Update on Anterior Cruciate Ligament Rupture and Care in the Female Athlete

Jeremy M. Burnham, MD[a,b], Vonda Wright, MD, MS[a,*]

KEYWORDS

• ACL • Anterior cruciate ligament • ACL reconstruction • Anterolateral ligament • Anterolateral complex • Female athlete • ACL outcomes

KEY POINTS

- Anterior cruciate ligament (ACL) rupture rates in females are on the rise.
- ACL reconstruction must not be a one-size-fits-all approach but must be individualized to restore the native ACL anatomy and address any concomitant injury to secondary stabilizers.
- ACL rehabilitation programs should target hip, core, and trunk neuromuscular control; allow adequate time for graft ligamentization; and address the psychosocial needs of the athlete.
- Return-to-sports assessment requires a multipronged approach; no one test can determine return-to-sports readiness, and a battery of tests is required.
- A team approach involving the surgeon, athletic trainer, therapist, patient, family, and coach is paramount in achieving optimal outcomes after ACL reconstruction.

Despite advances in the surgical care of patients with anterior cruciate ligament (ACL) rupture over the last 30 years, prevention of the initial injury remains elusive, especially in athletes 14 to 19 years old. Beginning with Title IX and female athletic participation increasing 10-fold over the last 40 years, ACL tear rates in female athletes have continued to plague female athletes, with rates estimated at 2 to 8 times those experienced by male athletes.[1] This finding is most true in cutting sports with periods of rapid deceleration, such as soccer, with rates twice as high as men. In basketball, rates of female athlete ACL rupture is 3 to 4 times that of male athletes.[2] The cause of these observations is multifactorial and not clearly defined. In addition, while a

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[a] UPMC Center for Sports Medicine, 3200 South Water Street, Pittsburgh, PA 15203, USA; [b] Sports Medicine at Bone & Joint Clinic, 7301 Hennessy Boulevard, 200, Baton Rouge, LA 70808, USA
* Corresponding author. 8000 Cranberry Springs Drive, Cranberry Township, PA 16066.
E-mail address: wrigvj@upmc.edu

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consensus exists as to the efficacy of ACL prevention programs in young female athletes, the optimization of program prescription is still unclear.

THE COST OF ANTERIOR CRUCIATE LIGAMENT RUPTURE

The incidence of primary ACL ruptures varies from 250,000 to 300,000 annually. Female athletes are not only at higher risk of sustaining an initial ACL rupture but also of contralateral ACL tear and reconstruction.[3,4] The Multicenter Orthopaedic Outcomes Network cohort found that females were more likely to need another ACL surgery[5,6] after the index procedure in a 7-year follow-up, with 0.7 ACL injuries per season for female soccer players versus 0.4 for men.[7]

Retear rates are also higher in female athletes younger than 25 years and with smaller primary grafts (less than 8 mm in diameter).[8] Even after successful primary reconstruction, 28% of all female soccer players and 34% of reconstructed players who returned to sport had a second ACL tear.[9] These injuries account for more than $2 billion in annual surgical and rehabilitative care dollars.[10,11]

In addition to the financial cost of ACL rupture and reconstruction, athletes experience extensive personal and social costs of injury and rehabilitation with loss of mobility, pain, social isolation, and alterations in scholastic performance, with 36% failing an examination after return from surgery performed midsemester, compared with 0% with surgery performed during a holiday.[12] In addition, female athletes are less likely to return to sports participation after ACL surgery when compared with boys.[13]

CAUSE OF HIGHER ANTERIOR CRUCIATE LIGAMENT RUPTURE RATES IN FEMALE ATHLETES

The reasons females are significantly more likely to experience ACL rupture are multidimensional and complex. Hagglund and Walden[14] identified age greater than 14 years, family history, and preseason knee pain as key risk factors for future rupture. Fatigue in young soccer players may also compromise athletes' neuromuscular feedback pathways and ability to quickly activate their muscles and respond to physical and visual cues, thus, increasing their injury rates.[15]

