Increasing the Effectiveness of Anterior Cruciate Ligament Injury Prevention Programs

Molly A. Guerero

Northwest University: Honors Thesis

Dr. Charlotte Easterling

April 1, 2024

Abstract

Injury to the anterior cruciate ligament (ACL), located in the knee joint, is a devastating and costly injury that can take athletes out of their sport for 9 to 12 months after surgery. About 120,000 athletes are affected by this injury every year in the United States (University of Wisconsin, 2017). This paper aims to summarize the research available on the topics of ACL risk factors and current ACL injury prevention programs to find potential improvement areas. Research methods include a literature review on peer-reviewed articles from journals in the field of sports medicine. Four main categories of ACL injury risk factors were found through this research: biomechanical, anatomical, hormonal, and environmental. Because biomechanical risk factors are the most well-known and are modifiable with training in comparison to the others, this is the primary focus of most ACL injury prevention programs (IPPs). These programs have been shown to be effective in reducing ACL injury rates. However, one limitation to ACL IPPs' success is their lack of implementation. Therefore, it was found that training coaches through online educational resources and professional development programs could be the key to helping coaches become confident and equipped to administer ACL IPP protocols to athletes. Overall, these improvements could help reduce the commonality of this injury and the significant financial costs associated, allowing athletes to continue being active in their sports and avoid long-term health implications.

Introduction

Injury to the anterior cruciate ligament (ACL) is often known to end an athlete's sports career or at best, postpone it for up to a year and continue with an extensive period of recovery. The ACL is located in the middle of the knee joint and functions to prevent the shin bone from sliding out in front of the thigh bone. A grade 1 ACL injury means the ligament is stretched but

not quite torn. Grade 2 injuries mean the ACL is partially torn and may require surgery if pain is severe. Last, a grade 3 tear means a complete or near complete tear of the ACL and surgery is almost always recommended (*Anterior Cruciate Ligament (ACL) Injury or Tear*, 2024). Every year in the United States, 120,000 athletes are impacted by ACL injuries, and after returning to their sport, about 6 to 32 percent of those athletes will experience a second ACL injury (University of Wisconsin, 2017). About 76.6% of ACL injuries result in surgery (Joseph et al., 2013). Anterior cruciate ligament injuries can be devastating to an athlete's sports career, medical costs and long-term health. The recovery time for an ACL reconstruction surgery is about 9 to 12 months before fully returning to a sport, and even then, many players are not yet back to their full strength, speed, and performance. The surgical reconstruction cost range is between $5,000 to $17,000 per patient. With post-op treatments and other societal costs, the total cost can be up to $38,000 per patient (Padua et al., 2018). This cost puts a heavy burden on an individual and their family members or guardians. Most of these ACL injuries occur via non-contact or indirect contact mechanisms and are associated with uncontrolled lower extremity biomechanics (Padua et al., 2018).

Although various knee injuries have occurred since the beginning of time, the first ACL repair took place in 1895 while ACL reconstruction using tissue from the same individual was instituted in the early 1900's (Schindler, 2012). Because there is always risk for injury involved with sports and being physically active, a cure for ACL injuries has not been found; however, researchers have noted many correlations such as the higher risk that is prevalent in female athletes. Female athletes can be particularly more at risk for this injury due to anatomical, biological, and hormonal differences. Because of these implications, preventative measures have been researched for the past three-plus decades, focusing on neuromuscular training, biomechanical movement correction, and overall improvement in athletic performance (Arundale

et al., 2022). Despite the substantial evidence that these protocols reduce the risk of injury, ACL tears continue to be one of the most serious and common injuries due to lack of implementation of these precautionary measures. This research aims to summarize the information available on ACL risk factors, how current ACL injury prevention programs address these factors, and potential improvement areas.

Methods

Research methods included a literature review of peer-reviewed articles on ACL risk factors, current ACL injury prevention program practices, and potential improvement areas. Search engines Google Scholar and PubMed were used to find peer reviewed journals dating from 2011 to 2023 to gain a comprehensive analysis of where ACL research has come from and where it is going. Journals that were used in this research include *Journal of Athletic Training, British Journal of Sports Medicine, The Journal of the American Academy of Orthopaedic Surgeons, National Library of Medicine, Journal of Orthopaedic Research, Journal of Preoperative Practice, Applied Sciences, Journal of Sport Rehabilitation, Medicine and Science in Sports and Exercise,* and *Cureus.* In the "Implementation" section, resources from the *National Federation of State High School Associations* were reviewed and recommended such as the educational programs that are freely provided to coaches, athletes, and more. Based on the information gathered, suggestions for potential areas of improvement were made to help advance the progress of current ACL injury prevention programs.

