Review Article

Prevention Methods to Reduce Anterior Cruciate Ligament Injuries

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ABSTRACT

Anterior Cruciate Ligament (ACL) injuries are more common among female athletes with 16% of them experiencing ACL injuries during their careers. These injuries can cause physical and mental stress for athletes and can potentially derail their careers. Despite various prevention strategies, no consensus exists on the most effective intervention. Therefore, gaining knowledge of the anatomy and physiology of the ACL is essential in finding effective intervention methods for preventing ACL injuries. This review examines four major prevention methods to reduce ACL injury risk, which include stabilizing the trunk during landing, preventing the medial movement of the knees, using the correct lower muscles for absorption, and using all the lower extremities equally. Studies show that implementing these techniques lowers the ACL tear rates. In addition to these techniques, future studies should also explore new methods to enhance injury prevention and improve athletic performance.

Keywords: Anterior Cruciate Ligament, Prevention methods, Prevention interventions, ACL injury, Reducing ACL injuries

INTRODUCTION

Anterior cruciate ligament (ACL) injuries can change the trajectory of an athlete's career by causing major damage to their physical and mental health along with incurring high healthcare costs. Annually, more than 200,000 ACL injuries occur in the United States with the majority occurring among the athletic and military population (1). Of these injuries, 70% result from a non-contact injury, while the remaining 30% arise from immediate contact with an individual. (1). As many as 16% of female basketball players may experience an ACL injury during their careers, which is 2 to 4 times more frequent than male athletes (2). Therefore, adopting effective preventive strategies is vital to mitigate adverse consequences.

Several studies have examined the utility of different techniques to reduce ACL injury and often recommend adoption of multicomponent preventative programs. This review highlights four major ACL preventive methods that have been proven to reduce injuries by enhancing strength, agility, balance and flexibility. These include the core strengthening programs that help stabilize the trunk during landing (3), interventions that improve internal and external focus in preventing excessive knee movement while airborne (4), perturbation exercises that help the athlete absorb the landing using the correct muscles (5), and optimized jumping techniques that promote balanced

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use of the lower extremities, minimizing ACL strain (6). Implementing these strategies may significantly reduce ACL injury rates and improve long-term athletic performance.

ANTERIOR CRUCIATE LIGAMENT ANATOMY AND PHYSIOLOGY

ACL runs from the medial part of the anterior intercondylar area of the tibia to the lateral part of the posterior intercondylar area of the femur (Figure 1). The ACL helps stabilize the knee joint by preventing any excess forward movements of the tibia or knee rotations (7). The mean length of the ACL is 32 mm (varies from 22-41 mm), and the mean width is 9.55 mm (varies from 7-12 mm) (8). It is a band-like structure comprising an organized collagen matrix, which accounts for 75% of its weight. The total collagen consists of 90% of type I collagen and 10% of type III collagen. The remaining 25% consists of fibroblasts, such as elastin and proteoglycans (9). The ACL is usually divided into three zones, proximal, middle, and distal.

The ACL has two bundles, the anteromedial and the posterolateral, which are named based on their tibial insertions. The anteromedial bundle originates from the proximal part of the femur and inserts into the anteromedial portion of the tibia. (10) The posterolateral bundle starts from the distal part of the femur and inserts into the anteromedial portion of the tibia. The anteromedial bundle tightens, and the posterolateral bundle relaxes when the knee is flexed, and the opposite occurs when the knee is extended. (10). Therefore, the two bundles maintain the anteroposterior and rotatory stability of the knee, respectively (11).

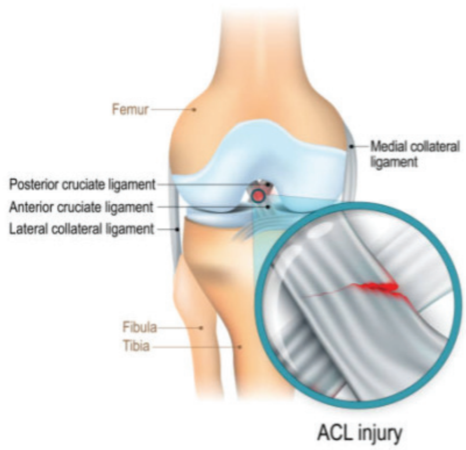

Figure 1. Anatomy and location ACL injury - The image shows a tear of the Anterior Cruciate Ligament.

