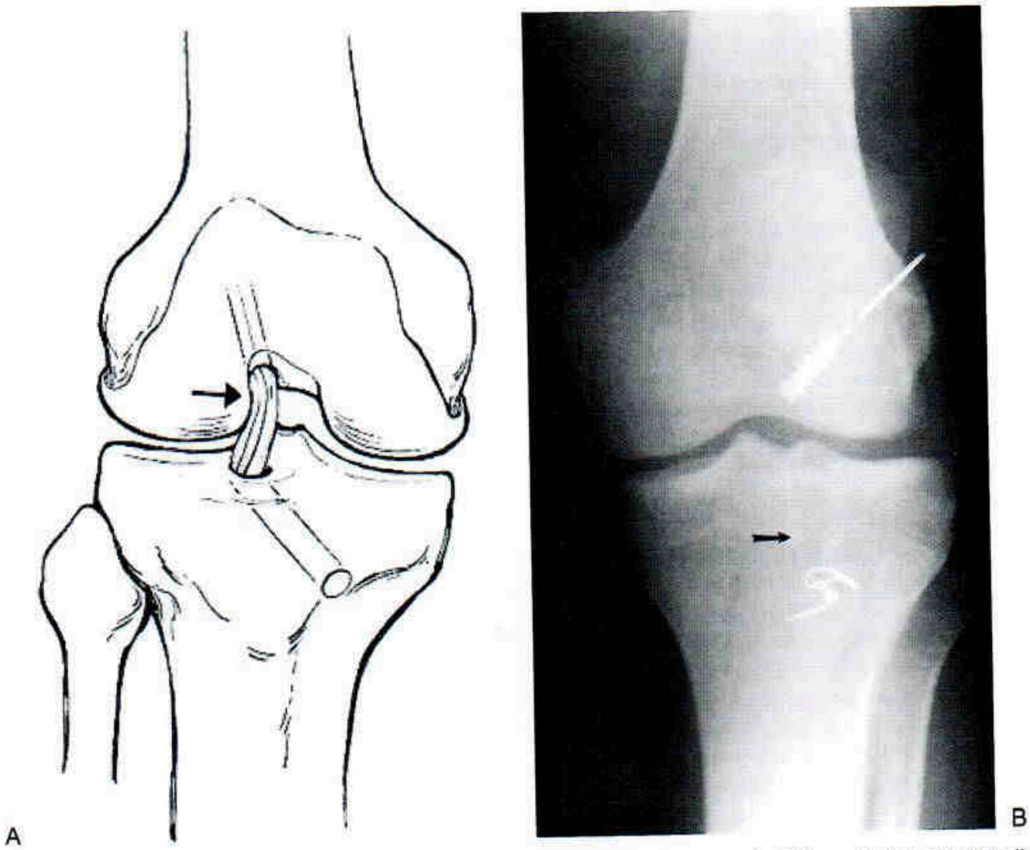


FIG. 8. A: Lateral placement of the tibial tunnel can result in impingement of the anterior cruciate ligament graft against the medial side of the lateral femoral condyle (*arrow*). **B:** Lateral placement of tibial tunnel (*arrow*).

rigid initial fixation at both ends of the graft using interference screw fixation of the bone blocks (87,90). Undersized or poor-quality bone blocks, however, may provide inadequate purchase for the interference screw, which compromises graft fixation.

Although initially hamstring tendon grafts were thought to be too weak, recent studies have demonstrated that equally tensioned four-stranded hamstring tendon grafts are the strongest and stiffest autografts currently available (91). However, use of single-stranded hamstring grafts or unequally tensioned four-stranded hamstring grafts in the chronically ACL-deficient knee with lax secondary restraints may provide inadequate initial graft strength and potentially lead to failure of the primary reconstruction.

The use of allograft tissue offers many advantages, including decreased surgical time, smaller incisions, less surgical dissection, availability of variable graft sizes and shapes, and avoidance of donor site morbidity (62,92,93). There are various disadvantages, however, including potential transmission of diseases such as acquired immunodeficiency syndrome and hepatitis; irradiation is required to neutralize such viruses, which weakens the allograft biomechanically (62). The dose of radiation required to neutralize the human immunodeficiency virus has been demonstrated to weaken the graft by approximately 27% (94). Also, graft incorporation has been shown to be slower for allografts than for autografts (see details later) (95). The secondary effects of irradiation and delayed biologic incorporation may place allograft ACL reconstructions at increased risk for failure, particularly in the chronically ACL-deficient knee (62).

Failure of Graft Incorporation

The ultimate success of any biologic ACL replacement graft depends on the ability of the replacement tissue to survive and maintain its initial biomechanical properties in the intraarticular environment of the knee, and to incorporate with the host. Graft incorporation is known to be influenced by various mechanical factors such as graft placement, graft impingement, graft tensioning, stress shielding of the graft, and application of deleterious stresses to the graft in the early healing phase (70,81). Little is known, however, about the biologic variables that control the rate and extent of ACL graft incorporation.

Experimental studies have shown that both autograft and allograft tissues undergo the same biologic process of graft incorporation, which consists of graft necrosis, revascularization, cellular repopulation with cells of extrinsic origin, collagen deposition, and graft maturation and remodeling. This complex biologic healing response has been called *ligamentization* because it results in a replacement structure that grossly resembles the normal ACL (96–98). Jackson et al. (95) using a goat model have demonstrated that the time course and extent of graft remodeling are slower and less complete in allografts than in autografts. In this study the allografts were also found to be biomechanically inferior to autografts. The biologic factors responsible for the delayed graft incorporation of allografts have not been completely identified at the present time; however, recent work by Harner and Fu (99) has identified a low-grade immunologic reaction (cellular and humeral) to the allograft.

Trauma and Reinjury

Factors that can lead to traumatic failure of the primary reconstruction include overaggressive rehabilitation, premature return to athletics before adequate or complete graft incorporation and reestablishment of neurophysiologic control of the lower extremity, and a significant reinjury after initial functional stability was restored and full activities were resumed. The common factor responsible for traumatic graft failures is the inability of the ACL graft to withstand the tensile loads applied to it during the particular stage when it is injured. Although the use of an accelerated rehabilitation program has significantly reduced postoperative and donor site morbidity, there are concerns that early return to unrestricted activities such as running and sports-specific activities puts the immature ACL at risk and may result in a higher long-term graft failure rate.

Although probably not the most common cause of traumatic failure, an overaggressive rehabilitation program can apply tensile loads that may injure or stretch the immature graft during the early healing period. An overaggressive rehabilitation program can also result in fixation site failure and an early loss of stability. Traumatic graft failure may also occur when a patient attempts to return to strenuous activities before the graft has incorporated or neurophysiologic control of the leg has been reestablished. The incidence of traumatic reruptures has been reported to range from 2.2% to 2.7% (29,30,70). The traumatic event is usually similar to the initial ACL injury, often accompanied by a "pop," immediate hemarthrosis, and an increase in anteroposterior laxity.

PREOPERATIVE ASSESSMENT

Clinical Evaluation

Preoperative evaluation is one of the most important aspects of revision ACL surgery. First and foremost, it must be determined if the previous surgery has truly failed. Because of the different categories of failure and overlap among them, determining whether the patient's residual complaints are primarily caused by graft failure can at times be very difficult. Current indications for revision ACL surgery include instability with activities of daily living or athletic activities, and the presence of pathologic anterior laxity on clinical examination that reproduces the patient's sensation of giving way. The patient also must have realistic expectations of the revision ACL surgery. Clinical results of revision ACL, including subjective and objective indicators, do not match those of primary ACL. All criteria must be met before proceeding with surgery.

History

A thorough evaluation first involves taking a detailed patient history. The sequence of events leading up to the patient's presentation should be examined. Such information may shed light on the possible mechanism of failure. Patients who present with a gradual onset of instability after initially having a stable knee may have graft failure secondary to gradual stretching of the ligament secondary to nonanatomic graft placement or attrition of the ligament secondary to impingement. Patients who state that the knee was never stable after the primary surgery should be suspected of having a failure of graft fixation or, more commonly, a failure to address associated ligamentous laxity. The history leading up to the aforementioned types of failure is quite distinct from that of the patient who has returned to a pre-injury level of activity and has sustained graft failure secondary to the onset of new trauma.

The surgeon must clearly differentiate the patient's primary complaint: *pain* or *instability*. Patients with either complaint may demonstrate increased laxity on physical examination; however, each complaint has a different prognosis and treatment plan. Instability can often be improved by revision ACL surgery; however, pain, which is usually associated with injury or damage to articular cartilage, must be addressed separately or simultaneously by microfracture, osteochondral grafting, chondrocyte transplantation, meniscal allograft, or osteotomy.

Review of the patient's previous medical record is especially important. Relevant information that should be obtained by reviewing the patient's medical records includes findings of the previous examination under anesthesia (associated ligamentous laxity); surgical technique used (endoscopic versus two-incision); graft source; associated pathology; type, size, and manufacturer of the hardware used for graft fixation; and intraoperative complications that may have occurred. As part of the chart review, the report of the postoperative period and rehabilitation protocol should be examined critically. Factors in the postoperative period that potentially may have contributed to failure of the primary surgery include an overly aggressive rehabilitation program, return to sports activities before neuromuscular control of the lower extremity was established, problems regaining full range of motion, development of a reflex sympathetic dystrophy, and infection.

Physical Examination

A comprehensive physical examination including an evaluation of the entire lower extremity must be performed. The overall alignment of the lower extremity and gait pattern (varus thrust) should be examined. Varus alignment can lead to excessive loads on the reconstructed ACL and eventually result in graft failure. In these cases, a tibial-femoral osteotomy should be performed simultaneously with the revision ligament surgery or in a staged fashion. The patient's range of motion should be assessed. Measurements of the heel-height difference and heel-to-buttock distance are useful ways to assess the loss of extension and flexion. A staged procedure should be considered if there is a loss of extension sufficient enough to result in anterior knee pain, quadriceps muscle weakness, or a bent-leg gait pattern. Regaining a pain-free full range of motion is of the utmost importance before revision ACL surgery.

The ACL status of the primary reconstruction should be assessed using the Lachman test, anterior drawer test, pivot-shift test, and KT1000 or KT2000 arthrometer testing. The secondary restraints must also be closely evaluated. The medial secondary restraints to anterior tibial translation include the superficial MCL, the POL, and the posterior horn of the medial meniscus. The medial structures are evaluated by comparing valgus rotation at 0 and 30 degrees of flexion, and external tibial rotation at 30 and 90 degrees of flexion to rotation in the opposite normal knee. Similarly, the lateral and posterolateral structures are evaluated by comparing varus rotation at 0 and 30 degrees of flexion, and external tibial rotation at 30 degrees of flexion to rotation in the opposite normal knee. Failure to recognize and treat associated ligamentous laxities may result in failure of the revision ACL reconstruction.

The location of previous skin incisions should be examined carefully. The primary graft may have been harvested through a vertical, oblique, or transverse incision. Based on the length and orientation of the original harvest incision, the surgeon must decide whether it is possible to harvest the revision graft through the original incision or whether a new incision is required.

Radiographic Examination

Radiographic assessment should include a complete knee series: standing anteroposterior, 45 degrees posteroanterior flexion weightbearing, and lateral with the knee in maximum hyperextension, notch, and Merchant views. These radiographs will help in evaluating the overall status of the knee: limb alignment, degenerative joint changes, bone quality, type and placement of hardware, tunnel placement and enlargement. Other imaging modalities that may be used in selected cases include bone scintigraphy, computed tomography, and MRI. Bone scintigraphy can be used to determine osseous homeostasis and may be of help in detecting infection and early radiographically silent arthritis. Computed tomography is helpful in defining the extent of tunnel enlargement and osteolysis. Tunnel enlargement has been most commonly associated with synthetic grafts and allografts (47,48,100). Information about the size of the bone tunnels is useful in terms of planning graft selection and determining whether to bone-graft the enlarged tunnels concurrently or as part of a staged procedure (Fig. 9). MRI with sagittal images through the plane of the ACL graft can be helpful in assessing integrity of the ACL graft. In most cases, however, clinical examination and plain radiographs are sufficient to determine the status of the primary ACL graft, and MRI is only necessary in selected cases.

