The ACL-Deficient Knee

Natural History and Treatment Options

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Anterior cruciate ligament (ACL) injuries are common and have been the subject of many laboratory and clinical papers. However, because patients with asymptomatic ACL-deficient knees do not present themselves, a true natural history of these injuries may never be known. This article will discuss some of the past and current studies in the literature that have shaped current knowledge about the ACL-deficient knee.

Epidemiology

It has been estimated that 95,000 ACL injuries occur each year. Overall, there are more males affected than females. However, when controlled for the number of male to female participants in sports, the ratio reverses and there is a female to male ratio of from 2:1 to 4:1. Of the 95,000 injuries each year, approximately half will have surgical ligament reconstruction. A recent publication by Gottlob and colleagues estimates the cost of reconstruction (including postoperative rehabilitation) at $11,500 (US) per patient versus $2,000 for non-operative treatment.

Function

The forces about the knee are balanced through surrounding bony, ligamentous, and muscular structures. The stresses observed in any one structure depend on the position of the knee and the relative intactness of the other structures.

The ACL serves as the primary restraint to anterior subluxation of the tibia on the femur. It has two functional components, an anteromedial and a posterolateral band. The anteromedial band is tighter during positions of knee flexion, while the posterolateral band is tighter during positions of extension. While the two bands are described as separate structural units, they function together throughout the arc of motion of the knee to prevent subluxation.

The ACL has a secondary function in resisting other forces on the knee. It is a major secondary restraint to internal rotation and a minor restraint to external rotation. This stabilizing effect is lost as the knee assumes a more flexed position. The ACL offers only minor resistance to varus and valgus forces.

In addition to the structural stabilizing function of the ACL, it is also thought to provide a stabilizing function through a neurologic feedback mechanism. Mechanoreceptors, which exist on the ACL, have been described as relaying joint position information, which is involved in muscular stabilization of the joint.

Injury

ACL injuries have been described as occurring by two mechanisms. The first mechanism involves deceleration and pivoting, as when changing the direction of movement. EMG studies of normal subjects performing these type of cutting movements show that the foot strike occurs at approximately 22 degrees of flexion, quadriceps contraction is 161% of maximal voluntary contraction, and hamstring contraction is only 22%. With the knee in slight flexion, the secondary restraints to anterior translation are minimal while the anterior displacing force of the quadriceps contraction is maximal. The relatively minor stabilizing efforts of the hamstrings leaves the ACL as the sole restraint to translation and vulner-
able to injury. The second mechanism is involved, for example, when landing on a single planted leg and falling with a valgus force to the leg and maximal quadriceps contraction. Again, there is maximal contraction of the quadriceps when the knee is in slight flexion and minimal secondary stabilizers.

**Evaluation**

The evaluation of a patient with a suspected ACL injury begins with a thorough history. Patients with these injuries have a typical presentation. The injury usually occurs in a non-contact event. Patients may hear or feel a “pop” and will not be able to continue participating in their competition; swelling will usually develop within a few hours. Patients with chronic injuries may have recurrent episodes of instability and subsequent effusions. With this history, alone, the likelihood of an ACL injury has been estimated to be 70%.

In performing a physical examination, the physician should begin with inspection of both knees to evaluate the patient for an effusion and possible muscular atrophy in the patient with a chronic deficiency. The uninjured leg should be examined to develop a baseline normal exam that can be used to compare the exam of the injured knee. Provocative tests that have been described to evaluate the ACL include the Lachman, the anterior draw, and the pivot shift.

The Lachman test is performed with the knee flexed to 30 degrees, with an anterior displacing force on the tibia. The amount of translation and the quality of the endpoint are evaluated. A side-to-side difference compared to the contralateral knee of greater than 3 mm has been measured in 90% of ACL-deficient patients. Similarly, a soft endpoint is considered to be a sign of ACL injury.

The anterior draw test is similar to the Lachman, however, it is performed with the knee at 90 degrees of flexion. Katz and Fingerworth looked at the relative sensitivity and specificity of these tests and found that the Lachman was 82% sensitive and 96% specific, while the anterior draw test was only 41% sensitive and 95% specific. Some authors have described the differences in sensitivity based on several factors. First, the intra-articular secondary stabilizers such as the bony contact area and meniscus are stronger stabilizers at 90 degrees compared to 30 degrees. Second, the hamstring muscles, which are likely to be in spasm during an acute injury, are at more of a mechanical advantage to resist the anterior displacing force when the knee is flexed to 90 degrees. Finally, the hemorrhosis that is present makes evaluation of the knee difficult at 90 degrees because of decreased joint volume and patient discomfort.