ACL Injury Risk Factors

ACL Injury Risk Overview

High school and college level female athletes particularly in pivoting and cutting sports like basketball and soccer are up to six times greater risk of knee injury, specifically of the ACL,

than male athletes competing in the same sport (Hadzovic, 2020; Marx, 2012). One article addresses the differences between male and female movements that can put women more at risk for injury (Sutton & Bullock, 2013). There are four categories of risk factors that are recognized: biomechanical, anatomical, hormonal, and environmental. Biomechanical is described as the function, motion, and technique of an individual's body parts. Anatomical is defined as factors relating to one's bodily structure. Hormonal is described as the influence of sex hormones in the body. Another risk factor category is environmental, which can be described as surroundings that impact one's performance and biomechanics (Sutton & Bullock, 2013).

Biomechanical Risk Factors

Biomechanical risk factors refer to the function, motion, and technique of an individual's body parts that put them more at risk for injury. Regarding ACL tears, this type of injury "usually (70%) occurs through non-contact mechanisms that include; sudden deceleration, landing and pivoting maneuvers which are repeatedly performed" (Papoutsidakis, 2011). In the mechanics of a non-contact ACL injury, the ACL undergoes an excess of force in sudden movements that stress it beyond its maximum length, thus tearing the ligament. This injury can also occur during landing or pivoting with the knee(s) bent too far in causing valgus deformation toward the center of the body, knees bent too far in causing varus deformation away from the center of the body, or internal rotation about the knee joint. These biomechanical movements will result in the ACL stretching beyond its maximum length and incurring an injury.

Having a strong contraction of the quadriceps and not enough knee flexion can also increase ACL loading and injury susceptibility. Because the ACL originates at the medial wall of the lateral femoral condyle and inserts into the middle of the intercondylar area, it will be shorter when the knee is flexed in 90 degrees compared to zero degrees when standing straight or with

knees flexed less than 90 degrees (Papoutsidakis, 2011). Additionally, a strong contraction of the quadriceps can apply a force to the anterior proximal end of the tibia at the knee joint, thus pulling the tibia forward in anterior displacement and stretching the ACL beyond its capacity. While a contraction of the quadriceps pulls the tibia forward, the hamstrings tend to pull the tibia backward and stabilize the knee during landing or pivoting movements. Therefore, if the knee either is not in enough flexion to shorten the ACL or the hamstrings do not exert enough force to counter the quadriceps and stabilize the knee joint, an ACL tear may result.

Another study on biomechanical risk factors in elite female football [soccer] players revealed that analysis of certain movements can be used to guide ACL screenings and specific injury prevention training. A total of 322 elite senior and junior female soccer players underwent a series of preseason tests to assess isometric strength in hip adductors and abductors, eccentric strength in knee flexors, countermovement jump [CMJ] kinetics, and single leg hop kinematics. The participants' demographics and history of injury were also recorded. Over the next 18 months, the results showed that fifteen of the participants experienced non-contact ACL injuries (Collings et al., 2022).

Based on their preseason assessment, multiple risk factors were identified: prior ACL injury, a lower isometric hip adductor to abductor strength ratio, greater CMJ peak take-off force, and greater knee valgus and ipsilateral trunk flexion in single leg hop. A multivariable prediction model was generated to classify ACL injury from uninjured soccer players based on CMJ peak take-off force, dynamic knee valgus, and ACL injury history. The model identified the ACL injured soccer players with 78% accuracy. They also found that lower limb strength comparison between legs and CMJ kinetics were not associated with an increased risk of ACL injury (Collings et al., 2022). Because of the comprehensiveness of this study in identifying female athletes that are at greater risk for ACL injury, the identified risk factors could help guide

or improve the current ACL screening protocols in not only elite female soccer players but potentially in other athlete populations as well. The components discussed in this section such as deceleration mechanics, imbalanced quadricep and hamstring flexion, greater knee valgus in landing or pivoting, asymmetrical hip muscle strength, and jumping take off-force are some of the biomechanical movements that can increase risk for ACL injuries. However, many of these movements can be modified and corrected with training over time.

Anatomical Risk Factors

Some anatomical factors include an increased angle in the quadriceps known as the Q-angle and posterior tibial slope, which may make girls and women more vulnerable to ACL injury. These risk factors were similarly recognized in biomechanical studies comparing the knee flexion [bending at the knee] angles in men and women during athletic tasks. Female athletes were found to display smaller knee flexion angles during activities such as running, jumping, and cutting. This is important because individuals with a smaller knee flexion angle during "athletic tasks" were at greater risk than individuals with a greater knee flexion angle (Sutton & Bullock, 2013).

