KNEE INJURIES IN FEMALE SOCCER PLAYERS: A FOCUS ON THE ACL

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ABSTRACT

Knee injuries are extremely prevalent in high pivoting sports such as soccer, with non-contact anterior cruciate ligament (ACL) injuries being the most common. Female athletes are up to eight times more likely to experience ACL injuries compared to males. The purpose of this study was to investigate the possible reasons why females are so much more likely to experience ACL injuries and identify methods which can be used to prevent such injuries. A review of textbooks and articles regarding the anatomy and biomechanics of the knee was conducted followed by a review of articles on the topic of anatomical, biomechanical, neuromuscular, and hormonal differences between males and females. This investigation identified multiple risk factors under each category which place females at an increased risk of ACL tear. A later review of the diagnosis and treatment showed that ACL injuries are the most well understood of the major ligament tears which occur in the knee. Treatment options include non-operative methods and surgical methods, depending on the patient and extent of the injury. Finally, a review of the literature regarding prevention programs demonstrated that it is possible to decrease the risk of ACL injury in females through neuromuscular and biomechanical training.
INTRODUCTION

Soccer is one of the many sports which involves quick turns and pivoting. The anterior cruciate ligament (ACL) is crucial for the stabilization of the knee during such movements. Therefore, it should not be surprising that non-contact ACL injuries are the most common injuries in soccer. Players generally accept this as a risk they are willing to take for the sake of the game they love. This is especially true for competitive female soccer players who are warned by their coaches that they are at an increased risk for ACL injury compared to males. Unfortunately, this warning does not come with an explanation or a way to counteract this risk.

Based on a review of multiple studies, there are multiple possible explanations why females are at an increased risk for ACL injuries, and these have been used to generate prevention programs which are effective in decreasing this risk. Therefore, the purpose of this study is to present these findings, so that female soccer players no longer have to simply accept that they are at an increased risk for ACL tears. Instead, they can understand why and how to prevent ACL injury. In order to better understand the literature, which discusses these gender specific risk factors which may put females at risk for injury, this thesis will also include sections which discuss knee anatomy and biomechanics as well as diagnosis and treatment of various knee injuries to get a full picture of the beauty and complexity of the knee.
CHAPTER 1: NORMAL ANATOMY AND BIOMECHANICS

1.1: OVERVIEW

The knee is one of the largest and most complex joints in the human body. Located between the femur and the tibia, its strategic design gives the joint both durability and flexibility which are crucial to maintaining support and locomotion. Compared to other hinge joints, which include the interphalangeal joints, the elbow, and the ankle, the knee is minimally reinforced by the neighboring bones which gives the knee more freedom in its movement \(^8^3\). The importance of this additional flexibility of the knee is exhibited in the many quick turns that are constantly occurring in various sporting activities. How is the knee able to be so flexible yet stable enough to not give out every time an athlete pivots? The answer is muscle and connective tissue. The knee is composed of many ligaments and cartilage structures which serve as static stabilizers. The bones of the knee are the site of attachment of multiple muscles via tendons which are the dynamic stabilizers of the joint \(^8^1\). Each one of these structures can be damaged, and as a result, the knee is susceptible to a wide range of injuries which can leave an athlete off the field or court for many weeks.

1.2: STATIC STABILIZERS

The femur, tibia, and patella (knee cap) articulate at the knee via three important joints: medial tibiofemoral joint, lateral tibiofemoral joint, and patellofemoral joint. While the fibula does not directly articulate at the knee joint, it is important in the stabilization of the knee because it is the insertion point of the lateral collateral ligament \(^8^3\). The medial tibiofemoral joint is the articulation of the femur and tibia via the medial femoral condyle (knob-like structure) and the medial tibial plateau (flat surface). Both of these structures are covered by a layer of hyaline cartilage, also known as articular cartilage, which reduces
friction during movement to prevent damage and serves as a shock absorber. The lateral tibiofemoral joint is composed of the same structures as the medial tibiofemoral joint except on the lateral side of the knee. The patellofemoral joint is the articulation of the femur and patella within the patellofemoral groove and the posterior surface of the patella. Both of these structures are again covered with a layer of articular cartilage to reduce friction. Figure 1.1 is a photo taken during an arthroscopic procedure of the medial tibiofemoral joint. The photo shows the extremely smooth nature of the articular cartilage of the medial femoral condyle and tibial plateau. In addition to articular cartilage, there are two other important components of the knee, the menisci, which are crucial to reducing friction and increasing shock absorption.

The menisci are located between both the lateral and medial articulations of femoral condyles and tibial plateaus. These are crescent-moon shaped fibrocartilage pads which are composed of collagen and elastin. While the medial and lateral menisci are similar in function, they are shaped differently. As shown in Figure 1.2, the medial meniscus is more “C”-shaped with the posterior horn being thicker than the anterior horn, and the lateral meniscus is more circular. Because the medial meniscus is more tightly attached to the knee capsule, it is less mobile than the lateral meniscus, and this may
be related to the observation that medial meniscal tears occur twice as often as lateral meniscus tears. Blood is supplied to the menisci from the superior and inferior geniculate arteries, but because these are located around the periphery of the menisci, the central sections are mostly avascular and are supplied with nutrients from the synovial fluid. Figure 1.3 shows the geniculate arteries of the knee. Therefore, these areas do not heal well after an injury.

Both the medial and lateral menisci serve many important functions. First, the menisci provide the knee with additional stability due to the fact that they form a concave structure relative to the femoral condyles which prevents them from rolling off the tibial plateau. Figure 1.4, A and B, shows a simplified structure of the menisci between the femoral condyle and the tibial plateau before and after a meniscectomy, respectively. Second, they act as shock absorbers by dispersing the force due to the weight of the body over a larger area. They also decrease contact stress between the tibial plateau and femoral condyles which acts to prevent damage to the articular cartilage. Figure 1.4, C and D, shows the relative measurements for peak contact pressures of regions of the tibiofemoral joints before and after a meniscectomy, respectively.
After the meniscectomy, the contact pressure increases significantly at the central aspect of the joint which supports the menisci function as shock absorbers. Third, they contain nerve endings which are important for proprioception. All diarthroses joints, including the knee, are classified structurally as synovial joints which are joints enclosed in a cavity filled with synovial fluid formed by an articular capsule. Synovial fluid is a clear to light-yellow fluid which coats the articular cartilage in the knee to further decrease friction and absorb shock. The articular capsule is composed of a fibrous outer membrane and an inner synovial membrane. Figure 1.5 shows the locations of the fibrous membrane and the synovial membrane in the knee. The fibrous outer membrane is made of mostly collagen fibers and is a continuation of the periosteum of the femur, tibia, and fibula. This membrane is flexible but also provides tensile strength to keep the bones in place, making it a static stabilizer. Deep to the fibrous membrane is the synovial membrane, a layer of areolar connective tissue. One very important function of this membrane is to secrete synovial fluid into the cavity containing the medial tibiofemoral joint, lateral tibiofemoral joint, and patellofemoral joint. Synovial fluid serves as a lubricant in the knee to further reduce friction between the femur, tibia, and patella as well as act as a shock absorber. Since many areas of cartilage in the joint are avascular, the synovial fluid is involved in supplying nutrients to and removing wastes from chondrocytes, such as seen in the central

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Figure 1.5: The knee as a synovial joint.
portions of the menisci. It also contains phagocytes responsible for the uptake of debris due to normal wear-and-tear and microbes. The abundant ligaments of the knee joint are also important static stabilizers. The first type of ligaments in the knee are intracapsular, and these include the anterior cruciate ligament (ACL) and the posterior cruciate ligament (PCL). Based on their name and location alone, it should be known that these ligaments are located inside the articular capsule of the knee where they cross over each other. Even though they are inside the capsule, the ACL and PCL are not actually soaked in synovial fluid because there are folds in the synovial membrane which keeps the ligaments isolated. The ACL extends from the anterior tibial eminence through the intercondylar notch to the posteromedial side of the lateral condyle. The ACL is composed of an anteromedial (AM) bundle and a posterolateral (PL) bundle which are named based on their relative insertion locations on the tibia. The AM bundle contributes more to anteroposterior knee stability while the PL bundle contributes more to rotational stability. While the main function of the ACL is preventing the anterior translation of the tibia from under the femur (anterior dislocation), it has many other secondary functions, such as preventing internal rotation and varus, medial flexion of the knee which is shown in Figure 1.6. The PCL extends from the posterior area of the tibia through the intercondylar notch to the lateral portion of the medial condyle. The PCL, like the ACL, is also composed of an AL bundle and PM bundle which differ in laxity depending on the degree of knee flexion, and contribute to the overall function of

Figure 1.6: Common deformities of the knee.
the PCL, to prevent the tibia from sliding posteriorly from under the femur (posterior dislocation)\(^8\). Secondarily, it also functions in resisting medial flexion, lateral flexion, and external rotation\(^8\). Interestingly, the PCL is approximately 120-150% thicker than the ACL which makes it less likely to tear\(^1\).