TYPES OF ACL TEARS

Four different types of tears, from type I to type IV, have been reported previously (12). However, with advances in MRI imaging, the type V of ACL tear, has been identified recently (13). Type I tear occurs in the proximal part of the ACL. Type II tears are located in the proximal part, nearer to the center. Type III tears are located in the middle part. Type IV and type V tears both occur in the distal part, with type V being the most distal of all types (13). In a pediatric and adolescent population study, most of the tears were reported to be distal bony avulsions (type 5) (14). In children aged 1 to 13 years, tears were equally likely to be proximal or distal and among adolescent aged 14-17 years, most tears were type III (middle region). They did not find sex and sports injury mechanisms to have a role in tear location distributions. On the other hand, the same investigators noted that among 353 patients who had an MRI scan with ACL tears, 16% had type I tears, 27% had type II tears, 52% had type III tears, and only 3% had bony avulsion Type V tears (14). These data inform surgeons about who may benefit from ACL preservation surgery vs ACL reconstruction, which is of interest in the pediatric and adolescent population.

RISK FACTORS OF ACL INJURY

ACL injuries result from a combination of internal and external risk factors. The external factors include many types such as task-specific demands and environmental conditions (e.g., weather). The internal factors include the alignment of the lower extremity, the size of the notch between the femoral condyles, and the slope of the tibial plateau (15). Females have a higher risk of ACL injuries due to biomechanical differences (16). They often land in an extended posture, focusing more on the quadriceps which results in a modified muscle activation and more awkward knee motions than men. The incidence rates of ACL injuries per 1,000 athletes who played basketball were higher in females (female: 0.20 95% confidence intervals [0.16–0.25] vs male: 0.07 [0.05–0.08]. Notably, ACL injuries are more often seen in people participating in competition games than those during training (17). ACL injuries are mostly a result of a non-contact injury, such as excessive leg rotation, decreased knee flexion, and improper landing or pivoting movements (18).

PREVENTION METHODS FOR ACL TEARS AND INJURIES

Four major methods have been reported to prevent ACL injuries, all of which are rooted in Neuromuscular training (NMT). NMT focuses on neuromuscular control, dynamic joint stability and optimizing movement patterns to reduce injury. Proven preventive methods include stabilizing the trunk from swinging medially, preventing the knee from moving medially during landing, using the correct muscles for absorption, and landing equally with all the lower limbs (19). Multiple interventions and studies have demonstrated that these methods help decrease the risk of ACL injuries and help athletes have long and successful careers (Table 1).

Preventing Medial Trunk Movement

Stabilizing the trunk (chest, abdomen, pelvis, and back) from swinging medially is critical to prevent ACL injuries. As someone moves, the trunk needs to be stabilized and should not move as the person is landing, which can be accomplished by strengthening the core (Figure 2). Jeong et al. performed a study to test the validity of core-strengthening interventions to prevent ACL injuries (3). The participants were enrolled in a 10-week core strengthening program and followed a specific study protocol. The protocol consisted of jogging 1.3 km, followed by core strength training and stretches for 15 minutes. The study showed that the endurance of the trunk in the intervention group was significantly higher than the control group ($p<0.05$). This led to changes in the biomechanical outputs, such as the force exerted on the knee and the hip abduction angle suggesting that these interventions could decrease ACL injuries.

Similarly, Parsons et al. performed a study to test if verbal and visual feedback improved jump-landing kinematics in young girls (20). The girls were given verbal and visual feedback to see if it would improve

Table 1. Summary of different interventions to reduce ACL injury and their results

Study	Intervention	Results	Benefits
Jeong et al. (3)	1.3 km jogging followed by core strength training and stretches for 15 minutes each for 10 weeks	Intervention group had a higher trunk endurance score than the control group ($p<0.05$).	Preventing the trunk from swinging while movement; Using all lower extremity muscle equally
Parsons et al. (20)	One session of video and verbal feedback to improve jump landing kinematics in adolescent girls	The angle of right knee flexion increased from 42.2 to 63.4 degrees, and the angle of left knee flexion increased from 71.9 to 89 degrees.	Preventing the knee from moving medially; preventing the trunk from swinging while moving
Bonato et al. (23)	7 international players were chosen to participate in a program that used exercises that focused on general activation, strength and mobility, and agility and plyometrics.	The experimental group didn't have any players suffering from ACL lesions, and the control group had 7 players suffering from ACL lesions at the end of one standard season.	Using correct muscles for absorption; using all lower extremity muscles equally
Johnson et al. (5)	Perturbation exercises using a platform/roller board combination, unilateral stance on a roller board, and unilateral stance on a tilt board, each with therapist perturbations in multiple planes	There was a 43 % [CI: 32%-55%] difference in the EMG measurement of the pre activity of the vastus lateralis semitendinosus when compared to the control group.	Using correct muscles for absorption; Using all lower extremity muscles equally
Newton et al. (6)	Parallel back squats and vertical jumps using two legs, and the force exerted on both legs were measured	Significant differences were found for all the measures between 4.2% and 16%, except for the average force put on each leg.	Using all lower extremity muscles equally

their jump-landing kinematics. No difference between the landing mechanics was found with this method; however, the statistical analysis showed a difference in maximum hip flexion between the two groups, suggesting some potential benefits with this intervention.

