The Factors Affecting Anterior Cruciate Ligament Tears in Female Athletes

A Synthesis of the Research Literature

A Synthesis Project

Presented to the

Department of Kinesiology, Sport Studies, and Physical Education

The College at Brockport

State University of New York

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Education

(Physical Education)

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March 12, 2019

THE COLLEGE AT BROCKPORT

STATE UNIVERSITY OF NEW YORK

BROCKPORT, NEW YORK

Department of Kinesiology, Sport Studies, and Physical Education

Title of Synthesis Project: The Factors Affecting Anterior Cruciate Ligament Tears in Female Athletes: A Synthesis of the Research Literature

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Date: 3/14/19

Accepted by the Department of Kinesiology, Sport Studies, and Physical Education, The College at Brockport, State University of New York, in partial fulfillment of the requirements for the degree Master of Science in Education (Physical Education).

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3/18/19

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Abstract

Research has shown that female athletes are more likely to injure their anterior cruciate ligament (ACL) than male athletes (Elliot, Goldberg, & Kuehl, 2010). Although female athletic opportunities have increased over the past few decades, this increased risk for ACL injuries may deter some individuals from participating in sport, especially those that involve quick movements where knee injuries are more prevalent (e.g., soccer, basketball). Thus, the purpose of this synthesis is to identify risk factors specific to female athletes that contribute to their increased ACL vulnerability. A search procedure utilizing SPORTDiscus, Academic Search Complete, and Physical Education Index was conducted to identify articles in the critical mass. Findings from the critical mass indicated that anatomical (e.g., ACL size, hip anatomy, femoral condyle size), biomechanical (e.g., hip muscles and hamstring and quadriceps ratio), and physiological (e.g., the menstrual cycle and estrogen) factors contribute to the higher probability of ACL injuries in female athletes. These findings can help determine effective and efficient prevention programs to limit these factors. A successful ACL prevention program for female athletes includes knee laxity assessments, stretching, strength training, and plyometric training. With continued research, definitive risk factors and prevention strategies can be identified so that female athletic participation continues to grow and result in longer athletic careers.

Keywords: [Anterior Cruciate Ligament, female athlete, anatomical risk factors, biomechanical risk factors, physiological risk factors]

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Chapter 1

Introduction

In the blink of an eye, a knee injury can ruin an athlete's career. The most common knee injury found in an athletic population is the tearing or rupturing of the Anterior Cruciate Ligament (ACL) (Țifrea, Paschalides, & Costache, 2015). A ligament is a short band of fibrous tissue that connects two bones to hold a joint together. The ACL crosses the underneath of the femur to the top of the tibia. While holding the knee joint in place, the ACL is also preventing the femur from any backward movement away from the tibia or vice versa. The ACL is one of the most critical ligaments in the knee to help with its function on rotary stability during pivoting movement (Mall, Lee, Cole, & Verma, 2013).

The ACL is a critical component to the knee kinematics for explosive movements especially in sports that require cutting and pivoting movements (Mall, et al., 2013). The predominant muscles that are key components to the function of the ACL are the hamstring and quadriceps. Contraction of both the hamstring and the quadriceps assist for dynamic knee stabilization. The quadriceps muscle group assists the knee in full extension, creating a shearing force on the ACL, which increases strain to the ligament. In opposition, the hamstrings co-contracts, which helps reduce the shearing strain on the ACL caused by the quadriceps (Abate, Vanni, & Pantalone, 2013). Therefore, the quadriceps and hamstring muscle groups are crucial components to the functionality of the ACL.

Athletes most likely to suffer an ACL injury when they stop moving suddenly, jump or land incorrectly, or are tackled (Bing, Yu, & Garrett, 2007; Pappas, Zampeli, Xergia, & Georgoulis, 2013). Physiologically, the injury of the ACL occurs when the knee joint undergoes any axial loading that is beyond the normal physiologic range (Abate, et al., 2013). When a ligament is injured, it is called a sprain. In terms of ligament sprains, there are three classifications. The first-degree sprain of the ACL is a slight stretch of the ligament in which the knee joint can still maintain stability. The second-degree sprain of the ACL is when the ligament stretches far enough that it partially ruptures. The third-degree sprain of the ACL is a rupture of the ligament (i.e., the ligament tearing in two), which creates complete instability of the knee (Hooda et al., 2018; Țifrea et. al., 2015). A rupture of the ACL ligament is common in sports with high impact on an athlete's knee joint that involve pivoting and cutting movements, such as soccer, football, and basketball (Abate et al., 2013).

Once the ACL is injured, it puts the whole knee in a vulnerable state, which impacts the athletes' performance and possibly the opportunity to continue to playing his or her sport in the future. When the ACL is fully torn, the rehabilitation process to achieve full functionality of the ACL is extensive and can take roughly twelve months. There are both surgical and non-surgical procedures available (Hetsroni et al., 2013). However, rehabilitation will always include some variation of physical therapy. Unfortunately, the procedure for reconstruction of the ACL is not guaranteed to last forever, and there is always a possibility of re-tear (Sanders et al., 2017).