The pivot shift test is performed with internal rotation of the leg and a valgus directed force to a minimally flexed knee. With flexion of the knee, the anterior tibial subluxation that is created with the internal rotation will reduce as the pull of the iliotibial band moves posterior to the joint. With reduction, there will be a palpable shift. This test was found to be 82% sensitive and 98% specific; however, due to patient guarding, this test may be difficult to perform.

Radiographic evaluation begins with plain film radiographs. A tibial spine fracture may be evident on the AP or plateau view and represents an avulsion of the ACL. Similarly, lateral capsule avulsion, a Segond fracture, is seen as a small vertically oriented fracture at the lateral margin of the tibial plateau and is pathognomonic for an ACL disruption. In chronic injuries, one may see osteophyte formation, hypertrophy of the tibial spines, and joint space narrowing.

Magnetic resonance imaging (MRI) is an invaluable test to help confirm the diagnosis of an ACL injury. On T1 and T2 images, the normal ACL fibers can be visualized as they course from the tibial spine to the lateral femoral condyle. T1 images may demonstrate the absence of the normal fibers, while T2 images will demonstrate hemorrhage and edema within the injured ligament. MRI is 95% accurate in diagnosing ACL injuries. MRI can also diagnose concomitant injuries such as meniscal tears, osteochondral defects, bone bruises, and other ligamentous injuries that may influence patient treatment.

**Review**

There have been many studies in the literature looking at the outcomes of patients with an ACL deficiency. However, the true natural history of the ACL-deficient knee will probably never be known because most of those studies involve symptomatic patients who present for treatment. When trying to gain a consensus opinion from the available studies, one must be careful not to compare apples to oranges. Patient populations, study definitions, treatment methods, follow-up periods, and outcome measures all vary. Knowledge of fundamental concepts pertaining to the ACL-deficient knee is necessary to help critically evaluate these studies.

**Laboratory Studies**

Some of the early investigations into the ACL-deficient knee were laboratory studies involving dogs. Marshall and Olsson investigated the significance of osteophyte formation in these animals. They found that osteophyte formation began early and was the result of metaplasia at the capsular margin, not the result of chondral damage. Osteophytes formed at the periphery and remodeled with time to widen the knee joint. They also found that the cartilage surfaces of the knee were relatively intact and concluded that the radiographic changes were not related to arthritis, rather they were indicative of a remodeling process in attempts to stabilize the joint.
McDevitt and colleagues examined the knees of dogs that had the ACL ligaments percutaneously cut. The authors reported that the changes presented mimicked the changes seen in dogs with naturally occurring arthritis, including capsular hyperplasia, softening of chondral surfaces, and increased proteoglycan content. The study concluded that this ACL-deficient dog model could be used to study the natural history of arthritis.

It is important to understand some of the limitations of this model, and an understanding of the difference between dog and human knees is critical. The dog has a digitigrade knee that is loaded in flexion and has its medial and lateral compartment loaded equally. The human knee is a plantigrade knee which is loaded in extension and loads the medial compartment more than the lateral compartment. Therefore, the dog knee is more dependent on the ACL, because it functions in positions of near flexion where the secondary stabilizers to anterior translation are not engaged. In addition, humans can modify their environments and avoid activities that may cause subluxation and increased stress on their ACL-deficient knee.

More recently, Lohmander and colleagues have investigated ACL deficiency in humans by examining synovial fluid from patients with ACL tears. In one study, they looked at asymptomatic individuals with ACL injuries. Analysis of the synovial fluid revealed that enzymes responsible for cartilage breakdown and actual cartilage degradation products were elevated in all patients regardless of the time from initial injury. In another study, Dahlberg and colleagues followed asymptomatic individuals with an ACL injury. The authors found increased levels of enzymes and breakdown products. However, these levels returned to normal six months after the injury. These results are supported by more recent work by Cameron and colleagues who found elevated levels of cytokines for three months after ACL injury. Based on these studies, it appears that at the time of the initial ACL injury, an inflammatory cascade is set into motion and resolves over several months if the patient becomes asymptomatic. If, however, the patient continues to have symptoms related to their ACL deficiency, they continue to have degradation within their knees.

