Anterior cruciate ligament injuries in female athletes: risk factors and strategies for prevention

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Anterior cruciate ligament (ACL) injuries are among the most common and debilitating knee injuries in professional athletes with an incidence in females up to eight-times higher than their male counterparts. ACL injuries can be career-threatening and are associated with increased risk of developing knee osteoarthritis in future life. The increased risk of ACL injury in females has been attributed to various anatomical, developmental, neuromuscular, and hormonal factors. Anatomical and hormonal factors have been identified and investigated as significant contributors including osseous anatomy, ligament laxity, and hamstring muscular recruitment. Postural stability and impact absorption are associated with the stabilizing effort and stress on the ACL during sport activity, increasing the risk of noncontact pivot injury. Female patients have smaller diameter hamstring autografts than males, which may predispose to increased risk of re-rupture following ACL reconstruction and to an increased risk of chondral and meniscal injuries. The addition of an extra-articular tenodesis can reduce the risk of failure; therefore, it should routinely be considered in young elite athletes. Prevention programs target key aspects of training including plyometrics, strengthening, balance, endurance and stability, and neuromuscular training, reducing the risk of ACL injuries in female athletes by up to 90%. Sex disparities in access to training facilities may also play an important role in the risk of ACL injuries between males and females. Similarly, football boots, pitches quality, and football size and weight should be considered and tailored around females' characteristics. Finally, high levels of personal and sport-related stress have been shown to increase the risk of ACL injury which may be related to alterations in attention and coordination, together with increased muscular tension, and compromise the return to sport after ACL injury. Further investigations are still necessary to better understand and address the risk factors involved in ACL injuries in female athletes.

Take home message

- Anterior cruciate ligament (ACL) injuries are among the most common knee injuries in professional athletes, with an incidence in females up to eight-times higher than their male counterparts.A personalized approach that includes anatomical, biomechanical, and external factors should be considered to prevent ACL injuries.
- Sex disparities in access to training facilities may also play an essential role in the risk of ACL injuries between males and females and require increased attention.

Introduction

Anterior cruciate ligament (ACL) injuries are among the most common and debilitating knee injuries in young adults. The annual incidence of these injuries in professional athletes is 0.21 to 3.67% compared with 0.03% in the general population.[1,2] In professional athletes, ACL injuries can be career-threatening owing to time lost from play, lower return to preinjury level of function, and increased risk of concurrent knee injuries after resuming sporting activity.[3-6] In addition to the early physical and psychological morbidity, these injuries are also associated with increased risk of developing knee osteoarthritis in later life.[1,7,8] As the large majority of ACL injuries

are sustained from a noncontact pivot injury, identifying risk factors and developing appropriate preventative strategies may help to reduce the burden of these injuries on the patient, sporting institution and healthcare system.

Female athletes have a two- to eight-fold increase in the incidence of ACL injuries compared with their male counterparts.[9-13] In addition, as the number of female athletes participating in sporting activities continues to increase worldwide, the number of ACL injuries continues to rise annually. This trend is likely to continue owing to several global initiatives promoting sex equality in sporting activities and national funding programmes to increase female participation in competitive sports.[14,15] Importantly, patient outcomes in relation to return to sporting activity and risk of reinjury have been shown to be significantly worse in female athletes compared with male athletes. A recent study of 1,338 patients undergoing ACL reconstruction (ACLR) in Australia reported that female athletes had a significantly lower rates of return-to-sport compared with their male counterparts (65% vs 75%; p = 0.001).[16] The increased risk of ACL injury in female patients has been attributed to various anatomical, developmental, neuromuscular and hormonal factors.[3-5,17,18]

This review explores the evidence-based risk factors, clinical outcomes of ACLR, current training programmes, and preventative strategies in relation to ACL injuries in female athletes.

