**Prevalence, Risk Factors, and Assessment of Anterior Cruciate Ligament (ACL) Injuries and the Efficacy of ACL Injury Prevention Programs**

**Intro:**

The anterior cruciate ligament (ACL) is a major stabilizer of the knee, its main function is to prevent anterior translation of the tibia relative to the femur.1 The ACL also adds stability through its secondary roles; the prevention of excessive movements in the following directions: “knee extension, IR/ER rotation of the tibia, and genu valgus and varus.”1 The ACL helps to protect the knee meniscus and articular cartilage from sheering forces and excessive loading, especially during jumping, deceleration, and cutting activities and thus, injury of the ACL typically occurs during sports.1 Injury to the ACL can occur from contact, an estimated 28% of ACL injuries typically resulting in an imposed valgus force at the knee, or non-contact mechanisms of injury where no physical contact between bodies occurs.2 It is estimated that non-contact ACL injuries account for 66%-80% of all ACL injuries.3–5 This paper will discuss the prevalence, risk factors, and assessment of ACL injuries and then focus on the efficacy of prevention programs at reducing non-contact ACL injuries.

**Prevalence:**

It is estimated that 100,000-250,000 ACL injuries occur every year in the U.S.5–7 Female athletes are at a significantly greater risk (estimates between 2-6 times more likely) for ACL injury than their male counterparts.4,8,9 Depending on the severity, an ACL can be treated conservatively with interventions such as physical therapy or with surgery, which can be costly - $17,000-$25,000/ACL injury.1 Noyes et al. estimates that there are 125,000-200,000 ACL reconstructive surgeries in the U.S.3 Cumulatively, ACL injuries are estimated to cost between $625 million – $3 billion annually.5,10 An ACL injury can increase the risk of early onset degenerative knee osteoarthritis 10 times, resulting in pain and disability at a fairly young age (30-40) because a majority of these injuries occur in the adolescent female population.1 Also, a majority of people that sprain or rupture their ACL will develop osteoarthritis within 10-15 years of the initial injury even with surgical intervention.5 Other concerns related to ACL injury are possible loss of athletic scholarships, lower reported grade point averages, and psychological effects of the injury.1,5 The top 3 women’s high school sports with the greatest incidence of ACL injury are soccer (11.7/100,000 athletic exposures (AEs)), basketball (11.2/100,000 AEs), and gymnastics (9.9/100,000 AEs).1

**Risk Factors:**

There are a multitude of proposed risk factors associated with non-contact ACL injuries which have been postulated and studied to account for the increased incidence in females compared to males.11 The number one risk factor according to Wilk et al. is a previous ACL injury, with the second injury most commonly occurring on the contralateral knee.12 Some research indicates the possibility of anatomical and anthropometric differences - females have been thought to have the following: an increased Q angle, smaller intercondylar femoral notch resulting in an ACL with less fibers and smaller cross sectional area, and a posterior tibial slope making them more prone to ACL injury.11 There may also be some form of familial and genetic predisposition not fully understood.11,13 In regards to laxity, a cadaveric study performed found females had a more significant laxity especially with internal rotation, anterior translation at 50 degrees of knee flexion, while males were found to have significantly increased stiffness.4 These differences are considered to be non modifiable and they would unlikely be changed through prevention programs, but increased awareness of these possible factors is important for completeness.11 Conflicting evidence has been found regarding hormonal differences, with some studies suggesting that laxity fluctuates at various times throughout the menstruation cycle and another study found laxity is reduced with increased use of oral contraceptives.11,14 The evidence related to these factors is not conclusive and they certainly can’t account for non-contact ACL injuries among males. It should also be noted that environmental factors have also been thought to play a role - increased risk with elements that increase friction such as dry ground, artificial turf, or shoe to surface interaction.15 Also, fatigue is considered to be a modifiable risk factor and was found to negate the effects of neuromuscular training in the Pfeiffer et al. study.15

