



Published in final edited form as:

Curr Phys Med Rehabil Rep. 2015 March 1; 3(1): 43–49. doi:10.1007/s40141-014-0076-8.

ABCs of Evidence-based Anterior Cruciate Ligament Injury Prevention Strategies in Female Athletes

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Context

Anterior cruciate ligament (ACL) injury is a major concern in physically active females. Although ACL reconstruction techniques have seen significant advances in recent years, risk associated with re-injury and future osteoarthritis remains a major concern. Thus, prevention of ACL injury is a logical step to protect and preserve healthy knee joints in young athletes. The current report aims to summarize a list of evidence-based prevention strategies to reduce ACL injury in female athletes. A list of six critical principles, which come from documented, large scale clinical trial studies and further analyses, were presented with ABC format including age, biomechanics, compliance, dosage, exercise, and feedback. Also, a grade for evidence and implications of future research is noted. Finally, in the conclusion section, importance of collaborative efforts from healthcare practitioners, researchers, and personnel associated with athletics is addressed.

Key terms

Prevention; Evidence-based; ACL; Strategies; Female athletes

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Conflict of Interest

D Sugimoto, GD Myer, LJ Micheli, and TE Hewett all declare 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.

INTRODUCTION

Anterior cruciate ligament (ACL) ruptures are a major concern in the fields of Orthopaedics and Sports Medicine, particularly in young female athletes. ACL injury occurrence in young female athletes is two to four times higher in cutting, jumping, and pivoting sports compared with males.¹⁻³ Because the ACL plays an integral role in knee joint mechanics, an individual with an ACL rupture often experiences functional difficulties, including inability to decelerate, cut, and pivot, in addition to the presence of pain and effusion in the knee joint.⁴ At present, a reconstructive surgery is used to replace the torn ACL. Approximately 350,000 individuals seek ACL reconstruction (ACLR) surgery in the United States annually.⁵ The cost associated with ACL rupture and reconstruction is estimated to be about \$2 billion per year.⁶ Although ACLR is commonly performed to restore knee function, there are several limitations to this approach for the young athlete. The time devoted to post-ACL rehabilitation is approximately six to nine months^{4,7} or longer, which results in the greatest time lost from athletic participation compared to ankle and traumatic head injuries.⁸ Approximately 30–35% of physically active middle and high school athletes choose not to return to their original sports after their initial ACL rupture.⁹ In addition, about 24% of high school athletes who had ACLR surgeries sustain secondary ACL rupture within one year after return to their sports.¹⁰ Furthermore, 42% of female soccer players who had ACLR demonstrated radiographically observable knee osteoarthritis (OA) signs within 10 years, and 75% of them commented that the OA symptoms negatively affected their quality of life.¹¹ Another study reported 71% of individuals who had an ACLR surgery developed a moderate level of knee OA within 10 to 15 years.¹²

Because of the unfavorable knee joint health issues associated with ACL rupture, prevention of ACL injury should be a priority. A key to the development of effective prevention strategies is to identify modifiable risk factors.^{13,14} While some studies report an association between ACL injury and anatomical,^{15,16} hormonal,¹⁷ and genetic¹⁸⁻²⁰ components, they are not modifiable in current medical practices. Conversely, biomechanical and neuromuscular factors are modifiable by neuromuscular training (NMT).²¹⁻²⁴ Control of the magnitude of external loading at the knee joint by improvement of muscular support²⁵ and alteration of athletic techniques²⁶ through NMT appears to be an effective intervention to reduce injury risk.²⁷ Historically, since the 1990s, 14 large scale clinical trials have been published to test the efficacy of NMT on ACL injury reduction in female athletes.²⁸⁻⁴¹ From the documented evidence based on the original studies and further analyses, this report aims to generate a list of evidence-based prevention strategies to reduce ACL injury in female athletes and to identify suggestions for future research implications to optimize implementation of NMT.