Some studies have shown that the ACL experienced the most strain when the vertical ground reaction force was at its peak, right after the foot made initial contact with the ground (Yu & Garrett, 2007). For example, this peak ACL strain could be during the first point of landing after a volleyball spike approach or after jumping for a rebound in basketball when the legs are still relatively straight or stiff, and the knee flexion angle is smallest. Landing in a stiff or straight legged position prevents the force of impact from being dispersed throughout the rest of the body and the floor, and consequently, the knee joint will take the brunt of the impact. This can result in excessive loading on the ACL, which may be enough to tear or rupture that ligament

or even damage other structures inside the knee. Despite being a greater anatomical risk factor for women, knee flexion angle is something that can be trained and corrected in an athlete's biomechanics as they perform running, jumping, hopping, and cutting maneuvers. Therefore, knee flexion angle is an important factor to understand anatomical risk and biomechanical risk for ACL injuries (Sutton & Bullock, 2013).

This disparity in knee flexion angles between men and women may be partially explained not only by the differences in Q-angles, but also by intercondylar notch widths and ACL cross-sectional area. The intercondylar notch is an area in the knee joint that houses the stabilizing ligaments like the ACL. Females have smaller intercondylar notch width, which contributes to a smaller ACL cross-sectional area [CSA] compared to men. There is no definitive correlation between the ACL notch and CSA size in relation to the risk of ACL injury, but this is a potential explanation of difference in knee flexion angle between men and women (Sutton & Bullock, 2013).

Some other anatomical implications for ACL injury that have been researched are changes in hip strength and range of motion as young female soccer players get older. A three-year longitudinal study followed fourteen female youth soccer players starting at ages fourteen to fifteen. Specific factors to indicate hip mobility were measured annually: passive hip internal rotation, external rotation, abduction, and adduction range of motion. To indicate hip strength, isometric hip abduction and extension strength were calculated using a dynamometer measuring device. Repeated and separate ANOVA's [Analyses of Variance] were utilized to compare the participants' hip strength and range of motion over the three consecutive year study (Nguyen et al., 2017).

Across the three-year study, the results found that there were no changes in hip abduction strength or extension strength. However, longitudinal changes in hip mobility were seen in increased hip internal rotation and abduction while hip adduction and external rotation decreased. These results showed that as these young female soccer players matured, they experienced changes in hip range of motion even though their hip strength remained the same. The resulting asymmetry in hip mobility may contribute to decreased activation and force production in the hip muscles during athletic movements and maneuvers. Consequently, this decreased muscle activation in the hips can contribute to changes in knee and ankle biomechanics that have been shown to increase ACL injury risk (Nguyen et al., 2017).

Though not a comprehensive list, some of the known anatomical risk factors for ACL injury include increased Q-angle, increased posterior tibial slope, smaller knee flexion angles, and hip muscle strength and mobility. Because structure determines function, many of these anatomical risk factors are directly tied to unsafe biomechanical movements such as improper landing techniques that put athletes at greater risk for injury.

Hormonal Risk Factors

Because women are more prone to ACL injuries than men, studies have been observed from a sex hormone perspective in attempt to see if certain times in a woman's menstrual cycle make her more prone to knee laxity and tibial displacement. One systematic review of ten observational studies from 2015 to July 2022 suggested that sex hormones could potentially play an important role by weakening tissue while oral contraceptives might decrease ACL laxity (Moriceau et al., 2022). The studies included female subjects ages 13 to 49 years who had had their menstrual cycle for at least a year. Individuals who were post-menopausal or pregnant and those with genital or other serious diseases (i.e. cancer) were excluded from the studies. The

studies looked specifically at factors such as knee laxity, anterior tibial displacement, and ACL injury risk during different stages of a woman's cycle. Some of these studies also compared knee laxity between women taking oral contraceptives and women that did not take oral contraceptives. The specific sex hormones that were observed were estradiol and relaxin. Estradiol, a major type of estrogen made in the ovaries, is a sex hormone that can affect knee laxity during the menstrual cycle. Relaxin also causes muscle and joint relaxation during a woman's menstrual cycle but will be produced in much higher amounts during pregnancy (Moriceau et al., 2022).

