ACL Injury and Rehabilitation

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Abstract The anterior cruciate ligament (ACL) is a primary restraint to anterior tibial translation and a significant contributor to both static and dynamic knee stability, especially for sports and activities that require deceleration and aggressive cutting and pivoting movements. ACL injuries have a significant impact on individual function and on the health care economy, and continue to be prevalent and disproportionate, affecting more women than men. Factors have been identified which can help predict success in non-operative treatment, and surgical procedures have advanced to the point of ensuring a reliable outcome with respect to joint stability. Rehabilitation interventions focus on enhancing lower extremity strength, stability, and neuromuscular control. Both operative and non-operative treatment options, however, have been associated with an increased risk of later osteoarthritis. ACL prevention programs have attempted to correct flaws in movement patterns and neuromuscular control, but long-term data on the efficacy of these programs and of specific interventions are lacking.

Keywords Anterior cruciate ligament · ACL · ACL injury · ACL rehabilitation

Introduction

The anterior cruciate ligament (ACL) is the primary restraint to anterior tibial translation. It is a collagenous structure approximately four times as long as it is wide, and has two major bundles that function as a unit to provide isometric

knee stabilization [1]. The ACL contributes in a significant way to knee stability, especially with respect to dynamic cut/pivot and deceleration movements. Activities that involve cutting and pivoting movements or sudden deceleration with change of direction account for approximately 70 % of acute ACL injuries [2]. Most ACL injuries are noncontact in nature, and most tears are complete tears of the ligament [3].

ACL Anatomy and Biomechanics

The ACL is a collagenous ligament that originates on the anterior intercondylar region of the tibia and inserts on the posteromedial aspect of the lateral femoral condyle. Although it functions as a single ligament, it contains two main bundles: an anteromedial bundle, which is rigid in flexion, and a posterolateral bundle, which is rigid in extension [1]. Forces on the ACL are highest in the final 30° of the knee extension and also with knee hyperextension. The ACL provides rotary control and limits internal tibial rotation. It also functions as a secondary restraint to valgus and varus stressors throughout the range of motion [4]. The main blood supply of the ACL arises from the middle geniculate artery, and innervation is via a branch of the tibial nerve, the posterior articular nerve [5]. In addition to static stability, the ACL contributes proprioceptive feedback, which is thought to enhance dynamic control. Studies have shown persistent proprioceptive deficits even in a knee that has undergone ACL reconstruction [6, 7].

Epidemiology of ACL Injury

In the United States, there are approximately 100,000 ACL injuries (estimated to be 1 in 3,000 individuals) each year.

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Estimated annual surgical costs are nearly US\$1 billion [3, 8–11]. It is estimated that over 2 million ACL injuries occur each year worldwide [12]. A National College Athletic Association (NCAA) survey reported ACL injury to be the second most common injury of the lower extremity [3]. A 3- to 7-times greater injury incidence has been observed in women [3, 8–10, 13]. Noncontact ACL injuries have multiple risk factors, and it is difficult to determine the relative contributions of various factors. Factors postulated as influencing injury risk include biomechanical, anatomic, environmental, neuromuscular, and hormonal [8, 14–16]. Hormonal factors have been postulated to contribute to the increased incidence of ACL injuries in females, but research has not proven this to be an independent risk factor. Narrow intercondylar notch dimensions have been associated with an increased risk of ACL injury, with a lower intercondylar notch width index and intercondylar notch width stenosis predisposing to ACL injury [17]. Neuromuscular control patterns and biomechanical patterns have been found to be amenable to specific prevention programs [8]. ACL injuries appear to occur more commonly on artificial turf [18]. They are common in sports that require rapid deceleration, change of direction, and impact absorption, such as basketball, volleyball, and soccer [8, 18]. They are also common in downhill snow skiing due to the long lever arm of the ski and the rigid ski boot which transmits significant rotational and translational forces to the knee [2].