Anatomical factors

An important anatomical difference in male and females is the size of osseous anatomy. It has been postulated that the smaller femoral anatomy translates to a smaller femoral notch that impinges on the ACL and this increases the risk of ACL injury.[19] Other authors have suggested that a smaller notch-width index translates directly to a smaller ACL, which theoretically has reduced tensile strength and increased risk of rupture.[20] Another important anatomical consideration has been the tibial slope as this helps to determine the position of the tibia relative to the femur. It has been shown that female patients with ACL injures have increased tibial slopes compared with male patients with ACL injuries, and patients with ACL injuries tend to have greater tibial slopes compared with the general population.[21,22] The increased posterior tibial slope may translate to increased strain on the ACL with greater peak anterior tibial acceleration. More recently, there has been increasing interest on differences between male and female athletes in relation to ligamentous laxity that may affect the risk of ACL injury. Ligamentous laxity has been identified as a risk factor for ACL injury, with knee hyperextension and increased mediolateral knee laxity identified as risk factors for ACL injuries in in professional athletes.[21,22]

Hormonal factors

There has been renewed interest in endogenous hormonal fluctuations during the menstrual cycle, and how these changes in hormone levels impact the risk of ACL injuries. Fibroblasts located on the ACL have oestrogen receptors, and oestrogen directly impacts the laxity of ligaments and the overall limb alignment. Variations in the levels of oestrogen during the menstrual cycle may therefore play a significant role in the risk of ACL injury, particularly during the follicular and ovulatory phases, when the levels of progesterone are insufficient to suppress the effects of oestrogen on the ACL.[17] It has also been suggested that hormonal fluctuations in other hormones, such as relaxin, may increase the risk of ACL rupture.[17,23] The ACL of female patients has been shown to have concentrations of relaxin receptors, and the levels of relaxin have been shown to peak during the luteal phase of the menstrual cycle. This may increase laxity in the ACL and increase the risk of rupture.[24,25] Importantly, there is no conclusive evidence on how fluctuations in hormone levels impact the risk of ACL rupture. The existing evidence is mostly based primarily on predicted hormone levels and not on actual serum measurements, which would require continuous sampling of blood samples from athletes pre- and post-ACL injury.

It has been shown in retrospective studies that patients taking the oral contraceptive pill may be reduced risk of ACL injury. This may be attributable to the oral contraceptive pill reducing hormonal fluctuations and any changes in the laxity of the ACL during the menstrual cycle. Data from the Danish Knee Ligament Reconstruction Registry showed that the adjusted relative risk of having ACL reconstruction was 0.82 in female athletes taking the oral contraceptive pill compared to those that were not.[26] Similar findings have been reported in a large retrospective study of 82,874 female athletes, which reported taking the oral contraceptive was associated with a 63% reduction in the risk of sustaining an ACL injury.[27] It is important to note that many of these studies are retrospective in nature and prone to sampling errors, potential confounders, and limited reporting of adverse events and complications. At present, there is no clear role for the use of the oral contraceptive as a protective measure for reducing ACL injury.[28] Albright et al[29] reported a significant association between a previous diagnosis of hypovitaminosis D and increased rates of both index ACL tears (+ 81% within two years of diagnosis) and revision ACLR (+ 28%), together with relevant physical and psychological consequences, including depression.[30,31]

Biomechanical factors

It has been postulated that the hamstring muscles act as an agonist by preventing anterior tibial translation, while the quadriceps act as an antagonist by straining the ACL. When female patients land, they preferentially contract their quadriceps muscles than their male counterparts. This results in a stiff-legged extended landing posture that increases the risk of ACL injury compared with the knee flexed and more ACL-protective position.[32-37] The latency between ACL activation at the time of foot contact and hamstring activation is 50 to 180 ms, while the time from initial foot contact to ACL disruption is 40 to 105 ms.[38] Therefore, any additional latency in hamstring recruitment may increase the difficulty of resisting the ACL stress caused by the increased ground reaction (GRF) during the landing phase. In addition, males have the ability to increase their hamstring to quadriceps ratio (representing the strength of the hamstring muscle – peak torque) during sport motion.