An ACL injury requiring surgery is commonly fixed by repairing the ligament with a bone-patellar tendon-bone graft, hamstring autografts, and cadaveric specimens (Jones et al., 2015). Following an ACL reconstruction surgery, the athlete must complete a minimum of six to twelve months of strength and functionality training in order to return to as near as possible regular knee function. Physical therapy is crucial for return to play and for a better quality of life (Prince et al., 2015). However, research shows that the majority of athletes that show excellent knee function at their six month post operational rehabilitation process, have a greater risk of a secondary ACL injury (Prince et al., 2015). Thus, even if an individual undergoes ACL reconstruction surgery and extensive physical therapy, there is an increased probability of tearing the ACL compared to preinjury.

A first-degree ACL sprain can be treated non-operatively through strengthening exercises and physical therapy to help bring the injured knee back to function. Strengthening exercises tend to focus on strengthening the hip extensor, hip abductor, quadriceps, and hamstring muscles (Ambegaonkar, Mettinger, Caswell, Burtt, & Cortes, 2014; Nguyen et al., 2017). Even with non-operative ACL rehabilitation, there is still a significantly higher chance that an athlete will undergo a secondary injury or a second ACL injury. Without surgery after an ACL injury, an athlete has a 63% chance of secondary meniscal tears, osteoarthritis, and total knee arthroplasty (Sanders et al., 2015). Research has shown that 40% of athletes who tear their ACL and chose the non-operative route initially, chose surgery after (Ireland & Gaudette, 1997). Many decide to have ACL reconstruction within the two years after the tear due to knee laxity and vulnerability. This devastating injury has detrimental influences on an athlete's performance. Many athletes over time may choose to never return to their sport, due to the fear of reinjury, the pain of the knee joint, or lack of ability to fully recover (Ireland & Gaudette).

In addition to surgery and physical therapy, an athlete may go through physical and psychological impairments that affect quality of life and play (Filbay, Ackerman, Dhupelia, Arden, & Crossley, 2018). With damage to the ACL, there is a higher risk for injury to the other soft tissues that could create more knee pain, a possible dislocation, or eventually osteoarthritis (Estes, Cheruvu, Lawless, Laughlin, & Goswami, 2015). Quality of life can be impaired for an individual who has injured their ACL from anywhere of 5 to 25 years following the injury due to knee related issues, health related issues, and other additional factors depending on pathology. For example, athletes who injured their ACL reported a high level of pain present during knee extension and limitations of activity due to physical health, bodily pain, self-rated health, and future health expectations (Filbay et al., 2015). Moreover, athletes with an ACL injury reported mental health issues, such as a decrease in energy and fatigue and an increase in anxiety and depression, which may result in decreased participation in social activities and a lack of overall motivation. Therefore, an ACL injury can have impairments on an individual that could last long term, regardless of operative or non-operative management.

A more controversial topic around ACL injuries is the high rate of ACL injuries in female athletes (Hutchinson, & Ireland, 2001; Ireland & Gaudette, 1997).). In fact, research has demonstrated that women are eight times more likely to tear their ACL than men, and they are at a higher rate of tearing their ACL a second time after surgery (Elliot et al., 2010). Likewise, females are more likely to re-injure their ACL after reconstructive surgery and males (Nawasreh, Adams, Pryzbylkowski, & Logerstedt, 2018). Therefore, females are at a greater risk to tear their ACL in general and are more likely to tear their ACL a second time while participating in sports. This topic is becoming more prominent as female participation in sport is drastically increasing, especially over the last 40 years. In 1972, the passage of Title IX encouraged females to participate in sport by creating more opportunities for them to play (Laiblem & Sherman, 2014). However, as opportunities for female athletes increase as well as their participation in sports, so have the number of ACL injuries (Arendt & Dick, 1995). Consequently, female participation may become compromised especially for sports with pivoting movement knowing that there is a higher risk of ACL tears.

Scope of Synthesis

The purpose of this synthesis is to identify potential risk factors to explain why female athletes are more vulnerable to injuring their ACL compared to male athletes. Specifically, this synthesis will examine anatomical, biomechanical, and physiological differences between males and females that may contribute to the higher incidence of ACL injuries in females. Increased knowledge of the causes for vulnerability in the female knee may help prevent future injury and lead to longer, more successful careers for female athletes.

Operational Definitions

Anterior Cruciate Ligament. "The anterior cruciate ligament runs diagonally in the middle of the knee. It prevents the tibia from sliding out in front of the femur, as well as provides rotational stability to the knee." (American Academy of Orthopedic Surgeons)

Anatomical Risk Factors. The vulnerable measures of a person's internal workings that would increase an individual's chance of an ACL injury (Estes, Cheruvu, Lawless, Laughlin, & Goswami, 2015).

Biomechanical Risk Factors. The vulnerable measurements of the structure or movement that would increase an individual's chance of an ACL injury (Hewett, Ford, Hoogenboom, & Myer, 2010).

Physiological Risk Factors. The vulnerable measurement of the bodily part functions that would increase an individual's chance of an ACL injury (Abate et al., 2013).

Chapter 2

Methods

Search Procedure

In order to find the critical mass of articles for this synthesis, I used the following online databases through The College at Brockport Library: SPORTDiscus, Academic Search Complex, and Physical Education Index. The initial search term that were used in the search was “Anterior Cruciate Ligament,” in which SPORTDiscus showed 9,504 results, Academic Search Complete showed 9,569 results, and Physical Education Index showed 14,127 results. In order to narrow down the results, the search was restricted to full articles from peer-reviewed academic journals. This step brought SPORTDiscus to 2,664 results, Academic Search Complete to 3,410 results, and Physical Education Index to 13,935 results. To narrow down the search further, the following keywords were used: “Anterior Cruciate Ligament tear,” and “female athletes.” With those key words alone, SPORTDiscus gave 19 results, Academic Search Complete gave 24 results, and Physical Education Index gave 33 results.