Neuromuscular and biomechanical differences have also been thought to play a role in the gender differences and are the risk factors most often targeted in prevention programs.7 One theory (the quadriceps dominance theory), which has been supported, is that women have an abnormal firing pattern – the quadriceps firing before the hamstring – creating an increase in anterior translation of the tibia in relation to the femur before the hamstrings stabilize and counter the quadriceps force, which reduce the peak strain in the ACL.1,7,11,12,16 In regards to biomechanical differences, females are more likely to have improper running form, jumping, landing, and cutting technique, which can lead to a valgus collapse, which is thought to be a common injury position.1,12 Decrease coordination, increased ankle rigidity, and more random movement patterns were also found to increase risk.6 Upon landing, female recreational athletes have been found to have “less hip flexion, increased proximal tibial anterior sheer force, and increased peak knee extension compared to their males with similar characteristics.17 Stop jump tasks, two footed take off and landing, were found to account for about 70% of ACL injuries out of 100 that were analyzed on video.17 A study by Bing et al. found that in order to minimize impact at landing, active hip and knee flexion is required, the greater the angular velocity, the less of a peak ground reaction force.17 The study also noted the impacts of knee and hip angle at landing, more force on the ACL when the leg is in a more extended position, with significant differences found between females and males at initial foot impact in both hip and knee flexion angles.17

The incidence of an ACL injury may be related to age, as injury rate differences begin to appear around 12-13 as puberty begins.1,11 The difference between genders takes an interesting turn throughout development when comparing rates between similar sports (basketball, soccer, volleyball, track, baseball/softball).1 For example, the ACL injury rate for girls compared to boys is 2.5 to 6.2 times greater during high school, 2.4 to 4.1 times greater during college, and in adulthood there is almost no difference.1 The coupling of longer moment arms and a larger body mass to control as a result of a growth spurt are also possible factors contributing to an increase in ACL injury during adolescence.1,11 These same changes occur in males during growth spurts, however, males may be able to make up for this strength or neuromuscular control deficit with higher levels of testosterone.1,11

**Diagnosis:**

An ACL sprain can be either a partial tear or complete rupture, grades I-III, mild to severe in terms of the degree of laxity, III representing the greatest degree of laxity and severity.1,18 An ACL injury can be assessed clinically through an objective exam composed of a complete patient evaluation including history, palpation, and various special tests.19 The Lachman’s test, anterior drawer test, and the pivot-shift test are all performed with the patient in supine and are the most common and clinically useful special tests used to aid the diagnosis of an ACL sprain.1,20 The Lachman’s test was found to have a pooled sensitivity of 85% (95%CI, 83-87%), a specificity of 94% (95%CI, 92-95%), and has been found to have similar accuracy to that of an MRI’s capability for diagnosing and categorizing ACL tears.1,20 Imaging can be useful in regards to surgical planning, and used in pediatric patients and patients in the acute stage with high levels of pain as they may be difficult to test because of muscle guarding.1 Muscle guarding in general can alter the sensitivity and specificity of these tests, most notably during the pivot shift test.1 The pivot shift test has a high specificity of 98% (95%CI, 96-99%) but poor sensitivity of 24% (95%CI, 21-27%).1 Partial tears are more difficult to assess clinically because the small millimeter differences when comparing the injured side to the non injured side, which may be difficult to judge.21 The anterior drawer test at the acute and chronic stages has a pooled sensitivity of 52% (95%CI, 52-58%) and pooled specificity of 92% (95%CI, 90-94%), although has been found to be more useful in the chronic stage.20 Not surprisingly, arthroscopic evaluation is the gold standard for diagnosis because this provides an actual view of the ACL but is invasive and not without risks associated with surgery.20