Age: Start early

Evidence shows that younger athletes have better outcomes from NMT than older athletes. In a recent study, fewer ACL injuries were documented in younger athletes who performed NMT compared to older athletes who also performed NMT.²⁷ Compared to female athletes over age 20 years as a reference, 14–18 years old and 19–20 years old female athletes

demonstrated a reduced risk of sustaining ACL injuries by 72% and 52%, respectively from NMT.²⁷ Among the 14 reviewed studies, two studies used identical NMT programs for female soccer players.^{32,38} The only difference between these two studies appeared to be the age of the soccer players. A comparison of the results of these two studies shows that the 14–18 years old female soccer players demonstrated an 81% reduction (88% in 1st year and 74% in 2nd year) in ACL injury incidence;³² while the ACL injury reduction in collegiate female soccer players (mean age of 19.9 years old) was 70%.³⁸ It is theorized that sensorimotor function is more adaptable when individuals are in the developmental stage.^{42,43} Thus, it is likely better to start NMT when athletes are in their early teens.^{44–46}

Biomechanics: Change the risk movements

A prospective study that investigated modifiable risk factors in female high school soccer and basketball players reported that those who sustained noncontact ACL injury had increased knee abduction moments, limited knee flexion angles, greater ground reaction force (GRF), and asymmetrical landing pattern compared to female athletes who did not experience ACL injury.⁴⁷ Among the four risk factors, increased knee abduction was the strongest indicator of increased ACL injury risk, with 73% and 78% specificity and sensitivity respectively.⁴⁷ In addition, a retrospective video study that analyzed injured female athletes with ACL injury reported that those who suffered an ACL tear demonstrated increased lateral trunk flexion angles as well as knee abduction angles.⁴⁸ Another prospective study also identified deficits in trunk control as a risk factor for future ACL injury in female collegiate athletes.⁴⁹ The combination of this evidence indicates that decreased knee flexion and asymmetrical landing patterns do not sufficiently attenuate landing force, which results in greater GRF. The elevated GRF vectors lateral to the femoral head have been attributed to lateral trunk flexion. In order to counterbalance the force and lateral trunk flexion, hip adductor muscles need to be activated, consequently increasing hip adduction. As a result of this sequence of biomechanical events, the knee joint is placed in an abducted “valgus” position.⁵⁰ Thus, it is critical to recognize that knee abduction or valgus movement is a predictor of future ACL injury.⁴⁷ Additionally, the involvement of the posterior kinetic chain in this force production is important, which will be discussed in sections “E” and “F.”

Compliance: If you don't do it, it does not work

Compliance or adherence to the NMT is critical to the success of any ACL prevention intervention and is associated with the incidence of ACL injury occurrence. Coaches and athletes who complied with prescribed NMT programs were included in the overall compliance rate and extracted from six studies.^{28–31,37,39} When the overall compliance rate was greater than 66%, an ACL injury reduction rate of 82% was recorded.⁵¹ However, when the overall compliance rate dropped to less than 66% or 33%, the rates of ACL injury reduction were found to be 44% and 12%, respectively.⁵¹ Several studies^{31,37} documented low compliance rate as a major limitation and noted that an absence of available NMT time was due to constant competitions, infrequent practice days, and occasional academic and holiday breaks possibly hindering the execution of the NMT intervention. To investigate potential barriers to NMT implementation, a set of questionnaires was delivered to high

school soccer coaches through a web-based survey and phone follow-up.⁵² The results indicated that soccer coaches who implemented NMT regularly had more experience (greater than seven years of experience as a coach), and were further aided by the presence of healthcare practitioners including athletic trainers and strength and conditioning personnel. Therefore, having healthcare practitioners is a critical step for implementation of NMT, and athletes need to perform NMT regularly in order to attain the prophylactic effects and reduce ACL injury.

Dosage: The more you do it, the less ACL injury

The duration and frequency of NMT sessions were found to be directly associated with ACL injury reduction.⁵³ In 14 reviewed studies, NMT duration and frequency were carefully examined and analyzed. Based on the extracted information, the volume of NMT (minutes spent per week during in-season), a combination of duration and frequency of NMT session, was developed and categorized into three different classifications: low (up to 15 minutes per week), moderate (15–30 minutes per week), and high (more than 30 minutes per week). This analysis demonstrated an inverse dose-response association between NMT volume and ACL injury: The more time the athletes spent performing NMT, the fewer ACL injuries they sustained.⁵³ This study indicated that a prescription of at least 20 minutes per NMT session, several times per week in-season as well as in pre-season was necessary in order to attain full prophylactic effectiveness.⁵³ Another study investigated the association between NMT program duration and movement retention ability and also reported a dosage effect: The longer athletes performed NMT, the longer athletes retained the prophylactically favorable movements.⁵⁴ Hence, in order to minimize ACL injury risk, it is recommended that NMT sessions are performed longer, more frequently, and over a greater time period.