In addition to these two intracapsular ligaments, there are many more extracapsular ligaments which contribute to the medial and lateral stability of the knee.

The medial collateral ligament (MCL), also known as the tibial collateral ligament, is a wide, flat ligament which extends from the medial epicondyle of the femur to the medial condyle of the tibia\(^8\). The deep layer of the MCL is also firmly attached to the medial meniscus\(^3\). The MCL prevents lateral flexion (valgus) of the knee\(^8\). The posterior oblique ligament (POL), shown in Figure 1.7, is a thickening of the MCL which extends from the adductor tubercle, a protuberance located proximal to the medial condyle, to the posterior tibia, and it also functions as a medial stabilizer to prevent valgus\(^8,69\). The lateral collateral ligament (LCL), also known as the fibular collateral ligament, is a rounded ligament that extends from the lateral condyle of the femur to the lateral
side of the fibular head. The function of the LCL is to prevent medial flexion (varus) of the knee. While all the ligaments are crucial to the normal function of the knee, the ACL, PCL, MCL, and LCL are considered the major ligaments which are all shown in Figure 1.8.

1.3: DYNAMIC STABILIZERS

The hamstrings provide dynamic stabilization to the posterior aspect of the knee. These include the semimembranosus, biceps femoris, and semitendinosus which are shown in Figure 1.9. The semimembranosus of the hamstrings provides posteromedial support to the knee. Because it originates on the ischial tuberosity of the hip and inserts posteriorly at the medial condyle of the tibia, its primary function is flexion of the lower leg, but an extension of the tendon at the tibia inserts more anteriorly which gives it a secondary function, internal rotation of the knee. Therefore, it resists excessive external rotation of the knee. The distal end of the semimembranosus tendon is also connected to the posterior horn of the medial meniscus which acts to pull the meniscus during flexion to keep it from being pinched by the medial femoral condyle and tibial plateau which can lead to meniscal damage. Another important hamstring is the biceps femoris which originates on the ischial tuberosity and inserts at the head of the fibula and lateral
tibial condyle via a multiple layered tendon. The functions of the biceps femoris are flexion of knee and external rotation when the knee is flexed. Thus, it has the opposite function of the semimembranosus, in terms of rotation which makes sense since their insertions are on opposite sides of the tibia. The third hamstring muscle is the semitendinosus which originates at the ischial tuberosity, like the other hamstrings, and inserts medial to the tibial tuberosity at the pes anserinus, the same location of insertion as the sartorius and gracilis. Some of the functions of the semitendinosus are knee flexion and, if the knee is flexed, medial rotation. The tendons which insert at the pes anserinus are important since they provide medial stability and resist lateral stresses (valgus). Two other ligaments which contribute to knee flexion are the gracilis and sartorius, shown in Figure 1.11.

The calf muscle is another important muscle which provides dynamic stability to the knee which include the medial and lateral head of the gastrocnemius, shown in Figure 1.10. The medial gastrocnemius originates on the posterior aspect of the medial femoral condyle and the lateral gastrocnemius originates on the posterior aspect of the lateral femoral condyle, but both heads of the gastrocnemius share a common tendon, the Achilles tendon, which inserts into the posterior aspect of the calcaneus. Thus, the gastrocnemius functions in both plantar flexion and knee flexion which are important in dynamic stability during walking and running.
The quadriceps are additional muscles which are important in knee extension and proper movement of the patella. The quadriceps are composed of the vastus medialis, vastus lateralis, vastus intermedius, and rectus femoris. The vastus medialis originates at the intertrochanteric line of the hip as well as the medial aspect of the linea aspera of the femur. The vastus lateralis originates at the greater trochanter and the lateral aspect of the linea aspera. The vastus intermedius originates at the anteriolateral surfaces of the femur shaft. Lastly, the rectus femoris originates at the anterior aspect of the inferior iliac spine as well as the ilium. All of the quadriceps muscles share a common tendon which inserts onto the distal patella which is connected to the tibia via the patellar ligament. Therefore, all quadriceps, shown in Figure 1.11, are muscles are involved in knee extension.

Two other less well known muscles involved in knee movement located deep to the gastrocnemius are the popliteus and plantaris. The popliteus originates on the lateral side of the lateral femoral condyle and inserts posteriorly at the proximal end of the tibia. Based on its location, the popliteus functions in flexion and internal rotation of the knee. Therefore, the popliteus is important in resisting excess external rotation. The plantaris originates at the distal end of the femur on the supracondylar ridge of the femur and inserts posteriorly at the calcaneus. Thus, it is involved in plantar flexion of the foot as well as flexion of the knee.
1.4: BIOMECHANICS OF EXTENSION AND FLEXION

Contrary to popular belief, the most important function of the quadriceps, hamstrings, and calf muscles are to produce passive forces to balance external forces acting upon the knee in order to attain mechanical equilibrium. These external forces are often the result of reactive forces due to the foot-ground contact, according to Newton’s Third Law of Motion. This ground reaction force acts to flex knee. In response to this, the major extensors, the quadriceps will generate tension in order to balance this force. The direction and amount of force the quadriceps are able to exert is dependent on the angle of the patellar tendon. This angle is dependent on the position of the patella which is dependent on the angle of flexion of the knee. Thus, the amount of torque the quads are able to produce at the knee is determined by the complex relationship between muscle fiber recruitment and degree of flexion.

In the event that the force of the quadriceps is insufficient due to the position of the patella, the ACL and PCL are the key to preventing the tibia from sliding anteriorly or posteriorly, respectively. For example, if the flexion angle is small, the angle of the patellar tendon is large, and the horizontal translational force contributed by the quadriceps (labeled $T_H$ in Figure 1.12a) is greater than that generated by the external force (labeled $W$ in Figure 1.12a). Therefore, the ACL generates a tension force (labeled $A$ in Figure 1.12a) that is necessary in order to keep the tibia from sliding anteriorly. Also, if the flexion angle is large, the angle of the quadriceps tendon is small, and the horizontal translational
translational force generated by the external force (labeled W in Figure 1.12b) is greater than that generated by the quadriceps force (labeled \( T_H \) in Figure 1.12b). Thus, the PCL must generate a force (labeled \( P \) in Figure 1.12b) to keep the tibia from sliding posteriorly. Based on both figures 1.12a and 1.12b, it should be clear that the vertical component of the forces generated by the quadriceps and ACL/PCL are balanced by the tibiofemoral contact force (not shown in Figures 1.12a and 1.12b) which is distributed across the surface of the tibia by the menisci.

Because the hamstrings and gastrocnemius act as flexors, they can also contribute to the balancing of the quadriceps and external forces which decreases the load on the cruciate ligaments providing a protective function to them; the amount of their contribution relative to the cruciate ligaments is dependent on the angle of flexion of the knee. For example, there is a critical flexion angle where the forces from the major muscle and the antagonistic muscle balance each other, and no cruciate ligament forces are necessary. This angle will vary depending on an individual’s muscle strength and pattern of activation. While antagonistic muscles can serve a protective function to a certain extent, they can also replace the function of ligaments when they are damaged, but this can have negative consequences which will be discussed later. Figure 1.13 shows the hamstrings (labeled as H) acting as antagonistic muscles to the quadriceps (labeled as T).