**Efficacy of prevention programs:**

Prevention programs most often target neuromuscular and biomechanical risk factors and include a combination of components aimed at increasing stability and improving biomechanics including: balance, plyometrics, strength training, resistance training, flexibility, agility training, core strengthening, jumping and agility training with or without verbal or video feedback.15 All but 1 of the 18 systematic reviews found favored prevention programs. The following four systematic reviews main objective was to evaluate the efficacy of ACL prevention programs. Stojanovic et al. found moderate evidence to support the overall efficacy of prevention programs at reducing ACL injuries in sports athletes in their systematic review.22 In contrast, a recent systematic review by Grimm et al. looked at the efficacy and bias of knee injury prevention programs, finding 3 that used ACL specifically as an outcome.23 Grimm found that these 3 RTCs did not show an overall reduction of ACL injuries, however, the focus of this review was not on ACL injuries but on knee injuries and only included 3 ACL specific studies.23 Gagnier et al. conducted a similar type of review in regards to the efficacy of prevention programs and found similar results in favor of intervention with a pooled (IRR=0.49; 95%CI, 0.30-0.79), showing a 51% risk reduction in favor of prevention programs.24 A systematic review by Sadoghi et al. conducted a search of studies comparing ACL prevention versus no other training.5 They were able to locate 9 studies (5 soccer, 2 handball, 2 combination of soccer, basketball, and volleyball) and performed a pooled risk ratio, which was found to be 0.38 (95% CI, 0.23-0.89) P=0.021. These results overwhelmingly favor prevention programs, finding a significant 62% reduction of risk.5

**Neuromuscular & Biomechanical factors:**

ACL prevention programs typically target biomechanical and neuromuscular risk factors through interventions such as balance, plyometrics, and proprioceptive training.25 Hewett et al. and Yoo et al. performed separate, yet similar systematic reviews and meta-analysis on the effects of neuromuscular interventions at reducing ACL injuries in female athletes - both analyzing the same 6 studies, with Yoo et al. adding the Pfieiffer et al. study.25,26 Not surprising, the overall pooled results were almost identical in favor of prevention training (OR=0.40, 95% CI, 0.26-0.61-Hewett et al., 0.27-0.60-Yoo et al.).25,26 Neuromuscular retraining may be effective at reducing ACL injury because injury is thought to occur quickly, about 40 ms, after initial contact, during the rapid deceleration when landing and pivoting.1,3 Still more research is needed in this regard to determine the dosage and time needed for neuromuscular changes to take effect for recommendations.3

Pappas et al. conducted a systematic review and meta-analysis to see if prevention programs could modify cutting tasks and reduce biomechanical factors, such as valgus collapse, and other risk factors believed to be associated with ACL injury.7 The results found that prevention programs were able to significantly reduce biceps femoris activation from occurring early and EMG changes also showed an increase in medial hamstring activation, while showing a decrease in quad activation.7 The results found that prevention programs were not effective at reducing knee valgus moment, knee IR moment, VGRF at initial contact, or increasing knee flexion moment.7 The authors concluded that individualized training with verbal feedback was a key component in the reduction of ACL injury prone positions and should be included in programs, especially targeted toward female athletes.7 Padua et al. conducted a systematic review to see how effective ACL prevention programs are at changing vertical ground reaction force and sagittal plane knee biomechanics during jumping tasks.10 Overall, Padua et al. found moderate level evidence based on the review containing 9 articles with varying results and methodological quality to support prevention programs at improving sagittal plane biomechanics, with better results when multi components were used.10 There was strong evidence to support the use of verbal feedback and individualized training to reduce the VGRF, which is when the ACL is maximally loaded during landing. However, the results did not show a significant improvement across studies in proximal anterior tibial sheer force or pooled knee flexion-extension moment.10

**Gender and Age:**

It appears that both male athletes and female athletes can benefit from an ACL prevention program. When the groups in the Sadoghi et al. systematic review were stratified based on sex, females reduced their risk by 52% RR=0.48 (95% CI, 0.26-0.89), while males athletes participating in the prevention programs reduced their risk by 85% RR=0.15 (95% CI, 0.08-0.28).5 Holden et al. performed a systematic review and meta-analysis regarding gender differences in landing biomechanics and found that adolescent females had a significantly greater knee valgus during landing and that this gender difference widened as individuals matured.27 The authors also reported a significant difference in knee flexion angle, which was significantly reduced in females at ages 12-14 compared with males the same age, but no significant differences were found in regards peak ground reaction force or postural stability.27