Surgical Planning

Once the preoperative evaluation has been completed, the surgeon should have determined the cause of the primary failure and determined whether the patient is a candidate for revision ligament surgery. Patient compliance and motivation are important factors that are critical to the success of revision ACL surgery. If revision ACL surgery is recommended, the patient must be given a realistic expectation of the expected outcome and must not be promised too much. In general, the results of revision ACL surgery have been favorable with regard to improvement of stability; however, the results are not equivalent to those of primary ACL surgery (29,73,74,101,102). Revision ACL surgery is very complex and should be considered salvage surgery. False expectations for the revision surgery may lead to a subjective judgment of failure by the patient in spite of the technical success of the procedure.

The success of revision ACL surgery is multifactorial and is influenced by the cause of the primary failure, the preoperative laxity of the knee, and the status of the menisci, articular cartilage, and secondary restraints. The primary goals of revision ACL surgery are to stabilize the knee, to prevent further damage to the menisci and articular cartilage, and to maximize the functional level of the patient.

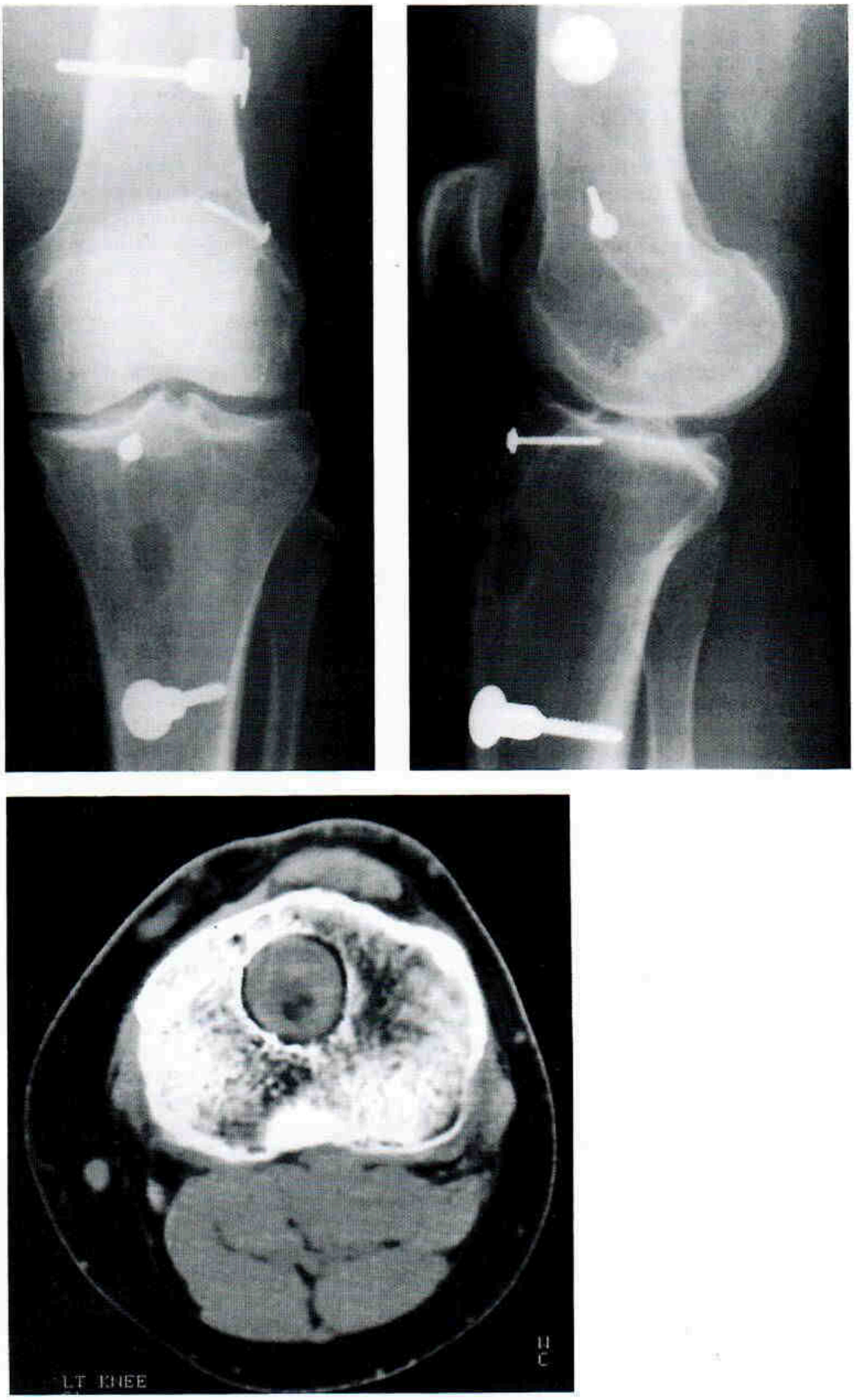
Graft Selection

Graft selection for the revision procedure depends on the type of graft used for the primary reconstruction, the placement of incisions used to harvest the primary graft, the presence of enlarged bone tunnels, and the presence of associated ligamentous laxity. Synthetic ligaments are not currently recommended for primary or revision ACL surgery because of the high complication and failure rates reported with their use (47,48,100). At the present time graft selection options for revision ACL surgery consist of autograft and allograft tissue.

Autogenous graft options include patellar tendon, reharvest of the ipsilateral patellar tendon or contralateral patellar tendon, quadriceps tendon, and semitendinosus-gracilis hamstring tendons. The advantages of autograft tissues include elimination of the risk of disease transmission, lack of additional cost, elimination of possible immune reactions, and superior biologic incorporation. The major disadvantages of autograft tissue are donor site morbidity (131,132), limitation of the size and number of grafts available, and the increased surgical dissection required to harvest the graft tissue.

The patellar tendon and Achilles tendon are the most commonly used allografts (Fig. 10). Newer allograft sources have included the anterior tibialis tendon and semitendinosus-gracilis hamstring tendons. Use of these latter sources is secondary to the increased use and decrease availability of the more common patellar tendon. The advantages of the use of allograft tissue are the lack of donor site morbidity, the availability of variable graft shapes and sizes, the ability to customize bone blocks to accommodate enlarged bone tunnels, and the decreased incision size and decreased surgical dissection. Concerns about allograft tissues have focused primarily on the issues of disease transmission, the effects of secondary sterilization (i.e., radiation and freezing techniques) on the initial mechanical properties of the graft tissue, and the possibility of an immune response. The risk of disease transmission is probably the major deterrent to the routine use of allograft tissue. The reported risk of disease transmission according to the American Academy of Orthopaedic Surgeons 1 in 3 to 4 million, with no reportable cases since the advent of better testing techniques such as polymerase chain reaction analysis (103,130). Freezing the allograft tissue does not kill viruses that transmit disease. In an attempt to eradicate viruses, allograft tissue is commonly secondarily sterilized with radiation (dosage of 1.5 to 2.5 Mrad) (94). This dosage of radiation has been shown to alter the collagen structure and reduce the tensile and biomechanical strength of the allograft tissue (91).

Comparison studies of allograft and autograft in an animal model have demonstrated that autograft and allograft tissues undergo the same healing process; however, the time course for allografts appears to be prolonged, and the biologic response is less robust than that seen with autograft tissue (95). Clinical results of primary ACL reconstructions performed with irradiated allograft tissue, and reconstructions in chronically ACL-deficient knees performed with nonirradiated allograft tissues have in general been favorable (29,30,70,102,104). The results of the use of irradiated allografts in chronically ACL-deficient



A B C

FIG. 9. A, B: Failed synthetic anterior cruciate ligament reconstruction. Note the marked enlargement of the tibial tunnel on the anteroposterior radiograph. **C:** Computed tomographic scan demonstrating marked enlargement of the tibial tunnel. Revision required a staged procedure. Stage 1 was the removal of the artificial ligament and bone grafting of the bony defects. After consolidation of the bone graft, the residual instability was addressed by ligament reconstruction.

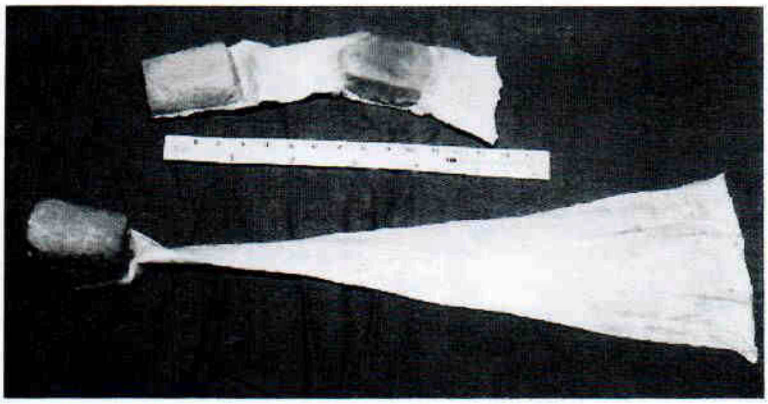


FIG. 10. Patellar tendon and Achilles tendon allografts. Large bone blocks can be fashioned to fill enlarged bone tunnels.

knees, however, appear to be inferior to those of autografts used in acutely or chronically ACL-deficient knees or of nonirradiated allografts (70,102,105). Because of delayed biologic incorporation, use of allografts is probably contraindicated in revision cases in which failure of the graft to incorporate was the cause of the primary failure.

Because the patellar tendon is the most commonly used autograft for primary ACL reconstruction, this type of reconstruction is also the most common type of ACL reconstruction requiring revision surgery. Autograft options for revision of a failed patellar tendon reconstruction include

Ipsilateral hamstring tendons
Ipsilateral quadriceps tendon
Reharvest of the ipsilateral patellar tendon
Contralateral patellar tendon

Although concerns have been raised about the tensile properties of hamstring tendon grafts, recent studies have demonstrated that hamstring tendon grafts are stronger and stiffer than 10-mm patellar tendon grafts (91). The tensile properties of the hamstring tendon grafts from the young patients (23 years to 43 years) who typically undergo ACL reconstruction has recently been investigated by Hamner et al. (91). This study reported a mean failure load of 3,560 ± 742 N and a stiffness of 855 ± 156 Nm for quadrupled semitendinosus grafts and a mean failure load of 4,140 ± 969 N and stiffness of 807 ± 164 N per mm for combined doubled semitendinosus and gracilis grafts, values significantly higher than those reported for 10-mm patellar tendon grafts from similarly aged donors (Fig. 11).

Potential disadvantages of hamstring tendon grafts include their smaller diameter compared to patellar tendon grafts and the lack of bone blocks at the ends of the graft (140). The typical tunnel size for patellar tendon reconstruction is between 9 and 11 mm, compared to 7 to 9 mm for four-stranded hamstring tendon grafts. Because of the smaller diameter of the hamstring tendon graft bone tunnels, it is not possible to overdrill the existing patellar tendon bone tunnel. If the surgeon desires to use a hamstring tendon graft in a knee in which the placement of the existing patellar tendon bone tunnels are satisfactory, either the extraarticular position of the new bone tunnels must be diverged from the path of the preexisting bone tunnels or the preexisting bone tunnels must be overdrilled and bone-grafted, and the reconstruction performed as a two-stage procedure. By converting to a two-incision technique in cases in which the primary ACL reconstruction was performed using an endoscopic technique, or converting to an endoscopic technique when the primary ACL reconstruction was performed using a two-incision technique, it is usually possible to diverge the femoral tunnels (Fig. 12).