Passive flexion of the knee is complemented by internal rotation of the tibia about its long axis which suggests activation of the popliteus. The MCL is the primary restraint to internal rotation, and the ACL is the major secondary restraint.
It is important to note that the roles of the muscles can be reversed if the external force acts to extend the knee rather than flex it. In that case, the hamstrings would be the major flexor acting to balance the external force, and the quads could act as the antagonistic muscles which could unload the cruciate ligaments. Passive extension of the knee is complemented by external rotation of the tibia about its long axis which suggests activation of the biceps femoris. The LCL and other lateral ligaments serve as the primary restraint to internal rotation, and the PCL is the major secondary restraint.

While this is a simplified model since it does not include collateral ligaments and it considers the heads of the muscles as a single collective unit, it is sufficient in demonstrating the importance of the interaction between muscles and ligaments while walking or running.

1.5: BIOMECHANICS OF ABDUCTION AND ADDUCTION

In addition to external forces which act in the sagittal plane, there are also many external forces which can act in the coronal plane which can lead to abduction (valgus) and adduction (varus) of the tibia. These forces can again be due to reactant forces of foot-ground contact. If these forces only have a small component in the lateral direction, contact forces between the lateral and medial tibial plateau and femoral condyles (labeled $F_L$ and $F_M$, respectively) can balance the external force (labeled $W$), as shown in figure 1.14. However, this diagram does not consider the pressure distribution due to the meniscus. If the load (labeled $W$) is directed more medially, as shown in figure 1.15a, the lateral tibial plateau and femoral condyle are no longer in contact, so to prevent
varus of the knee, the external force and the medial contact force is balanced by the force generated by the ACL (labeled A) and LCL (labeled L) instead. This is only possible because the tensile forces generated by both the ACL and LCL have components directed upward and laterally, shown in Figure 1.15b. In contrast, if the load is directed more laterally, the medial plateau and femoral condyle are no longer in contact, so to prevent valgus of the knee, the external force and the lateral contact force is balanced by the PCL and MCL instead.

It is important to note that the theoretical models described above are only applicable when the knee is in full extension. When the knee is flexed, there is internal rotation of the tibia which changes the angle of the ACL and, therefore, its ability to balance external forces and muscular forces.

1.6: BIOMECHANICS OF THE MENISCI

As demonstrated in Figure 1.16, application of a load to the menisci causes the tissue to be pushed axially toward the outside of the space between the tibia and femur. In a normal, healthy meniscus, the majority of the collagen fibers are oriented circumferentially which enables the meniscus to generate a circumferential force that is able to balance the axial force that pushes the
menisci outward. The proper function of the menisci is dependent on their strength and attachments to various structures of the knee via meniscal ligaments. The strategic placement of these meniscal ligaments is crucial in controlling meniscal movement as the tibia and femur move relative to each other which is necessary to keep pressures exerted on the bone surfaces to a minimum.
CHAPTER 2: KNEE INJURIES IN SOCCER

2.1: OVERVIEW

Every soccer game is filled with a wide variety of stresses to the lower extremities of the body. These stresses can range in their severity to cause either acute or overuse injuries. In soccer, acute injuries (muscular and ligamentous strain) occur more often than overuse injuries (tendonitis and synovitis)\(^{67,55}\). Compared to the many injuries which can occur due to soccer, knee injuries are known to have the most severe effects in the years following the injury. The acute injuries to the knee can be classified as non-contact or contact in which contact refers to a force applied directly to the knee due to contact with another player. The many quick turns and cutting movements made consistently throughout a game leave soccer players vulnerable to various non-contact injuries. As a contact sport, there are also multiple opportunities for contact injuries. Of these two types of injuries, non-contact injuries tend to be more common as a result of stress from excessive twisting of the knee\(^ {101} \).  

2.2: CONTACT INJURIES

Two of the major ligaments are susceptible to contact injuries: PCL and MCL. While more common in American football, the PCL can be torn if there is hyperextension of the knee due to a direct blow to the anteromedial aspect of the tibia and the tibia moves posteriorly behind the condyles of the femur as shown in Figure 2.1\(^ {3,37} \). The effects of a PCL rupture are greatest when the knee is in a flexed position\(^ {3} \). Therefore, the knee may buckle when in a bent position such as when going down the stairs. The PCL is not very susceptible to damage due to twisting motions because it inserts and originates very close to

Figure 2.1: PCL rupture mechanism\(^ {37} \)
the axis of rotation which means the force exerted on the ligament during rotation are relatively small. While a torn PCL can be an inconvenience, it may not cause pain.

The most common cause of an MCL tear is a direct blow to the lateral side of the knee which results in stretching of the MCL past its physiological limits, causing it to tear, shown in Figure 2.2. Upon tearing, the individual may hear a pop, and both swelling and pain are common. While the LCL can be torn in the same manner but on the opposite side, this is less likely because the medial side of the knee is less exposed than the lateral side. The torn MCL lacks the same amount of tensile force which causes the knee to buckle to the side.

2.3: NON-CONTACT INJURIES

The most common injuries in soccer are non-contact and involve quick twisting motions which frequently occur in soccer. The two structures of the knee most susceptible to damage due to twisting motion are the menisci and ACL.

As discussed previously, the key to normal function of the menisci is their ability to generate circumferential force in order to balance the radial force produced due to a vertical load on the knee joint. In the event that the circumferential fibers of the menisci are weakened or the strength of their tibial insertional ligaments are weakened, a tear is likely to occur. Because the menisci act as secondary restraints to rotation of the knee along a vertical axis, the menisci...
can also be torn in the event of excessive or quick rotation of the tibia which is the most common cause of meniscal tears in soccer\textsuperscript{44,101}. The direction, location, and extent of the tear determines the effect the injury will have on the function of the meniscus as well as treatment options\textsuperscript{44}. With regard to direction, a radial tear disrupts the circumferential fibers while a longitudinal tear disrupts radial fibers. Both types of tears are shown in Figure 2.3\textsuperscript{6}. Because the circumferential fibers play a more crucial role in the ability of the meniscus to resist loads on the knee, radial tears are more significant than longitudinal tears\textsuperscript{44}.

One common cause of a longitudinal tear is rotational stress of the knee while the knee is partially bent. When the femur undergoes internal rotation, the medial meniscus is pushed posteriorly and toward the center of the knee, but this is prevented by the posterior meniscal ligaments. If these ligaments were to fail, this movement would not be inhibited and the posterior part of the meniscus would become trapped between the femur and tibia, and upon extension of the knee, the meniscus would tear longitudinally\textsuperscript{90}. A similar mechanism is common to longitudinal tears of the lateral meniscus as well, but it involves the movement of the anterior horn of the lateral meniscus moving anteriorly and centrally when the posterior meniscal ligaments fail\textsuperscript{90}.

While longitudinal tears of the medial and lateral meniscus are equally common, radial (transverse) tears are more common in the lateral meniscus due to its curvier shape compared to the medial meniscus, as shown in Figure 1.2\textsuperscript{90}. Radial tears occur when large amounts of anteroposteriorly directed stress are applied to the center of the meniscus, and the risk of such
stresses can increase when there is decreased mobility of the meniscus \(^{90}\). One example of this could be if the anterior horn of the meniscus became lodged between the tibial plateau and femoral condyle during flexion which would prevent the meniscus from sliding backward upon extension causing excess tension in the circumferential fibers \(^{89}\).

Upon initial injury of the meniscus, people generally feel pain when the knee is straightened \(^{54}\). This could possibly be attributed to the decreased ability of the meniscus to distribute pressure evenly on the tibiofemoral surface. If there is a loose fragment of the meniscus, severe pain will be experienced whenever it is caught between the tibia and femur. They will also experience catching or locking of the knee. Many people also experience swelling of the knee which is due to damaged blood vessels or synovium, the synovial membrane \(^{54}\). While the symptoms can disappear over time, they often do not and will require treatment \(^{54}\).