A systematic review and meta-analysis of 14 included studies by Myers et al. looked at the influence of neuromuscular prevention programs on female athletes at different age ranges.9 The results support intervention (RR=0.54; 95% CI, 0.35=0.83) and suggest that the optimal time resulting in the greatest reduction of relative risk is mid teens (14-18yrs: RR=0.54; 95% CI, 0,35=0.83, P=0.001), compared with late teens (18-20yrs: RR=0.48; 95% CI, 0.21=1.07, P=0.073) and early adults (>20yrs: RR=1.01; 95% CI, 0.62=1.64, P=0.966).9 The authors suggest that it is possible that a greater effect is seen in the mid-teen age group because there may be a higher amount of low quality players, which tends to fade out later as sports become more competitive.9

**Which components are most effective?**

Prevention programs typically include a single component or a combination of the following interventions: balance, plyometrics, strength training, neuromuscular training, resistance training, flexibility, agility training, core strengthening, jumping and agility training with feedback or video feedback.15 Taylor et al. conducted a systematic review and meta-analysis in order to see which components of a prevention programs are the most effective at reducing ACL injury in terms of relative duration.28 The results favored programs that included static stretching while results did not favor programs that included balance.28 The authors, including, Stojanovic et al., point out that balance training may be difficult to implement due to the need for specialized equipment and amount of time required, yet acknowledge the conflicting evidence found in research.22,28 However, the authors note that these results are from few studies and caution against drawing any strong conclusions from these results.28

Strength and agility training, although not statistically significant, did show beneficial results as well, although it was noted that progressive overload was not used during strength training.28 This highlights the difficulty in trying to isolate specific components of multicomponent prevention programs. Alentorn et al. cite a Herman et al. study that found strength training 3 x’s per week, while significantly increases strength, does not alter movement patterns during a stop jump task.15 Interestingly, another systematic review by Yoo et al. found that plyometrics and strengthening was most effective, while balance training was not found to be effective.26 A systematic review and meta-analysis of 13 included studies evaluating which specific components in a neuromuscular based prevention programs reduced ACL injury risk in young females by Sugimoto et al. found a significant reduction in ACL injuries when strengthening exercises (Russian/Nordic Hamstring curls being the most common) and proximal control exercises were included, but not for balance or plyometrics alone.29 Overall, most authors recommend a multi-component program and the Sugimoto et al. study provides evidence to support this recommendation.29 Stojanovic et al. calls for prevention programs combining strength training with a combination of plyometrics in multi directional planes, and verbal or visual feedback for landing technique.22 The findings in the Bing et al. study, mentioned in the Risks section above, support the inclusion of jump retraining in ACL prevention programs, especially for female athletes at high risk, such as volleyball, gymnastics, and basketball.17

**Which prevention program is most effective?**

A systematic review by Noyes et al. focused on the effectiveness of neuromuscular retraining prevention programs at reducing ACL injury rate per 1,000 athlete exposures in adolescent athletes.3 The authors included 8 studies for review and found that the following programs significantly reduced non contact ACL injuries: Sportsmetrics program, Prevent Injury and Enhance Performance (PEP), and Knee Injury Prevention program (KIPP), with a NNT=70-98.3 The results of this study may be biased by the relation of the author to the Sportsmetrics program, which is administered by the Noyes Knee Institute.3 Another major weakness of this study is that 3 of the included studies found to significantly reduce the incidence of injury had a much higher total injury occurrence compared to the 5 programs found to not have a significant effect, which may have skewed the results.3 Another systematic review, which contained 7 out of the 8 studies included in the above Noyes et al. study, by Michaelidis and Koumantakis focused on female athletes and the effectiveness of prevention programs but found different results.30 They included 13 studies in their review and found that for soccer players, three programs significantly reduced ACL injury: PEP, Harmoknee preventive training program (HPT), and the Walden Program.30 Herman et al. conducted a systematic review focused on the neuromuscular warm up to decrease all lower limb injuries during sports and also cites the Mandelbaum et al. 2005 study, included in both of the systematic reviews, found the PEP to be the most effective at reducing ACL non-contact injury.31 There are multiple studies showing PEP to be effective among soccer players and it is free and uses little equipment.32 However, there are many factors to consider if choosing among prevention programs, such as cost, targeted population, compliance, effectiveness at reducing other lower extremity injuries, and sport.23