Three of the ten studies revealed increased levels of estradiol in the ovulatory phase compared to the follicular phase. Estradiol levels were highest directly before ovulation. These high levels of estrogen and estradiol are present to trigger the production of LH or luteinizing hormone, which will trigger ovulation. Luteinizing hormone is present twenty-four to forty-eight hours before the release of an egg. In addition to triggering ovulation, estradiol was observed to cause changes in collagen formation and joint laxity. However, there was not an association between ACL injury and the presence of estradiol (Moriceau et al., 2022).

Another sex hormone, relaxin, causes muscle and joint relaxation typically in preparation for pregnancy. In some of the studies used in the systematic review, it was found that the concentrations of relaxin were 6.0 pg/mL in 36.8% of cases during the luteal phase. A relaxin concentration of this magnitude was reported to be a risk factor for ACL rupture. Interestingly enough, although relaxin concentration is highest in the luteal phase, knee laxity or tibial anterior displacement was reported to be greater during the ovulatory phase when estradiol levels are highest. Yet, it was also observed that women taking oral contraceptives had lower relaxin concentrations and lower ACL laxity, appearing to reduce the risk of an ACL tear by reducing

anterior tibial translation. This finding may suggest a lower risk of ACL injury or tears in women who take oral contraceptives due to the lower concentration of relaxin (Moriceau et al., 2022).

Five additional studies on oral contraceptives revealed decreases in hormonal fluctuation of estradiol and relaxin, decreased ACL laxity, and reduced ACL tear rate compared to women not taking an oral contraceptive (Moriceau et al., 2022). This could be explained because oral contraceptives often provide artificial hormones, and thus, decrease or stop natural hormone production such as estradiol and relaxin to prevent ovulation and natural shedding of the uterine wall. Therefore, without the regular hormonal surges that occur naturally throughout the cycle, the body may not experience as many fluctuations in knee and ligament laxity. This could potentially decrease the risk of ACL injury and tear rates.

In reviewing the menstrual cycle, these studies concluded that the menstrual cycle does influence laxity in the knee. The studies showed that certain hormone levels raised during the ovulatory and luteal phases of the menstrual cycles, which occurred when anterior tibial translation was greater in the knee. It also found a decreased risk of ACL injury in women taking oral contraceptives. However, the systematic review could not state a statistically significant correlation between ACL injuries and the menstrual cycle (Moriceau et al., 2022).

Environmental Risk Factors

Surface Friction

One environmental risk factor that has been identified in non-contact ACL injuries in the sport of handball [football] is shoe and playing surface friction. Studies showed that more non-contact ACL injuries occurred when the playing surface was dry due to an increase in friction between the sole of the shoe and playing surface (Papoutsidakis, 2011). Dry playing surfaces allow for better performance at greater speeds and quicker cutting maneuvers. However,

increased speeds when making sharp turns or pivots also increases the risk of injury, especially if players have not been trained in how to perform maneuvers properly. This also brings turf or artificial grass into question since an increase in ACL tears occurred on these playing surface areas compared to real grass (Papoutsidakis, 2011).

Injury by Contact

Another environmental factor that can result in ACL injury is impact or contact from another player. Since about 70% of ACL injuries occur through non-contact mechanisms, it would be assumed that about 30% are due to some form of contact or impact (Papoutsidakis, 2011). Additionally, a study on NFL athletes reported that 58% of ACL injuries were associated with contact in addition to brisk deceleration, and shallow knee and hip flexion angles that are typically associated with non-contact ACL injuries. This same study reports that only 27.5% of cases were by contact mechanisms but 68% were described as "non-contact involved indirect contact" (Schick et al., 2023). These observations are important because they reveal how both direct and indirect contact are often involved in ACL injuries. Contact could range from direct impact to the knee to indirect impact to some other area of the body. Although indirect contact may not be the root cause of the injury, it may be enough to provide distraction, throw a player slightly off balance, and alter their biomechanics enough to load the ACL beyond its stretching capacity. Because this study just looked at football, which is a high contact sport in general, it is important to note that ACL injuries can vary across different sports.

ACL Injury Rates Between Sports

Looking at statistical differences in ACL injury rates between sports, one epidemiological study called the "National High School Sports-Related Injury Surveillance Study" compared ACL injury occurrences within 9 different sports from 100 randomly chosen high schools across

the United States. A certified athletic trainer from each of these participating schools reported the injury and occurrence details for four sports seasons from 2007 to 2012. For boys, the chosen sports included football, basketball, soccer, wrestling, and baseball. For girls, the sports included soccer, volleyball, basketball, and softball (Joseph et al., 2013). The statistically rich results of this epidemiological study revealed that there is much variation between sports, gender, and playing circumstances.