Similar to all the other ligaments of the knee, the ACL has a limit to the amount of tensile force it is able to withstand, and when that force is exceeded, there is tearing of the ligament. As described in chapter 1, the knee moves in such a way that the external forces and forces produced by the muscles are able to be balanced by the tensile forces generated by the ligaments. Thus, excessive forces applied to the knee by the muscles and external forces result in excess loading of the ACL \(^{97}\). In soccer, the ACL is subjected to the greatest stresses when a player is pivoting or cutting where the knee is in a position of valgus, adduction, and internal rotation \(^{51}\). The anterior shear force generated by the quadriceps is the major contributor to ACL loading while the valgus position of the knee further strains the ACL \(^{97}\). Another aspect to consider is that while pivoting, the knee is almost at full extension \(^{8}\). This is important because as the angle of flexion decreases, loading of the ACL increases which is partly due to the increase in the angle
of the ACL relative to the tibial plateau and the posterior direction of the tibia during extension of the knee \(^{97}\).

Interestingly, in some cases of ACL injury, a person may not experience pain and they may hear a popping noise \(^{54}\). Even if the injury is not painful, because the ACL is a major stabilizer of the knee, injury to this ligament can cause severe instability which will require treatment, either physical therapy or surgery depending on the extent of the tear \(^{54}\).
CHAPTER 3: GENDER DIFFERENCES OF THE KNEE

3.1: OVERVIEW

The idea that female athletes are at a greater risk to injure their ACLs compared to males is nothing new. In 1995, a 5-year evaluation of ACL injuries in collegiate level men’s and women’s soccer showed that women were twice as likely to sustain a contact ACL injury and three times as likely to sustain a non-contact ACL injury compared to men \(^5\). Since then, the number of females participating in sports at a competitive level has continued to increase and so has the chance that women will withstand ACL injury compared to men. Some studies have obtained data which show that women are up to 10 times more likely to sustain ACL injuries \(^{15}\). These significant epidemiological studies have led to numerous investigations of the possible reasons for this increased prevalence of ACL injuries in females. The reasons can be classified as anatomical, neuromuscular, hormonal, and biomechanical differences between the male and female knee \(^{28}\).

3.2: ANATOMICAL DIFFERENCES

One anatomical difference between the male and female knee is that women may be more likely to have an increased posterior tibial slope (PTS) which is defined as the angle between the line perpendicular to the tibial shaft (A-B) and the line parallel to the posterior to anterior inclination of the tibial plateau (A-C), as shown in Figure 3.1 of the medial PTS \(^{15,82}\). Because the medial and lateral sides of the tibial plateau are asymmetrical, the effects of both the medial PTS and lateral PTS have been investigated. If the lateral PTS is steeper than the medial PTS, weight bearing is
likely to cause external rotation of the femur and internal rotation of the tibia because the lateral femoral condyle slips off the tibial plateau which leaves the contact point between the medial femoral condyle and medial tibial plateau to serve as the axis of rotation, as demonstrated in Figure 3.2 \cite{15,76}. In addition to rotation, an increased lateral PTS causes significant anterior tibial translation \cite{15,25}. Since the function of the ACL is to oppose internal rotation and anterior tibial translation, it is clear why increased lateral PTS puts excess strain on the ACL. The cutting movements which occur on a regular basis in soccer involve anterior tibial translation and internal rotation, so these movements are further accentuated in people with an increase PTS.

Based on the anatomy of the tibiofemoral joint, it is not surprising that the meniscus may also contribute to risk factors for ACL injury in women, specifically the meniscal slope (MS)—the angle between the line tangential to the most superior aspects of ipsilateral posterior and anterior menisci and the line perpendicular to the longitudinal axis of the tibia \cite{15}. Figure 3.3 shows the lines used to measure the MS and PTS in the same knee \cite{30}. 

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**Figure 3.2**: Internal tibial rotation due to increased PTS \cite{15}

**Figure 3.3**: How to measure medial MS and PTS \cite{30}
Multiple studies have been performed which show the importance of the meniscal slope to knee stability as described in chapter 1. In 2011, a clinical research study investigating the association between noncontact ACL injuries and meniscal slope was completed by Hudek et al. They observed that the lateral meniscal slope was greater among both male and female subjects with ACL injuries compared to the control subjects, those without ACL injury. They also observed that female control subjects had greater overall meniscal slopes compared to the male control subjects. Thus, the meniscal slope could also possibly play a role in ACL injury mechanisms in females. One large difference between the meniscal slope and the tibial slope is that the meniscal slope changes depending on the knee’s degree of flexion and axial load because of the mobility of the menisci. Unfortunately, the study described above did not account for this, as they measured only the lateral and medial meniscal slopes at full extension without weight bearing. Therefore, further study is required to determine more accurately the effect of the meniscal slope on ACL injury in females compared to males.

Another difference of the tibiofemoral articulation between females and males is the size of the femoral notch. Studies have shown that women tend to have smaller femoral notches compared to men. Figure 3.4 demonstrates the large difference between a narrow (a) and wide (b) femoral notch. While there have been many studies investigating narrow intercondylar notch as a risk factor for ACL injury, the methods and results have differed. However, one recent meta-analysis study by Zeng et al. resulted in convincing data that a narrow intercondylar notch is

![Figure 3.4: X-ray images of a narrow intercondylar notch (a) and much wider intercondylar notch (b)](image-url)
increasingly associated with ACL injury and some have obtained data which support this hypothesis.\textsuperscript{100,15} One proposed mechanism of ACL injury upon non-contact twisting of the knee is that the ACL becomes pinched between the border of the femoral notch and the tibial plateau\textsuperscript{15}. Therefore, a narrower intercondylar notch would increase the likelihood of impingement of the ACL upon twisting. Many orthopaedic surgeons support this theory as many notchplasties are performed during ACL repair surgery to decrease the chance of re-injury.\textsuperscript{15}

Another possible anatomical difference between the structure of the male and female knee is the actual size and strength of the ACL. According to a study performed by Anderson and colleagues which measured the ACL cross-sectional area in 50 male and 50 female basketball players, the ACL is smaller in females.\textsuperscript{4} While other studies have produced similar results, the methods are not consistent, so further study is needed to come to this conclusion.\textsuperscript{15} A study by Lipps et al. on cadaveric knees found that in addition to women having a smaller ACL cross-sectional area compared to men, they also had fewer collagen fibrils per unit area.\textsuperscript{40} Since collagen contributes to the tensile strength of ligaments, this observation suggests that the female ACL is unable to withstand as great of strain. In addition, a smaller ACL experiences a greater amount of strain in response to applied forces at the knee compared to a larger ACL which could be because the force is not distributed across as large of a cross-sectional area.\textsuperscript{26} Based on the information about femoral notch width and ACL cross-sectional area, there is an unfortunate relationship between the two. If the ACL cross-sectional area is large, it experiences less strain, but it is more likely to be impinged by the femoral condyle.\textsuperscript{15} Then if the ACL cross-sectional area is small, it is less likely to be impinged on, but it experiences more strain.\textsuperscript{15} More studies are needed to determine if it is worse to have a smaller, weaker ACL that is less likely to be impinged or a larger, stronger ACL that is more likely to be impinged.
One final anatomical difference which has been attributed to the increased occurrence of ACL injuries in females compared to males involves the Quadriceps (Q) angle, the angle between the line that connects the anterior superior iliac spine of the hip bone to the midpoint of the patella and the line connecting the tibial tubercle to the midpoint of the patella, as shown in Figure 3.5. Due to the fact that women have wider hips than men, it is not surprising that women have a larger Q angle as well. There has been some evidence that a larger Q angle is associated with athletic knee injury. This may be attributed to the idea that if the Q angle is large then upon contraction of the quadriceps, there will be an increased lateral force on the knee which could increase the amount of strain on the ACL.