**Compliance, timing of intervention, and duration**

The systematic review and meta-analysis by Sugimoto et al. evaluates compliance rate with neuromuscular training in female athletes on the efficacy of ACL prevention programs, with 6 included studies.33 The compliance rate ranged from 10.7% to 100% and the mean between the 6 studies was 45.3%.33 Not surprisingly, the data showed that as the compliance with neuromuscular training increased the incidence of ACL injury decreased, indicating the importance of compliance in prevention and efficacy of prevention programs.33

The interventions were targeted toward athletes across studies at different times, preseason versus in-season versus a combination of the two.30 Prevention programs which are included in the warm-up and begin in the preseason seem to be most effective.15 A comprehensive systematic review by Yoo et al. provides evidence to support the implementation of ACL prevention programs during pre-season *plus* in-season, which was found to be more effective than either preseason or in-season alone.26 Michaelidis et al. recommends that preventative training start in preseason for 6 weeks during a warm-up, dropping off to 1-2 days/week during the in-season for the greatest effect and adherence.30

Sugimoto et al. performed a meta analysis in regards to the dosage effects and found an inverse relationship, a greater reduction in ACL injury with a more time spent performing prevention training: a 24% difference between the high volume (>30 min/week) versus the low (up to 15 min/week) and mid volume (15-30 min/week) neuromuscular training sessions.34 While the results are favorable and significant the external validity may be low as increased training times may be perceived as too long and may reduce the adherence rate, reducing the overall effectiveness.15

**NNT**

The number needed to treat (NNT) is the number of people that need to partake in the prevention program in order for one person to benefit. The NNT was found in the Sadoghi et al. study with a large range from 5-187.5 Herman et al. also found a large range as well and reported on the NNT in specific programs: Prevent Injury and Enhance Performance (PEP) and the Harmoknee program (HPT), with NNT=70, 146, respectiviely.31 A systematic review by Grindstaff et al. searched and pooled 6 studies with similar prevention training interventions and found the NNT=89 (95% CI, 66-136) and relative risk reduction (RRR)=70% (95% CI, 54-80) for female athletes among studies that included soccer, handball, and basketball.35 Sugimoto adds to this by conducting a systematic review and meta-analysis of 12 individual studies in order to find a more accurate NNT and RRR.36 In order for female athletes to reduce 1 non-contact ACL injury, the pooled data suggest a NNT=108 (95% CI, 86-150) and a RRR= 73.4% (95% CI, 63-81).36 While these numbers appear large by both estimates, the effects should be considered in relation to athletic teams, which consist of fairly large groups and the implementation weighed with the deleterious effects of an ACL injury.36

**Conclusion:**

ACL injuries typically occur during sports and sport related activities due to the higher stresses and forces that take place during cutting and jumping maneuvers, so much of the research found was aimed at populations involving sports.1 Because of this, many of the ACL prevention programs and systematic reviews of ACL prevention programs involve, as one might expect, populations with the highest incidence and risk factors as indicated above, namely female athletes, with an emphasis found in adolescent and collegiate female athletes. A majority of the studies included in the systematic reviews specifically included female soccer players.1 This is not surprising as the number of women and girls participating in soccer alone in the U.S. is high, estimated to be around 1.5 million.37 The evaluation of ACL prevention programs and their effectiveness was based on 18 systematic reviews found because they represent the highest level of evidence and methodological quality. The major weaknesses of the systematic reviews found was significant heterogeneity, varied age groups from high school to professional athletes, studies with high attrition rates, low compliance rates, and the inclusion of non-randomized studies. However, the funnel plots, when performed, revealed no publication bias.5 Also, many of the systematic reviews found contained many of the same individual studies, indicating the need for more research.