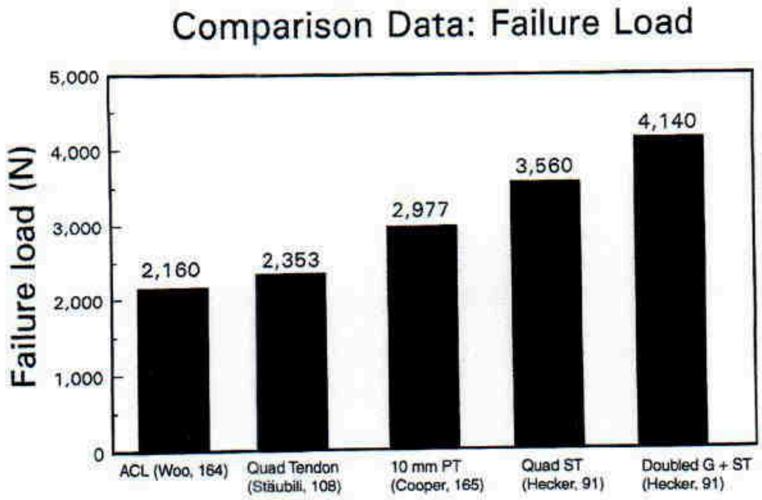
A second potential disadvantage of hamstring tendon grafts is their inability to fill bony defects. In cases of femoral tunnel enlargement, one has the option of using the over-the-top position and thereby avoiding the need to drill a bone tunnel. In cases in which the tibial tunnel is enlarged, however, bone grafting and a staged reconstruction is usually required.

A third potential disadvantage of hamstring tendon grafts is the longer elongation to failure and lower stiffness of many hamstring graft fixation techniques. Recent biomechanical testing, however, has demonstrated that the stiffness and elongation to failure of doubled gracilis and semitendinosus grafts fixed in the femur with bioabsorbable interference screws, the Bone Mulch Screw, the TransFix system, LinX-HT (Mitek, Westwood, MA), and Endo button with continuous polyester loop (Smith & Nephew Endoscopy, Inc., Andover, MA) are similar to those previously reported for patellar tendon grafts fixed with interference screws (107). It is our feeling that lower-stiffness hamstring fixation techniques require a longer period of cyclical loading before graft fixation, higher initial graft tension, and fixation at 20 to 30 degrees of flexion. At the present time, there have been no published clinical results on the use of hamstring tendons for revision ACL surgery.

Stäubli has recently refocused attention on the use of the quadriceps tendon as an alternative graft source for primary and revision cruciate ligament surgery (69,108,109). Biomechanical testing has shown that the quadriceps tendon is about the same strength as the patellar tendon but has lower initial stiffness. The cross-sectional area of the quadriceps tendon, however, is significantly greater than that of the patellar tendon (quadriceps tendon = 65 mm^2, patellar tendon = 36.8 mm^2). The large cross-sectional area of this graft source and the presence of a bone block at one end make possible its use to fill enlarged bone tunnels. One area of potential concern about this graft source is that harvest of a second bone block from the superior pole of the patella may place the patella at risk of fracture in revision cases. Purnell and Lamoreaux (110) have reported good results in 14 patients with an average follow-up of 3.5 years using a 9- to 11-mm–wide quadriceps tendon graft to revise failed primary ACL reconstructions. All knees were reported to have less than 2 mm side-to-side difference as measured using the KT1000 arthrometer, the hop test averaged 94%, and isokinetic strength testing at 240 degrees per second and 60 degrees per second averaged

A

B



C

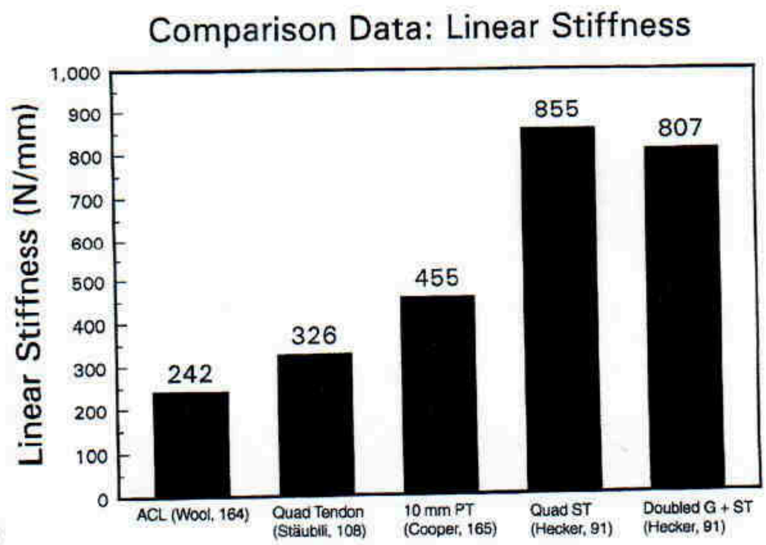


FIG. 11. A: Doubled gracilis and semitendinosus grafts. **B, C:** Mean failure loads and linear stiffness for commonly used anterior cruciate ligament (ACL) grafts. G, gracilis tendon; PT, patellar tendon; Quad, quadriceps; ST, semitendinosus tendon.

82%. Complications included one nondisplaced patellar fracture 1 year after surgery.

Reharvest of the patellar tendon from the ipsilateral knee is another potential option for revision of a failed primary patellar tendon reconstruction. Proctor et al. (111) using a goat model have demonstrated that the patellar tendon donor site fills with scar repair tissue, and the tensile properties of this new tissue are significantly reduced compared to those of the normal contralateral patellar tendon at 21 months after surgery. Similar findings have been reported in a dog model by LaPrade et al. (112). As a result of these findings, both authors have recommended that alternative grafts be used for revision ACL surgery. Kartus et al. (58) reported the clinical results using the reharvested patellar tendon to perform revision ACL surgery in 20 patients. The ipsilateral patellar tendon was reharvested and used as the revision ACL graft source in ten patients, and the contralateral patellar tendon was used in another ten as a control. The Lysholm score, International Knee Documentation Committee rating, and Teg-

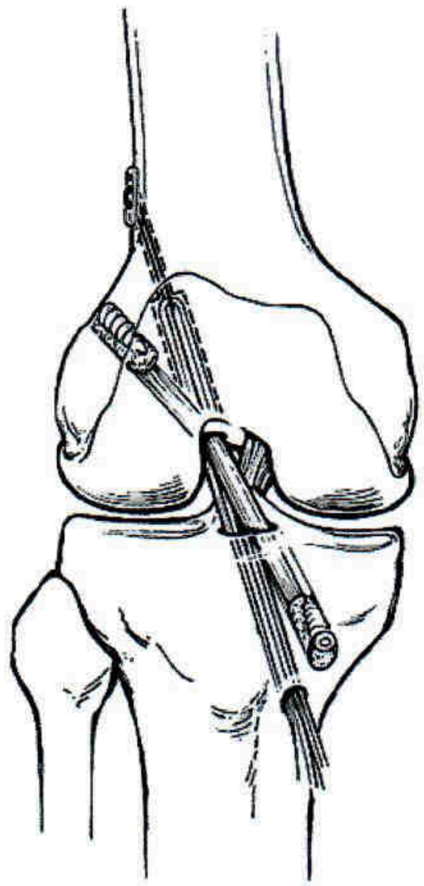


FIG. 12. Conversion of a one-incision anterior cruciate ligament (ACL) reconstruction to a rear-entry two-incision ACL reconstruction or vice versa. Rear-entry femoral tunnel has a more horizontal orientation, whereas the one-incision endoscopic ACL reconstruction is more vertical and divergent.

ner activity levels were reported to be significantly lower in patients who underwent reharvest of the ipsilateral patellar tendon. One patellar fracture and one patellar tendon rupture were reported to have occurred in the reharvest group. Because of the significantly lower functional scores and 20% incidence of major donor site complications in the reharvest group, the authors do not recommend the use of the reharvested ipsilateral patellar tendon for revision ACL surgery.

Use of the contralateral patellar tendon provides the same advantages as use of the primary patellar tendon. However, use of the contralateral patellar tendon carries the risk of creating a problem in a knee that was previously normal. Rubinstein et al. (113) reported on the use of the contralateral patellar tendon as a graft source in 26 patients. They found that all patients had regained full range of motion by 3 weeks and that quadriceps strength had returned to 93% at 1 year and 95% at 2 years postoperatively in the donor knee. No patient complained of patellofemoral pain in the donor knee; however, patellar tendinitis occurred in 55% of the patients during the first year but was said to be rarely restricting and to resolve after the first year. Based on their experience, the authors felt that the donor site morbidity from harvesting the contralateral patellar tendon was minimal and that this was a good option for revision surgery.

Autograft options after a failed hamstring primary ACL reconstruction include

Ipsilateral patellar tendon
Ipsilateral quadriceps tendon
Contralateral hamstring tendons

In most cases the graft of choice is the ipsilateral patellar tendon. In cases with tunnel enlargement, however, use of the quadriceps tendon with its larger cross-sectional area may be advantageous.

TECHNICAL CONSIDERATIONS IN REVISION ANTERIOR CRUCIATE LIGAMENT SURGERY

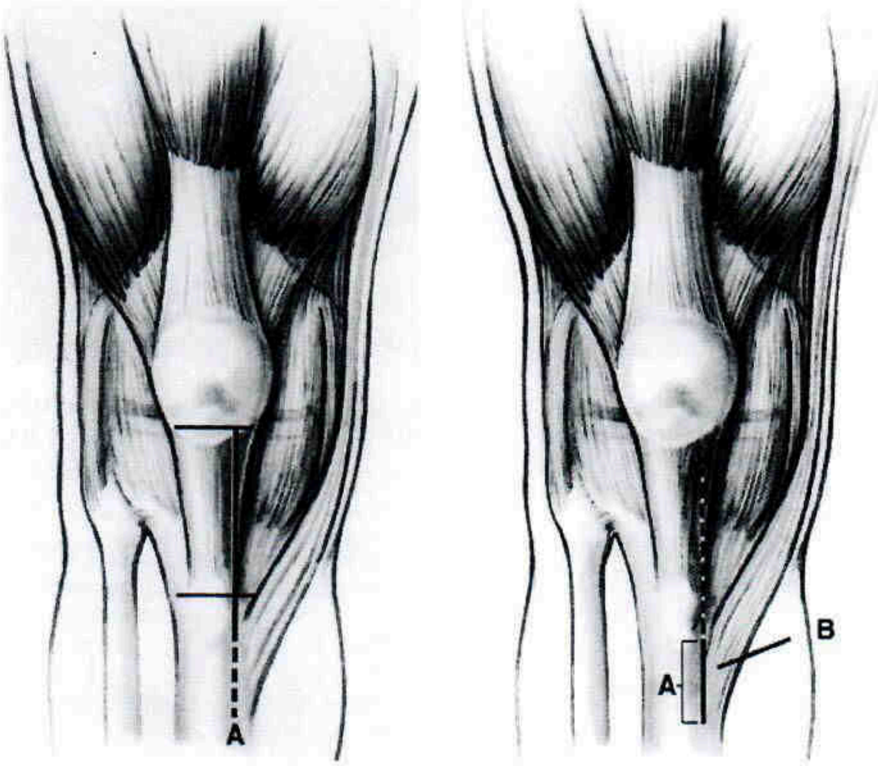
Skin Incisions

Careful planning of skin incisions around the knee is needed to avoid wound-healing problems. Meticulous surgical technique and handling of the soft tissues is critical. In general, previous incisions should be used or extended if they allow simultaneous hardware removal, graft harvest, and proper placement and fixation of the new graft. Old vertical incisions can be extended proximally or distally to harvest either a patellar tendon or hamstring tendon graft for the revision procedure (Fig. 13). Extension of the old vertical incision also allows for removal of the tibial fixation hardware, drilling of the tibial tunnel, and tibial fixation. Short transverse incisions can be crossed with a vertical incision. In cases in which multiple skin incisions were used in the primary procedure or in which the skin viability is in doubt, the use of allografts can minimize subcutaneous dissection and the creation of large skin flaps.