Pathophysiology

Acute ACL injury is associated with a high incidence of lateral meniscal tears. Chronic ACL injury is associated with medial meniscal tears and articular cartilage injury [19]. An ACL-deficient knee is susceptible to instability events (subluxations) if the person returns to aggressive “at risk” activities, which usually involve rapid deceleration and rapid change of direction. Repeated episodes of instability are thought to lead to meniscal and articular cartilage injury, and compromise ability to return to high demand athletic activity. A smaller percentage of ACL-injured individuals may experience “functional” instability, with give-way episodes occurring during activities of daily living. A large segment of persons with ACL injuries can function well, and limit or prevent subluxation events by avoiding high-risk activities [20].

The development of osteoarthritis in an ACL-injured knee is caused by both intra-articular processes initiated at the time of injury combined with changes in joint loading over time. ACL injuries combined with a meniscus tear increase the risk of subsequent x-ray-appreciated osteoarthritis [21, 22•]. The development of osteoarthritis in

isolated ACL injuries is reported to be lower than in combined ACL and meniscal injuries (0–13 vs. 21–48 %) [22•, 23, 24]. ACL reconstruction is not associated with significant reduction in the prevalence of knee osteoarthritis [22•, 23, 24]. Meniscal injury is commonly associated with ACL injury and is a risk factor for the development of osteoarthritis in the future [22•, 25, 26]. Non-operative treatment of ACL tears without associated meniscal injury reveals no or very little osteoarthritic change after 15 years [27]. Quadriceps weakness, which may be due to muscle inhibition or impaired neural activation, has been documented after ACL injury, and is also thought to be a contributing factor to the development of osteoarthritis [28]. Proprioceptive deficits which persist after ACL injury, and even after surgical ACL reconstruction, may also contribute to an increased risk of knee instability and subsequent chondral injury [8, 22•, 29].

ACL Injury Assessment

History

An accurate history is one of the essential components of a diagnosis of ACL injury, and an accurate history and physical exam can diagnose a great majority of ACL injuries. The patient will usually relate a history of feeling a “pop” or “give-way” of the knee during an aggressive cut, pivot, or deceleration movement [5]. Landing awkwardly from a jump or “knee hyperextension” are other mechanisms of injury. The patient usually experiences rapid swelling of the knee, and usually will be unable to return to sport or activity due to pain, swelling, and a feeling of instability. Acute hemarthrosis is associated with ACL injury a high percentage of the time, and ACL injury should be a prime consideration in any individual with acute traumatic knee swelling.

Physical Examination

The diagnosis of ACL injury can be assessed by performing the Lachman test, which challenges the ACL’s ability to control anterior tibial translation in 20–30° of knee flexion with the femur stabilized. The Lachman test is the “gold standard” physical exam assessment for ACL disruption, and is more sensitive than the Anterior Drawer test as menisci and condylar containment are not as much a factor in 30° of flexion [30–34]. Increased tibial excursion without an end point indicates ACL disruption. Hamstring relaxation is essential to accurately performing the Lachman test, as the hamstrings are antagonists of anterior tibial translation. A thorough examination of the knee for associated meniscal or other injury should be performed,

though muscle guarding, effusion, and limited and painful motion may make examination difficult.

Imaging

Knee radiographs are usually obtained to assess osseous status and to detect evidence of other injuries. Radiographs can also detect associated findings, such as lateral tibial plateau (Segond) fracture or avulsions of the tibial spine [5]. Ultrasound evaluation can be used as a screening tool when physical exam assessment is uncertain [35]. An MRI evaluation is the gold standard imaging study used to confirm ACL injury and to evaluate for associated meniscal, ligament, and articular cartilage injury [36, 37].

Supplemental Assessment

Ligament arthrometry (KT-1000, KT-2000) can be used to objectively measure and compare anterior tibial translation [2]. Functional testing (distance hops, vertical jump) can be used to assess dynamic knee stability, and is also used to assess return to play readiness after surgical or nonsurgical treatment; however, despite a significant amount of research, there is no true single functional test that will objectively determine when an athlete is ready to return to play [38, 39].