The study found that football had the highest rates of ACL injuries with boys being four times as likely to injure an ACL than in any other boys' sport. The lowest ACL injury rates for boys were in basketball and baseball. For girls, soccer and basketball had the highest ACL injury rates with girls being twice as likely to injure an ACL in soccer than in any other girls' sport. Additionally, girls were four times as likely to incur an ACL injury in soccer or basketball in comparison to volleyball or softball. Looking at the sports with the greatest number of ACL injuries, there is commonality in being contact sports and utilizing cutting maneuvers more frequently than other sports that were analyzed. In sex comparable sports, girls sustained about 3.4 times more ACL injuries than boys, once again reinforcing the known disparity that girls have higher risk for ACL injuries than boys. The data also implied that there is a difference in severity of ACL injuries between sports as 96.3% of ACL injuries in boys' basketball required surgery while 54.9% of ACL injuries in baseball required surgery. With athletes moving and changing directions at great speeds while also responding to impact by other players, there will be increased risk for injury. Also, with players playing and moving at higher speeds in competition compared to in practice, there will be increased risk for injury as mentioned earlier regarding surface friction. About 74.9% of ACL injuries occurred in competition compared to practice (Joseph et al., 2013).

Risk Factor Research Needs

In addition to the more well-known information on ACL injury risk factors, it is also important to recognize that there are still multiple areas on this subject that require further study. Based on the risk factors mentioned previously, some topics that still require more research are menstrual cycles and playing field cost considerations. The potential impact of these areas and their need for more research are explained in more detail below.

Menstrual Cycle Research

Despite statistically inconclusive results on a correlation between the menstrual cycle and risk of ACL injury, there are still many applications of this research (Moriceau et al., 2022). One practical application toward ACL injury prevention could be informing young women about the effects of hormonal fluctuation in their joint laxity. Helping young athletes become more aware of changes happening in their body may make them more conscious of their joints, possibly being able to notice if they feel more lax or flexible than usual during the ovulatory and luteal phases. Additionally, the effects of oral contraceptives on women's hormonal levels and joint laxity can be helpful in identifying which women may have more or less risk for ACL injury. However, because the phases of the menstrual cycle may not be the best determinant of risk for ACL injury in women alone, they may not be a necessary factor to include in an ACL injury prevention program and further research is needed in this area (Moriceau et al., 2022).

Playing Field Cost Considerations

Turf typically costs more upfront to install than natural grass; however, it is often chosen as an alternative because it is cost effective in the long run due to saving on water and maintenance. It would be interesting to conduct a study comparing the costs of ACL injuries that occur on turf fields and see if that is more or less than what was saved in the process. This could raise some ethical questions such as whether a school or community looking to save costs would

find it worth it to invest in natural grass to help reduce the known risk of injury that comes along with a turf field. This topic is not fully investigated in this paper, so further research is still needed. However, it does make one ponder what is more important: saving money or saving young athletes from a life-altering injury.

ACL Injury Prevention Programs (IPP)

Due to the seriousness of ACL injuries, multiple types of programs have been created to help reduce this type of injury by countering modifiable risk factors, the main one being biomechanical. These are called ACL injury prevention programs (IPP). ACL IPP's can be highly effective due to focuses on neuromuscular training, biomechanical movement correction, and overall improvement in athletic performance. Neuromuscular training programs are the most commonly used for prevention and include a "combination of plyometric exercises, core strengthening exercises, exercises to strengthen the muscles of the lower extremities, agility exercises, flexibility exercises, and balance exercises" (Hadzovic et al, 2020). The Sportmetric Program, the first and largest ACL injury prevention program scientifically supported to decrease serious knee ligament injuries in female athletes, is an example that utilizes these neuromuscular training exercises (Barber-Westin, 2013). Because many athletes who experience ACL injuries often have imbalances in quadricep and hamstring muscle strength, creators of these programs not only focus on strengthening the knee joint but also realize the importance of overall strength in stability and movement. Furthermore, one crucial aspect in continuing to reduce injury risk is making sure the athlete has proper form and biomechanical movements while performing exercises. Individuals are put at more risk for anterior cruciate ligament injury when landing with knees in greater-than-normal valgus, too much external rotation, or not enough flexion (Sutton & Bullock, 2013). Neuromuscular training programs can help combat and highlight these implications while increasing muscle balance and overall performance.

However, it is critical to have program trainers competent in coaching athletes through exercises to correct risky movements and increase the ACL IPP's effectiveness.