ACL injury, however, is not likely due to completely random events but is thought to follow specific repetitive movement patterns that result in more than 70% of all ACL ruptures in female athletes occurring in noncontact situations. The most commonly identified knee position during ACL rupture is an eccentric contraction of the quadriceps (quad) in stiff knee landing, a planted foot with internally rotated hip, valgus knee position in near full extension, and with an upright trunk position.[16–18]

Chappell and colleagues[19] identified quad dominance during landing as a factor resulting in increased ACL loading in landing. Quad dominance is an imbalance in the strength of the knee extensors and flexors as well as recruitment and coordination. This imbalance results in an athlete landing with the knee in nearly full extension and placing high forces across the ACL. Functional training focusing in part on hamstring strength has been shown to help improve dynamic valgus control of the knee and reduce the quad dominance patterns found in women.

In addition, biomechanics contribute to the risk. Excessive subtalar pronation and internal tibial rotation increase ACL strain and increase the detrimental effect of the female athletes' anterior knee laxity. These forces, in conjunction with puberty-related neuromuscular deficits, result in dynamic joint instability during unconscious proprioceptive movements. It is unlikely that a single high-energy movement into this position causes the rupture. It is more likely that repetitive jump-landing in this dropped hip and valgus knee position or with every running step (an average of 1000 steps per mile) creates excessive overload stress to the ACL that simply fatigues with time and ruptures in a noncontact situation.[20]

In a study of 721 female high school athletes, Pappas and colleagues[21] investigated these concepts even further and described 3 biomechanical deficit profiles associated with an increased ACL injury risk in female athletes. Sixty percent of the studied female athletes fit into one of the 3 profiles associated with higher risk of injury. Twenty-four percent demonstrated a combination of high quad and leg dominance deficits. These athletes had increased lower extremity asymmetry and decreased hamstring strength relative to quad strength. The second most common deficit profile, the trunk-leg-ligament group, accounted for 22% of athletes and consisted of athletes with trunk, leg, and ligament deficits. This group reinforced the theory that ACL risk is multifactorial and underscored the difficulty in identifying specific factors associated with injury risk. Finally, 14% of athletes were classified as the ligament-dominance group. These athletes had higher dynamic knee valgus angles and moments, thus, were at greatest risk for noncontact ACL injury. The data obtained by Pappas and colleagues[21] may assist clinicians in designing targeted rehabilitation and prevention programs based on patients' biomechanical profiles.

In addition to the neuromuscular factors exposing female athletes to higher risks of rupture, anatomic studies of structure and mechanical properties of female versus male ACLs find that female ACLs are smaller, have lower tensile linear stiffness with less elongation at failure, and lower energy absorption and load at failure than male ligaments.[22] Renstrom and colleagues[2] reported that female knees have greater tibiofemoral joint laxity and lower joint resistance to translation and rotation as defined as greater than 2 mm side-to-side difference on KT-1000 (MEDmetric Corporation, San Diego, CA).

Bone configuration in female athletes is also thought to contribute to the higher incidence of ACL ruptures in this group. Smaller femoral notch size and greater posterior tibial slope of the lateral knee with resultant increased anterior tibial translation are cited as contributors to suboptimal knee mechanics.[23–25]

Multiple studies have pointed to the role of sex hormones, estrogen, testosterone, and progesterone in the incidence of ACL rupture. Hormone levels of estrogen, testosterone, and progesterone in male and female athletes are not well understood and vary greatly depending on exertion level, nutritional status, and athlete body fat content. Although sex hormone receptors are found on ACL tissue, currently no direct molecular mechanisms of rupture have been identified.