From the initial search, multiple keywords were identified to be able to use in finding more articles that would support this synthesis. There was one article in particular that was found on Academic Search Complete that helped narrow down the important risk factors that assisted in a secondary search using the following keywords: “menstrual cycle”, “anatomical,” and “biomechanical” (Abate, et al., 2013). When searching “ACL tears,” and “menstrual cycle,” SPORTDiscus provided two results, Academic Search Complete provided four results, and Physical Education Index provided zero. When searching “ACL tears,” and “anatomical,” six results were provided by SPORTDiscus, ten results were provided by Academic Search Complete, and eight results were provided from Physical Education Index. When searching

"ACL tears," and "biomechanical," SPORTDiscus returned 16 results, Academic Search Complete returned 24 results, and Physical Education Index returned 11 results.

From the studies found in the secondary search, more keywords were discovered to help maximize content in an effort to identify the risk factors of females tearing their ACL. These keywords included "sex differences," "risk factors," "estrogen levels," "hip shape," "muscular strength," and "hamstring and quadriceps strength." All keywords were paired with the primary key word of "ACL tears." In the database of SPORTDiscus, "ACL tears" with "sex differences" provided 12 results; "ACL tears" with "risk factors" provided 46 results; "ACL tears" and "estrogen levels" and "ACL tears and "hip shape" provided zero results; "ACL tears" and "muscular strength" provided two results; and "ACL tears" and "hamstring and quadriceps," provided 16 results. In the database of Academic Search Complete, "ACL tears" with "sex differences" provided 18 results; "ACL tears" and "risk factors," provided 68 results; "ACL tears" with "estrogen levels" provided one result; "hip shape" provided zero results; "ACL tears" with "muscular strength" provided 12 results; and "ACL tears" and "hamstring and quadriceps" provided 21 results. Lastly, in the database of Physical Education Index, "ACL tears" with "sex differences" provided 12 results; "ACL tears" with "risk factors" provided 30 results; "estrogen levels" provided one result; "hip shape" provided zero results; "ACL tears" and "muscular strength" provided three results; and "ACL tears" and "hamstring and quadriceps" provided zero results. Though these were broad terms, each search within each database provided more information to help narrow down the relatable and supportive content for the critical mass.

Criteria for Inclusion

Articles that were included in the critical mass for this synthesis had to meet certain criteria to assist in addressing the differences between male and female risk factors of an ACL injury. First, each article had to be full text from a peer reviewed academic journal. These criteria were used to ensure the quality of the research contained within each article and that the complete article could be obtained. In addition, each article had to be published within the last 25 years due to the prevalence of research on this topic during the timeframe. Although some of this research may be considered old or out-of-date, there is still a significant amount of information that was given about the female risk factors 25 years ago that are also considered risk factors today. Articles included in the critical mass also needed to include female athletes, at any age, in relation to ACL injuries. The articles that were included also had to focus on sports with high pivoting movements, such as football, soccer, or basketball. After applying all of the inclusion criteria, 13 articles were included in the critical mass of this synthesis.

Data Analysis

Once the articles were identified from using the criteria for inclusion, it was necessary to decide how to properly and effectively organize the articles based on commons themes or topics. The articles that were primarily used in the critical mass identified possible risk factors in females along with ACL functionality and biomechanics. These articles were then organized into an article grid (see Appendix A), that identifies the major components of each article. Using the article grid, articles were compared and contrasted resulting in the identification of major themes. For further organization of the articles in the critical mass, a coding table was created using the identified themes (see Appendix B). Each article was then coded into the table. Since each initial theme was very broad, sub themes were created. For example, as seen in the coding table (Appendix B), anatomical differences is a main theme with subthemes of hamstring to quadriceps ratio, knee laxity, and hip shape. The articles were then recoded, as needed, using the updated coding table

Chapter 3

Results

This section provides the reader with a synthesis of the critical mass of 13 articles regarding the identification of risk factors that make female athletes more prone to tearing their ACL over male athletes. The risk factors are organized in to three major sections: anatomical factors, biomechanical factors, and physiological factors. Each risk factor is followed with more narrow concepts to explore the cause for female knee vulnerability (see Appendix B.).

Anatomical Factors

The ACL is a small band of fibrous tissue that connects the femur to the tibia, with its main function being knee joint stabilization (Hewett et al., 2005). Once the ACL is injured, then the supporting soft tissue around the knee joint is damaged as well, causing a greater instability in the knee. An important characteristic the ACL has that affects its functionality include the notch width index, length, mass, and volume. Compared to males, females possess a smaller ACL, which is shorter in length, smaller in cross sectional area, and smaller in both volume and size (Estes et al., 2015). Moreover, individuals who had torn their ACL had an even significantly smaller ACL than those who had not. One of the components that helps keep ligaments strong is collagen fibrils. The larger the ligament, the more collagen fibrils the ligament has (Liu et al., 2009). Therefore, a smaller ACL contains less collagen than a larger ACL making it more vulnerable to injury. Due to the fact that anatomically females have a smaller ACL in general, they are more prone to an ACL injury than males.