3.3: BIOMECHANICAL DIFFERENCES

The biomechanical differences between the male and female knee are related to musculature and general laxity of the knee joint. As described in Chapter 1, the major dynamic stabilizers of the knee, including the quadriceps and hamstrings, can be activated to decrease the strain exerted on the ACL. Studies have shown that the cross-sectional areas and overall strength of the leg muscles associated with the knee are greater in males than females. This would suggest that males are better able to decrease tension in the ACL by activating larger and stronger muscles. In addition to differences in the overall strength of leg muscles in males compared to females, there is also a difference in the quadriceps to hamstring strength ratio in males and females. Some studies have shown that the hamstrings are significantly weaker than the quadriceps in females while males do not exhibit this quadriceps dominance.
Contraction of the quadriceps muscles pulls the tibia anteriorly, and contraction of the hamstring muscles pulls the tibia posteriorly. The insertion sites of the hamstring tendon on the tibia and quadriceps tendon on the patella which is connected to the tibia via the patellar tendon are shown in Figure 3.6. Therefore, if the anterior force generated by the quadriceps is greater than the posterior force generated by the hamstrings, the forces acting on the ACL will increase resulting in an increased risk of rupture. This discovery could have a significant impact on treatment and prevention of such injuries because it could indicate that hamstring strengthening could be the key to decreasing the incidence of ACL injuries in females. In addition to weaker hamstrings in females compared to males, the results of a study using the sit-and-reach test (where a patient sits down with their legs out straight in front of them and they try to reach past their toes) demonstrated that hamstring flexibility increases in females after puberty while it decreases in males. Based on the importance of the hamstring muscles in opposing anterior strain of the ACL, it is not surprising that the few studies performed which have investigated the effect of hamstring flexibility indicate that it could contribute to a decrease in dynamic stability. One proposed reason for this is that lax hamstrings could lead to delayed activation resulting in quadriceps dominance.

While the leg muscles play an important role in dynamic stability of the knee, the musculotendinous structures which cross the knee joint may also provide passive resistance to
displacement through joint compression. A study by Shultz and colleagues demonstrated a strong association between lower extremity lean (muscle) mass and laxity in the frontal and transverse planes of the knee. Laxity in the frontal plane means the knee is more susceptible to forces which result in varus or valgus, and laxity in the transverse plane means the knee is unable to generate the torsional stiffness necessary to oppose forces which cause internal or external rotation. In addition to the musculotendinous structures, the ligaments and capsule of the knee also play a large role in knee laxity, a measure of the ability to resist a displacing load.

An important study by Scerpella and colleagues assessed generalized ligamentous laxity in collegiate athletes with non-contact ACL injuries and those without, as a control. For their study, they used the Beighton nine-point scale which attributes points for the following:

- Hyperextension of the knee beyond -10°
- Hyperextension of the elbow beyond -10°
- Ability of the thumb to touch the forearm with wrist flexion
- Extension of the fifth MCP (metacarpophalangeal) joint past 90°
- Ability of the palms to touch the floor with complete extension of the knees; they also measured AP (anterior-posterior) tibial translation. Some of these movements are shown in Figure 3.7. The study demonstrated a significant association between generalized ligamentous laxity and AP laxity with non-contact ACL injuries, and it also showed an increased generalized ligamentous laxity and AP laxity in females compared to males. As a pivoting sport, soccer requires rapid deceleration and acceleration movements which exert an extreme amount of forces on the tibia. Since there is increase AP laxity in females, the tibia could possibly translate further.
before the muscles can be activated to oppose the displacement. The further the tibia translates, the greater the strain on the ACL. While there is little evidence, another interesting example of joint laxity’s effect on tibial translation is related to increased foot pronation. In 1996, a study performed by Janice Loudon and colleagues showed excessive navicular drop, a measure of foot pronation shown in Figure 3.8, in female athletes with ACL injuries as opposed to those without. In 2002, another study performed by Trimble and colleagues indicated that increased foot pronation could result in anterior translation of the tibia. Given the importance of both muscle strength, muscle mass, and ligamentous laxity in knee stability, it is easy to see how females could be at a disadvantage when it comes to both passive and dynamic stability and why there is an increased incidence of ACL injuries in females.

### 3.4: NEUROMUSCULAR DIFFERENCES

Although muscle mass and overall strength play an important role in dynamic stability of the knee, the recruitment pattern of muscle fibers is equally significant. As indicated previously, if there is an imbalance in the forces generated by the hamstrings and quadriceps, there is increased stress on the ACL. This can also happen if there is disproportional recruitment of these muscles, a neuromuscular problem. Multiple studies have revealed such neuromuscular imbalances in females compared to males using electromyography, such as increased activation of the quadriceps and decreased activation of hamstrings relative to each other. In addition to
proportional recruitment of quadricep and hamstring muscle fibers, the pattern of recruitment is also important. One study by Cowling and Steele showed that while female hamstrings are activated sooner than male hamstrings during landing exercises, they suspect that the male activation pattern shows more synchrony between the quadriceps and hamstrings. If the quadriceps and hamstrings are not activated at the same time, then there is an imbalance of the anterior-posterior forces acting on the knee.

In addition to differences in the activation patterns of both the quadriceps and hamstrings in females, there are also differences in the activation patterns of, specifically, the medial and lateral quadriceps. A study performed in 2005 by Gregory Myer and colleagues demonstrated decreased activation of the medial quadriceps compared to the lateral quadriceps in females compared to their male counterparts. Co-contraction of medial and lateral quadriceps cause compression of the knee joint which increases the articular contact forces between the tibial plateau and the femoral condyles. These forces contribute to the ability of the knee to oppose valgus-varus movement and anterior-posterior translation. If there is a decreased medial-to-lateral quadriceps activation ratio, there will be less medial compression which can contribute to dynamic knee valgus demonstrated by females when executing cutting maneuvers in soccer. On top of unbalanced medial-lateral quadriceps activation, multiple studies have also shown increased lateral hamstring activation in females. This will decrease medial compression and limit the knee’s ability to resist valgus even more.

Because the ACL is highly innervated and has many mechanoreceptors, it plays an active role in dynamic stabilization of the knee. In 1999, a study by Susan Rozzi and colleagues showed decreased proprioception at the knee in females compared to males because women took significantly longer to detect knee joint extension. Rozzi et al. infer that the decreased
proprioception in females may be due to increased ligamentous laxity which makes sense since stretch receptors would undoubtedly be affected if the ligaments are inherently less taut in females. A test performed by Solomonow and colleagues showed that ACL stress moderately inhibits the quadriceps and activates the hamstrings, showing that the ACL is involved in a stretch reflex.

Along with decreased proprioception to extension of the knee joint, a recent study performed by Song Lee and colleagues showed that females have lower proprioception in pivoting under weightbearing conditions using an offaxis elliptical trainer. Women took longer to detect both internal and external pivoting movements controled by a motor which moved the footplate 1°/second. Figure 3.9 shows an overhead view of the pivoting footplates. This important discovery suggests that women may be less able to detect pivoting positions which could potentially cause injury. Again, this difference in proprioception could potentially be due to the generalized ligamentous laxity exhibited in females. Lee and colleagues also tested lower leg pivoting stiffness by using motors to generate pivoting perturbations and having the subjects try to maintain a target position. From this test, they were the first scientists to show that females generate lower leg pivoting stiffness than males which could be an indicator of decreased neuromuscular control.
3.5: HORMONAL DIFFERENCES

Considering the most obvious difference between males and females involves the reproductive system, the hormonal differences between males and females is likely to play a role in the increased prevalence of knee injuries in females. Unfortunately, the actual effects of the different sex hormones in males and females are the most controversial compared to the anatomical, biomechanical, and neuromuscular differences. The two main types of female hormones secreted by the ovaries are estrogens (estradiol and estrone) and progesterone, and the male hormone secreted by the testes is testosterone. Figure 3.10 shows the very similar chemical structures of estradiol, progesterone, and testosterone. These sex hormones are all steroid hormones which have a wide variety of functions. Estrogens and progesterone function to regulate oogenesis and the female reproductive cycle, maintain pregnancy, and promote the development and maintenance of female secondary sex characteristics. Testosterone regulates spermatogenesis and promotes the development and maintenance of male secondary sex characteristics. As described previously, increased knee joint laxity in females may contribute to their increased ACL injury rates. Some recent studies have shown that the rhythmic changes in hormone levels during the menstrual cycle may have a significant influence on knee joint laxity.

Between 1996 and 1997, multiple discoveries were made regarding sex hormone receptors in fibroblasts in the human ACL. In 1996, Stephen H. Liu and colleagues discovered...
the existence of estrogen and progesterone receptors, and in 1997, Ward P. Hamlet and colleagues discovered androgen receptors \(^{41,27}\). Both studies utilized immunolocalization \(^{41,27}\).