Rupture incidence during the ovulatory cycle is greatest during the preovulatory phase[11] at 9 to 14 days[1] and declines as the menstrual cycle progresses.[26,27] Our current understanding of the effect of cycle-dependent changes in ligament mechanical characteristics is not clear. Although during the midpoint of the menstrual cycle the ACL does seem to have 0.5 mm more laxity, this is just the opposite of most data citing increased tear rates during the preovulatory phase.[28,29] The significance of this relationship is not well understood. It is possible that decreased ligament compliance in the preovulatory phase could contribute to the higher tear rate. However, it is possible that the increased tear rates seen during the preovulatory phase are due to changes in neuromuscular control and muscle contractility and not due to changes in the mechanical properties of the ACL.

In fact, the greatest effect of hormone influence on ACL rupture is most likely due to differences in neuromuscular growth and maturation during puberty rather than through direct effects on the ligament. Despite large increases in female height and weight during puberty, relatively low surges in testosterone in girls result in less strength gain relative to boys. This lower strength gain may be the cause of the neuromuscular deficits and imbalances witnessed in ACL–at-risk athletes, with girls using ligaments and bone structure to modulate joint motion instead of muscle strength during activity.

Finally, external factors, such as footwear, playing surface, and type of competition, may contribute to sex nonparity in ACL rupture. Higher cleat number and artificial turf pitches increase the coefficient of friction and rate of ACL injury.[30,31]

PREVENTION OF ANTERIOR CRUCIATE LIGAMENT TEAR

Given the mounting evidence that ACL rupture results from repetitive biomechanical stresses across the ACL due to deficits in the neuromuscular coordination of muscle and knee joint, there is a great interest in preventing ACL rupture by training young athletes. The goal is to improve muscle firing patterns and to enhance unconscious motor responses in the central nervous system to produce a state of muscle readiness, increase motor control, and dynamic stability.

No universal program currently exists; however, all programs should include hip and hamstring training, core stability, balance, agility, and verbal feedback on landing techniques.[32] Sugimoto preformed a meta-analysis of 14 neuromuscular training (NMT) studies including more than 23,000 athletes. The meta-analysis reviewed 7 level 1 trials looking at study design, sports, age, dosage, exercise, and verbal feedback. They found a significant reduction of ACL tears by 17.2% to 17.7%. Furthermore, they identified the critical components as younger age, NMT dosage greater than 20 minutes twice a week, greater exercise variation, and verbal cueing. Multiple studies found athletes participating in 6 weeks of preseason training focusing on plyometrics, weight training, and flexibility were 3.6 times less likely to sustain knee injury.[10,33–35]

These programs focus on the gluteal muscles as key protectors against knee valgus, with the gluteus medius keeping the hip in abduction in landing, cutting, and direction change. Gluteus maximus was also a key predictor of lower extremity injury.[36] The programs should include progressive core stability, hip and hamstring strength, functional exercises (for establishing neuromuscular control), calf training (to ensure critical ankle stability and postural control to stabilize the knee during deceleration), learning how to absorb landing force/preventing knee buckling, as well as feedback-driven plyometric technique modification.[36–40]

Johnson and colleagues[41] found that training outcomes for youth athletes are related to their psychological resilience. This resilience can be modulated by constructive communication, rich interaction with significant family members, a strong belief in the importance and efficacy of their own actions, and learning to set reasonable goals.

Ideally, ACL prevention programs should consist of 15 to 18 target training sessions over 6 to 8 weeks at a frequency of 2 times per week both before season and in-season. These sessions should begin in the prepubertal period and be designed in an age and maturation-specific manner with a focus on NMT with fatigue resistance.[15]

Interestingly, ACL prevention programs have not been found to increase on-field speed and agility performance, thus, making adherence by coaches and athletes difficult as there is not a dual benefit.[42] Hagglund and colleagues[43] found that coach-led training is most effective because of high compliance and resulted in fewer injuries in soccer.

