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WOMEN'S ISSUES (MA GOOLSBY, SECTION EDITOR)

# ACL Injury prevention in female athletes: review of the literature and practical considerations in implementing an ACL prevention program

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**Abstract** Female athletes are at 3.5 times risk of sustaining a non-contact ACL injury compared with males. Research has shown that this gender discrepancy results from differences in neuromuscular adaptations and biomechanics related to landing techniques. Studies have examined the preventative effect of ACL prevention programs, which have been designed to address these risky neuromuscular and biomechanical patterns. We review the key studies on ACL prevention in female athletes and summarize the critical components of ACL prevention strategies that have been shown to successfully decrease ACL injury risk. We also discuss recommendations and practical considerations in the implementation of ACL prevention programs in various community settings.

**Keywords** ACL · ACL prevention · ACL injury · Injury · Knee Injury · Injury prevention · Non-contact · Anterior cruciate ligament · Prevention program · Female athletes · Females · Neuromuscular · Landing · Plyometrics · Injury risk · Athletes · Sports · Soccer · Basketball · Volleyball · Knee valgus · Hamstring recruitment · Prevention training · Biomechanics · Practical

## Introduction

The rate of noncontact ACL injuries is 2–9 times greater in females than males, with an average increased incidence of 3.5–4 [1, 2]. ACL injuries can have major consequences on the athletic involvement and overall wellbeing of affected female athletes, both recreationally as well as competitively. Post-operative rehabilitation can take at least 6–9 months, delaying return to sport and in some cases preventing return to prior intensity and skill level. History of ACL injury is associated with various consequences, including chronic knee problems, knee instability, meniscus tears, cartilage injuries, and development of osteoarthritis, all of which can be debilitating [3].

The most common type of ACL injury seen in female athletes is via a noncontact mechanism. A noncontact ACL injury in sport is an injury in which the athlete tears the ACL during an awkward movement that does not involve direct contact with another athlete. On average 70%–78% of ACL injuries occur via a noncontact mechanism [4, 5].

Noncontact ACL injuries are more commonly seen in high risk sports such as soccer, basketball, team handball, football, and volleyball [4]. Most noncontact ACL injuries occur while the individual is landing from a jump, rapidly stopping, cutting, or suddenly decelerating with change in direction [4, 6].

The gender discrepancy in ACL injury rates is not seen until puberty onset. A variety of factors have been extensively studied through the years to determine why females are more at risk than males for sustaining a noncontact ACL injury. Research has focused on differences in level of conditioning, skill level, femoral notch size, ACL dimensions, degree of knee laxity, Q angle, and hormonal differences. The results of these studies have been mixed, and some of these factors, being static and un-modifiable, are less conducive to intervention. Thus, attention has shifted to factors more consistently shown to place females at increased risk for ACL injury than males, namely differences

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in landing techniques and neuromuscular recruitment patterns [7–9]. These factors are modifiable and therefore conducive to intervention via programs that can be implemented to help prevent ACL injuries *before* they occur.

## Risky landing patterns and Neuromuscular adaptations increase risk for ACL injury

There has been a great deal of discussion to determine the key components that should be included in the ideal ACL injury prevention program. To do so, one must understand the critical factors that predispose female athletes to ACL injuries.

Females have a higher tendency to have risky landing patterns that are associated with ACL injury. The majority of ACL injuries occur during landing from a jump or sudden deceleration. The ACL has been shown to be under higher degrees of stress when the knee is in extension or only minimally flexed (such as 5–20 degrees as opposed to 60 degrees) and when it is under valgus stress (also often described as knee internal rotation) which are common mechanisms in female athletes who have injured their ACL [6]. Females tend to land from a jump in a more erect position than males (insufficient knee and hip flexion), and also have greater hip internal rotation and hip adduction when decelerating or landing [10]. Also, their movements involve more internal rotation of the hip along with external rotation at the tibia than males, leading to increased knee valgus [7]. Taken together, these tendencies increase forces on the knee and are associated with greater risk for ACL injury [6–10].