Because fibroblasts produce and secrete collagen, they are responsible for the majority of the load-bearing function of the ACL \(^{60}\). Therefore, the presence of estrogen and androgen receptors in fibroblasts suggests estrogen, progesterone, and testosterone could have an impact on the laxity of the ACL.

Another study by Liu et al. showed a significant decrease in fibroblast proliferation and collagen synthesis in rabbit ACLs when exposed to increased, but still physiologic, levels of 17\(\beta\)-estradiol, an estrogen \(^{41}\). Thus, the net effect of increased estrogen during the follicular phase could alter the composition of the ACL, increasing the risk for injury \(^{78,28}\). While the study by Liu et al. investigated the effects of estrogen alone, a study by Warren D. Yu and colleagues investigated the effects of estrogen and progesterone separately and in combination on fibroblast proliferation and collagen synthesis \(^{98,79}\). This study is important because, as demonstrated in Figure 3.11, estrogens and progesterone are released in combination but at different levels during the female reproductive cycle \(^{28}\). The study by Yu et al. showed that increased estradiol levels alone resulted in decreased fibroblast proliferation and procollagen type I synthesis. However, as levels of progesterone were increased in combination with estrogen, there was a decreased inhibitory effect which implies that progesterone lessens the effects of estrogen \(^{98}\). One interesting explanation for this

![Figure 3.11: Graph of various hormone levels versus menstrual day/cycle](image)
antagonistic relationship between estrogen and progesterone was described by W. Lee Kraus and colleagues using a model system in 1996. Their model showed that an activated progesterone receptor complex interferes with an estrogen receptor’s ability to interact properly with transcription factors, a process referred to as quenching. Unlike estrogen and progesterone levels in females which are cyclic, testosterone levels in males peak at 25 years old and decrease with age. In 1977, Yamamuro et al. found a positive correlation between collagen content and levels of testosterone in the hip joint capsule of male rats. This could suggest a similar relationship between collagen content and testosterone levels on the knee joint.

There have been many studies which investigate knee laxity during the different phases of the menstrual cycle, but the results have widely varied. Some studies show increased laxity of the ACL near ovulation or post-ovulation while others showed no significant change in any of the phases. Based on the studies which showed that estrogen decreases fibroblast proliferation and collagen synthesis, it is logical that ACL laxity would be lowest near ovulation when estrogen levels peak. In a systematic review of nine studies which investigate the hormone cycle and ACL laxity relationship, Zazulak and colleagues identified multiple limitations which could possibly explain their conflicting results. These limitations include small sample size, unspecific subject criteria, and variable testing methods. The meta-analysis performed by Zazulak et al. suggested the menstrual cycle may have a significant effect on ACL laxity. The results of one study performed by Park et al. which addressed the limitations

![Figure 3.12: Chart showing the average displacement of the ACL at different phases of the menstrual cycle.](image)
described by Zazulak et al. showed that when an anterior displacement force of 89 N was applied to the knee of female subjects in the ovulation phase, anterior tibial displacement was significantly greater than when measured in the luteal phase (see Figure 3.13)\(^6\).

In addition to inconsistencies in studies regarding knee laxity and the hormone cycle, there are inconsistencies between studies about knee laxity and injury findings. For example, studies about injury indicate that ACL injuries occurred more often during the pre-ovulatory phase\(^9\). This conflicts with the hypothesis that the increased prevalence of knee injuries in females is due to increased laxity since laxity is expected to be least when estrogen is low, such as during the pre-ovulatory phase. Thus, the injury data supports the case that changes in hormone concentrations during the menstrual cycle do not influence knee laxity. However, given the data that demonstrates a direct relationship between estrogen levels and fibroblast proliferation and collagen synthesis, the injury data could simply suggest that there are multiple factors involved. This is a more likely explanation considering the many studies which investigate the anatomical, biomechanical, and neuromuscular differences between the male and female knee.
CHAPTER 4: DIAGNOSIS AND TREATMENT OF SOCCER KNEE INJURIES

4.1: OVERVIEW

While it is never pleasant to tear a knee ligament or meniscus, it is an injury that is easily diagnosed and treatable with time. Unlike with a disease or infection, doctors are almost always able to see or feel the problem. The special tests orthopaedic surgeons use on a daily bases are almost as accurate as an MRI, and both options are non-invasive. Treatment may not be quite as simple as the diagnosis, but the advancements that have been made in surgical techniques have made surgery a valid option, especially for ACL reconstruction where a golden standard has been set. Even though surgery has become more effective, physicians and patients have to always consider nonoperative treatment which can be just as effective and comes with fewer risks.

4.2: DIAGNOSIS

The first step to any diagnosis is talking to the patient to learn about their history. Some of the important questions asked by physicians are shown in Table 4.1. It is imperative for the physician to know about both the nature of the injury, symptoms, and any problems experienced before the incidence to come to the correct diagnosis.

The next step is a comprehensive physical examination of both the uninjured leg and the injured leg. It is imperative that the physician first examines the uninjured leg to establish the patient’s relative norms. This thorough physical examination involves observation, assessment of range of motion, palpation, a neurovascular
examination, and special tests. X-rays and MRIs can also serve as important tools for diagnosing ligament tears, meniscal tears, bone bruises, and more. While each of the aspects of the physical examination play an important role in diagnosing soccer related injuries, the focus in the following paragraphs will be on the special tests described by Kerri Browne, MSBS, PA-C and Christopher A. Kurtz, MD in their CME (continuing medical education) article. The valgus stress test and the varus stress test are used to assess the integrity of the MCL and LCL, respectively. In the valgus stress test, the physician pushes the knee inward with one hand while pushing the ankle outward with the other hand, as shown in Figure 4.1. They do this first with the knee at 0° of flexion and then again at 30° of flexion. In the varus stress test, the physician pushes the knee outward while pushing the ankle inward, the opposite of the valgus stress test. Again, they do this with the knee at 0° of flexion and then again at 30° of flexion. Increased laxity at 30° indicates an isolated collateral ligament injury (MCL or LCL depending on the test) while increased laxity at 0° indicates cruciate ligament injury in addition to collateral ligament injury.

Observations, range of motion (ROM), palpation, and multiple tests are the key to diagnosing meniscal tears. If a patient is unable to fully extend the knee and/or they are sensitive to palpation along the lateral or medial joint line, this is an indication of a meniscal tear. In the Apley compression test, the patient lies on their stomach with their knee flexed 90°. The physician then rotates the tibia externally and internally while applying downward pressure, as
shown in Figure 4.2. If there is clicking or the patient experiences pain, the test indicates a meniscus injury. McMurray’s test is another method used to diagnose a meniscal tear. In this test, the patient lies on their back with the knee fully flexed. The doctor rotates the foot outward and applies an inward force while passively straightening the leg. Any clicking is indicative of a lateral meniscal tear. If the doctor, instead, rotates the foot inward and applies an outward force while passively straightening the leg, this tests for a medial meniscal tear. There are three tests used to diagnose ACL tears. The first is the anterior drawer test. The patient lies in the supine position with the knee flexed at a right angle, and the doctor stabilizes the patient’s foot by sitting on it.

To test the integrity of the ACL, the physician pulls the tibia anteriorly at the proximal end of the tibia while palpating the knee along the medial and lateral anterior joint lines to determine the extent of anterior tibia translation, as shown in Figure 4.3. Increased laxity of the injured leg is suggestive of an ACL injury. The second and preferred test is the Lachman’s test. In this test, the patient lies in the supine position with their leg at rest over the physician’s leg. The physician flexes the knee between 20° and 30°, stabilizes the femur with their hand, and pulls the tibia anteriorly with the other hand, as shown in Figure 4.4. Again, increased laxity of
the injured leg is suggestive of an ACL injury. The pivot shift test is a third test which evaluates the capacity of the ACL to resist tibia rotation. In this test, the patient lies on their back with their knee fully extended. Similar to the valgus stress test, the physician pushes the knee inward and rotates the tibia, but they also apply an upwards force. The physician slowly bends the knee, and if the physician feels anterior shift of the tibia or hears a clunk at about 30° of flexion, this is a positive test for an ACL tear.