Hardware Removal

During the preoperative planning phase the surgeon should review the specific fixation device used during the primary reconstruction so that appropriate instrumentation to remove the hardware is available at the time of the revision procedure. Special equipment to remove a stripped or buried screw (ACL ReDux Instrumentation, Smith & Nephew Endoscopy, Andover, MA) should also be available at the time of the revision procedure. To properly seat the extraction device, the surgeon must completely remove all soft tissue and bone from around the implant. Failure to do so may result in stripping of the hardware, in which case extensive bone removal may be required to remove the implant (Fig. 14).

Preexisting hardware can often be left in place unless it interferes with the revision tunnels or fixation of the graft, or is loose (142). In general, tibial fixation devices must be removed to drill a new tibial tunnel and adequately fix the new graft. If the primary reconstruction was performed using a two-incision technique, the femoral fixation device can often be left in place by drilling a divergent tunnel using an endoscopic technique (92). In cases of a malpositioned anterior femoral tunnel screw placed endoscopically, the screw can often be left in place because the new femoral tunnel can be drilled behind the old one (Fig. 15). Removing these screws may weaken the bone and can result in a large bony defect on the femur. Endoscopically placed screws



A,B

FIG. 13. A: Hamstring tendon grafts can be harvested, and tibial fixation removed, by extending the lower portion of the vertical patellar tendon harvest incision distally over the pes anserinus (*dashed line A*). A short transverse patellar tendon harvest incision can be crossed by a vertical incision to harvest the hamstring tendons and remove tibial fixation hardware. **B:** Patellar tendon graft can be harvested by extending original vertical hamstring harvest incision (B); a new vertical incision (*dotted line*) can be used to harvest the patellar tendon.

that are prominent, however, may require removal as they may impinge on the new ligament. If removal of an endoscopically placed screw is necessary, it is important to determine from the original operative notes through which portal the screw was inserted to insure parallel placement of the guidewire and screwdriver at the time of removal. Failure to insert the screwdriver parallel to the axis of the screw may result in stripping of the screw.

Prosthetic Ligament Removal

Removal of a prosthetic ligament can present a major challenge. The surgeon must have a through understanding of the technique used to implant the various types of prosthetic ligaments. Preoperative computed tomographic or MRI scans are useful in evaluating tunnel enlargement and osteolysis. If there is a significant bony defect, grafting with autogenous iliac crest bone will be required after the revision ACL reconstruction once the bone graft has been incorporated.

The removal of Gore-Tex, Dacron, and carbon fiber synthetic ligaments presents a special set of problems. These grafts have been associated with significant inflammatory reactions secondary to the creation of synthetic fiber particles. These particles have been shown to stimulate an inflammatory response, which can destroy bone and cartilage. An attempt should be made to remove the ligament *en bloc* without the use of drills or shaver blades, which may create tiny particles that can lead to further synovitis and osteolysis. Bone gouges or trephines can be used to loosen the ligament attachments from the walls of the bone tunnels on both the tibial and femoral sides (Fig. 16). Ligament augmentation devices, which should be fixed to bone at one end, can also be a challenge to remove. Review of the operative notes should indicate which end of the ligament augmentation devices is fixed to bone. The end of the ligament augmentation devices that is fixed to bone should be freed from the walls of the bone tunnel with a bone gouge or trephine.

Revision Notchplasty

Revision notchplasty is necessary in almost all revision ACL reconstructions, as some degree of notch regrowth will occur after most ACL reconstructions. Revision notchplasty is required to visualize the previous femoral tunnel and the over-the-top position, and to prevent impingement of the new graft. Four-stranded hamstring tendon grafts and quadriceps tendon grafts have a significantly larger cross-sectional area than the normal ACL, and a larger notch is required to accommodate these grafts. Careful review of the flexion weightbearing or tunnel-view radiographs gives information on the notch architecture and helps determine the amount of bone to be removed. Excessive bone removal should be avoided as it can lead to compromise of the patellofemoral and tibiofemoral articular surfaces (112). Excessive bone removal from the medial wall of the lateral femoral condyle can also result in lateralization of the femoral tunnel, which thus changes the axis of the new ligament. An impingement rod as described by Howell et al. (26,27,79) can be used at the time of surgery to determine if an adequate notchplasty has been performed.

Bone Tunnels

The most important and technically demanding aspect of revision ACL surgery involves the placement of new bone tun-

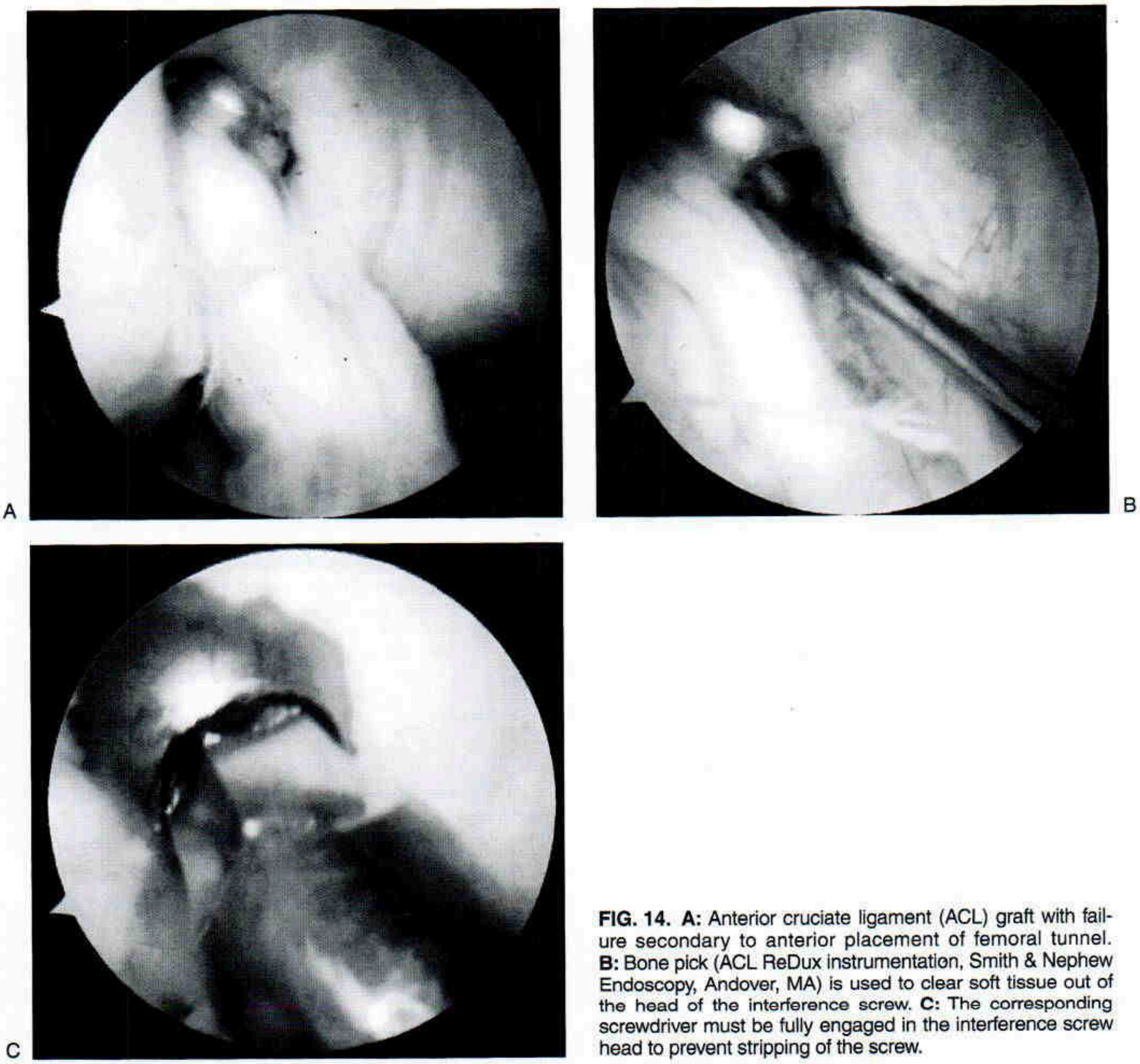
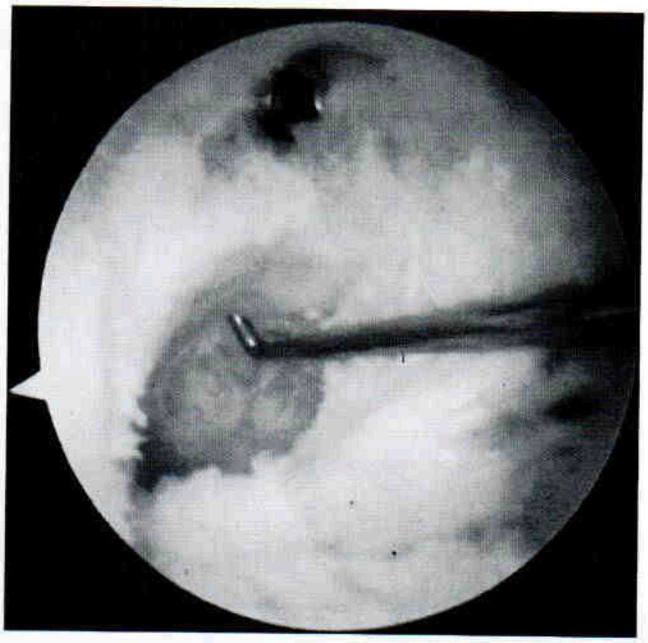


FIG. 14. A: Anterior cruciate ligament (ACL) graft with failure secondary to anterior placement of femoral tunnel. **B:** Bone pick (ACL ReDux instrumentation, Smith & Nephew Endoscopy, Andover, MA) is used to clear soft tissue out of the head of the interference screw. **C:** The corresponding screwdriver must be fully engaged in the interference screw head to prevent stripping of the screw.

nels. If the original ACL graft was positioned too posteriorly and a posterior cortical wall blowout occurred at the time of the original reconstruction, the guidewire for the revision hamstring tendon graft bone tunnel is positioned at the optimal site for the bone tunnel and an Endo button is used to fix the femoral end of the graft (Fig. 17). If the original femoral tunnel is in optimal position, the intraarticular position of the original tunnel can be maintained and a divergent new tunnel drilled using a different surgical technique (Fig. 14A). If the original femoral tunnel has been positioned more than one tunnel diameter anterior to its optimal position, it will be possible to drill a new tunnel in the optimal position without tunnel overlap (Fig. 18). Intraoperative radiography or fluoroscopy can be used to confirm proper placement of the femoral guide pin before the drilling of the new tunnel. If the position of the original femoral tunnel is less than one tunnel diameter anterior to its optimal position, however, then the potential for tunnel overlap exists. Three options are available for dealing with enlarged femoral bone tunnels. The first option is to avoid drilling a femoral bone tunnel by placing the hamstring tendon graft in the over-the-top position (Fig. 19). The study of Karlson et al. (63) demonstrated no significant difference in outcome for hamstring tendon grafts placed through a femoral drill hole and grafts positioned in the over-the-top position. The second option consists of removing the old ligament and bone-grafting the resulting defect with iliac crest bone as the first stage, followed by revision ACL reconstruction after consolidation of the bone graft (Fig. 20). The third option is to use an allograft with large bone block to fill the enlarged bone tunnel (Fig. 21).