Program Effectiveness

Many sports medicine professionals have created and tested the effectiveness of prevention programs in order to address the prevalent risks involved with ACL injuries among specifically female athletes. For example, Dr. Jay Hertel presented his findings at the 2010 meeting of the American Orthopedic Society for Sports Medicine, revealing that participation in an ACL-injury prevention program reduced the risk of noncontact ACL injury by 71% (Marx, 2012). Another study utilizing the "Prevent Knee Injury and Enhance Performance" Program found that a group of 1,041 high school female soccer players participating in the program training for a two-year period experienced an 88% decrease in ACL injury compared to the control group during the first year and a 74% decrease in the second year. This program took a neuromuscular approach that utilized proprioceptive exercises, stretching techniques, proper landing techniques, knee and hip muscle activation, reducing excess valgus, increasing core and lower limb strength, and proper deceleration techniques (Schick, 2023). These studies show that prevention programs can be effective when properly implemented and utilized.

Program Limitations

A limitation to IPPs can be the level of participation and commitment expressed by the athletes themselves. In the National Athletic Trainers' Association (NATA) position statement on prevention of ACL injury, it was reported that IPP sessions of less than 20 minutes and longer than 20 minutes both experienced reductions in injury risk; however, sessions longer than 20 minutes reduced risk of ACL injury 26% more than sessions less than 20 minutes. It was also reported that at least two training sessions per week reduced the risk of ACL injury by 27%

compared to a single session per week (Padua et al., 2018). If an athlete is not motivated to fully participate in an exercise program, the results will understandably be less beneficial than those who put more work and effort into injury preventative measures. Therefore, to maximize ACL injury prevention, the frequency of IPP sessions ought to be at least 20 minutes long and two to three times per week at minimum. Although better implementation will not eradicate ACL tears from the sports world, it could help reduce the number of devastating injuries to teenagers and young adults (Marx, 2012; Schick, 2023).

IPP Implementation Recommendations

Although ACL injury prevention programs are capable of decreasing risks involved specifically with female athletes, one problem remains: ACL injuries continue to be a common and devastating sports injury due to lack of implementation. Although athletes hold a responsibility to themselves in putting in the work to participate, coaches' lack of ability and knowledge to train athletes and properly deliver ACL IPP can further hinder prevention programs' effectiveness. Coaches have a role and responsibility to become more knowledgeable in this area; however, there are present difficulties in finding educational opportunities to do so. Educational workshops are not common and are typically in person when they do happen, requiring significant resources and time for coaches to attend. Furthermore, many were postponed or cancelled during Covid-19. The ability to identify and correct high-risk movements during the neuromuscular training exercises and athletic activities has been reported as a crucial factor in the effectiveness of injury prevention; therefore, a lack in educational courses for trainers causes a significant roadblock in effectiveness. Thankfully, online educational workshops could solve this problem by delivering information efficiently to many individuals at a time (Russomano, 2020).

One online educational workshop, created to teach coaches how to deliver injury prevention protocols to athletes, was analyzed for its effectiveness in a study conducted with 468 coaches from different sports. The workshop consisted of a series of instructional videos accessed through a computer system. The results of the study showed that nearly two-thirds of all participants demonstrated an increase in knowledge by a mean score of 33% immediately after the workshop. Participants rated the workshop favorably and 90% highly recommend the workshop to other coaches (Russomano, 2020). The study's results reveal that online educational workshops improve participants' knowledge on how to better implement and teach injury prevention protocols to athletes. Coaches can learn how to identify and correct high-risk movements in neuromuscular training exercises while helping improve athletes' overall strength and performance. In addition to helping trainers be more qualified to coach exercises, online educational workshops can help coaches learn how to encourage and positively motivate participation in athletes.

Another important resource for online educational resources is the National Federation of State High School Associations (NFHS). Being a nationally recognized advocate organization for high school athletics, with 51-member state associations including Washington D.C., NFHS serves 19,500 high schools and over 12 million young people (NFHS, 2018). The NFHS operates by writing high school sports playing rules, supporting administrators to increase athletic opportunities for students, and providing educational programs for leaders, athletes, referees, and coaches. One of the many educational resources they provide is an elective training course on "ACL Injury Prevention" that has been available since December of 2018 (NFHS, 2018). The course content includes causes of ACL injuries, identifying and correcting movement deficiencies, and how to effectively lead a neurodynamic warmup before practices and games.

These are the most effective aspects to preventing ACL injuries, which one may recall being mentioned and discussed in more detail earlier in this paper.