Exercise: Include a variety of exercises

NMT that consists of multiple types of exercises demonstrates greater reduction in incidence of ACL injury, compared to NMT with only a single exercise modality (e.g. plyometrics, resistance training, balance training).⁵⁵ The number of ACL injuries was not reduced in two studies,^{29,35} in which only one type of exercise was incorporated. Conversely, NMT with multiple exercise modes demonstrated ACL injury risk reduction ranging 29%–79% relative to the control group.⁵⁵ The main question remaining is “What type of NMT is most effective for prophylaxis of ACL injuries?” NMT can be mainly classified into four different modes: balance, plyometrics, strengthening, and proximal control training. One strengthening exercise commonly incorporated in NMT is the “Russian/Nordic hamstrings curl.” Using this technique, enhancement of hamstrings peak torque and to increase in knee flexion in dynamic movements were documented in these studies.^{21,22,56} Since decreased knee flexion is one of the risk factors for ACL injury, flexing the knee in dynamic movements may help to reduce the GRF. In terms of GRF reduction, three studies reported 17–26% of GRF reduction with landing after six to nine weeks of plyometric training.^{21,57,58} In addition to the GRF reduction, athletes tend to exhibit less knee abduction or lower extremity “valgus” when they perform plyometric exercises.

Proximal control training has also received attention for risk reduction.⁵⁵ Proximal control training refers to exercises that focus on enhancing stability of segments proximal to the knee joint through strengthening and learning adequate control in dynamic movements. Recent studies have added exercises for the hip, lower trunk, and upper body such as the plank^{37,41} and side plank^{37,41} as well as sit-ups/abdominal curl,^{28,39} push-ups,⁴⁰ and upper body weight training including bench press, pullover, pull-down and hyperextension.²⁸ Since deficits in trunk control, especially lateral trunk flexion, has been identified as a risk factor for future ACL injury,^{48,49} it is logical that those exercises may contribute to enhance trunk stabilization. A study that focused on examining the effect of proximal control training reported a reduction in knee abduction angle during single leg squat.²² Lastly, balance and dynamic stabilization exercises can be useful to enhance awareness of body control. This is particularly important because deficits in trunk control were found to be a risk factor for ACL injury.⁴⁹ In addition, numerous studies have demonstrated favorable kinematic and kinetic changes to the knee joint from balance exercises.^{23,24,59} In summary, performing only one of the exercise modes alone is probably ineffective in ACL injury prevention or may confer insufficient protection. In order to attain maximal prophylactic effects, a successful NMT program should incorporate a variety of exercises within NMT.⁵⁵

Feedback: Your voice is powerful

The majority of the reviewed NMT studies incorporated a “feedback” system, which appears to be beneficial. A few studies supplied an instructional video DVD and written materials to highlight risk movements and emphasize appropriate movement patterns prior to the start of the study.^{37,38,40} For instance, studies instructed coaches and athletes to check knee alignment during the NMT and encouraged correction of improper knee alignment by using simple verbal cues including “knee over the toe,” and “don’t let knees cave inward.”^{28,33,34,40} A few studies reported biomechanically favorable alterations with verbal feedback. For example, knee flexion angle increases were reported using verbal and video feedback in female volleyball players.⁶⁰ Furthermore, a group of female athletes who received NMT with verbal feedback decreased knee abduction angles significantly when compared to a group that performed NMT alone.⁶¹ Finally, video instruction given to alpine skiing instructors and patrollers resulted in a 62% reduction in ACL injury while no ACL injury reduction was observed in the control group that did not receive video instruction.⁶² Therefore, it is highly recommended to use a feedback system incorporating verbal cues while athletes are performing NMT.