Similar options exist for dealing with a malpositioned tibial tunnel. If the tibial tunnel is more than one tunnel diameter too anterior to its optimal position, then a new tunnel can be

A



B

FIG. 15. **A:** Patellar tendon anterior cruciate ligament reconstruction with failure secondary to anterior placement of femoral tunnel. Hardware removal was not necessary because there was sufficient room to drill behind the original femoral interference screw. **B:** Arthroscopic view. The probe is located at the over-the-top position. The new tunnel has sufficient room behind the misplaced anterior tunnel.

drilled in the optimal position without tunnel overlap occurring (Fig. 22). The slightly anterior tibial tunnel (less than one tunnel diameter anterior to its ideal position) presents a slightly more challenging problem. Options include drilling a new tunnel or expanding the existing tunnel until it is located in the optimal position. The resulting gap between the anterior wall of the old tunnel and the revision graft can be filled by using an allograft with a large bone block, or the tunnel can be bone-grafted with an autogenous iliac crest bone graft concurrently. Another option consists of positioning the intraarticular portion of the new tunnel at the optimal location and changing the external starting position, thus diverging the two tunnels. If the original tibial tunnel was optimally placed, then a divergent tibial tunnel can be drilled by changing the external starting position (Fig. 23).

A tibial tunnel placed more than one tunnel diameter posterior to its optimal position can be handled by drilling the new tunnel in optimal position (Fig. 24). A tibial tunnel placed slightly posteriorly (less than one tunnel diameter from its optimal position) is perhaps the most challenging problem. Because of the potential for tunnel overlap and the new graft's falling posteriorly into the old tunnel location, this situation is best handled by removing the old ligament and tibial fixation hardware and bone grafting the old tibial tunnel. The ligament reconstruction is then performed once the bone graft has consolidated.

Graft Fixation

During the early postoperative period, graft fixation is the weak link in the ACL reconstruction (85). Because of the variations in the type of replacement graft, tunnel placement, bone quality, and surgical techniques used during revision ACL reconstruction, the surgeon must be knowledgeable and proficient in all methods of ACL graft fixation. Interference screw fixation has been demonstrated to be the strongest and stiffest fixation technique for bone-tendon-bone grafts (87,90). Interference screw fixation strength is dependent on the local bone quality, however. In revision cases, bone stock and bone quality may be compromised, which renders interference screw fixation inadequate. Under these circumstances alternative fixation methods such as tying bone block sutures around a screw and washer should be considered. If the posterior femoral cortex was violated during the primary reconstruction, use of an endoscopically inserted interference screw is also not possible. In this situation, the surgeon has the option of using a two-incision approach and fixing the femoral bone block with an outside-in interference screw, tying the bone block sutures around a screw and post or fixation button. Alternatively, the Endo button can be used in this situation, because this implant relies on the integrity of the lateral femoral cortex and does not depend on fixation within the bone tunnel.

Although direct fixation of hamstring tendon grafts with metal or bioabsorbable interference screws has become an increasingly popular method of graft fixation and may provide adequate fixation strength when used in primary ACL reconstructions, potential tunnel overlap and poor bone quality may make this an unreliable method of fixation for revision ACL surgery. Brown et al. (107) have demonstrated that hamstring tendons fixed on tibia with spiked ligament washers and on the femur with the Bone Mulch Screw, the TransFix system, or Endo button have adequate fixation strength even in osteopenic bone.

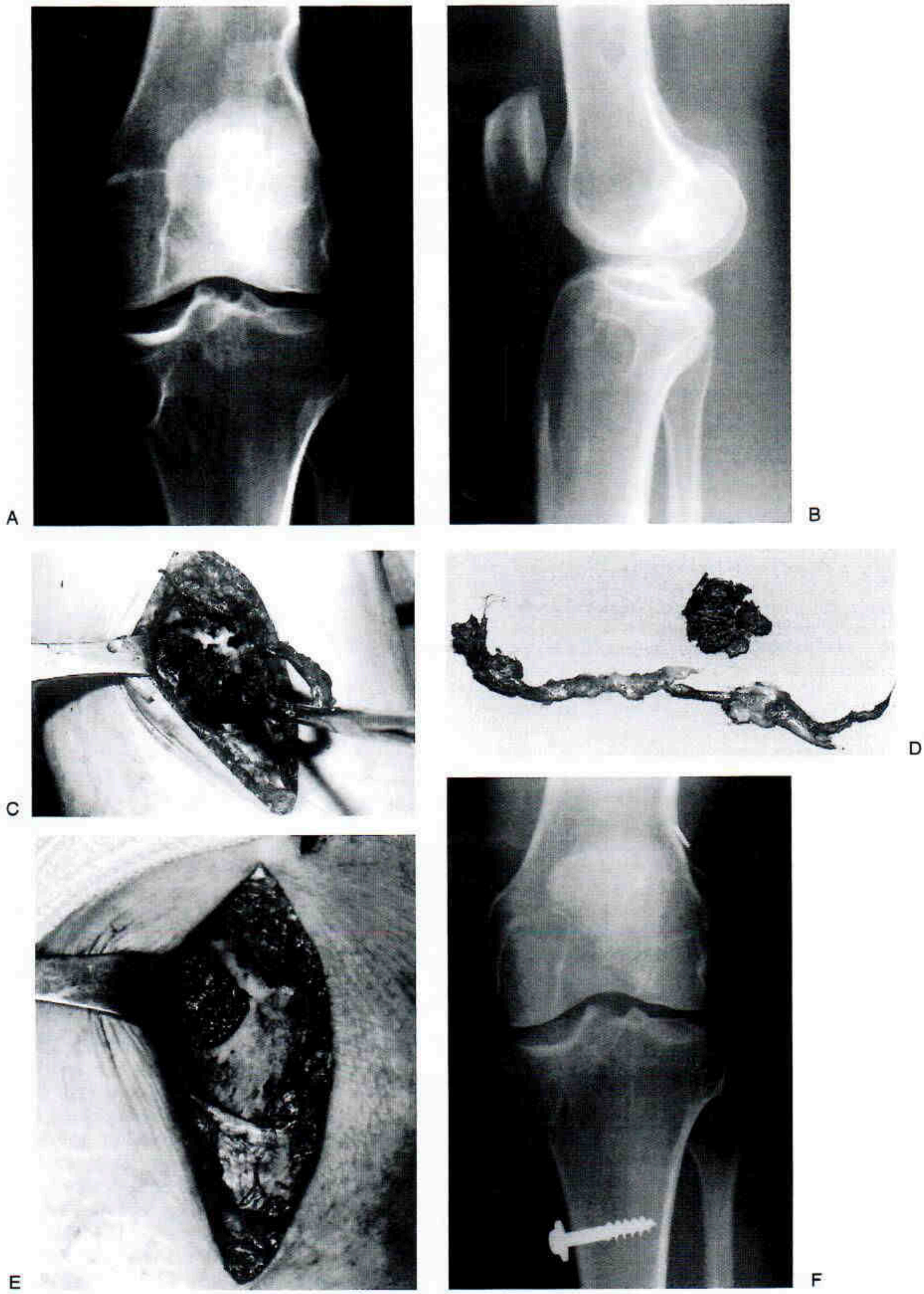


FIG. 16. A, B: Patient underwent anterior cruciate ligament reconstruction with carbon fiber synthetic ligament 15 years earlier. Anteroposterior and lateral radiographs demonstrate lytic changes in the proximal tibia and distal femur. **C:** Removal of carbon ligament from the tibia. **D:** Removed carbon fiber ligament. **E:** Autogenous iliac crest bone graft was required to fill the bone defects after removal. **F:** Revision anterior cruciate ligament reconstruction with doubled gracilis and semitendinosus was performed 3 months later after consolidation of bone graft.

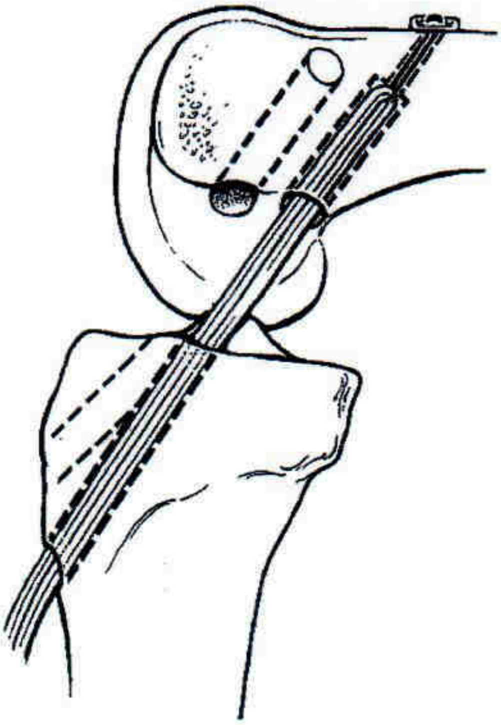


FIG. 17. If the original femoral tunnel violates the posterior cortex, a new tunnel can be drilled in the optimal position and the graft fixed to the femoral cortex with an Endo button (Smith & Nephew Endoscopy, Andover, MA).

Associated Ligamentous Laxity

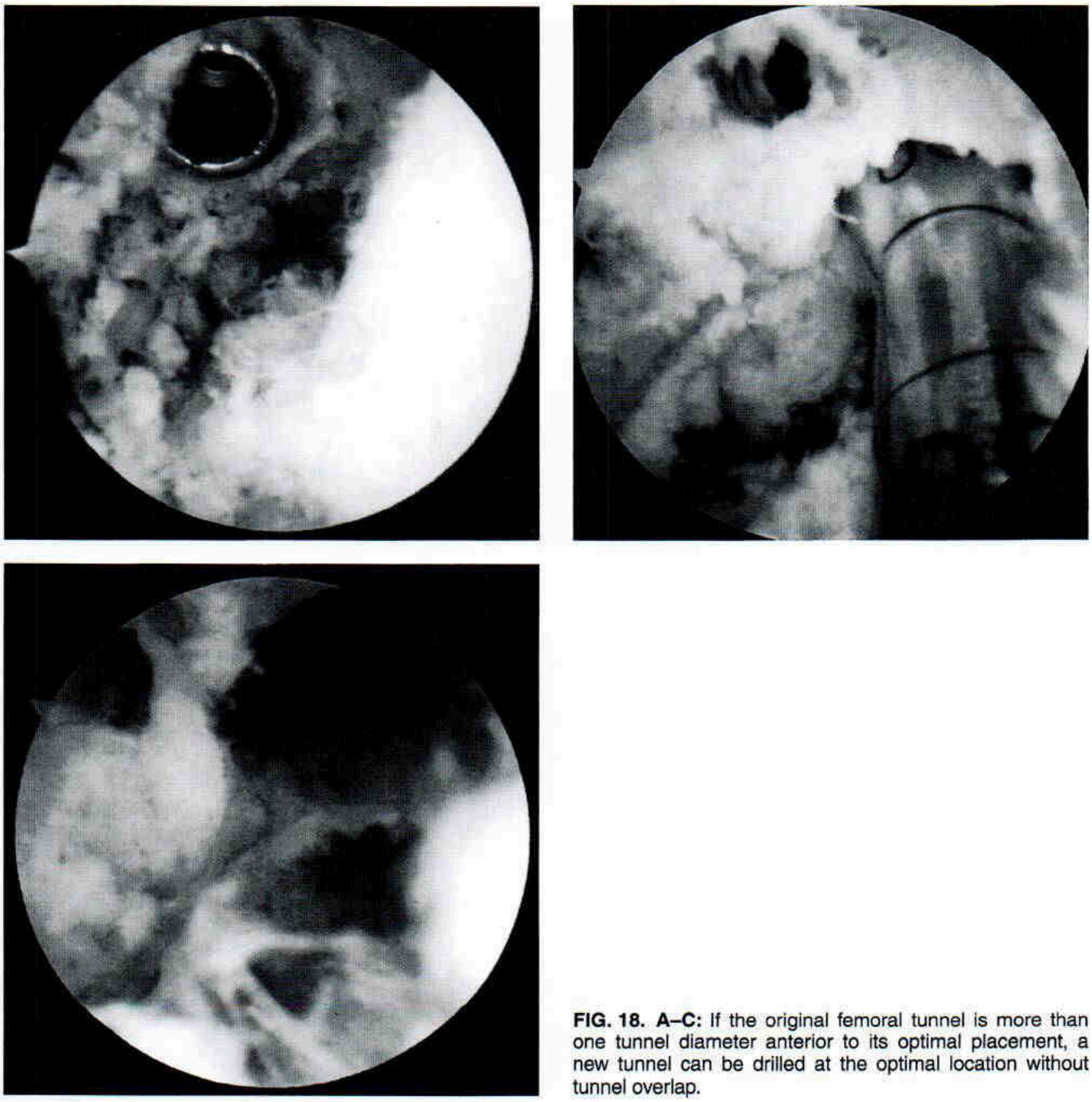
Failure to address the secondary restraints may result in application of abnormal loads to the revised ACL reconstruction and eventual failure of the reconstruction. The secondary restraints to anterior translation on the medial side of the knee, which may need to be addressed at the time of the revision procedure, include the superficial MCL, the POL, and the medial meniscus. Chronic laxity of the MCL can be addressed by recession of the femoral attachment site or advancement of the tibial insertion of the lax ligament. In cases in which the existing ligamentous tissue is inadequate, an autogenous semitendinosus graft or Achilles tendon or patellar tendon allograft may be used to reconstruct the MCL. The POL can be tightened by advancing the femoral side of the ligament as described by Hughston and Eilers (165), and Paulos et al. (89). If this tissue is inadequate, then the POL can be reconstructed with a strip of semimembranosus as described by Muller (114).