When breaking down the kinematics of the ACL functionality, external and internal hip rotation is an important component (Philippon et al., 2012). When looking at the structure of the hip, the femoral head interlocks with the pelvic girdle in the acetabulum. The connection of the femoral head in the acetabulum of the pelvic girdle is a factor for the range of motion of the hip (Bedi et al., 2016). The movement of the femoral head and the acetabulum is compromised by the femoral-head to neck offset, which is a component to the overall connection of the leg and hip. Research has shown that femoral head-neck offset in females is significantly more diminished when compared to males (Philippon et al.). With a diminished femoral head to neck offset, there is an increased probability of an injury to the ACL. In fact, Philippon et al. found a positive relationship between diminished femoral head-neck offset and ACL injuries in females. Although not causational, this finding suggests that the more diminished the femoral head-neck offset, the more likely an ACL injury could occur in female athletes.

Another anatomical feature that can affect ACL vulnerability in females is the femoral condyle. A condyle is the round part at the end of the bone, almost like a knuckle. Hoshino et al. (2012) defines condyle offset as “the smallest distance between the transcondylar and the anatomical axis” and condyle offset ratio as “calculated by the average radius of the two best fit condyle spheres” (p. 1284). Research shows that females who have injured their ACL have a significantly larger condylar offset ratio then those females who did not tear their ACL (Hoshino et al.). Interestingly, males had no significant relationship between condyle offset ratio and an ACL injury. Therefore, it appears that a larger condylar offset in females makes them more vulnerable to an ACL injury than males.

The anatomical differences in females compared to males discussed above can contribute to an increase risk tearing their ACL; however, they may also influence biomechanical risk factors for female athletes. These are discussed next.

Biomechanical Factors

The ACL is most commonly injured in sports that require quick cutting movements, quickly stopping from moving, or jumping or landing incorrectly (Pappas et al., 2013). When looking at the biomechanics of the sports that require these dynamic movements, the knee and the hip joint are two critical components that assist to the lower extremities. Specifically, during cutting or jumping movements the hip will undergo external or internal rotation (Philippon et al., 2012). Muscles responsible for internal and external hip rotation include hip abductor and hip extensor muscles. The hip abductor muscles include the gluteus minimus, gluteus medius, and tensor fascia lata. The hip extensor muscles include the hamstrings and the gluteus maximus. When there is a limited range of motion in the hip joint, especially during rotation, stress is increased on the knee, making the ACL more vulnerable to injury. The ACL ruptures when the hip reaches its max threshold for its range of motion (Lopes et al., 2016). The strength of the hip abductors and extensor muscles is critical to assist the with its range of motion. If the hip abductors and extensors are not strong enough during the dynamic movements, the ACL is at a vulnerable state. Evidence suggests that females typically have weaker hip abductor and extensor muscles than males (Nguyen et al., 2017). Therefore, during quick cutting and stopping movements, when the hip is internally or externally rotating, females are at a higher risk of an ACL injury, due to their weaker strength in their hips that puts higher stress on the knee.

The major muscles involved in the biomechanical breakdown of these quick dynamic movements involve the hamstring and the quadriceps (Ambegaonkar et al., 2014). The quadriceps and the hamstring co-activate in explosive movements as the quadriceps is responsible for knee extension and the hamstring is responsible for knee flexion (Pamukoff et al., 2017). The female hamstring is at an unequal measurement to the quadriceps because usually females are more quadriceps dominant over their hamstring, meaning their quadriceps are stronger. Research demonstrates that females use less force with their hamstring during explosive movements than males (Pamukoff et al.). The absence of the force needed from the hamstring to be at a near equal with the quadriceps causes the ACL to be more vulnerable (Hannah et al., 2015). When comparing quadriceps hamstring force, the female hamstring is typically weaker than the male hamstring, which produces an unequal hamstring quadriceps force ratio and creates vulnerability in the knee. Thus, unequal hamstring to quadriceps force ratio is a risk factor as to why females are more likely to tear their ACL than males.

Physiological Factors

Along with anatomical and biomechanical risk factors, there are physiological differences between females and males that can contribute to ACL vulnerability. These differences mainly concern hormone distribution and production. Each hormone has a different effect on the body (Stijak et al., 2015). When there is a hormone imbalance in an athlete, the body is at a vulnerable state, creating an increased risk for a potential injury (Abate et al., 2013). In fact, studies show that females who rupture their ACL had a significantly different production of hormone levels than that of females who did not rupture their ACL (Abate et al.; Stijak et al.).

The presence of specific hormones has also been shown to increase the risk for ACL injuries. For example, knee laxity (i.e., looseness of the knee joint) has been shown to be affected by the presence of estrogen. Estrogen is a hormone that promotes female characteristics of the body and is produced during the menstrual cycle. Within the knee joint soft tissue, collagen, a structural protein, assists in keeping the knee strong. The presence of estrogen diminishes collagen, which decreases the ability to absorb the explosive movements in sports that include fast cutting and pivoting movement (Stijak, et al., 2015). Therefore, the presence of estrogen in the body causes a greater movement amplitude in the knee, which increases the risk for ACL injury.

While in the menstrual cycle, a female's hormones are imbalanced, specifically with the level of estrogen in her body. The high levels of estrogen during their menstrual cycle contributes to knee laxity, creating vulnerability in the ACL (Abate et al., 2013). Conversely, testosterone acts as a protectant in connective tissue, which makes the ACL structurally stronger. Likewise, testosterone is a hormone that indirectly influences an individual's muscular strength. Males tend to have higher levels of testosterone, and, therefore, have a stronger ACL (Stijak et al., 2015). Overall, the production of estrogen during the menstrual cycle and the lack of testosterone production in females is a physiological factor that contributes to the high risk of an ACL tear in female athletes.