Though multiple interventions have demonstrated success in preventing the medial trunk movement, it is also important to note that not all of this type of intervention yield consistent results. Zebis et al. also performed a study testing the core strength and its effect on ACL injury prevention (21). Using an NMT program, this study tested the usefulness of core strengthening interventions. The program included exercises that involved wobble boards, balance mats, and balls. The program led to a 43% [95% CI: 32%-55%] difference in the EMG (electromyography) measurement of the pre-activity of the vastus lateralis and semitendinosus when compared to the control group. However, no recorded differences were found between the kinetic and kinematic variables showing any potential clinical benefits. Further studies using the NMT programs to show a direct correlation between the program and a decrease in ACL injuries are needed.

Preventing the knee from moving medially

As an athlete lands, they must ensure that their knees are not moving inward, reaching a knock-knee position (Figure 3). As the knee starts to move medially, this causes a low knee flexion angle. A low knee flexion angle has been linked to higher anterior tibial shear force, which increases stress on the ACL (20). Parsons and colleagues showed that focusing on keeping the knee from moving medially can decrease the injury rate of the ACL (20). In their study, the angle of the left knee flexion increased from 71.9 to 89 degrees after two weeks of intervention. The right knee flexion also increased from 42.2 to 63.4 degrees. They concluded that an increase in knee flexion decreases higher anterior tibial force, which leads to less strain on the ACL (20).

Dalvandapour et al. studied whether attention during ACL injury prevention exercises improves jump landing kinematics. The study had 3 groups that used the Prevent Injury and Enhanced Performance (PEP) program, with one group using an external focus (EF) of attention, one group using the Internal Focus (IF) of attention, and a control group. The study showed a higher knee flexion angle in the groups that used EF which led to a decrease in the ACL injuries, and an improvement in the jump landing kinematics. (4) These two studies with different intervention methods have shown the importance of an athlete keeping their knee from moving medially as they land. These interventions can be easily implemented with the need for minimal resources.

Using correct muscles for absorption

While landing, an athlete must use all the lower limb muscles to absorb landing on the ground. If too much pressure is exerted on one muscle, then the likelihood of ACL injury increases (Figure 4). Johnson et al. performed a study testing this theory by comparing two prevention programs (5). Participants included female athletes who had previous ACL injuries and were randomized to one of two

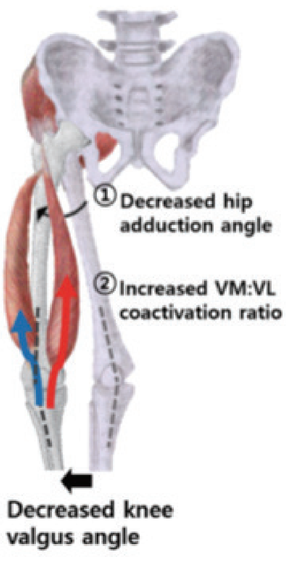

Figure 2. Preventing medial movement of the trunk causes less knee valgus- The image shows how a decreased hip adduction angle leads to a higher *Vastus Medialis* to *Vastus Lateralis* activation ratio, resulting in less knee valgus (3).

Figure 3. Knock kneed position- The figure shows a common risk factor of ACL injury, where the knee moves medially, creating the Knock-Kneed position (22).

prevention programs: strengthening, agility, plyometric, and prevention (SAPP), or SAPP plus perturbation training (SAPP+PERT). SAPP+PERT exercises used a platform/roller board combination, unilateral stance on a roller board, and unilateral stance on a tilt board. The therapist created individual perturbations by moving the equipment across multiple planes. The study results demonstrated that neither program outperformed the other, and an equal number of participants had a retear following the intervention. When retear risk was evaluated in participants from both the SAPP and SAPP+PERT training programs, contralateral ACL injury risk decreased when compared to standard rates. This lower rate of ACL injuries was attributed to an emphasis on proper landing technique and movement patterns during agility, plyometric, and performance activities.

Furthermore, Bonato et al. tested the effect of the NMT program and the effect of strengthening the ACL and the muscles adjacent to the ligament (23). Seventeen international players from the premier Italian National League were chosen to participate. The program consisted of "general activation exercises, mobility exercises, strength exercises, plyometric exercises, and agility exercises," which significantly helped increase the strength of the lower limbs used for landing in these athletes. The benefits of increasing muscular strength and stability of the ACL were clearly demonstrated, as the experimental group had none with ACL lesions after the intervention. In contrast, seven athletes among the control group had ACL lesions at the end of one standard season. These lesions were assessed by physicians and captured using an electronic method. These results demonstrate that the risk of ACL injury would be lower among those who focus on building the strength of the muscles near the ACL which makes it easier for the absorption to be equivalent.