Posterolateral instability (the LCL, the popliteal tendon, and the popliteofibular ligament) is often subtle and overlooked in the face of an otherwise successful ACL reconstruction (101,146). In chronic cases in which a definitive LCL is present and the popliteal attachments to the fibula and tibia are intact, a proximal advancement of these structures as described by Noyes and Barber-Westin and others (65,88,115) can be used to tighten these structures at the time of revision ACL surgery. In cases in which the LCL is thin or deficient, we prefer to reconstruct the LCL with one-half of the biceps femoris tendon and suture the remaining LCL tissue to the autogenous graft. The biceps tendon is tubularized and passed through a bone tunnel positioned at the lateral femoral epicondyle (Fig. 25). To potentially avoid drilling the transfemoral tunnel for the LCL biceps tendon graft through the femoral side of the ACL graft, the transfemoral tunnel for the LCL reconstruction should be drilled before passing the ACL graft. If the biceps tendon has previously been injured or is felt to be inadequate, the LCL can be reconstructed with doubled autogenous semitendinosus or gracilis tendons as described by Aglietti et al. (10) (Fig. 26).

We prefer to address chronic laxity of the popliteus complex with a doubled autogenous semitendinosus graft (153). The graft is fixed on the medial side of the distal femur with an Endo button and on the tibia and fibular head with sutures tied over buttons. Combined injuries to the LCL and popliteus complex can be treated using the biceps and semitendinosus tendons (159) (Fig. 27). In cases in which autogenous grafts are not available, the LCL and popliteal complex are reconstructed with an Achilles tendon or patellar tendon allograft as described by Veltri and Warren (116) and Noyes and Barber-Westin (65).

The integrity of the meniscal cartilage is important to the functional outcome of an ACL-deficient knee. Biomechanical studies have demonstrated that the medial meniscus is a secondary restraint to anterior translation and varus-valgus stability in the ACL-deficient knee (105,117). In contrast, the lateral meniscus has not demonstrated biomechanically in cadaver studies or clinical follow-up to function as a secondary restraint to anterior translation in the ACL-deficient knee (118). At the present time, the indications for and role of meniscal transplantation have remained controversial (Fig. 28). Those patients who have undergone previous subtotal and complete meniscectomies may be the perfect candidates for meniscal transplantation in the face of ACL deficiency. Meniscal transplantation may have a place in revision ACL surgery because it may allow restoration of the important brake-stop mechanism in a knee that has previously undergone total or subtotal medial meniscectomy. In support of this concept, Garrett (119) has reported significantly better KT1000 arthrometric results for ACL reconstructions performed with concomitant medial meniscal transplantation than for a group of patients who underwent isolated ACL reconstruction with persistent medial meniscal deficiency. Similar results have been documented in a study by Shelbourne demonstrating greater laxity as measured by KT1000 arthrometer after ACL reconstruction in knees that had previously undergone medial meniscectomy than in knees with intact meniscus (133).

The treatment of the patient with failed ACL reconstruction secondary to osteoarthritis is a true dilemma. The treatment of combined osteoarthritis and ACL deficiency is complex and controversial. Historically these patients have been advised to follow a conservative course. The mainstay of treatment has been analgesics and antiinflammatory drugs, physical therapy, unloading bracing, and modification of activities. In the last five years, however, a number of studies have reported encouraging results with osteotomy, isolated ACL reconstruction, or a combined procedure. The role of ACL reconstruction in the osteoarthritic knee is controversial. Some authors have suggested that osteoarthritis is a contraindication to ACL reconstruction (120,121). Concerns include increased pain, joint contact forces, and constraint leading to an increased progression of osteoarthritis. Others have advocated reconstruction to improve stability, function, and proprioception, and help reduce pain and



A B C

FIG. 18. A–C: If the original femoral tunnel is more than one tunnel diameter anterior to its optimal placement, a new tunnel can be drilled at the optimal location without tunnel overlap.

advancement of arthritic changes within the knee. Patients with such a condition present with either pain or instability or a combination as the primary complaint. The surgeon must attempt to decipher which complaint is the overwhelming symptom, for the treatment plans are distinctly different. In many cases this can be difficult to determine. Surgical options for the arthritic ACL-deficient knee include the following:

Instability: isolated ACL reconstruction
Pain: isolated HTO
Pain and instability: ACL reconstruction and HTO

Isolated ACL reconstruction in the face of osteoarthritis with a primary complaint of instability has been evaluated and is a reasonable approach. Shelbourne and Stuube reported on a group of 33 patients who had chronic ACL deficiency at a mean of 44.8 months (122). Inclusion criteria were meniscectomies before reconstruction, radiographic evidence of mild arthritis, and grade III or IV changes at the time of arthroscopy. Alignment was not determined. All patients underwent a standard ACL reconstruction using autogenous patellar tendon. There was significant improvement in function (modified Cincinnati Knee Questionnaire score: preoperative, 55; postoperative, 81) and pain relief (modified Cincinnati Knee Questionnaire score: preoperative, 55; postoperative, 81). There was a significant improvement in knee stability as measured with the KT-1000 arthrometer from 8.3 mm preoperative to 2.7 mm postoperative. A subsequent follow-up study included 58 patients with chronic ACL deficiency who had radiographic evidence of arthritis (123). Thirty patients were available for 5-year follow-up (mean

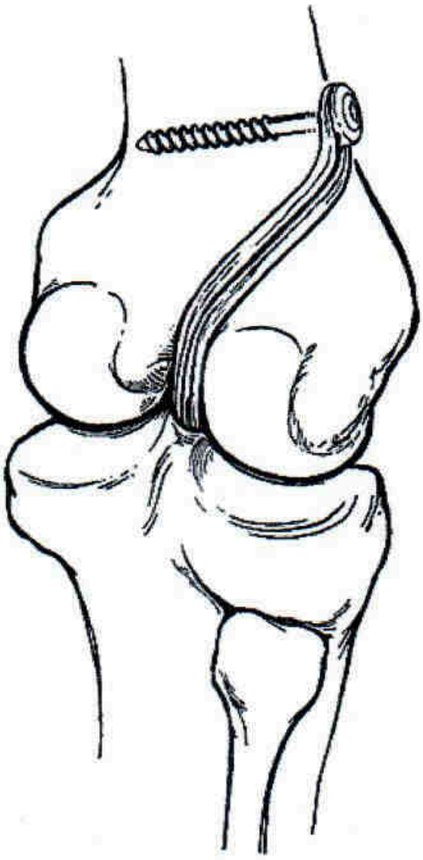


FIG. 19. Enlarged femoral tunnels can be bypassed by using the over-the-top position.

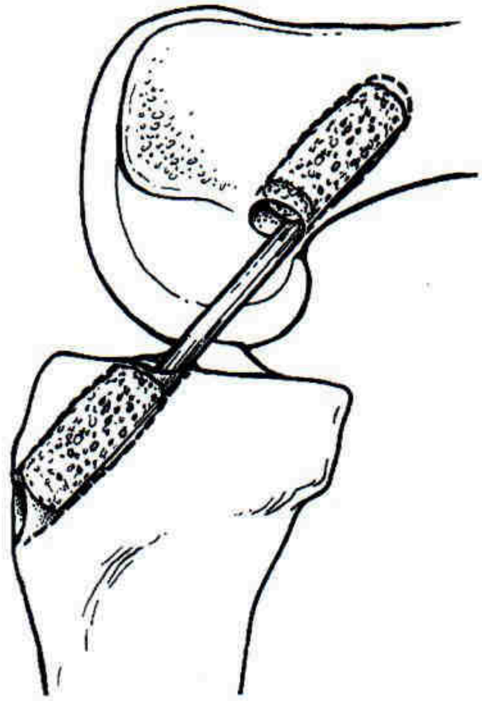


FIG. 21. A patellar tendon allograft with large bone blocks can be used to fill enlarged bone tunnels.

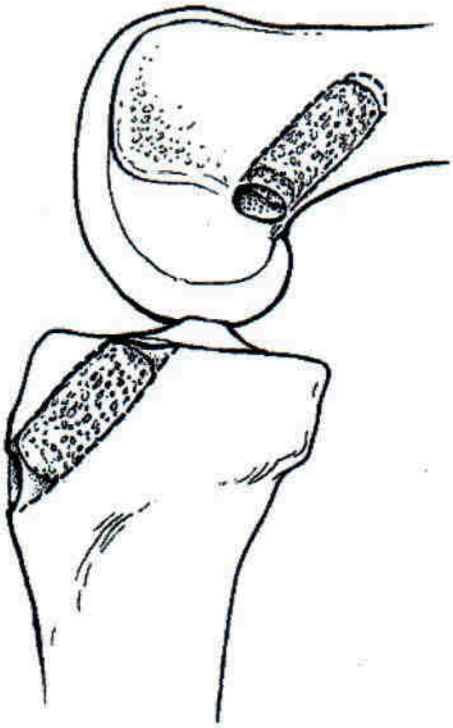


FIG. 20. Enlarged femoral tunnels can be grafted with iliac crest bone grafts.

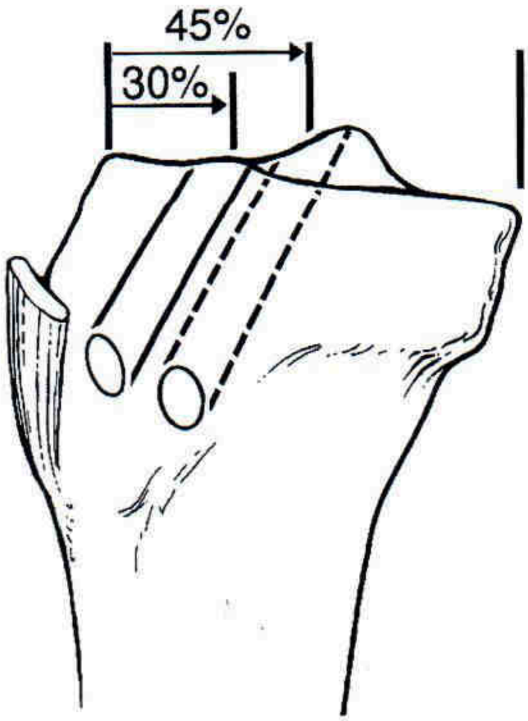


FIG. 22. If a tibial tunnel is located more than one diameter anterior to its optimal position (*solid lines*), a new tunnel can be drilled in the optimal position without potential tunnel overlap (*dashed lines*).