Summary

The current literature provides evidence that there are anatomical, biomechanical, and physiological risk factors that can contribute to the female athletes' population being more likely to tear their ACL than the male athlete population. In each risk factor, there are subcategories to further explain and identify the causes. Anatomically, the differences that expose females to a higher probability to injure their ACL is that females have a significantly smaller ACL, a more diminished femoral head offset, and larger femoral condyle. Biomechanically, the differences that increase the risk of a female tearing her ACL over a male is the weakness of their hip muscles that assist in hip rotation and diminish hamstring to quadriceps force ratio that assist in the knee flexion and extension in pivoting and cutting movements. Lastly, the physiological influences that differentiate between the higher risk of an ACL tear for females is their hormone imbalances, specifically the production of estrogen during their menstrual cycle, which diminishes their knee strength. Overall, these anatomical, biomechanical, and physiological differences give females a higher probability of an ACL injury when compared to males.

Chapter 4

Discussion

The ACL is at its most vulnerable point to rupture when it meets its maximum force loading threshold. However, each individual's maximum force loading threshold is different based on their anatomical, biomechanical, and physiological components. Evidence suggests that female athletes have a higher probability of suffering an ACL injury than male athletes (Estes, et al., 2015). The purpose of this synthesis was to identify the risk factors of ACL tears in female athletes. Risk factors that contribute to a weaker ACL in female athletes include lower limb strength, the size of the ACL, collagen fibrils, range of motion in the hip, and hormone imbalances (Lopes et al., 2016). The identification of specific anatomical, biomechanical, and physiological risk factors for females will give guidelines to find possible methods of treatment or prevention plans. Popular strategies to both prevent ACL injuries in the female athlete population include knee laxity assessments, stretching, strength training, and plyometric exercises. Implementing these strategies will help aid in the prevention of ACL injuries in female athletes (Meyer & Reid, 2016).

Knee Laxity Assessments

When considering the kinematics of ACL functionality, the important supporting anatomical structures are the hip and the knee joint. The pivoting maneuver that puts stress on the ACL is the co-activation of external and internal hip rotation, along with knee flexion and extension (Philippon et al., 2012). The limiting range of motion in hip rotation puts stress on the ACL. Anatomically and biomechanically females have a decreased hip range of motion compared to males. This factor is what causes stress from the hip, to stress on the knee, to overall stress on the ACL during a dynamic movement. To prevent the stress from occurring, athletes can be assessed on knee laxity both passively and dynamically.

Passive assessment. Athletes can have an individual assessment of their lower extremities without performing any movement to assess their knee laxity. The simple test used to accurately evaluate the rotatory knee laxity is the Pivot shift test (Kuroda et al., 2012). In the shift Pivot test, the athlete lies down and the examiner tests the stability of the knee overall. The examiner grasps the heel and the distal portion of the knee as the knee is in a fully extended position. From there, the examiner gives a valgus stress and an axial load while internally rotating and flexing the knee. A knee with higher laxity will have more tibial movement while the femur is rotating externally. Even though the Pivot shift test is unquantifiable, it is a reliable assessment that allows an evaluation of the vulnerability of the knee naturally. This passive assessment allows an opportunity to identify factors in the anatomy of the individual’s knee to create a specified training protocol (Kuroda, et al.). Athletes could also use quantitative assessments in the form of sensory tools to assess their pivot during movement. As the Pivot shift tests allows examination of the knee laxity, utilizing sensors for an additional assessment can allow quantifiable factors to be identified to help evaluate the biomechanical break down.

The Pivot shift test can be analyzed with a new measurement system using microelectromechanical systems (MEMS) - based sensors (Kuroda et al., 2012). This assessment is a combination of popular pivoting assessments that use inertial sensors and magnetic sensors. In this assessment, femoral and tibial acceleration and velocity in clinical grading are evaluated. The sensors detect a drop in femoral acceleration at the same time as reduction in the pivoting movement. Therefore, the sensors are allowing quantifiable observation on the athlete through their pivoting movement to analyze and correct the way they put stress on their body during the pivot (Kuroda, et al., 2012).

It is beneficial to assess the functional movement of the lower extremities, anatomically and biomechanically, to see how the body is moving and what components are putting stress on the ACL. While both safe, the assessments will allow an opportunity to create a more individualize intervention program to prevent ACL injuries in each athlete. Once the anatomical knee laxity is evaluated and broken down biomechanically, the risk factors must be addressed and corrected/improved by creating an effective prevention program. To create a stronger prevention program through assessments, it is beneficial to assess how to properly move/ perform to put less stress on the ACL.

Dynamic assessments. The knee and the hip joint are two critical components that assist the lower extremities in the dynamic movements that put stress on the ACL. Females have weaker lower extremity factors that contribute to the increase risk of ACL injury (Philippon et al., 2012). For this reason, it is important for females to get a dynamic movement assessment in their hip and knee joint. These dynamic movement assessments will allow an evaluation of the muscle activation in the individual athlete, allowing an opportunity to correct her form to prevent injury and allow creation of an effective individualized training program.