Clinical Studies
Numerous reports on ACL-deficient knees exist in the orthopaedic literature. In 1980, Fetto and Marshall looked at a group of 327 patients with knee injuries. The majority of patients (223) had an injury to their anterior cruciate ligament(s); 38% (75) of which were isolated injuries. The authors looked at non-operative and operative treatments. Operative treatment included direct repair and augmentation, while the type of non-operative treatment was not specified. They found that the results of isolated ACL injuries treated without surgery deteriorated with time and that early operative treatment should be recommended.

Giove and colleagues, on the other hand, reported on the importance of rehabilitation after ACL injury. They followed 24 patients in a structured rehabilitation program and found no difference in degenerative changes or range of knee motion. With less than 30 months follow-up in most cases, all patients returned to sports, with 59% returning to a pre-injury level of activities. Satku and colleagues had similar results; however, with longer follow-up, they found decreased function and degeneration of the affected knees.

At a time when surgical treatment of ACL injuries was increasing, McDaniel and Dameron looked at a group of 50 patients with ACL injuries treated non-operatively in an effort to establish a baseline for comparison with new techniques. Most of the patients also had meniscal injuries and were followed for over 10 years. There was a high incidence of anterior and rotatory instability, but a low incidence of radiographic changes. Results were better in those who had regained pre-injury thigh circumference; 72% returned to strenuous sports.

Sherman and colleagues looked at radiographic changes in patients with chronic knee injuries. These patients were divided into groups based on the type of deficiency. The group with ACL injury and meniscectomy had the worst radiographic appearance; however, after 10 years all the groups (including those with an isolated ACL injury) had a similar degenerative picture.

Noyes and colleagues published a two-part report on non-operative treatment of chronic ACL injuries in a young competitively athletic group. This group of patients had no specific treatment at time of initial injury; nearly half returned to competitive sport within 6 months. The initial difficulty with athletic activities progressed to difficulty with activities of daily living. In the second report, Noyes and associates then reported on the effects of rehabilitation in this group. They found that one-third improved, one-third remained the same, and one-third worsened over time.

In 1993, Dale Daniel and coworkers won the O’Donoghue award for a prospective non-randomized study of 236 patients with ACL-deficient knees. Factors correlated with late surgery for either meniscus or ligament reconstruction were the number of pre-injury hours of participation in level I (soccer, basketball, football) or II (tennis, skiing) sports, and the maximal displacement as measured on the KT-1000. Factors not related included patient age, sex, or activity during injury. Interestingly, they found a higher rate of arthritis in the operative group. However, this may be attributed to the fact that those patients who were encouraged to have surgery were younger, more active patients.

More recently, Murrell and colleagues looked at
meniscal and chondral damage at the time of ACL reconstruction in 130 consecutive patients. They found an increased incidence in meniscal damage and chondral surface damage in patients with chronic injuries; in patients with chronic meniscal injuries, there was an 18-fold increase in chondral damage.24 Similarly, Shelbourne and Gray looked at long-term outcomes of ACL reconstruction as related to operative findings. They found the articular cartilage status to be the most important factor related to objective and subjective results. Other important factors were the status of the medial and lateral menisci. Chronicity did not adversely affect the outcome if the cartilage and menisci were present.25

The Fate of the Meniscus

In 1936, King described the functions of the meniscus as increasing joint congruity, a source of lubrication, and a source of cartilage protection.26 Furthermore, in the ACL-deficient knee, the meniscus act as an important secondary stabilizer to anterior translation.27 Studies have shown that removal of as little as 15% to 30% of the meniscus will increase contact forces as much as 350%.28 This is supported by studies which have documented clinical progression of degenerative changes in patients after meniscectomy.18,20,25,29

Meniscal tears with associated ACL injury are common. Lateral meniscal tears are more common in acute injuries, occurring in 45% to 75% of patients, while medial meniscal tears are more common in chronic injuries, occurring in 73% to 91% of patients.30-34 The healing rate of repaired menisci in the ACL reconstructed knee is increased as compared to those in knees without ACL injury.35 Those knees undergoing ACL surgery have been found to have a meniscal healing rate of 92%, while those without an ACL injury had a healing rate of only 62%.1

Fate of the Articular Surface

It is not surprising that a traumatic event capable of rupturing the ACL will have a deleterious effect on the cartilage and osseous structures. Bone bruises, edema within the subchondral bone, can be found on 90% to 96% of MRIs performed to evaluate an ACL injury. In 1993, Graf and colleagues described these lesions as occurring on the middle portion of the lateral femoral condyle and the posterior portion of the lateral tibial plateau.36 Arthroscopic and histologic evaluation of bone bruises have revealed cartilage softening and chondrocyte degeneration. Additionally, the presence of this lesion has been correlated with larger and more persistent joint effusions, increased knee pain, and longer recovery.37,38