In Dr. David Hoch's article "Schools Should Utilize Free Courses in NFHS Coach Education Program," he confirms that it is true that membership is not required for this ACL injury prevention course (Hoch, 2015). You can receive additional benefits like more sports specific coaching or administrative courses for a membership cost of $35 per individual person. In addition to coach certification courses, one can also have access to over 14 free training courses regarding topics such as concussions, student leadership, sportsmanship, health and safety, playing rules and officiating, and some sports specific courses. Ultimately, there are numerous benefits included in the free subscription in addition to the free ACL injury prevention training course.

Furthermore, about the implementation of the free online training course for ACL injury prevention, Dr. Hoch explains that "one of the 14 legal duties of athletic administrators, as outlined in the National Interscholastic Athletic Administrators Association's Leadership Training Course 504, is providing training for their coaches" (Hoch, 2015). Training can be defined as professional development and the free courses provided can be utilized to fulfill that legal requirement.

At the beginning of the year or season, administrators can choose a relevant course like ACL injury prevention and ask that all coaches complete it. Online courses are easier to access, so coaches can better fit this training into their schedules as it is convenient for them and complete it within the timeframe set by the administrators. A timeframe of three weeks should give coaches and admin enough time to complete one of these courses. Afterwards, the athletic administrator can "schedule one every two or three weeks throughout the school year" to

continue the "professional development program" (Hoch, 2015). Having the athletic administrator as the contact person for their school also allows them access to view their coaches' progress and award certificates of completion, providing accountability and positive reinforcement to encourage learning.

Finally, because about 74.9% of ACL injuries occurred in competition compared to practice (Joseph et al., 2013), these courses should be assigned before athletes begin practicing for coaches to feel confident and effectively administer injury prevention methods during their preseason. With athletes playing and moving at higher speeds in competition compared to in practice, there will be increased risk for injury as mentioned earlier regarding surface friction. Therefore, it is important to emphasize injury prevention during a sport's preseason to help athletes build strength, motor control, agility, and overall performance to physically prepare them for those higher speeds and demands that occur in competition.

Utilizing these suggested timelines for online training is one easy and simple way to help overcome the lack of implementation in ACL injury prevention programs, which have been proven to be effective in decreasing risks involved specifically with female athletes (Marx, 2012; Schick, 2023). Without education and implementation, the ability to decrease risks of injury is compromised and worthless. However, with these changes, young athletes can improve their knowledge of preventative exercises, ability to recognize high risk situations, and neuromuscular coordination and awareness.

Conclusion

The implications of injury can have devastating physical and financial costs as discussed earlier; however, if injury is prevented, that time and money could go towards many other beneficial things like education, paying off debt, missions, non-profits, and more. Many athletes

also rely on athletic scholarships to be able to afford a college education and injury can become a big obstacle to achieving that dream. Even though studies have shown how prevention programs can reduce the occurrence of non-contact ACL injuries by 71-88% through addressing known biomechanical risk factors when properly implemented and utilized, the limitations of participation of the athlete and implementation by coaches and administrators continue to hinder the effectiveness of ACL IPPs (Marx, 2012; Schick, 2023). One of the key components to encouraging athletes to participate in ACL IPP sessions is having coaches who are confident and equipped to effectively administer injury prevention protocols. Therefore, if the effectiveness of these programs continue to be hindered by lack of implementation, the costs will continue to rise, and athletes will continue to face long roads to recovery. However, if resources such as online educational workshops and professional development programs become more commonly used by schools and sports programs, this may be vital to the success of ACL IPPs and helping athletes continue to be healthy and achieve their highest potential.

References

Anterior cruciate ligament (ACL) injury or tear. (2024, February 2). Johns Hopkins Medicine. https://www.hopkinsmedicine.org/health/conditions-and-diseases/acl-injury-or-tear#:~:text=Surgical%20treatment%20is%20recommended%20for,growth%20plates%2C%20and%20the%20type.

Arundale, A. J. H., Silvers-Granelli, H. J., & Myklebust, G. (2022). ACL injury prevention: Where have we come from and where are we going?. *Journal of orthopaedic research : official publication of the Orthopaedic Research Society*, *40*(1), 43–54. https://doi.org/10.1002/jor.25058

Barber-Westin, S., Noyes, F. R. (2013). *ACL Injuries in the Female Athlete: Causes, Impacts, and Conditioning Programs.* Germany: Springer Berlin Heidelberg.

Collings, T. J., Diamond, L. E., Barrett, R., Timmins, R. G., Hickey, J. T., Du Moulin, W., Williams, M., Beerworth, K., & Bourne, M. N. (2022). Strength and biomechanical risk factors for noncontact ACL injury in elite female footballers: a prospective study. *Medicine and Science in Sports and Exercise*, *54*(8), 1242–1251. https://doi.org/10.1249/mss.0000000000002908.