A dynamic movement that would properly examine the anatomy and biomechanics of the lower extremities that affect the ACL is the jump squat (Hewett et al., 2010). In the down phase of a jump squat, the individual should stand with feet shoulder width apart, toes turned slightly out, chest proud, squatting down keeping weight in the heels, flexing the knees to about 90 degrees with knees over the toes as the spine is in a neutral position. The knees must not cave toward the inside, so activating the hip abductors. In the up phase of the jump squat, the force is coming from the legs and heels as the individual is launched straight up, pelvis moving forward. In the landing phase, the individual must land softly by using the momentum from the landing, smoothly transitioning in to the next squat.

During the jump squat, females tend to land with less flexion in their knees than males due to their quadriceps dominance, which creates a shearing force on the ACL. Moreover, their knees tend to cave in easier during this movement due to their weaker hip abductors (Hewett, et al., 2010). With a dynamic movement assessment, such as the jump squat, females, especially high-risk females, can be clearly identified to create prevention strategies. A dynamic assessment will allow an opportunity to correct form and technique to assist female athletes in utilizing the appropriate muscles for ACL injury prevention, and, in turn, decrease the chances for an ACL injury (Hewett et al.). Therefore, to decrease their risk of ACL injury from anatomical and biomechanical components, female athletes would benefit from adding in dynamic movement assessments to their prevention program.

Stretching

One area in sport that is often underrated is the warm up and flexibility component before and after any physical activity. The body needs to be warm and the blood needs to be flowing in order to reduce risk of injury. Stretching has been shown to help prevent injuries and promote stronger muscles (Baechle, 2016). Since lower extremity muscle groups are important to the biomechanical and anatomical structural components of the ACL, completing stretches that highlight these muscles groups will effectively help reduce vulnerability in the ACL while making the lower extremities stronger. In order to strengthen the hip abductor, hip extensor, lower leg, and trunk muscles, it is critical to emphasis proper warm up of the larger and smaller muscle groups involved in the physical activity (Stojanovic & Ostojic, 2012).

To efficiently warm up the body before physical activity, the body must move. A warm up should include a jog, a sprint interval, and a backward run. Once the body has moved and is essentially warm, then the muscles involved in the physical activity must be stretched (Baechle, 2016). Static stretches that aid in properly warming up the lower body is a calf stretch, quadriceps stretch, hamstring stretch, inner thigh stretch, and hip flexor stretch (Stojanovic & Ostojic, 2012). Static stretching has been shown to maximally increase muscle leg strength in female athletes, reducing the risk of an ACL injury (Novaes Dos Santos et al., 2018). Therefore, in order for females to get the most effective ACL program, stretching must be incorporated as a key component to help reduce biomechanical and anatomical risk factors in females.

Strength Training

The knee and the hip joint are two critical components that assist the lower extremities in the dynamic movements that put stress on the ACL. Specifically, when looking at the biomechanics during cutting or jumping movements the hip will undergo external or internal rotation (Philippon et al., 2012). Anatomically the muscles responsible for internal and external hip rotation include the hip abductor (gluteus medius) and hip extensor (hamstring and gluteus maximus). Likewise, the gluteus maximus and gluteus Medius are primary muscles in keeping the pelvic stable during dynamic movements (Nguyen et al., 2017). In addition to the hip extensor and abductor muscles, the major muscles involved in the biomechanical breakdown of these quick dynamic movements of the knee involve the hamstring and the quadriceps (Ambegaonkar et al., 2014). Compared to males, females have weaker hamstring muscles, weaker hip abductor, hip extensor, and trunk muscles than males, which contribute to their higher risk of ACL injury. In a strength training program specific to female athletes, it is crucial to implement those exercises that will focus on strengthening the lower extremities as well as taking care of those muscles in every strength training component (Hewett et al., 2010). In a study done by Mehl et al. (2017), strength training was identified as a beneficial component to incorporate in ACL prevention programs, with exercises emphasizing hamstring strength, hip strength and abdominal strength.

Plyometric Training

Plyometric exercises can also be implemented in a strength training program for females for optimal prevention of an ACL injury. Plyometric exercises are dynamic, sport specific movements that incorporate quick explosive bouts of jumping and landing, much like the pivoting movement that puts the ACL under stress (Alexander, 2017). Plyometrics focuses on the landing technique, force reduction, overall strength and power inputs, which females tend to lack compared to males (Alexander, 2017). Plyometric movements address a proprioceptive and an additional biomechanical component on the muscles that stretching and weight training do not target (Willadsen, Zahn, & Dural, 2019). While allowing the body to undergo the sport specific dynamic movement, it will build up strength towards the activated muscles putting less stress on the ACL in high performance situations. Research suggests that plyometrics can decrease the risk of ACL injuries in females (Brown et al., 2014; Myer et al., 2006; Pfile, 2013). Therefore, plyometrics training is an important addition to a prevention program for females to reduce risk of ACL injury.

Limitations

This synthesis explores and identifies risk factors for ACL injury in females; however, there are a few limitations. First, there were a limited number of studies on each identified risk factor; thus, the results should be approached with caution. The articles included in the critical mass included participants of different ages and sports. As a result, it is unclear if the identified risk factors apply to females of all ages and for all sports. Additionally, all of the factors and components examined in the studied were internal factors. There are possible external factors as well that could be a possible risk factor to the reason females have a higher risk factor than males, such as the influence of the coach on ACL prevention.