Despite some varying results among individual studies, the evidence favors ACL prevention programs at reducing the injury rate in both females and males. While many of the systematic reviews reveal real potential at reducing injury rates, there is no consensus regarding which program, individual components of a program, training durations, or training amounts are most effective. However, there is evidence supporting better results with increased compliance, duration, individualized and skilled verbal feedback on biomechanics, and the use of multi-components over single components. A few of the authors concluded that training should be sport specific, for example, including cutting tasks for soccer and jumping for basketball.12,35 Moksnes and Grindem point out the need to focus prevention of ACL injuries in pediatric patients, especially as athletes participating in highly competitive sports are becoming younger, calling for prevention programs to start early, especially for females.38 The evidence found also supports interventions targeting female athletes beginning immediately after puberty. There appears to be a paucity of studies involving male athletes, which may suggest that there is a research gap in this area.

References:

1. LaBella CR, Hennrikus W, Hewett TE. Anterior Cruciate Ligament Injuries: Diagnosis, Treatment, and Prevention. *Pediatrics*. 2014;133(5):e1437-e1450. doi:10.1542/peds.2014-0623.

2. Micheo W, Hernández L, Seda C. Evaluation, Management, Rehabilitation, and Prevention of Anterior Cruciate Ligament Injury: Current Concepts. *Pm&R*. 2010;2(10):935-944. doi:10.1016/j.pmrj.2010.06.014.

3. Noyes FR, Barber-Westin SD. Neuromuscular Retraining Intervention Programs: Do They Reduce Noncontact Anterior Cruciate Ligament Injury Rates in Adolescent Female Athletes? *Arthrosc J Arthrosc Relat Surg*. 2014;30(2):245-255. doi:10.1016/j.arthro.2013.10.009.

4. Boguszewski D V., Cheung EC, Joshi NB, Markolf KL, McAllister DR. Male-Female Differences in Knee Laxity and Stiffness: A Cadaveric Study. *Am J Sports Med*. 2015. doi:10.1177/0363546515608478.

5. Sadoghi, Patrick von Keudell, Arvind Vavken P. Effectiveness of Anterior Cruciate Ligament Injury Prevention Training Programs. *J Bone Joint Surg Am*. 2012;94-A(9):769-776.

6. Paterno M V., Kiefer AW, Bonnette S, et al. Prospectively identified deficits in sagittal plane hip–ankle coordination in female athletes who sustain a second anterior cruciate ligament injury after anterior cruciate ligament reconstruction and return to sport. *Clin Biomech*. 2015. doi:10.1016/j.clinbiomech.2015.08.019.

7. Pappas E, Nightingale EJ, Simic M, Ford KR, Hewett TE, Myer GD. Do exercises used in injury prevention programmes modify cutting task biomechanics? A systematic review with meta-analysis. *Br J Sports Med*. 2015;49(10):673-680. doi:10.1136/bjsports-2014-093796.

8. Hilibrand MJ, Hammoud S, Bishop M, Woods D, Fredrick RW, Dodson CC. Common injuries and ailments of the female athlete; pathophysiology, treatment and prevention. *Phys Sportsmed*. 2015;3847(November):1-9. doi:10.1080/00913847.2015.1092856.

9. Myer GD, Sugimoto D, Thomas S, Hewett TE. The Influence of Age on the Effectiveness of Neuromuscular Training to Reduce Anterior Cruciate Ligament Injury in Female Athletes: A Meta-Analysis. *Am J Sports Med*. 2013;41(1):203-215. doi:10.1177/0363546512460637.

10. Padua D a., DiStefano LJ. Sagittal Plane Knee Biomechanics and Vertical Ground Reaction Forces Are Modified Following ACL Injury Prevention Programs: A Systematic Review. *Sport Heal A Multidiscip Approach*. 2009;1(2):165-173. doi:10.1177/1941738108330971.

11. Alentorn-Geli E, Myer GD, Silvers HJ, et al. Prevention of non-contact anterior cruciate ligament injuries in soccer players. Part 1: Mechanisms of injury and underlying risk factors. *Knee Surgery, Sport Traumatol Arthrosc*. 2009;17(7):705-729. doi:10.1007/s00167-009-0813-1.

12. Wilk KE. Anterior Cruciate Ligament Injury Prevention and Rehabilitation: Let’s Get It Right. *J Orthop Sport Phys Ther*. 2015;45(10):729-730. doi:10.2519/jospt.2015.0109.