The combination of riskier landing patterns and insufficient neuromuscular adaptations leads to greater ACL stress [11•]. Adequate musculature strength, along with appropriate muscle recruitment and timing, are important aspects of knee stability. The hamstrings, especially, are key in ACL prevention because, as the main knee flexor, they provide an opposing force to anterior tibial displacement [11•]. However, muscle strength is only 1 factor. Muscle preference and recruitment are also important for knee stability. In fact, studies have shown that females take longer to generate maximum hamstring torque, and have more quadriceps than hamstrings activation than their male counterparts, predisposing them to ACL injury [12].

## ACL prevention programs

Using this knowledge, various ACL prevention programs have been designed to try to correct deficiencies that increase noncontact ACL injury risk in female athletes. Factors that have been studied and incorporated into ACL prevention programs include muscle strengthening, muscle recruitment patterns, landing and decelerating patterns, proprioception, and plyometrics.

## Balance and Proprioceptive training

As early as 1996, Caraffa et al tested out a prevention program to see if proprioceptive training reduces the risk of ACL injury. In this study of Italian semi-professional and amateur soccer players, 20 control teams of 300 athletes were compared with 20 teams of intervention athletes who were instructed to balance on 1 leg using a balance board of increasing difficulty 3 days a week for 20 minutes. This training began at least 30 days before the season and was supervised. This resulted in a total of 70 ACL injuries in the control group compared with 10 in the intervention group ($P < 0.001$), indicating a significant risk reduction in ACL injury [13].

However this data has not been corroborated by more recent literature. In fact, in 2000, Soderman et al did a similar study using balance boards in 221 Swedish female soccer players in which 121 were randomized to a balance board regimen and 100 to their regular training. The athletes in the intervention group were each given their own balance board and instructed to balance on one leg daily for 10–15minutes for 30 days and then 3x/week for the rest of the season. There were no statistical differences in injury rates between the 2 groups [14]. Some of the flaws of this study include both large drop-out rates and high non-compliance rates. There was also a lack of supervision since the training was done at home. Balance and proprioceptive training may be useful to include in an ACL prevention program but on their own they are not sufficient. Neuromuscular and biomechanical adaptations need to be addressed.

## Incorporating landing patterns and Neuromuscular adaptations into ACL prevention programs

In 1999, Hewett et al in Cincinnati studied the effects of a neuromuscular training program in female high school soccer, volleyball, and basketball athletes. 366 female athletes in the intervention group were compared with 463 female athletes in the control group, as well as a 434 male control group of athletes who participated in the same sports. This was a 6 week pre-season program that incorporated supervised exercises working on flexibility, plyometrics, weight training (of the legs, core, and back), and proper landing patterns. This program involved many different jumping maneuvers including squat jumps, double-legged cone jumps, tuck jumps, and hop-hop-stick landing. It lasted 60–90 minutes per session and was done 3 times a week [15].

The groups were evaluated for incidence of knee injuries (specifically MCL and ACL injuries) throughout the season. Overall the female control group sustained a 3.6 times higher rate of total knee injuries compared with the female intervention group ($P = 0.05$), and 4.8 times higher rate of knee injuries compared with the male control group ($P = 0.03$). There were no noncontact ACL injuries in the intervention group; the 2 ACL injuries sustained in this group were specifically via a contact mechanism. Thus, there were significantly lower rates of noncontact ACL injuries in the female intervention group vs the female control group ($P = 0.01$). This translates to injury incidence, per 1000 player exposure, of 0 for the female intervention group, 0.35 for the female control group, and 0.05 for the male control group. This was a non-randomized study. Nonetheless the results are telling. A prevention program incorporating a multifactorial approach to ACL prevention can be successful in reducing ACL injury rates in female athletes [15]. This program has been modified and updated, and is now commonly known as Sportsmetrics.

In 2003, Myklebust et al examined the effect of a neuromuscular training program on ACL injury rates in Norwegian female team handball players. The first year's athletes were the control group with 942 players, the second year involved the first intervention group with 855 players, and the third year was the second intervention group with 850 players. The intervention was a training program that lasted 15 minutes, 3 times a week, for 5–7 weeks preseason, and then decreased to once a week during the season. The intervention involved 5 minutes on the wobble board, 5 minutes of floor exercises (focusing on awareness and knee position during cutting, jumping, and landing), and 5 minutes on balance mats (working on core stability). The athletes worked with a partner and provided technique feedback to each other. This was carried out by the coaches the first intervention year and then by trained physical therapists the second intervention year. The second intervention year also incorporated more sports specific maneuvers and was at a higher difficulty level [16].