Female athletes have a propensity to land with increased hip flexion and sustain this hip flexion angle for longer periods compared with male athletes; this may significantly contribute to their higher risk to experience a non-contact ACL injury.[39-41] Hewett et al[32] prospectively

studied knee kinematics during a vertical drop jump (VDJ) in a cohort of 205 female athletes, and reported that increased knee abduction, higher GRFs, and shorter stance times were observed in athletes that sustained ACL injuries during the season. Similarly, Krosshaug et al[42] prospectively investigated kinematics and kinetics variables in elite handball and Norwegian football players, and found that medial knee displacement during the contact phase was associated with up to 40% increase in the risk of ACL injury. Kamitani et al[43] followed 20 female elite football players, and found that fatigue was associated with increased risk of not being able to sustain a stable landing posture with VDJ. The authors also found that increasing levels of fatigue were associated with decreased hip flexion and ankle dorsiflexion. Ogasawara et al[44] reported repetition and training improved postural stability and impact absorption in a single leg landing phase within a physical and cognitive environment designed to mirror a non-contact pivot injury.

Several other biomechanical risk factors for ACL injury have gained interest, including dynamic knee valgus, weak hip abductor musculature, increased femoral anteversion and tibial torsion, and increased midfoot mobility, as they place the resting ACL under significant higher tensile strain.[42,45-48] In female athletes, the wider pelvis leads to a greater quadriceps-angle (Q-angle), with some studies reporting that Q-angles greater than 19° are associated with increased risk of ACL rupture.[17,39,40,49,50] Similarly, athletes with poor core strength and trunk control may lack dynamic stability, which allows for greater movements and moment arms outside the safe zone of the lower limb. Weak quadriceps musculature, increased Q-angle, poor core strength, and lateral trunk displacement are therefore important risk factors for ACL injury.

It has been shown that females have a lower hip abductor strength by percentage of body weight, delayed vastus medialis activation during a single leg vertical drop jump (VDJ) than male athletes,[41,50] and a higher degree of knee abduction in the landing phase.[39,51] Moreover, poor postural control leading to a more upright landing and a lower contribution of the hamstrings in restraining the anterior translation of the tibia on the femur, increases the stabilizing effort and stress on the ACL during sport activity.

Clinical outcomes after ACLR in female athletes

It has been shown that female athletes have 2.26-times increased risk of graft re-rupture following ACLR with hamstring autografts compared with bone-patellar tendon-bone (BPTB) autograft (95% confidence interval 1.15 to 4.44).[52-54] Similarly, Salem et al[55] reported that BPTB grafts in female patients aged 15 to 20 years are associated with reduced graft rupture rates when compared with hamstring autografts, but there was no difference in re-rupture rates in females aged 21 to 25 years. The authors suggested BPTB autografts were preferable in female patients aged under 21 years. Similarly, data obtained from the Norwegian Cruciate Ligament Registry has shown that ACLR with hamstring autografts are associated with 2.3-times greater risk compared with BPTB graft, with the largest difference in reinjury rates in patients aged between 15 and 19 years.[56] Furthermore, it has been shown that female patients have smaller diameter hamstring autografts than males, which may predispose them to increased risk of re-rupture following ACLR.[57-61] Some authors have suggested that hamstring grafts in female athletes should be prepared to ensure that their diameter is greater than 8 mm.[62,63] Persistent laxity from suboptimal graft diameter may also lead to an increased risk of chondral and meniscal injuries after return to activity.[64-67]

There is growing body of evidence that the addition of a lateral extra-articular tenodesis (LET) to the ACL reconstruction improves graft incorporation,[68] reduces rotatory instability,[69] and decreases the risk of graft failure by almost three times in elite athletes.[70] In female athletes, it has been shown that ACL reconstruction with LET is associated with excellent clinical outcomes and associated with no risk of re-rupture at immediate term follow-up.[71] The LET should be considered during ACL reconstruction in female athletes with small autografts, positive pivot shift tests, and high levels of sporting activity to minimize the risk of ACL reinjury.

Training and prevention programmes

Prevention programmes target key aspects of training including plyometrics, strengthening, balance, endurance and stability, and neuromuscular training. It has been reported that in combination, these programmes may help to reduce the risk of ACL injuries in female athletes by up to 90%,[72] and decrease the overall risk of football injuries in females by approximately 20%.[73] Recent publications on injuries in elite footballers have suggested screening tests to help identify risk factors, and focused on specific preventative exercises to help mitigate the effects of these risk factors.[74-76] It has been reported that up to 65% of non-contact ACL injuries may be prevented with individualized programmes focusing on neuromuscular control, strength, and technique.[39,42]