Using the correct muscles for muscle absorption has been shown to be a plausible prevention method that does not require many resources for implementation. However, some inconsistencies in the results and differences among studies indicate that further research is needed to clarify the magnitude of positive impact of these types of interventions.

Using all lower extremities equally

As athletes prepare for landing, they should focus on using all their lower extremities equally (Figure 5). A study performed by Newton et al. demonstrated how muscle imbalances can cause injuries among collegiate athletes when using their lower muscles equally. Fourteen Division one softball players were subjected to peak torque measures for isokinetic flexion and extension at 60 and 24 degrees. Also, measures of the maximum and average force imparted on each leg during parallel back squats, vertical jumps using two legs, and the athletes' performance in a 5-hop test were tested. Marginal differences between 4.2% and 16% were seen for all measures except for the average force applied on each leg (6). This study proved that a significant number of collegiate athletes also suffer from muscle imbalances, which can cause them to land improperly and increase the injury rate.

Fox et al. conducted a meta-analysis examining the effect of inter-limb asymmetry on different aspects of athletic performance (24). Results displayed the effects of lower-limb asymmetry on different outcome variables. Study results showed the negative effect of inter-limb asymmetry on sprinting performance (24). This analysis suggests that lower-limb asymmetry directly correlates

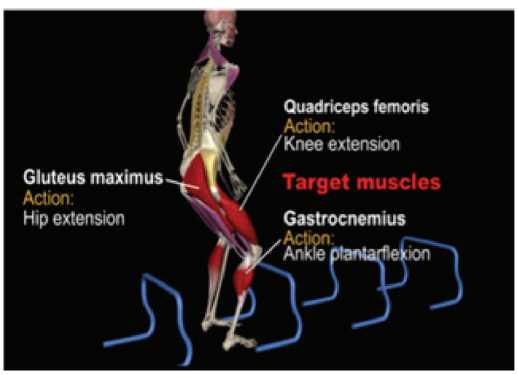

Figure 4. Correct muscles used for landing- The image shows how each muscle is used while an athlete is landing.

Figure 5. Uneven usage of lower extremities - The figure shows an uneven landing where the usage of the knee and the hip is not even (28).

with the sprinting performance of many athletes, which could cause major injuries due to non-contact motion. As most ACL injuries occur from non-contact movements, usually with very slight motions, the meta-analysis' findings highlight the dangers of lower-limb asymmetry in relation to ACL injury rates.

To provide methods to correct lower limb imbalances, Bishop et al. reviewed the best exercises and training programs to decrease asymmetry. They highlighted a study by Sannicandro et al., which used an experimental group and a control group of youth tennis players. (25) The experimental group underwent different methods, and the asymmetrical change was recorded. The single-leg hop proved to be the most effective of the different methods, reducing the asymmetry from 9.0% to 3.7%. (26). They also discussed a study by Gonzalo-Skok et al with two groups: a group focused on unilateral exercise (focusing on one leg at a time) and a group focused on bilateral exercises. After both groups completed similar training programs, the differences were recorded. The results from the unilateral groups showed major differences between the asymmetry in the lower limbs after the program with rate of asymmetry lowering from 9.6% to 4.8% (27). These studies reinforced that the asymmetry of the lower limbs is likely to be better in those athletes focusing on training one leg at a time (28).

Guideline recommendations

National Athletic Trainers Association position statement on prevention of ACL injury recommends participation in multi-component training programs that include feedback regarding technique and at least three of the exercise categories (29). They recommend that athletes should focus on strength, plyometrics, agility, balance and flexibility to reduce non-contact and indirect contact ACL injuries during physical activity.

CONCLUSION

ACL injuries are a common problem that can have serious physical and mental consequences, especially among female athletes. Studies suggest the potential benefits of four important preventative techniques—stabilizing the trunk, reducing medial knee movement, maximizing muscle absorption, and ensuring equal use of the lower extremities. Interventions that use targeted exercises, core strengthening exercise, and neuromuscular training are recommended as multiple studies have proven these interventions as the most effective in lowering ACL injuries. By incorporating these techniques into training plans, athletes can increase performance, avoid ACL injuries and extend their sports careers. Future studies should attempt to improve these techniques and make them available to a wider range of sports and populations along with identifying additional new methods to prevent ACL injuries.

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