Recommendations for Future Research

Future research should continue to examine current risk factors and identify additional risk factors that contribute to increased ACL tears in female athletes. For example, there are many anatomical and biomechanical risk factors for females that are studied compared to physiological components. There is evidence to suggest that females have weaker ACL ligaments due to the presence of estrogen and progesterone throughout their menstrual cycle. However, it would be helpful to identify which stages of the menstrual cycle a female is more prone to ACL tears. Likewise, it would be of interest to study the effects of a supplementation that increase collagen in ligaments to prevent the breakdown from estrogen and creating a stronger ACL.

Throughout the exploration of the articles for this synthesis, there was very limited discussion on the external influences for incorporating ACL prevention programs for female athletes. One factor that should be explored further is the influence coaches have on their athletes. Coaches have the responsibility to assist their athletes to achieve their optimal performance as well as look after their athletes' safety (Lee, Magnusen, & Cho, 2013). Thus, coaches need to be able to establish effective ACL prevention programs for their teams especially for female athletes. Therefore, it is important to examine how successful coaches can incorporate an ACL prevention program with their teams.

A final area that should be explored is the effectiveness of ACL prevention programs. While researching articles for this synthesis, many prevention programs and treatment protocols that were given; however, little insight was provided as to how successful those programs were once implemented. Thus, more research is needed to determine effective prevention programs for female athletes.

Conclusion

Female athletes are at greater risk to suffer an ACL injury compared to male athletes due to differences in anatomical, biomechanical, and physiological factors. These factors make the ACL more susceptible to injury and even rupture. An optimal program to reduce the risk of an ACL tear in female athletes must include appropriate assessments of knee laxity, stretching for the lower extremities, strengthening program with emphasis on vulnerable muscle groups, and plyometric training. Further research should be conducted to further narrow down the risk factors contributing to ACL injuries in female athletes. With the identification of conclusive risk factors, stronger prevention programs can be created for females to have the opportunity for longer, more successful careers.

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Appendix A
Synthesis Article Grid

Author	**Title**	**Source**	**Purpose**	**Methods & Procedures**	**Analysis**	**Findings**	**Recommendation**
Abate, M., Vanni, D., & Pantalone, A., (2013).	Mechanisms of anterior cruciate ligament injuries in female athletes: a narrative review.	*Journal of Orthopedics,*	To identify toe reasons for the sex differences in males and females with ACL tears.	Review of a Narrative, research English-Language articles. Biographies were hand searched and articles relating to the main topic were used.	Review of literature	Evidence that there is ligament laxity from estrogen level and that the menstrual cycle has individualized effects for ACL tears.	This will help pave the way to development of preventative and therapeutic procedures
Ambegaonkar, J., Mettinger, L., Casewell, S., Burtt, A., Cortes, N., (2014).	Relationship between core endurance, hip strength, and balance in collegiate female athletes	*International Journal of Sport Physical Therapy*	To identify the exact relationship between ACL injuries and hip strength, core endurance, and balance in female student athletes.	40 female athletes performed the SEBT to find a correlated relationship with lower extremities injuries with core endurance and hip strength	Star Excursion Balance Test (SEBT)	Overall hip strength was related, core endurance was not.	To look in to the measure of neuromuscular control to lower extremities

Bedi, A., Warren, R., Wojtys, E., Oh, Y., Ashton-Miller, J., Oltean, H., Kelly, B., & Warren, R., (2016).	Restriction in hip internal rotation is associated with an increased risk of ACL injury.	*Knee Surgery, Sports Traumatology, Arthroscopy,*	To examine if hip range of motion in dynamic movement correlates to ACL injuries	324 football athletes of the NFL had their rotational hip movement examined. The range of motion was also compared of those athletes who has an ACL strain or repair	Data analysis recorded from Excel, into SAS. Frequency variables were computed	Reduction of internal rotation of the hip was significantly related to ACL injury	More insight on this topic for better interventions and methods of recovery
Estes, K., Cheruvu, B., Lawless, M., Laughlin, R., & Goswami, T., (2015).	Risk assessment for anterior cruciate ligament injury	*Archives of Orthopaedic & Trauma Surgery,*	To get a better understanding of anatomical details of the knee joints suffering ACL tears to identify risk factors	MRI of 32 patients with ACL tears and of 40 patients without tears. Showing the femoral condyle and structural components of ACL	Evaluating the relationship of notch width, ACL length and width. Sensitivity analysis showing ligament functionality	NWI had no relationship, smaller ACL in length and width predispose females but because of the low collagen fibers.	Further research on ACL size in men vs women
Hannah, R., Folland, J., Smith, S., & Minshull, C., (2015).	Explosive hamstrings-to-quadriceps force ratio of males versus females	*European Journal of Applied Physiology*	To compare the differences of H/Q force ratio between males and females to explore ACL injury risks	20 males and 20 females neuromuscular performance was assessed during explosive movements	H/Q force and H/Q maximum voluntary force observed by electromechan ical delay	The weaker the H/Q force the more vulnerable the ACL Greater H/Q force in males than females	This study suggests other factors more important in determining the substantially higher knee injury rates of females.