There are also three tests used to diagnose PCL tears. The first is the posterior drawer test which is performed in similar manner as the anterior drawer test except the physician wraps their hands around the tibia and pushes it forward into posterior translation. Increased laxity of the injured leg compared to the other is suggestive of a PCL injury. The second test is the reverse pivot shift test. In this test, the patient lies in the supine position while the physician holds their leg at 45° of flexion, rotates their tibia outward, and applies an inward force on their tibia while moving the knee into extension. Again, if the physician feels the tibia shift anteriorly or hears a clunk, this result is indicative of PCL insufficiency. The posterior sag test is the third test in which the patient lies on their back with their hip and knee flexed at 90°. If the PCL is insufficient, the tibia will sag below the femur, as shown in Figure 4.5.
4.3: TORN PCL TREATMENT

Treatment of the PCL is dependent on a combination of factors: severity of the knee injury, the grade of the tear, symptoms, and activity level. The first treatment option is conservative, consisting of physical therapy which focuses on strengthening the quadriceps and proprioceptive training. By increasing the strength of the quadriceps, there will be increased dynamic posterior control of the tibia, putting less stress on the PCL. The proprioceptive training will enhance the ability of the body to sense posterior translation of the tibia and adequately activate the quadriceps. Conservative treatment is recommended if the knee injury is isolated to the PCL and the tear is only partial. Conservative treatment is initially recommended even if the injury is isolated to the PCL but is more severe, almost completely torn. In fact, the treatment is even more conservative because the risk of re-injury is increased. Traditionally, the knee is completely immobilized for 2-4 weeks with the leg extended or a dynamic PCL brace is worn for 3 months. When immobilization is recommended, the leg is always extended because the PCL is in a relaxed position, making the ligament tauter upon healing. If the patient’s symptoms do not improve with therapy and they experience prolonged pain, the injury may eventually require PCL reconstruction.

The second treatment option is surgery in which the PCL is reconstructed. This treatment is recommended when damage occurs to both the PCL and posterolateral corner, the collection of tendons, ligaments, and muscles which are located in the posterolateral corner of the knee. This is because this injury generally causes physical limitations to movement and can possibly lead to arthritis. Unfortunately, unlike with ACL reconstruction, there is no “golden standard” for PCL reconstruction. Due to variations in PCL reconstruction results, there is much debate over single versus double-bundle reconstruction, graft tension, tibial insertion location, and
femoral tunnel placement. Similar to ACL reconstructions, grafts can either come from tendons in the patient (autograft) or another person (allograft). Allografts are opted for when the patient demonstrates general ligamentous laxity, but they have some disadvantages. They take much longer to revascularize and mature.

Following surgical treatment, activation of the hamstrings should be avoided because this can cause further injury or stretch the graft, decreasing its strength. Instead, physical therapy would focus on strengthening the quadriceps. Athletes are able to play sports once they have adequate quadriceps strength and no pain which, for a typical double-bundle PCL reconstruction, takes between 6 to 9 months.

4.4: TORN ACL TREATMENT

Similar to PCL injuries, there are two treatment options for ACL injuries: conservative and surgical management. Physicians decide on the treatment type based on the patient’s overall health, symptoms and lifestyle. Conservative treatment is opted for when the patient has serious comorbidities which makes failure of the graft likely or the surgery dangerous. Nonoperative treatment is also chosen when the patient is asymptomatic with daily activities and leads a sedentary lifestyle. Therefore, surgery is unnecessary for a sedentary individual but very much necessary for an athlete who play sports where jumping, pivoting, and cutting are a common occurrence. Another indication for ACL reconstruction surgery are patients which return to moderate activity and often have incidents of their knee giving way. This giving way can cause meniscal tears and pain. Another case which requires surgery is patients with hypermobility, lax secondary restraints. These patients often experience instability with their daily activities.
If a patient is diagnosed with an ACL tear and their orthopaedic surgeon determines that surgery is the best treatment option, the patient generally has to wait two months before surgery. Surgeons elect to have their patients have an initial period of rehabilitation for their knee motion and quadriceps strength to return to normal. Studies have shown that delayed surgery is associated with a decreased rate of surgical complications and quicker return of knee movement and muscle function after the surgery. In those two months before surgery, the physician and the patient select a type of graft for the reconstruction. As discussed previously, the options are an autograft or allograft. The autograft source options are the patellar tendon, hamstring tendon, or quadriceps tendon. Each source has its advantages and disadvantages but the advantages of the patellar tendon graft make it the “gold standard.” It has great initial and long term fixation and overall stability. While the disadvantages of the patellar tendon graft include increased anterior knee pain and quadriceps atrophy, this could possibly be an advantage for women since they tend to exhibit quadriceps dominance. The allograft source options are the Achille’s tendon, patellar tendon, quadriceps tendon, tibialis tendon, and hamstring tendon. Some benefits of allografts include shorter surgery times, the ability to perform multiple ligament reconstruction, and the availability of a large size range. One of the problems with an allograft is the increased possibility of disease transmission. While the likelihood of this is extremely small with modern sterilization procedures, irradiation and ethylene oxide, these same procedures significantly weaken the graft. Thus, allografts have a higher failure rate and a slower healing rate.

Rather than discuss the step by step technique used by orthopaedic surgeons to reconstruct an ACL, it is more useful to discuss the important aspects of the technique used by surgeons and how this relates back to the normal anatomy and biomechanics of the knee. One
important aspect of the ACL reconstruction technique is the topic of notchplasty, surgical procedure in which the size of the intercondylar notch is increased. Some surgeons perform this for better visualization during surgery as well as ensure the graft is not impinged or abraded. For some patients, notchplasty may not be necessary.

The second important aspect of an ACL reconstruction surgery which can vary slightly depending on the patient and surgeon is the tunnel placement for the graft. When drilling into the tibia, the tunnel should begin medial to the tibial tubercle where the bone quality is best for drilling, and the angle should be at specifically 60° or 65°. A drill guide is used to assist with proper placement in the tibia. Upon exiting the tibia at the articular cartilage, the tunnel exit should be slightly medial to the original ACL tibial insertion. The tibial tunnel placement is very important for ensuring the graft is not impinged. The orientation of the femoral tunnel is also important for the successful function of the graft. If the tunnel is placed at the 11 o’clock position in the right leg or 1 o’clock position in the left leg, the graft replicates the anteromedial bundle, resisting anterior translation. If the tunnel is placed at the 10 o’clock or 2 o’clock position, the graft replicates the posteromedial bundle, resisting rotational knee movement.

One very controversial topic in ACL reconstruction is the idea of single versus double bundle reconstruction. While a traditional ACL reconstruction only consists of a single-bundle, there is a push more recently towards double-bundle grafts that resemble the AM and PL bundles of the original ACL. This sounds reasonable in theory, but recent research suggests that the double-bundle technique does not yield superior results in terms of knee stability.

The final variable aspect of ACL reconstruction surgery is how much the graft is tensioned upon fixation. This depends on multiple factors: the type of graft, laxity of the knee, and the fixation technique. For instance, a patellar tendon graft is very stiff, so it needs to be
fixated when the leg is extended to ensure that the graft stretches enough. For other grafts, fixation is done while the leg is flexed because the graft will reach proper tension upon extending the leg.

Following the initial recuperation phase after surgery, patients perform exercises to strengthen the quadriceps and hamstrings. Some exercises include walking, stationary cycling, and swimming. About 3-4 months after surgery, patients can generally start to run. The time to return to sports is roughly 6 months. Recovery time is completely dependent on the patient.

### 4.5: TORN MCL TREATMENT

Treatment of the MCL is dependent on the severity of the knee injury, grade of the tear, and symptoms. Usually, isolated MCL injuries occur when there is a direct hit to the lateral side of the knee. This high impact injury generally results in a grade III tear to the MCL. Similar to the treatment of PCL tears, treatment of grade III MCL tears is controversial. Traditionally, grade III tears were treated surgically, but recent research suggests that nonoperative treatment could be a viable option. In contrast, low-grade MCL tears, generally the result of non-contact injuries, are treated non-operatively.