CLINICAL MANAGEMENT

Most ACL injuries require surgical management in the form of ACL reconstruction, particularly in young, high-demand athletes. The key to achieving optimal outcomes is to approach ACL rupture management in a structured, evidence-based, yet individualized approach.[44,45] A thorough history and physical examination is paramount, and secondary stabilizers (such as menisci and collaterals) should be assessed for injury.

Once the decision is made to reconstruct the torn ACL, it is crucial to restore the patients' individual anatomy. This restoration includes matching the native femoral and tibial insertion sites, appropriate placement of bony tunnels, choosing the proper graft, and choosing the correct graft size. Although data have shown that grafts less than 8 mm in diameter are more likely to fail,[8,46,47] it is also possible to cause premature failure by using too large of a graft relative to femoral notch size. This large graft would cause impingement and, ultimately, rupture.[48] A substantial body of evidence has demonstrated that autograft is more reliable in young patients,[49,50] although the ideal autograft harvest site remains controversial.[51–55]

The bone-patellar tendon-bone graft has long been considered the gold standard. The benefit of its bone-to-bone healing is widely considered to result in faster graft incorporation and lower rerupture rates.[51] However, it usually requires a larger incision and is associated with an increased incidence of anterior knee pain. The hamstring tendon is one of the most popular options, requires only a small incision for harvest, and can readily be augmented with allograft to obtain a larger graft diameter,[56] if necessary. However, it takes longer to incorporate than grafts with a bone block[57]; some studies suggest a higher rerupture rate compared with bone-patellar tendon bone,[53] though most evidence shows no difference in outcomes between the two grafts. Some investigators have expressed concern about increased dynamic knee valgus instability after hamstring harvest, but clinical outcomes have not shown a difference. A third, though less used option, is the quad tendon. It is not associated with anterior knee pain,[54] has higher collagen density and surface area than bone-patellar tendon-bone, and has been associated with low failure rates.[58] The downsides to this approach include a less cosmetically pleasing scar from the harvest incision and there is often some degree of quad weakness in the initial postoperative phase.

High-grade rotatory instability requires additional consideration of abnormal bony morphology, meniscal injury, posterior menisco-capsular injury, anterolateral complex injury, generalized joint laxity, and other potential contributors to this instability.[59–65] In some cases, extra-articular reconstruction procedures may be needed, although the proper indications and long-term effects of these procedures are poorly understood.[66–71] Tibial-slope altering osteotomies may be indicated in patients with extremely high tibial slopes, although this procedure is usually reserved for revision cases.[72]

Although many surgical variations, graft choices, and technique differences in ACL reconstruction exist, restoration of the native ACL anatomy, utilization of autograft in young and active patients, identification of concomitant injuries, and individualization of the surgery according to specific patients' anatomy and functional demands will help maximize the chances of success.

RETURN TO SPORT

Optimal return-to-sport (RTS) guidelines after ACL reconstruction are well studied, yet poorly understood. Several components must be considered, including chronologic time from surgery; neuromuscular performance, including quad, hamstring, hip, and trunk strength; as well as psychological factors, including kinesophobia and patient hardiness.[4,39,73–77] Unfortunately, no single test can assess RTS readiness, and no single battery of tests is agreed on.

Time is an important consideration in RTS assessment. ACL reconstruction grafts undergo ligamentization, whereby they are incorporated into the native ACL site and undergo changes that result in a more similar histologic and structural appearance to the native ACL. However, reconstructed grafts never achieve the same strength, vascularity, or innervation as the native ACL. Furthermore, rehabilitation protocols were initially developed based on animal studies of ACL graft ligamentization. Human studies have demonstrated that, although the ligamentization process is similar to animals, it likely takes much longer in humans and the graft may not achieve optimal structural characteristics for more than 1 year after surgery.[57,78,79]