There were no statistically significant differences in overall ACL injury rates between the intervention groups and the control group. However, the non-compliance rates were overall high. Looking at the sub-groups, in the elite level of handball players there were better compliance rates overall than the lower divisions (42% vs 26% in intervention group 1, and 50% vs 29% in intervention group 2). In the elite intervention group there were statistically less ACL injuries compared with the elite control group ($P = 0.01$) [16].

It is important to note that these results included both contact and noncontact injuries. Contact ACL injuries are often unavoidable and result from a different injury mechanism, and therefore in order to assess the adequacy of the prevention program one must focus on the rates of non-contact ACL injuries. This can be challenging when the ACL injury rate may not be high enough to be able to separate out contact vs non-contact rates. Looking at the subset of athletes in this Norwegian study that specifically had non-contact ACL injuries, there were in fact significantly lower rates of ACL injury in the intervention group when compared with the control group ($P = 0.04$) [16]. Thus, taken in the proper context, this prevention program did significantly reduce rates of non-contact injuries in competitive female handball players.

In 2005, Mandelbaum et al studied the effects of implementing the PEP program (Prevent Injury and Enhance Performance Program) in a large group of female club soccer players via a non-randomized study. During the first year of the study 1041 female club soccer athletes (from 52 teams) in the intervention group were compared with 1905 athletes (from 95 teams) in the control group. During the second year of the study an additional 844 athletes (45 teams) in the intervention group were compared with 1913 athletes (112 teams) in the control group. The intervention was a 20 minute exercise regimen performed 2–3 times a week during 12 weeks of the season; there was no preseason component. The intervention athletes watched an educational video on safe and unsafe landing patterns, and participated in team workouts of stretching, strengthening, plyometrics, and soccer-specific agility drills, which replaced the team's warm-up during soccer practice. In the first year this resulted in 2 ACL injuries in the intervention group vs 32 in the control group, an incidence rate of 0.05 per 1000 athlete exposures in trained athletes vs 0.47 in untrained athletes. This is an 88% overall reduction in ACL injury rate in the intervention group ($P = 0.0003$). In the second year there were 4 ACL injuries in the intervention group compared with 35 in the control group, an incidence rate of 0.13 in trained athletes per 1000 athlete exposures vs 0.51 in untrained athletes. This is a 74% reduction in ACL injuries in the intervention group ($P = 0.005$) [17]. Of note, contact vs non-contact ACL injuries were not separated out.

In 2008 this same group studied the effect of the PEP program on NCAA division 1 women's soccer teams in a randomized controlled trial. 852 control athletes were compared with 583 intervention athletes who underwent the PEP protocol for 20 minutes in place of traditional team warm-up 3x/week for 12 weeks of the season. There were lower rates of total and noncontact ACL injuries in the intervention group but the difference was not statistically significant. However when the results were evaluated for the second half of the season, weeks 6–11, there were significantly lower rates of total ACL injury in the intervention group (5 vs 0, $P = 0.025$). Three of the 5 ACL injuries were noncontact but the study was not powered enough to show statistical significance in the noncontact ACL injury subset due to small numbers. Nonetheless, the significance in injury rate differences seen in the second half of the study suggests that the program takes some time to have an effect, thus arguing for implementing ACL prevention programs earlier, prior to the season, to have an effect on ACL injury rates [18].

Some have argued that if there had been a higher number of athletes in the study then there would have been higher ACL injury rates, resulting in greater differences between the 2 groups. This highlights a common challenge in studying ACL prevention programs - low overall ACL injury rates require high numbers of athletes to participate in prevention studies to be able to assess significant differences between trained and untrained athlete populations.