Hewett, T., Myer, G., Ford, K., Heidt, R., Colosimo, A., McLean, S., Van Den Bogert, A., Paterno, M., & Succop, P., (2005).	Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athlete: a prospective study.	*The American Journal of Sports Medicine*	To examine female athletes with ACL injury to see if there is neuromuscular and increased valgus joint loading increase injury	205 female athletes in high risk sports had their neuromuscular control and joint loading measured during jump-landing task.	Variance analysis, linear and logistic regression used to isolate predictors of risks for ACL rupture in females.	Knee motion and knee loading during dynamic tasks are ACL risk factor predictors	Monitor neuromuscular control of the knee joint for more effective targeted interventions.
Hoshino, Y., Wang, J., Lorenz, S., Fu, F., & Tashman, S., (2012).	Gender differences of the femoral kinematics axis location and its relation to anterior cruciate ligament injury: a 3D-CT study.	*Knee Surgery, Sports Traumatology, Arthroscopy,*	To be able to identify the differences in men and female of femur morphology in knee kinematics to ACL injury risks	3D CT scans of contralateral healthy femurs in 38 injured patients	Condyle offset ratio was calculated and then compared between men and women	Larger COR in women. Larger COR in injured ACL individuals. COR could be a possible risk factor for ACL injury in females	Further research femur morphology with knee kinematics to support these trends or find other common trends for ACL risks
Liu, X., Tingle, T., Linter, D.M., Lowe., W.R., Zhai, Q.J., Luo, Z.-P., (2009).	Differences in collagen gene expression in male and female anterior cruciate ligament injured athletes.	*Biology of sports*	To understand collagen for ACL strength	17 males 17 females with ACL tears. A sample was taken from their ACL	There was a significant difference between collagen in males and females	Females had a significantly lower collagen in ther ACL	

Lopes, O., Gomes, J., & Freitas Spinelli, L., (2016)	Range of motion and radiographic analysis hip in patients with contact and non-contact anterior cruciate ligament injury.	*Knee Surgery, Sports Traumatology, Arthroscopy,*	To compare range of motion in hip joint in male vs female in an ACL injury	MRI evaluation of the ipsilateral hip. Radiographic evaluation of hip joints.			To research more about non-contact and contact ACL injuries
Nguyen, A., Zuk, E., Baellow, A., Pfile, K., DiStefano, L., & Boling, M., (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*	To understand ACL tear risk factors such as hip muscle strength and ROM	14 females soccer players. Clinical measures of hip strength and ROM over 3 years. Digital inclinometer for rotational and muscle observation.	ANOVAs compared hip strength and ROM variables over the 3 years	ROM increased, hip abductor and extensor muscles decreased, decreasing strength in lower extremity, increasing ACL tear risk	
Pamukoff, D., Pietrosimone, B., Ryan, E., Lee, D., & Blackburn, T., (2017).	Quadriceps function and hamstrings co-activate after anterior cruciate ligament reconstruction.	*Journal of Athletic Training (Allen Press)*	To compare quadricep function between ACL injured individuals and un-injured individuals.	26 individuals with ACL injury, 20 individuals without ACL injury,			
Pappas, E., Zampeli, F., Xergia, S., Georgoulis, A., (2013).	Lessons Learned from the Last 20 Years of ACL-related vivo-biomechanics Research of the Knee Joint	*Knee Surgery, Sports Traumatology, Arthroscopy*	To identify a greater understanding of ACL related research	A review of articles	ACL injury aetiology, rehabilitation, prevention, and adaptations.	Certain neuromuscular deficits can predispose ACL injuries.	To examine a larger number of participants to gather more supportive facts

Philippon, M., Dewing, C., Briggs, K., Steadman, J., (2012).	Decreased femoral head-neck offset: a possible risk factor for ACL injury	*Knee Surgery, Sports Traumatology, Arthroscopy*	To determine head neck offset with the pelvis and it being a possible risk factor for ACL tears.	Group of 48 patients with complete ACL rupture compared with 42 non- ACL injured patients.	Comparison of radiograph view on the alpha angle	Strong correlation with diminished femoral head-neck offset and ACL rupture	More research to get a more refined understanding of these variables and help come up with more successful prevention programs.
Stijak, L., Kadija, M., Djulejić, V., Aksić, M., Petronijević, N., Marković, B., Radonjić, V., Bumbaširević, M., & Filipović, B., (2015).	The influence of sex hormones on anterior ligament rupture: female study,	*Knee Surgery, Sports Traumatology, Arthroscopy,*	Determine differences in concentrations of testosterone, and progesterone between females patients with and without ACL rupture.	Females subjects with knee joint injury were included. Sex hormones were established from saliva specimens	Salimetrics enzyme immunoassay and joint laxity was tested with “laxity scoring” according to Beighton, Solomon, and Soskolne	Females with an ACL rupture had lower testosterone levels and progesterone. Decreased levels of testosterone can be a leading risk factor to ACL tears	Additional research on larger group of patients to determine more definitive effects of hormones on joint laxity.

Appendix B
Synthesis Thematic Coding

	Anatomical				Biomechanical			Physiological		
Author	ACL Size	Hip Anatomy	Femoral Condyle Size	Related Info	Hip Muscles in Range of Motion	Hamstring and Quadricep	Related Info	Menstrual Cycle	Estrogen	Related Info
Abate, Vanni, & Pantalone (2013)				X			X	X	X	X
Ambegaonkar et al. (2014)						X				
Bedi et al. (2016)		X								
Estes et al. (2015)	X			X						
Hannah et al. (2015)							X			
Hewett et al. (2005)				X						
Hoshino et al. (2012)			X							
Liu et al. (2009)										X
Lopes et al. (2015)					X					

Nguyen et al. (2017)					X	X				
Pamukoff et al. (2017)					X	X				
Pappas et al. (2013)					X	X	X			
Philippon et al. (2012)			X		X	X				
Stijak et al. (2015)								X	X	X