Neuromuscular control and muscular strength are key factors in RTS. Although the importance of quad and hamstring strength to ACL rehabilitation are well known, hip and core strength have recently been shown to predict noncontact ACL injury.[80,81] The impact of hip, core, and trunk strength on ACL injury risk is even more robust in female athletes, as studies have shown more risky landing and cutting mechanics in females.[1,82] As the influence of the hip and trunk in the ACL injury mechanism is better understood, it is important to target rehabilitation efforts to treat these deficits and to use screening tests that can accurately gauge hip, core, and trunk function. Although many functional tests have been proposed, the single-leg hop tests, the single-leg step-down test (**Fig. 1**), and the Y-balance test (**Fig. 2**) have shown particular utility

Fig. 1. Single-leg step-down test. Note the dynamic knee valgus of the stance leg, indicating weak hip musculature, suggestive of increased ACL injury risk.

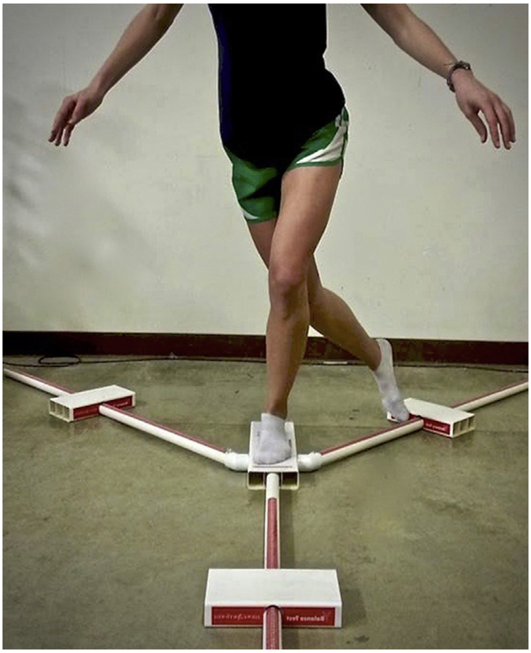

Fig. 2. Y-balance test. The subject's maximum reach distance in the anterior, posteromedial, and posterolateral directions is recorded; comparison of these values with the contralateral limb can predict lower extremity injury risk.

in the setting of ACL RTS testing.[37,78,83–85] Although the limb symmetry index (LSI) has been traditionally used to judge RTS readiness (85%–90% functional test performance compared with the uninjured limb), recent data have suggested that the uninjured extremity may exhibit postsurgical deficits; thus, the LSI must be interpreted with caution.

Even on completion of functional rehabilitation programs, motor deficits may persist, plaguing athletes with the same motor patterns that predisposed them to injury in the first place. Neuromuscular deficits may persist even 12 months after an ACL reconstruction; however, these deficits can be modulated by 6 weeks of kettle bell training for hamstring activation[86] and trunk control.[87] Hewett and colleagues[82] summarized the data on neuromuscular training programs and suggested that NMT programs most effectively decrease ACL injuries if they (1) include "plyometrics, balance, and strengthening exercises," (2) are performed more than once per week, and (3) are performed for a minimum of 6 weeks.

Another important but often overlooked component of RTS readiness is patients' psychological health. Several studies have demonstrated the importance of mental health on outcomes after musculoskeletal injury.[88–92] Furthermore, psychological traits, such as pain catastrophizing,[92] hardiness,[89] and kinesophobia,[90] have been linked to outcomes after ACL reconstruction, especially in younger patients. Therefore, it is important to consider the psychological state of ACL reconstruction patients and provide appropriate intervention when necessary.[41]

SUMMARY

The incidence of ACL rupture in female athletes is steadily increasing. As females continue to become more engaged in high-level and competitive sports, this trend is unlikely to change. Therapists, athletic trainers, coaches, and physicians must remain vigilant in implementing preventative NMT programs, effective screening tests, and appropriate treatment and rehabilitation when ACL rupture does occur. Although current knowledge and techniques have advanced significantly over the last decade, there remains ample opportunity to improve the outcomes of female athletes relative to ACL injury risk and rehabilitation.

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