The FIFA 11+ warm up programme, designed by FIFA Medical Assessment and Research Centre (F-MARC), has been shown to reduce sports-related injuries in up to one-third of young female athletes.[77] More specifically, neuromuscular and proprioceptive preseason protocol designed to train female athletes to avoid placing their knees in "at-risk positions" when landing has been shown to reduce the risk of ACL injury by 1.83-times compared with female athletes who did not participate in the prevention programme.[78,79] Similarly, Sugimoto et al[37] showed that a structured neuromuscular training programme may reduce the risk of ACL injury in young female athletes by 17%. The authors identified that the key elements of the training programme were training for longer than 20 minutes in duration, exercises more than twice per week, ensuring variation in exercises performed, and providing verbal feedback.

Sex disparities and extrinsic factors

Sex disparities in access to training facilities may play an important role in the risk of ACL injuries between males and females. It has been suggested that females have a lower training age considering the amount of time and exposure an athlete has had to structured, coached, and progressive training.[80]

Okholm Kryger et al[81] showed that only 32 scientific studies have been published on technology in women's football, reflecting the little attention and knowledge on the topic. On the other hand, research and development is progressing fast on the men's side.[82]

Football boots have 35% forefoot higher plantar pressure compared with standard running trainers, and optimal fit is necessary to stabilize the foot and the mobility of the lower limb.[83] However, football boots are designed primarily around the male foot anatomy, gait, and running kinematics, and these characteristics are distinctly different to those of their female counterparts.[84,85] Compromising proper fit of footwear in female athletes affects fatigue, mobility, and performance, and potentially increases the risk of injury.[81] A recent survey coordinated by the European Club Association's high performance advisory group on 350 female football players across Europe reported that 82% regularly experience discomfort wearing football boots.[86] Also, studs design and size affect the rotational traction, which varies depending on shoe outsoles, grass types, and climatic conditions. As shoe-surface traction has been recognized as a risk factor for ACL injury,[83,87] an outsole that produces increased traction (the boot getting stuck in the surface) may also increase the risk of injury. Thus, football boot selection is one of the few immediately modifiable factors that a player can influence based on the surface properties and climate conditions.[87]

Similarly, increased attention should be focused on pitch quality. International level players recognized poor pitch quality and artificial turf as the second and third main reasons for injury, after only poor muscle conditioning.[88] In addition, pitches can often be compromised because used the day after men's game, even though little evidence has been published on the contribution of artificial surfaces on injury rates.[89] Although no research has been done on the effect of football size and weight, it might be time to consider adjustments for a smaller and lighter ball like it has been done in basketball and handball.[83] Whether this is associated with increased ACL injury risk we cannot say it yet, but it is time for more kit and technology to be tailored to female needs and body shape.

Psychological factors in ACL injury and return to sport

High levels of personal and sport-related stress have been shown to increase the risk of ACL injury. This may be related to alterations in attention and coordination, together with increased muscular tension.[90] Bruder et al[91] found female athletes were 25% less likely to return to sport within the first five years after an ACL injury compared with their male counterparts. It has been suggested that fear of reinjury and lack of knee confidence are more likely to inhibit female athletes from returning to sports compared to males.[91,92] Also, while both males and females are motivated to be physically active, male athletes may be more likely to endorse competition and winning as motivators for sports participation and, therefore, exhibit more risk-taking behaviours.[93] Milewski et al[94] reviewed 176 patients with a mean age of 17 years undergoing ACLR and found that female athletes had significantly higher levels of injury-related stress and lower levels of perceived psychological readiness to return to sport compared with at six months after surgery.

In conclusion, a personalized approach that includes anatomical, biomechanical, and external factors should be considered to prevent ACL injuries in all young female athletes. Identifying key risk factors directly allows for the development of evidence-based prevention strategies. High levels of personal and sport-related stress are also shown to increase injury risk, which may be related to altered levels of attention and coordination, together with an increased muscular tension.[95] Further investigations are still necessary to better understand the effect of age, sex, graft type, sports participation, and functional performance on psychological recovery and rehabilitation after an ACLR.

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Data sharing

The data that support the findings for this study are available to other researchers from the corresponding author upon reasonable request.

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