Operative Versus Non-operative Treatment

The goal of treatment of ACL injury is to prevent episodes of recurrent knee instability and, theoretically, to protect the meniscus and articular cartilage from further trauma. This can be accomplished in two ways: nonsurgical treatment involving activity modification, lower extremity strength, and stability training and appropriate bracing, or surgical reconstruction of the ligament. If meniscal repair is performed, ACL reconstruction is the option of choice to protect the meniscal repair [40]. ACL reconstruction is also preferable in cases of functional instability with activities of daily living, in most cases of combined and multi-ligament injuries, and in patients with significant meniscal involvement that contributes to knee instability or that results in a mechanical block to knee motion [40]. Recent studies have reinforced the need for individualized assessment and treatment options. Many ACL injury “copers” can do well with a program of non-operative management emphasizing lower extremity strength and stability training [41]. One study evaluated non-operatively-treated ACL-injured individuals and found that 60 % of these individuals managed as well as ACL-reconstructed individuals in the short term. Of those who did not have initial reconstruction, 40 % eventually had arthroscopic intervention for meniscal involvement, but subsequently

also reached good functional status [42]. Many factors can influence an operative or non-operative decision. In addition, ACL injury can be devastating to the athlete, since it creates the loss of ability to perform an activity. Significant changes in mood state have been measured after injury, including grief and depression [2]. A support structure entailing family, friends, and the medical team is important for successful outcome of both surgical and nonsurgical treatments.

ACL Rehabilitation

Initial treatment for an ACL injury aims to reduce pain and swelling in the knee, regain normal joint movement, and strengthen the musculature around the knee. Regaining full knee extension is critical to a successful outcome, especially after reconstruction surgery. After acute injury, individuals will likely require assisted ambulation with crutches until weight-bearing pain resolves and gait mechanics normalize. A medial/lateral support brace may be used for combined medial collateral or lateral collateral injuries. Acute ACL injury treatment begins with institution of *PRICE* principles: *Protection* of the injured limb with crutches, *Relative rest* from at risk activity while maintaining aerobic conditioning as much as possible, and use of *Ice*, *Compression*, and *Elevation*. Bone bruises characteristic of ACL injury may initially make weight bearing painful, and studies indicate that these initial bone injuries may contribute to long-term damage to articular cartilage that predisposes to arthritis [36, 37]. If significant bone bruise involvement is seen on MRI, it seems prudent to limit weight bearing after injury, though the optimal time period for modified weight bearing has yet to be determined.

Progressive weight bearing and weight shifting can help to maintain neuromuscular activation patterns, and isolated and integrated lower extremity strengthening can be started as joint motion permits. In both post-surgical and non-surgical programs, isolated (open kinetic chain) and integrated (closed kinetic chain) strength training can be utilized and advanced along with low impact aerobic conditioning [43••]. Proprioceptively enriched exercises and stability training are introduced early and are advanced as status permits. Function-based movements are emphasized, along with sport-specific movements as applicable later in the course of rehabilitation [43••]. After the acute phase, rehabilitation after ACL injury can progress to recovery and functional phases. Recovery includes modalities as needed for pain, progressive strengthening, and sports-specific movement pattern progression. Functional phase activities include power and endurance of lower extremities, diagonal and multiplanar movements, increased neuromuscular and proprioceptive training, and

return to sport training [43••]. Neuromuscular training is an essential component of a rehabilitation program to optimize performance after ACL injury. Surgical reconstruction provides static stability, but dynamic stability is provided by muscle strength and coordinated muscle firing patterns [2]. Suboptimal neuromuscular patterns contribute to movement flaws, such as dynamic medial knee valgus, which can increase the risk of ACL injury, especially in female athletes. Correction of these flaws is associated with a reduced incidence of ACL injury [44, 45].