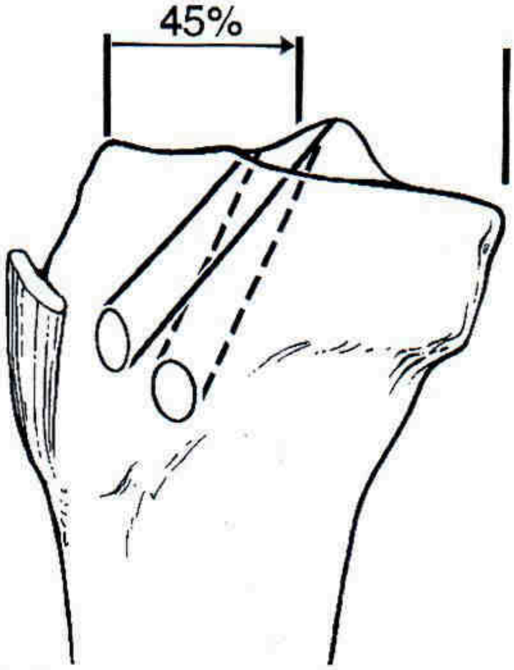


FIG. 23. The optimally positioned tibial tunnel can be created by changing the external starting position of the new tunnel in the sagittal and frontal planes.

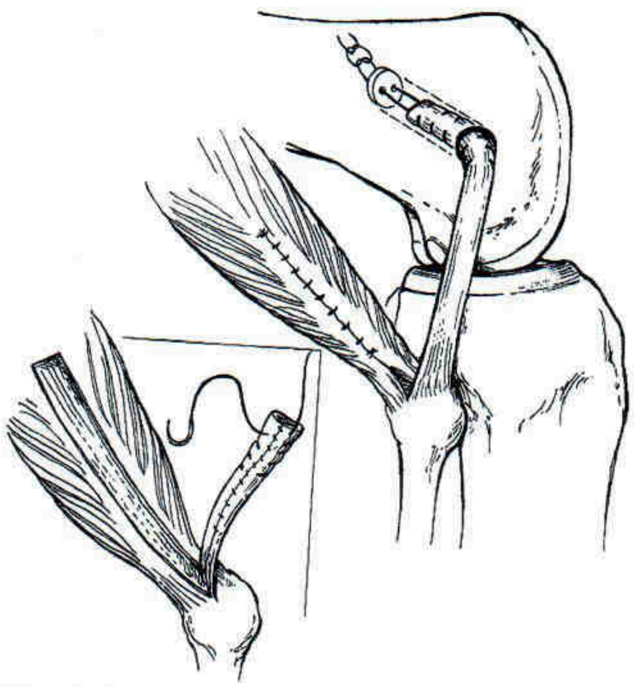


FIG. 25. The lateral collateral ligament can be reconstructed using a biceps tendon graft.

of 7.2 years). Similar results were noted within this group, with improved function, pain relief, and stability. The study found that patients with medial compartment arthrosis reported a better subjective total score (mean of 87) than patients with lateral compartment arthrosis (mean of 73) and bicompartmental arthrosis (mean of 79), but results were not statistically significant. Noyes and Barber-Westin evaluated 53 patients who underwent ACL reconstruction with a mean follow-up of 27 months (124). Inclusion criteria were extensive fissuring and fragmentation involving more than 50% of the articular surface (62%) or exposure of subchondral bone (38%). The lesions had to be larger than 15 mm in diameter. Alignment had to be normal as determined by weightbearing radiographs. Clinical results revealed 70% reduction in pain, eradication of giving way in 89%, and resumption of recreational activities in 79%.

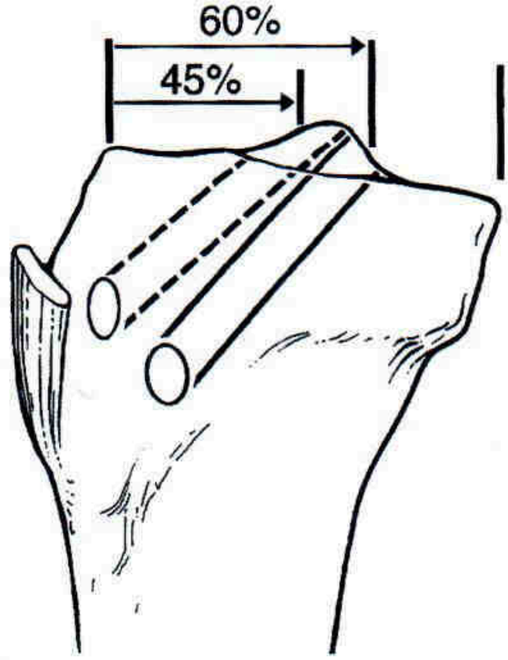


FIG. 24. If the original tibial tunnel is located more than one diameter posterior to its optimal position, a new tunnel can be drilled in the optimal position without tunnel overlap.

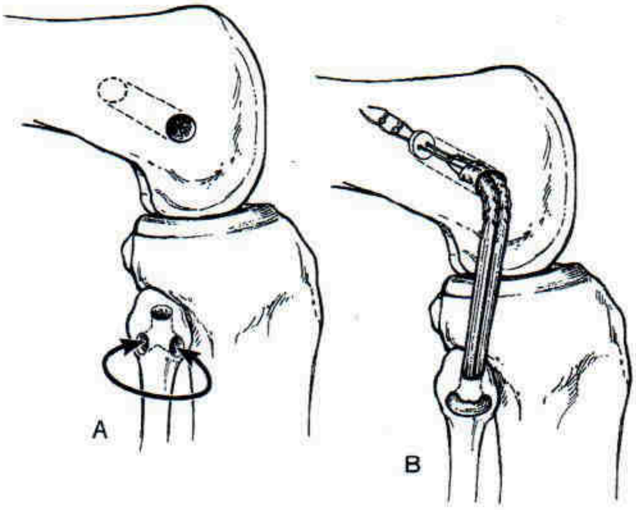


FIG. 26. A, B: Lateral collateral ligament reconstruction can be performed using a doubled semitendinosus graft.

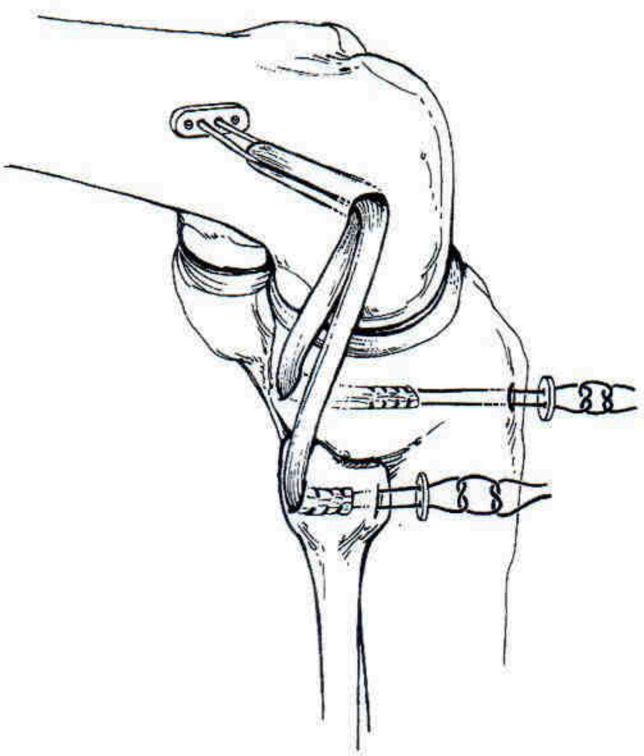


FIG. 27. Reconstruction of the popliteus tendon and popliteofibular ligament can be accomplished using a semitendinosus graft and Endo button (Smith & Nephew Endoscopy, Andover, MA) fixation.

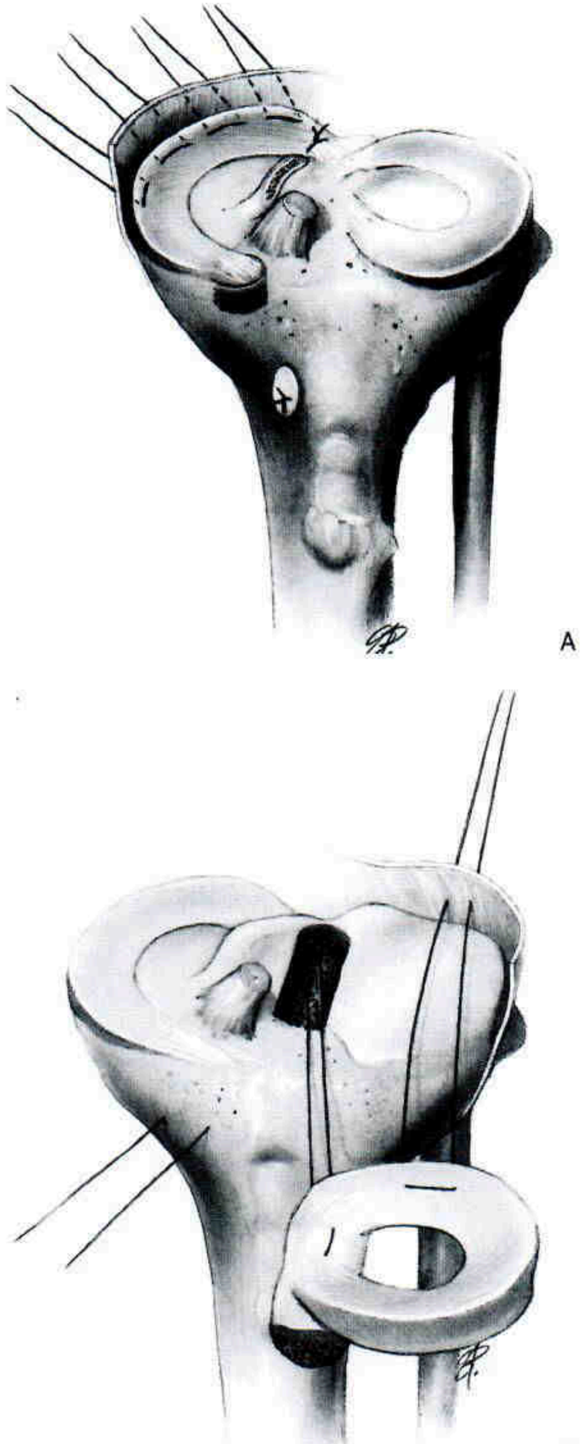
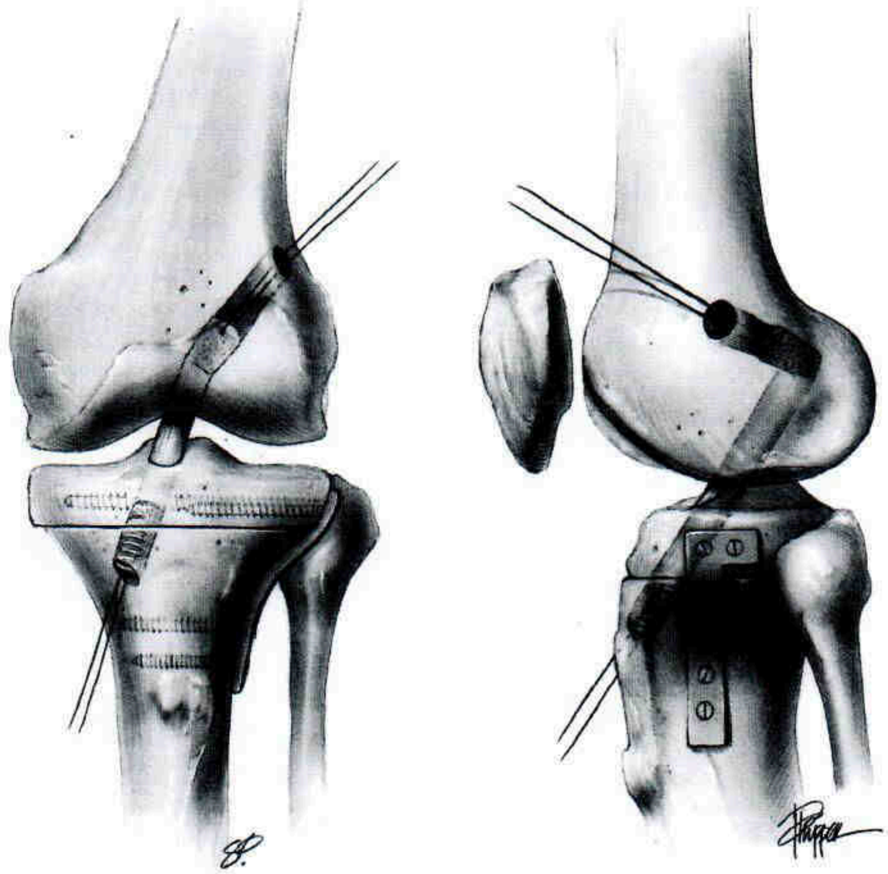


FIG. 28. A, B: Meniscal transplant techniques: tunnel.