13. Goshima K, Kitaoka K, Nakase J, Tsuchiya H. Familial predisposition to anterior cruciate ligament injury. *Asia-Pacific J Sport Med Arthrosc Rehabil Technol*. 2014;1(2):62-66. doi:10.1016/j.asmart.2014.02.002.

14. Gray AM, Gugala Z, Baillargeon JG. . . . Published ahead of Print Effects of Oral Contraceptive Use on Anterior Cruciate Ligament Injury Epidemiology. 2015;(October). doi:10.1249/MSS.0000000000000806.

15. Alentorn-Geli E, Myer GD, Silvers HJ, et al. Prevention of non-contact anterior cruciate ligament injuries in soccer players. Part 2: A review of prevention programs aimed to modify risk factors and to reduce injury rates. *Knee Surgery, Sport Traumatol Arthrosc*. 2009;17(8):859-879. doi:10.1007/s00167-009-0823-z.

16. Zebis MK, Andersen LL, Brandt M, et al. Effects of evidence-based prevention training on neuromuscular and biomechanical risk factors for ACL injury in adolescent female athletes: a randomised controlled trial. *Br J Sports Med*. 2015:bjsports - 2015-094776. doi:10.1136/bjsports-2015-094776.

17. Yu B, Lin C-F, Garrett WE. Lower extremity biomechanics during the landing of a stop-jump task. *Clin Biomech*. 2006;21(3):297-305. doi:10.1016/j.clinbiomech.2005.11.003.

18. DeFranco MJ, Bach BR. A comprehensive review of partial anterior cruciate ligament tears. *J Bone Joint Surg Am*. 2009;91(1):198-208. doi:10.2106/JBJS.H.00819.

19. Nitz, AJ, Bellew, JW, Hazle C. Evaluation of Musculoskeletal Disorders. In: Malone, Terry, McPoinl, Thomas, Nitz A, ed. *Orthopedic and Sports Physical Therapy*. Vol 3rd ed. Philadelphia: Mosby-Year Book, Inc.; 1997:165-189.

20. Benjaminse A, Gokeler A, van der Schans CP. Clinical Diagnosis of an Anterior Cruciate Ligament Rupture: A Meta-analysis. *J Orthop Sport Phys Ther*. 2006;36(5):267-288. doi:10.2519/jospt.2006.2011.

21. Dejour D, Ntagiopoulos PG, Saggin PR, Panisset J-C. The Diagnostic Value of Clinical Tests, Magnetic Resonance Imaging, and Instrumented Laxity in the Differentiation of Complete Versus Partial Anterior Cruciate Ligament Tears. *Arthrosc J Arthrosc Relat Surg*. 2013;29(3):491-499. doi:10.1016/j.arthro.2012.10.013.

22. Stojanovic MD, Ostojic SM. Preventing ACL injuries in team-sport athletes: a systematic review of training interventions. *Res Sports Med*. 2012;20(3-4):223-238. doi:10.1080/15438627.2012.680988.

23. Grimm NL, Shea KG, Leaver RW, Aoki SK, Carey JL. Efficacy and degree of bias in knee injury prevention studies: A systematic review of RCTs sports. *Clin Orthop Relat Res*. 2013;471(1):308-316. doi:10.1007/s11999-012-2565-3.

24. Gagnier JJ, Morgenstern H, Chess L. Interventions Designed to Prevent Anterior Cruciate Ligament Injuries in Adolescents and Adults: A Systematic Review and Meta-analysis. *Am J Sports Med*. 2012;41(8):1952-1962. doi:10.1177/0363546512458227.

25. Hewett, Timothy E. Ford, Kevin R. Myer GD. Anterior Cruciate Ligament Injuries in Female Athletes; Part 2, A Meta-analysis of Neuromuscular Interventions Aimed at Injury Prevention. *Am J Sports Med*. 2006;34(3):490-498.

26. Yoo JH, Lim BO, Ha M, et al. A meta-analysis of the effect of neuromuscular training on the prevention of the anterior cruciate ligament injury in female athletes. *Knee Surgery, Sport Traumatol Arthrosc*. 2010;18(6):824-830. doi:10.1007/s00167-009-0901-2.