ACL prevention interventions can also be used in rehabilitation, as many of the same factors that contribute to ACL injury can be modified in an attempt to optimize status and protect against future injury. “Ligament dominance” is a term used by Hewett to define the neuromuscular imbalance responsible for valgus collapse [44, 46••]. In this condition, ground reaction forces are not adequately absorbed during impact activities, and more force is imparted to the static restraints, including the ACL. Gluteal, hamstring, and gastrocnemius groups theoretically have a significant role in the prevention of ACL injury, as suboptimal recruitment of these groups during landing increases load transmission to the ACL. Hewett also uses the term “quadriceps dominance” to describe the female preference for preferentially activating their quadriceps muscles more than males when landing from impact [45, 46••]. Studies show that females who have not sustained ACL injuries have decreased quadriceps strength compared to the hamstrings [46••, 47]. It appears that rehabilitation focused on increasing hamstring strength can modify one factor which can contribute to ACL injury.

Suboptimal core strength, reliance preferentially on one leg, and fatigue have also been shown to be risk factors for ACL injury and should be addressed in rehabilitation programs as well as preventive programs [45, 46••, 48]. It is also important to remember that the treatment of ACL injury is inherently multidisciplinary. A coordinated team of physiatrists, orthopedic surgeons, physical therapists, athletic trainers, and, in select cases, sports psychologists, is essential to ensure optimal outcomes.

Most individuals return to sports activities approximately 6–9 months after ACL reconstruction. The criteria for return to sports after ACL injury involves many different parameters, including both objective and functional performance measures, such as single and triple leg hops for distance. The Lysholm knee score and Tegner activity scales can be used as patient-administered means of functional assessment after ACL injury [38, 39].

Shorter rehabilitation periods after surgical reconstruction may help to improve patient compliance, and studies show similar outcomes between accelerated versus non-accelerated rehabilitation programs [49]. A significant amount of research currently is focusing on primary

prevention of ACL injury, and on whether programs emphasizing enhanced neuromuscular control of the lower limb, especially in female athletes, (i.e. correcting dynamic medial valgus) can prevent injury if incorporated into a preseason or in-season prevention program.

Education and Comprehensive Treatment of ACL Injury

Education regarding surgical and nonsurgical treatment options for ACL injury is essential in order for the patient to make a well-informed decision. ACL injury can be associated with significant changes in mood state, including depression and grief over loss of sport or functional status. Sports psychology is often useful to provide education regarding coping strategies. The long-time course of rehabilitation after surgical or nonsurgical treatment requires motivation and dedication. Preoperative education of both patient and family can contribute to improved postoperative compliance [2].

Surgical Treatment

Surgical reconstruction with the “double bundle” technique has been advocated by some as being more “physiologic” and similar to the native ACL. Studies suggest that the double bundle technique provides improved control of knee rotation in a laboratory setting, but other studies have shown that a single bundle ACL reconstruction can restore anteroposterior and rotational laxity as well as double bundle reconstruction [50, 51]. In addition, no significant outcome difference has been found when comparing single bundle and double bundle reconstruction techniques [51]. Many seasoned sports orthopedists feel that, rather than the double or single bundle techniques, the experience of the ACL reconstruction surgeon should be considered [52•]

Conclusion

ACL injury is common, especially in sports involving sudden deceleration and cutting/pivoting, and a greater incidence of this injury has been observed in women. The decision of whether to pursue surgical or non-surgical treatment of ACL injury needs to be individualized to the person, and activity goals as well as associated injury should be considered in the decision. Further research is needed to better define who will benefit most from ACL reconstruction, who will best be able to “cope” with the injury, and which functional tests are the best predictors of good outcome. Operative procedures for ACL reconstruction focus on obtaining as anatomic a repair as possible, and both single bundle and double bundle techniques have

been shown to produce good results in the hands of a skilled ACL surgeon. ACL rehabilitation protocols focus on re-establishing knee range of motion, strength, neuromotor control of the leg, stability, and correction of movement flaws which could predispose to injury. Finally, variability exists in the design of ACL prevention programs; although certain factors seem to predispose to injury, the ideal components of an optimal program have yet to be defined.

Compliance with Ethics Guidelines

Conflicts of Interest E. Laskowski declares no conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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