In 2011, LaBella et al studied the effects of a neuromuscular warm-up program on ACL injury rates in high school female athletes in Chicago public schools. All head team coaches from high school women's soccer and basketball teams were invited to participate. There were a total of 90 coaches, 110 teams, and 1492 athletes who participated in the study. The athletes primarily came from low-income urban households. Intervention coaches went to a 2-hour training session prior to the season and learned how to implement a 20-minute warm-up designed to reduce ACL injuries. The warm-up involved plyometrics, balance, progressive strengthening, and agility exercises as well as instruction on how to avoid dynamic knee valgus and how to land from a jump with flexed hips and knees. Intervention coaches also received a DVD and laminated card summarizing the exercises. Control coaches were instructed to continue their standard warm-ups. Intervention coaches used the program as warm-up during practice throughout the season. A mean of 80% of intervention coaches reported complying with the warm-up regimen. The teams practiced for a mean of 3 times a week for 13 weeks, though it varied. At the end of the season there was a 56% reduction in total non-contact lower extremity injuries in the intervention group compared with the control group. There were 6 total ACL injuries in the control group vs 2 in the intervention group (injury rate of 0.48 vs 0.10, $P = 0.04$). The intervention group also had lower rates of ankle sprains, knee sprains, and gradual onset of lower extremity injuries [19]. This program is known as KIPP, Knee Injury Prevention Program. Specific details of the program were not included in the study.

Numerous ACL prevention programs have not been as successful in reducing ACL injury rates. One of the common problems with various ACL prevention programs that have failed to significantly lower injury rates is that it is difficult for a study to be powered enough to reveal statistically significant differences in ACL injury. In order for a study to show statistical significance, a large enough sample is needed in order to have high enough ACL injury rates to be able to compare differences between the 2 groups. Also time of implementation varies, whether it begins pre-season or upon start of the season. Other factors include frequency and duration of the prevention program. Results can also vary depending on level of skill, age group, and type of sport. However we can deduce some important learning points from the studies that have been done.

## Key elements of an ACL prevention program

### The ideal ACL prevention program: Incorporating what we have learned from ACL prevention studies

The research has shown us that a multi-factorial approach is needed to reduce the risk of ACL injuries in female athletes. Ideally an ACL prevention program should be initiated at or prior to the onset of puberty in order to prevent maladaptive neuromuscular and biomechanical patterns from developing in the first place. A good prevention program incorporates neuromuscular training/control, muscle strengthening, plyometrics, as well as education and feedback regarding body mechanics and proper landing patterns in a dynamic atmosphere [11•].

Programs that begin prior to season enhance the effectiveness of the program, particularly 6 weeks pre-season. It should last 15–20 minutes or longer, and be done at least 3 times a week. If the program can be continued throughout the season this may help maintain proper form. It can even be effective as a replacement of the traditional team warm-up.

The ACL program should incorporate feedback to the athlete regarding his/her landing technique and provide opportunities for the athlete to correct it while practicing proper mechanics. This can involve having a partner athlete, or coaching assistant, provide the feedback, or could include the use of mirrors and video to visually observe both good and bad form. The athlete should be taught to begin and end maneuvers with proper positioning involving knees and hips being sufficiently flexed, jumping/landing with knees over toes, while avoiding knee valgus upon landing, and remembering to "land softly" (landing with more weight on the forefoot) [11•].

Strength training should especially include hamstring strengthening and recruitment. Strengthening hip abductors may help reduce knee valgus, so gluteus strengthening should be included as well. Also, any asymmetry in strength and movement patterns should be addressed [11•, 20]. Some have also recommended incorporating core strengthening to help stabilize trunk motion [20].

Plyometrics should incorporate high intensity agility drills that work on footwork and quick explosive movements emphasizing power and speed, along with proper muscle recruitment and mechanics, with increasing difficulty. This can incorporate cutting, jumping, lateral movements, followed by addition of "perturbation", or disturbances, to see if proper form is maintained as the athlete is challenged and the situation begins to more closely resemble a real sports situation [20].

## Practical considerations in the implementation of an ACL prevention program

In order to enhance compliance the program should preferably be one that is easy to follow requires minimal equipment and resources, does not take too much time, and is preferably incorporated into team practice. Sufficient supervision (ie, by ATCs or coaches) assures that proper technique is taught and learned. The program should be challenging enough for athletes to be motivated to do it. In fact, for coaches to be motivated to incorporate the program, it is ideal if the exercises also simultaneously enhance performance.