The appropriate surgical decision making with regard to isolated HTO or osteotomy in combination with ACL reconstruction in the arthritic ACL-deficient knee has yet to be determined (Fig. 29). Classically, HTO has been described as a lateral closing wedge technique for an older patient population with medial compartment arthritis and varus malalignment. Noyes et al. introduced the concept of double varus (varus alignment with lateral ligamentous laxity) and triple varus (double varus knee with varus recurvatum caused by arcuate ligament complex deficiency) (115). Gait analysis of these patients revealed increased adductor moment related to previous subtotal or total meniscectomy. Such a condition increases medial compartment loads and eventual arthritis. There are few papers addressing ACL-deficient patients with varus gonarthrosis. Kirkley et al. reported on a group of eight patients with ACL deficiency, varus alignment, grade II or higher medial compartment arthritis, and a varus thrust (A. Kirkley, J. Roe, P. J. Fowler. HTO alone for the treatment of chronic ACL deficiency and varus gonarthrosis, *unpublished data*). The authors noted significant improvement with HTO alone of six patients in pain and instability symptoms in 2.5 years of follow-up. Two patients continued to have ongoing instability symptoms. Another study by Holden et al. (125) reviewed 51 young patients at a mean follow-up of 10 years. The average age was 41 years (range, 23 to 50). A subset of 14 patients was identified as ACL deficient. Instability was not the primary complaint; instead, pain during activities of daily living and sports activities was the presenting problem. Postoperatively after the HTO, 66% were able to return to recreational activities such as swimming, golf, and tennis. Only 10% were able to run. Recently, there has been interest in a newer technique using an opening wedge osteotomy. Patients' symptoms dictate the procedure; patients with ACL deficiency with osteoarthritis and pain as the primary complaint are best suited for isolated high osteotomy.



A,B

FIG. 29. Anterior cruciate ligament reconstruction and high tibial osteotomy. **A:** Anteroposterior. **B:** Lateral.

COMBINED ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION AND OSTEOTOMY

The combined procedure of ACL reconstruction and HTO is indicated in those patients who complain of both instability and pain. Surgically, the concurrent ACL and HTO procedure is very difficult and demanding, so that one may consider staged procedure. Dejour et al. (126) reported on 50 knees with chronic ACL deficiency combined with acquired varus alignment. The mean patient age was 29 (range, 18 to 42), and mean follow-up was 3.6 years. The HTO was performed first (74% closing lateral wedge and 26% opening medial osteotomy) and then ACL reconstruction with autogenous patellar tendon combined with Lemaire extraarticular augmentation (56%). Clinical results revealed significant improvement with both stability and pain relief. Patient satisfaction was high (91%). No progression of arthritis was noted radiographically.

Lattermann and Jakob reviewed 27 patients with ACL deficiency and medial compartment osteoarthritis (127). Patients were divided into three treatment groups: HTO alone (11 patients), staged HTO and ACL reconstruction (eight patients), and combined ACL reconstruction and HTO (eight patients). HTO alone was indicated in those patients in whom the predominant symptom was pain (mean age of 44 years). Staged HTO and ACL reconstruction was indicated for patients with pain and instability (mean age of 35 years). Combined HTO and ACL reconstruction was indicated in young athletic patients in whom instability was the primary complaint (mean age of 32 years). Statistical significance could not be determined because of the small number of patients in the individual groups. The HTO procedure used opening medial wedge osteotomy in ten patients and closing lateral wedge osteotomy in 17 patients. The ACL reconstruction was performed arthroscopically using autogenous patellar tendon graft. Results revealed that 91% of the patients in the HTO group had improved knee stability and significant pain relief with the ability to return to recreational activities. In the staged group, the HTO was performed first. Those patients that continued to have insufficient knee stability underwent ACL reconstruction 9 to 12 months later. Eight of the 19 HTO patients required delayed ACL reconstruction. Follow-up evaluation revealed that 38% of the patients had significant pain relief with the remaining patients describing some discomfort, although they were pain free with light activities of daily living. Six of the eight patients had no knee instability, and the two remaining patients had partial giving way. In the combined group, significant pain relief was achieved in 50% with the remainder having pain with moderate activities. Knee stability was improved in 63%. Complication rate was noted to be high in all three groups, with ten major complications reported. The authors concluded that HTO alone was adequate in the treatment of older patients with pain as the primary problem and that younger patients should be treated initially with HTO alone and a subsequent ACL reconstruction performed in 9 to 12 months should instability persist.

A study at the Hospital for Special Surgery by Williams et al. (74) evaluated a similar group of 25 patients with ACL deficiency and medial compartment arthritis. Two groups of patients were identified: those undergoing HTO alone (12 patients, mean age of 38 years) and those undergoing combined ACL and HTO (13 patients, mean age of 32 years). Mean follow-up was 43 months. Medial meniscectomy was performed on all patients. There was significant improvement in pain relief and knee stability in all patients as measured using a multiple scoring system (Hospital for Special Surgery knee score, Tegner activity level, Lysholm and Gillquist knee scores). Those patients undergoing HTO alone reported decreased subjective knee instability despite persistent objective instability (positive pivot shift and Lachman test results). There was no progression of medial compartment arthritis as documented by plain radiographs. Overall patient satisfaction was high (92%) with 23 of 25 patients able to participate in recreational sports.

REHABILITATION AFTER REVISION ANTERIOR CRUCIATE LIGAMENT SURGERY

The rehabilitation program after revision ACL surgery is influenced by both surgical and patient variables. Patient variables include the presence of generalized ligamentous laxity, bone quality, the preoperative laxity of the knee, patient size, limb alignment, and patient motivation and compliance. Surgical variables include the type of ACL replacement graft used, the type of graft fixation, graft placement, and the performance of concomitant extraarticular surgery. Because of the many patient and surgical variables, a "cookbook" type of rehabilitation program should not be used; rather, a customized protocol taking these variables into account should be developed.

In general, revision ACL surgery should be considered salvage surgery, and a less aggressive rehabilitation program should be used in most cases. Weaker initial graft fixation, laxity of secondary restraints, the potential need to address associated ligamentous injuries, and the presence of more significant articular cartilage changes make the use of an accelerated rehabilitation program inappropriate in most revision cases.

The major changes in the rehabilitation program after revision ACL surgery consist of a slower progression in weightbearing and functional exercises. Full passive extension to 0 degrees (avoidance of hyperextension), actively assisted exercises using the opposite leg, heel drags, wall slides, quadriceps isometrics, straight leg raises (quadriceps lag less than 10 degrees), ankle pumps, and patellar mobilization are all allowed immediately after surgery. In most cases, full range of motion should be reestablished by 6 to 8 weeks postoperatively. A straight leg orthosis is used until the patient demonstrates good muscular control of the leg. Assuming that no associated ligamentous surgery was performed, the weightbearing limit of the patient is increased a maximum of 25% of body weight per week. Patients are weaned off crutches no earlier than the end of week 4, and then only if they demonstrate good neuromuscular control of the leg and a normal or near-normal gait pattern. Exercise with a stationary bike is begun between weeks 4 and 6; however, weightbearing closed-chain exercises such as minisquats, lateral step-ups, toe raises, and the stair climber are delayed until the beginning of the sixth postoperative week. Jogging and running are delayed until 16 to 20 weeks after surgery. Turning, twisting, and pivoting drills are started at 24 weeks postoperatively. In general, most patients are advised against returning to twisting and pivoting sports before 9 months.

The experience at the Hospital for Special Surgery with regard to revision ACL surgery has been reviewed (101). The study identified 87 patients who experienced failure of ACL surgery during a 7-year period from 1989 to 1996. Grafts used for revision ACL included 62 autograft (56 patellar tendon, 5 hamstring tendon, and 1 iliotibial band) and 25 fresh frozen patellar tendon. The causes of failed ACL reconstruction included 41 technical errors, 22 traumatic reinjuries, 7 failures of graft incorporation, 8 failures to recognize associated injuries (alignment or combined ligament pattern), and 4 failures related to loss of motion. The time interval between primary and revision ACL surgery was 2.7 years (range, 6 months to 13 years). Overall mean follow-up from time of revision ACL was 2.1 years (range, 3 months to 6 years); 52 patients had a minimal follow-up of 2 years, of whom 43 were available to respond to a detailed outcome questionnaire and undergo physical examination. Use of the Hospital for Special Surgery knee ligament evaluation form revealed 62.8% good or excellent results compared to 95.5% good or excellent results in an age-matched group undergoing primary ACL, a statistically significant difference. Objective laxity tests revealed a 3.1-mm mean side-to-side difference at 30 degrees. No difference was noted between allograft and autograft recipients in the revision ACL group.

CONCLUSION

An increasing number of revision ACL reconstructions are being performed each year. Revision ACL surgery is challenging and cannot be approached in the same manner as primary ACL surgery. Successful revision ACL surgery requires a detailed history taking, a comprehensive physical examination, appropriate radiologic studies, and careful preoperative planning. The results of revision ACL surgery do not equal the results of primary ACL surgery, and this should be explained to the patient before surgery. To avoid repetition of errors that led to failure of the primary reconstruction, the cause of the primary failure must be clearly understood before proceeding with the revision procedure. Although graft failure is the most common reason for failure of the original reconstruction and performance of revision surgery, other non–graft-related problems such as loss of motion, extensor mechanism dysfunction, and degenerative arthritis can also result in an unsatisfactory outcome and residual complaints. Errors in surgical technique, specifically nonanatomic graft placement and failure to address associated ligamentous injuries at the time of the original procedure, are responsible for graft failures in most reported series. Preoperative planning must address the issues of graft selection, skin incisions, hardware removal, tunnel placement, graft fixation, and associated ligamentous injuries. Loss of motion and in some cases enlarged bone tunnels may require a staged approach. Because of the weaker initial graft fixation, laxity of secondary restraints, the potential need to address associated ligamentous injuries, and the presence of more significant articular cartilage changes, an accelerated rehabilitation program is inappropriate in most revision cases. Successful revision ACL surgery requires a motivated and compliant patient, a well-thought-out plan, and an experienced surgeon who is knowledgeable and proficient with regard to a variety of different surgical techniques, graft sources, and graft fixation techniques.

Given today's emphasis on maintaining fitness and the participation of all age groups in physical activities that place the ACL at risk of injury, the number of primary ACL reconstructions performed can be expected to continue to increase. Although surgical and rehabilitation advancements have improved the success rate of primary ACL reconstruction, the increasing number of primary reconstructions being performed can be expected to lead to an increasing number of patients who need revision ACL surgery.

Improvements in surgical technique and rehabilitation have enhanced the results of primary ACL surgery; however, unsatisfactory results can and still occur.

In general, the results of revision ACL reconstruction do not appear to be as favorable as those of primary reconstructions. The success rate of revision ACL reconstruction is determined by many factors, including the cause of the primary failure; the preoperative laxity of the knee; the status of the secondary restraints, menisci, and articular cartilage; and patient motivation and compliance. To maximize the success of revision ACL surgery, a methodical and organized approach is required. This chapter has reviewed the causes of failed ACL surgery, discussed preoperative evaluation and planning, and reviewed some of the technical considerations of revision ACL surgery.

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