27. Holden S, Boreham C, Delahunt E. Sex Differences in Landing Biomechanics and Postural Stability During Adolescence: A Systematic Review with Meta-Analyses. *Sport Med*. 2015. doi:10.1007/s40279-015-0416-6.

28. Taylor JB, Waxman JP, Richter SJ, Shultz SJ. Evaluation of the effectiveness of anterior cruciate ligament injury prevention programme training components: a systematic review and meta-analysis. *Br J Sports Med*. 2013:bjsports - 2013-092358 - . doi:10.1136/bjsports-2013-092358.

29. Sugimoto D, Myer GD, Barber Foss KD, Hewett TE. Specific exercise effects of preventive neuromuscular training intervention on anterior cruciate ligament injury risk reduction in young females: meta-analysis and subgroup analysis. *Br J Sports Med*. 2014:282-289. doi:10.1136/bjsports-2014-093461.

30. Michaelidis M, Koumantakis G a. Effects of knee injury primary prevention programs on anterior cruciate ligament injury rates in female athletes in different sports: A systematic review. *Phys Ther Sport*. 2014;15(3):200-210. doi:10.1016/j.ptsp.2013.12.002.

31. Herman K, Barton C, Malliaras P, Morrissey D. The effectiveness of neuromuscular warm-up strategies, that require no additional equipment, for preventing lower limb injuries during sports participation: a systematic review. *BMC Med*. 2012;10(1):75. doi:10.1186/1741-7015-10-75.

32. The PEP Program; Prevent injury and Enhance Performance. *St Monica Sport Med Res Found*. http://smsmf.org/files/PEP\_Program\_04122011.pdf. Accessed November 28, 2015.

33. Sugimoto D, Myer GD, Bush HM, Klugman MF, Medina McKeon JM, Hewett TE. Compliance with neuromuscular training and anterior cruciate ligament injury risk reduction in female athletes: a meta-analysis. *J Athl Train*. 2012;47(6):714-723. doi:10.4085/1062-6050-47.6.10.

34. Sugimoto D, Myer GD, Barber Foss KD, Hewett TE. Dosage Effects of Neuromuscular Training Intervention to Reduce Anterior Cruciate Ligament Injuries in Female Athletes: Meta- and Sub-Group Analyses. *Sport Med*. 2014;44(4):551-562. doi:10.1007/s40279-013-0135-9.

35. Grindstaff TL, Hammill RR, Tuzson AE, Hertel J. Neuromuscular Control Training Programs and Noncontact Anterior Cruciate Ligament Injury Rates in Female Athletes: A Numbers-Needed-to-Treat Analysis. *J Athl Train*. 2006;41(4):450-456.

36. Sugimoto D, Myer GD, McKeon JM, Hewett TE. Evaluation of the effectiveness of neuromuscular training to reduce anterior cruciate ligament injury in female athletes: a critical review of relative risk reduction and numbers-needed-to-treat analyses. *Br J Sports Med*. 2012;46(14):979-988. doi:10.1136/bjsports-2011-090895.

37. Walden, M. Atroshi, I. Magnusson, H. Wagner, P. Hagglund M. Neuromuscular training program reduces knee injuries among adolescent female soccer players. *J Pediatr*. 2012;161(5):970-971. doi:10.1016/j.jpeds.2012.08.053.

38. Moksnes H, Grindem H. Prevention and rehabilitation of paediatric anterior cruciate ligament injuries. *Knee Surgery, Sport Traumatol Arthrosc*. 2015. doi:10.1007/s00167-015-3856-5.

**From Allentorn-Geli 2009 part 2**11****

**From Labella et al.**1

****

**Search Strategy:**

**1) Female or male or men or women**

**2) Risk factors or prevalence or incidence or “rate of injury” or “injury rate”**

**3) ACL or “anterior cruciate ligament” or sprain or tear or injur\***

**4) “Training program\*” or “prevention training” or Prevent\***

**5) 1 and 2 and 3 and 4**