Hadzovic, M., Ilic, P., Lilic, A., & Stankovic, M. (2020). The Effects of a Knee Joint Injury Prevention Program on Young Female Basketball Players: A Systematic Review. *Journal of Anthropology of Sport and Physical Education*, *4*(1), 51–56. doi: 10.26773/jaspe.200109.

Hoch, D., CMAA. (2015, April 14). *Schools should utilize free courses in NFHS Coach Education Program*. National Federation of State High School Associations. https://www.nfhs.org/articles/schools-should-utilize-free-courses-in-nfhs-coach-

education-program/#:~:text=A%20complete%20listing%20and%20previews,at%20www.nfhslearn.com.

Joseph, A. M., Collins, C. L., Henke, N. M., Yard, E. E., Fields, S. K., & Comstock, R. D. (2013). A multisport epidemiologic comparison of anterior cruciate ligament injuries in high school athletics. *Journal of athletic training*, *48*(6), 810–817. https://doi.org/10.4085/1062-6050-48.6.03.

Marx, R. G., Mykleburst, G. (2012). *The ACL Solution: Prevention and Recovery for Sports' Most Devastating Knee Injury.* United States: Springer Publishing Company.

Moriceau, J., Fevre, A., Domínguez-Balmaseda, D., González-De-La-Flor, Á., Simón-Areces, J., & García-Pérez-De-Sevilla, G. (2022). The influence of the menstrual cycle and oral contraceptives on knee laxity or anterior cruciate ligament injury risk: a systematic review. *Applied Sciences*, *12*(24), 12627. https://doi.org/10.3390/app122412627

NFHS. (2018, December 11). *New ACL Injury Prevention course available on NFHS Learning Center*. National Federation of State High School Associations. https://www.nfhs.org/articles/new-acl-injury-prevention-course-available-on-nfhs-learning-center/.

Nguyen, A. D., Zuk, E. F., Baellow, A. L., Pfile, K. R., DiStefano, L. J., & Boling, M. C. (2017). Longitudinal Changes in Hip Strength and Range of Motion in Female Youth Soccer Players: Implications for ACL Injury, A Pilot Study. *Journal of sport rehabilitation*, *26*(5), 358–364. https://doi.org/10.1123/jsr.2015-0197.

Padua, D. A., DiStefano, L. J., Hewett, T. E., Garrett, W. E., Marshall, S. W., Golden, G., Shultz, S. J., & Sigward, S. M. (2018). National Athletic Trainers' Association Position

Statement: Prevention of Anterior Cruciate Ligament Injury. *Journal of Athletic Training*, *53*(1), 5–19. https://doi.org/10.4085/1062-6050-99-16

Papoutsidakis, A. (2011). Predisposing factors for anterior cruciate ligament injury. *British Journal of Sports Medicine*, *45*(2), e2. https://doi.org/10.1136/bjsm.2010.081570.5

Russomano, J., Ologhobo, T., Janosky, J. J., Goldsmith, S., Marx, R. G., Kinderknecht, J., & Robbins, L. (2020). The Effectiveness of Online ACL Injury Prevention Education for Sports Coaches. *Orthopaedic Journal of Sports Medicine.* https://doi.org/10.1177/2325967120S00203.

Schick, S., Cantrell, C. K., Young, B. W., Mosher, Z. A., Ewing, M. T., Elphingstone, J., Brabston, E. W., Ponce, B. A., & Momaya, A. (2023). The mechanism of anterior cruciate ligament injuries in the National Football League: a systematic video review. *Cureus*. https://doi.org/10.7759/cureus.34291

Schindler O. S. (2012). The story of anterior cruciate ligament reconstruction--Part 1. *Journal of perioperative practice*, *22*(5), 163–171. https://doi.org/10.1177/175045891202200505

Sutton, K. M., & Bullock, J. M. (2013). Anterior cruciate ligament rupture: differences between males and females. *The Journal of the American Academy of Orthopaedic Surgeons*, *21*(1), 41–50. https://doi.org/10.5435/JAAOS-21-01-41.

Yu, B., & Garrett, W. E. (2007). Mechanisms of non-contact ACL injuries. *British Journal of Sports Medicine*, *41*(Supplement 1), i47–i51. https://doi.org/10.1136/bjsm.2007.037192

University of Wisconsin. (2017). ACL Injuries and Basketball. *UW Health: Sports Rehabilitation.* https://www.uwhealth.org/sports-medicine/physical-therapy-athletic-training/acl-injuries-and-basketball/45341.