Studies are being done to assess the effect of various ACL prevention programs on indices of sports performance [21]. For instance, in 1 study of high school female basketball players who underwent 90–120 minute neuromuscular training sessions 3 times a week for 6 weeks, VO2 max was significantly increased [22]. In another study, 41 female athletes underwent a 6 week training program that incorporated plyometrics, core strengthening, balance, resistance, and speed training; this resulted in significantly improved maximum squat and bench press, single-leg hop distance, vertical jump, and sprint speed [23]. Though these studies are promising, more research needs to be done to assess the effects of ACL prevention programs on performance. ACL prevention programs could potentially be designed to also enhance sports performance, increasing their benefits and compliance. This can help make ACL prevention programs more marketable to coaches and athletes.

Screening tests can be used to identify athletes who are at greater risk for ACL injury and therefore more in need of ACL prevention training. The drop vertical jump test is an example of a screening test that was designed to identify individuals with poor jump/landing mechanics who exhibit excessive knee valgus [24]. Neuromuscular programs designed by Sportsmetrics aimed at female basketball players and volleyball players have been successful at correcting poor biomechanics and improving landing patterns as identified by the drop vertical jump test [22, 24].

A recent analysis of 12 ACL prevention programs calculated the number needed to treat (NNT) for ACL prevention programs to be able to prevent 1 ACL injury. The pooled NNT was calculated to be 108 for non-contact ACL injury prevention, with a 73% relative risk reduction for participation in ACL prevention programs [25•]. Individually, the NNT calculated for the Hewett et al study was 93 (and RRR of 100%), for the Myklebust et al study the NNT was 135 (and RRR of 39%), for the PEP program the NNT was 70 (and RRR of 82%), and for the KIPP program the NNT was 191 (RRR of 66%) [25•]. This data provides the sports medicine community with practical numbers and may help justify implementing ACL prevention on a large scale to successfully reduce ACL injuries in female athletes. Alternatively, if screening tests are used to identify high-risk individuals, ACL prevention could be directed to athletes who need it the most.

## Resources for ACL prevention

There are a number of resources available to coaches, parents, and sports practitioners who wish to participate in and/or implement ACL prevention programs in their communities.

The Santa Monica Sports Medicine Foundation has made the PEP (Prevent Injury and Enhance Performance) Program available to the public at http://smsmf.org/pep-program. A PDF version, web version, and video of their program are available on their website.

The Cincinnati Children's Hospital and Sports Medicine Biodynamics Center hosts an annual ACL prevention workshop for all sports practitioners interested in learning about how to implement evidence-based concepts of ACL prevention into practical exercise drills. Information can be found on http://www.cincinnatichildrens.org/news/release/2009/acl-conference-11-03-2009/.

The Sportsmetric program made available by the Cincinnati Sports Medicine Research and Education Foundation provides a trademarked certification course for sports practitioners interested in becoming instructors for the Sportsmetrics ACL prevention program. There are also programs specifically designed for various sports. Information on certification courses as well as videos for interested athletes can be found on http://sportsmetrics.org/.

The KIPP (Knee Injury Prevention Program) is available to interested athletes as well as coaches for a fee by the Lurie Children's Hospital of Chicago in the Chicago area. Application information can be found on http://www.luriechildrens.org/en-us/care-services/conditions-treatments/institute-sports-medicine/Pages/our-care/knee-injury-prevention-program/knee-injury-prevention-program.aspx.

## Conclusion

Female athletes on average have a 3.5 times greater risk for sustaining non-contact ACL injuries compared with males. This gender discrepancy stems from maladaptive neuromuscular recruitment patterns and poor jumping/landing biomechanics that lead to greater risk for ACL tears in women. There is promising evidence that these patterns can be prevented and corrected by participation in an ACL prevention program. The ideal ACL prevention program incorporates exercises and drills that emphasize plyometrics, neuromuscular training, and muscle strengthening, as well as education and feedback regarding body mechanics and landing technique. It would ideally begin 6 weeks prior to the season, can be as short at 20 minutes, and can be done in place of a typical warm-up.

Creating prevention programs that also simultaneously enhance sports performance can further motivate coaches and athletes to participate on a larger scale. Thus, further research needs to be done to identify components of ACL prevention programs that simultaneously enhance sports performance.

ACL injuries in female athletes can have detrimental consequences on overall wellbeing, contribute to chronic knee problems, and impair future sports involvement. Wide scale implementation of ACL prevention programs may hopefully one day narrow the gender gap in injury rates in female athletes.

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