The significance of these subchondral bone and cartilage injuries has also been investigated. Second-look arthroscopy at 6-year follow-up found areas of cartilage thinning in the regions of prior bone bruises.39

Drongowski and colleagues, in a retrospective study, evaluated patient disability as it related to running. The authors found that those patients with chondral damage, not meniscal injury, were more negatively affected.40

Neuromuscular Considerations

Neuromuscular control of the knee is aided by feedback mechanisms that involve proprioceptive receptors on the ACL. Injury to the ACL has been shown to lead to decreased proprioception in the joint.5,41-43 The impact of surgical reconstruction on joint proprioception is controversial in the literature. Studies have shown a decrease in proprioception in the ACL-deficient knee that improves with ACL reconstruction, but does not reach the level of those without ACL injury.41-43 Furthermore, the type of reconstruction, either bone-patella-bone or hamstring, was not found to affect the final proprioceptive status.5 Barrett found an interesting correlation between proprioceptive ability and subjective outcome: patients with better proprioception had better subjective results despite objective findings of ACL laxity.41

Adaptive changes in gait patterns are seen in the ACL-deficient knee. The quadriceps avoidance gait averts external flexion moments that would require quadriceps’ muscle firing at positions of near extension. By avoiding these conditions, the patient is able to minimize anterior displacing forces.11

Late Deformity

The mechanical axis of the leg represents the weight-bearing line of the limb. This axis can be represented by a line drawn from the center of the hip to the center of the ankle, and passes slightly medial to the center to the knee. Injury to the structures of the limb can alter this axis, creating deformity of the extremity.44 Noyes and Simon described the varus deformity patterns that can occur in the ACL-deficient knee:

1. The single varus knee includes injury to the cartilage and meniscus that allows the medial joint line to close down, shifting the mechanical axis medial;
2. The double varus knee results from an injury to, or chronic stretching of the lateral structures; loss of lateral support leads to further medial translation of the weightbearing axis and an increased varus deformity; and
3. The triple varus knee involves further injury to the knee and translation of the axis with associated hyperextension deformity.44

Treatment Considerations

The goal when taking care of a patient with an ACL injury is to prevent recurrent injuries while allowing the patient to return to his desired level of work or sports. Treatment decisions on lifestyle modifications should be
made with the patient, but some general guidelines do exist.

Patient age is an important consideration. With the volume of literature supporting a high incidence of meniscal tears in patients with chronic injuries together with the fact that most younger patients will be unwilling to significantly modify their activities, ACL reconstruction is the preferred treatment.1,18,20,23,25,29 In the older patient, there is support for both operative and non-operative treatment.45-47

Patients who experience recurrent episodes of instability will do poorly, therefore, activity level is another important factor to consider. Patients with a sedentary lifestyle are likely to do well with non-operative treatment, while those patients who compete in jumping or cutting sports are less likely to tolerate non-operative treatment. However, competitive athletes in non-cutting sports such as swimming, biking, or running may be able to compete without difficulty.1,4,23

In assessing an individual’s surgical risk, Daniel and colleagues looked at the maximal laxity and amount of participation in level I and II sports. Patients with less than 5 mm of tibial displacement and who participated in less than 50 hours of high-risk activities per year, had a low risk of requiring future surgery. If the same patient participated in more than 200 hours of high-risk activities, they were at moderate risk. Those patients with more than 7 mm of displacement who participated in less than 50 hours of high-risk activities were at moderate risk, and the patients with more than 50 hours of participation were at high risk.4,23

Summary

Injury to the anterior cruciate ligament removes the major stabilizing structure to anterior tibial translation. The initial trauma may lead to meniscal and cartilage damage, predisposing the knee to early degenerative changes. Moreover, a knee with an isolated ACL rupture may have recurrent episodes of instability that can lead to a similar degenerative course. At this time, one cannot accurately predict which patients will tolerate ACL deficiency, and which patients will not. Current long-term studies support a progressive worsening condition in the ACL and meniscal deficient knees. Physical therapy together with lifestyle modifications may be necessary. Those unwilling to make these types of changes or those with associated injuries may benefit from ACL reconstruction.

References

2. Gottlob CA, Baker CL Jr, Pellissier JM, et al: Cost effec-