Grade of the Evidence: Practice evidence-based medicine

Following analysis of the quality of the evidence from the reviewed studies, seven of the investigations that evaluated NMT and ACL injury risk reduction^{30,33,36–38,40,41} were rated as level I (high quality individual randomized control trial), while seven studies^{28,29,31,32,34,35,39} were rated as level II (lower quality clinical trial and cohort study). Although the number of level I and II studies are equivalent, recent meta-analysis supports consistency of evidence with 11 of the 14 reviewed studies demonstrated fewer ACL injuries in NMT intervention groups compared to control groups.^{27,53,55} A summary effect of the meta-analysis indicated that noncontact and overall ACL injury risk can be reduced

by 73% and 44% respectively.⁶³ No publication bias was detected (Egger's regression, $p=0.41$) in these analyses.^{27,53,55} The level of evidence can be evaluated from A (consistent and good quality patient-oriented evidence), B (inconsistent evidence or limited quality patient oriented evidence), C (consensus, usual practice, opinion, disease-oriented evidence) scale based on Strength of Recommendation Taxonomy (SORT).⁶⁴ Based on the consistency of the results from the included clinical trials, the SORT grade for the current evidence is "A" (recommendation based on consistent and good quality patient-oriented evidence).^{27,53,55}

Sports and sex: More evidence is needed for sport and male specific prevention strategies

When the documented evidence is broken down based on sport, 10 of the 14 studies implemented NMT for soccer players,^{28–30,32,35,37–41} and few studies included handball,^{31,33,34} basketball,^{28,35,40} volleyball,²⁸ and floorball athletes.³⁶ Since epidemiological studies have demonstrated higher ACL injury risk in basketball when compared to soccer,¹ more studies are necessary to determine effectiveness of NMT on ACL injury in basketball athletes as well as handball athletes. Variability of ACL injury reduction was found based on different sports (Figure 1). Wide 95% confidence intervals observed in basketball and floorball indicate the need for more evidence. Moreover, male athletes were traditionally used as a comparison group for female athletes, especially in biomechanical studies.^{48,65–68} Investigation of risk factors specific to males is warranted. Recent review studies concluded that existing evidence is related to environmental and anatomical risk factors⁶⁹ and advocated the need to identify modifiable risk factors in the male population.⁷⁰ The upshot is, more studies are essential to determine sport and sex-specific responses to NMT and ACL injury reduction. However, in the meantime, sport and sex-specific NMT programs can be empirically modeled after presently available programs for women.

Conclusion

Although numerous studies have been conducted and published on ACL injuries, an upward trend in incidence of ACL injury is still being reported.⁷¹ One study reported that athletes who experienced prior knee surgery including ACL-R before collegiate athletic participation were 7–20 times more likely to sustain another knee injury during their collegiate careers.⁷² In current medicine and science, it is difficult to treat or reverse progression of knee OA, which is a common long-term sequella of ACL injury.^{11,12} Therefore, it is necessary to continue to pursue preventive interventions. Many studies have now reported prophylactic effectiveness of NMT for ACL injury in female athletes. The goal of this report is to present available evidence and future research implications with a simple ABC list format. In this way, healthcare practitioners can use these recommendations in their clinical practices as ACL injury prevention strategies and help to reduce ACL injury incidence in physically active females. Evidence-based medicine should be practiced instead of only considered as "just a concept." It is time to translate this documented evidence of ACL prevention into actual practice. With collaborative efforts from healthcare practitioners, researchers, and others associated with athletic activities, preventive medicine can move forward.

Acknowledgments

The authors would like to acknowledge funding support from National Institutes of Health/NIAMS grants R01-AR049735, R01-AR05563, and R01-AR056259. The authors acknowledge members and supporting personnel of the Micheli Center for Sports Injury Prevention, the Human Performance Laboratory of the Cincinnati Children's Hospital Sports Medicine, and Sports Health & Performance Institute and Sports Medicine Biodynamics Laboratories of the Ohio State University. All authors are independent of any commercial funder, had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analyses.

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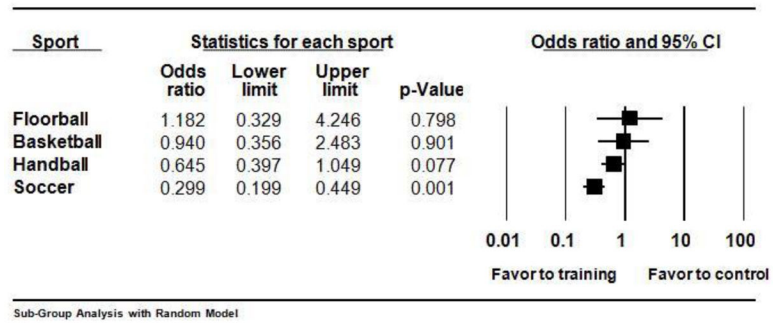


Figure 1.
Subgroup analysis by sport with random model from 14 reviewed studies

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