Treatment of MCL tears becomes even more controversial when other ligaments or structures of the knee are involved. If both the ACL and MCL are torn, there are a sequence of treatment followed. First, depending on the grade of the tears, both ligaments are treated nonoperatively with a brace. If the MCL heals, and the knee is medically stable, the ACL is reconstructed. If the MCL does not heal, and the knee is still not medically stable, both ligaments are reconstructed. If the MCL and the posteromedial capsule are injured, they should be surgically repaired or reconstructed because the PMC contributes largely to medial stability of
the knee. In addition, studies have shown that a damaged PMC leads to poor outcomes of MCL repairs/reconstructions.

As usual, there are multiple techniques used and graft options for reconstructing the MCL. One interesting technique presented by Kim et al. is reconstruction of both the MCL and POL, a component of the posterior medial capsule, using a single autograft from the semitendinosus tendon. The graft remains attached to the tibia in its original anatomic location, and using a screw and washer inserted on the medial epicondyle, the graft is wrapped around the screw and sutured to the head of the semimembranosus tendon, as shown in Figure 4.6. Such as for all grafts, tensioning of the graft varies. This technique has proved successful in restoring medial stability of the knee.

**4.6: TORN LCL TREATMENT**

Isolated grade I and II LCL tears are treated nonoperatively while treatment of a grade III tear is controversial. One study by Bushnell et al. about LCL tears in football players showed that nonoperative treatment of isolated grade III tears allowed players to return to football sooner than with surgery. Thus, patients can avoid the dangers of surgery and have an equal chance of returning to football in a shorter amount of time. As tempting as this treatment option sounds, the study used a small sample size, so more studies are needed before a “golden rule” for isolated grade III LCL tears can be identified. Isolated LCL injuries are rare, and other structures of the knee are often damaged as well. The more complex the injury, the more complex the treatment.
If surgery is necessary, there are multiple techniques and graft options for surgeons to choose from. Some of these options include a semitendinosus graft, quadriceps tendon graft, Achilles tendon graft. These grafts can be used with or without a bone plug.

Unfortunately, there have been minimal clinical studies that compare different LCL reconstruction techniques, and for those studies that have, the patients have had associated ACL, PCL, or other injuries.

4.7: TORN MENISCUS TREATMENT

Treatment of meniscal tears is dependent on the patient’s symptoms as well as the location and severity of the tear. Non-operative treatment is effective for meniscal injuries, particularly those that are degenerative and complex. Conservative treatment involves exercises that strengthen the muscles of the leg, increase flexibility, and improve proprioception. Because this treatment is often effective, most orthopaedic surgeons initially suggest non-operative treatment, and only if the patient continues to experience pain and symptoms does a physician recommend surgery.

There are two options for surgery: meniscectomy and meniscal repair. The surgeon’s recommendation depends on the location and severity of the tear. Because of the importance of the meniscus in knee stability, surgeons try to conserve as much of the meniscus as possible. The peripheral portions of the meniscus, referred to as the red-red portion by most texts, is rich in blood supply due to the adjacent geniculate arteries. This blood supply makes this region the most likely region to heal. Therefore, tears in the peripheral region are repaired with a suture. If the tear occurs in a more central portion of the meniscus, a partial meniscectomy is performed because the injury is unlikely to heal. It is important that the rim of the meniscus is preserved because this is the most important region for knee stability. While the initial
outcomes of partial meniscectomy procedures are overall positive, studies have shown that they result in accelerated degenerative changes at the knee. There has been a recent push towards meniscal repair over meniscectomy when possible which has led to advancements in repair techniques. For instance, recently developed devices allow sutures to be added without accessory incisions that could be damaging to the neurovasculature. However, there are instances where the location of the tear makes techniques using accessory incisions necessary, the inside out or outside in techniques. Figure 4.7 shows the location of the cannula and sutures used in the inside out, outside in, and all inside techniques.
CHAPTER 5: KNEE INJURY PREVENTION

5.1: OVERVIEW

As discussed in chapter 2, there are two types of knee injury mechanisms: contact and non-contact. The only way athletes can prevent contact injuries is to avoid physical contact with other athletes which is impossible when playing contact sports, such as soccer, basketball, and football. In contrast, there is evidence that non-contact ACL injuries can be prevented with various programs.

5.2: PREVENTION PROGRAMS

According to a recent review which investigated the effects of prevention programs on knee injuries, it was concluded that the prevention programs studied were ineffective at reducing knee injuries overall and ACL injuries in male soccer players. In addition, the review also concluded that the prevention programs were not effective at reducing overall knee injuries in female soccer players but were effective at reducing ACL injuries. The focus of the prevention programs was on neuromuscular training and muscle strengthening which target the biomechanical and neuromuscular risk factors which put females at risk for ACL tears. Unlike the female anatomical and hormonal risk factors, the biomechanical and neuromuscular risk factors are more readily modifiable.

There are multiple types of exercises used for neuromuscular training. Two important examples are balance and plyometric exercises. The balance board, shown in Figure 5.1, used in physical therapy sessions is a good way to work on proprioception. This and other exercises that target proprioception are especially important in females because they have shown decreased proprioception compared to their male counterparts. Plyometric training involves jumping exercises which use only body weight as the resistance. These exercises exploit the stretch-
shortening cycle of muscles which allows the muscles to exert more force upon stretching due to their elastic properties. Plyometrics are an excellent way to enhance muscle recruitment and mechanics. Figure 5.2 shows an example of a plyometric exercise. These exercises are extremely important in females because they have shown increased activation of the quadriceps compared to the hamstrings and initial activation of the quadriceps before the hamstrings. Plyometric exercises address these risk factors by training the muscles, nervous system, and connective tissue to appropriately respond to ligamentous stretching and promote improved body mechanics.

It is important to progressively add perturbations in order to check for proper form when the athlete is in a more game like situation.

Strength training is another important component of the prevention programs which reduce the risk of ACL injury in females. Because females have shown quadriceps dominance, hamstring strengthening exercises are particularly important. By strengthening the hamstring muscles, less stress is put on the ACL since they are better able to counteract the anterior force generated by the quadriceps. Figure 5.3 demonstrates some possible
hamstring strengthening exercises\textsuperscript{66}. In addition to the hamstrings, it is also important to strengthen the core muscles which stabilize the trunk\textsuperscript{2}. A stronger core makes athletes better able to maintain their balance and keep the trunk rigid and over the pelvis and legs, making injury less likely\textsuperscript{2}.

Figure 5.3: Examples of hamstring strengthening exercises\textsuperscript{66}
REFERENCES


Conclusion

The amount of research that has been completed about why females are at a greater risk for ACL tears than males is surprisingly large. There is so much evidence that points to differences between genders which can possibly contribute to ACL tear risk. As a female athlete, learning about this risk can be discouraging, but it is important to look at the positives. The prevention methods described in this brochure to address the biomechanical and neuromuscular differences between males and females have been effective. Now, instead of just waiting for an ACL tear, female soccer players can actively decrease their risk by working on their hamstrings and proprioception. Then, if a female athlete does happen to tear her ACL, she can find comfort in the fact that she did everything she could to prevent it and treatment has advanced so much that she will be back in the game in no time.

About the Author
Vanessa Peña

I am an Honors student in the Department of Physiology at the University of Arizona. I have been playing soccer since I was five years old. As soon as I started playing competitively, I can remember my coach telling the team that we were all at an increased risk for ACL injuries because we were girls, but he never explained why. Like everyone, I did not think I would be part of the statistic, but I tore my ACL during an intramural indoor soccer game during my junior year at the U of A. Needless to say, the experience influenced my decision to write my honors thesis about ACL injuries in soccer players. In addition to me wanting to understand personally why I am at an increased risk for ACL tears, I want other female soccer players to understand the reasons as well and take steps to prevent it. I hope that I succeeded and that my fellow female soccer players are off doing some plyometric exercises right now.

ACL Injuries in Female Soccer Players

Soccer is one of the many sports which involves quick turns and pivoting. The ACL is crucial for the stabilization of the knee during such movements. Non-contact ACL injuries are the most common knee injuries in soccer. While players are aware that they are always at risk for such an injury, female players are up to 8 times more likely to tear their ACL than males. The purpose of this brochure is to briefly explain some of the possible reasons for this increased risk in females and describe prevention methods.

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Why females?

Once studies about prevalence of ACL injuries between genders showed that females are at an increased risk, numerous studies were initiated to determine why. The research revolved around four main areas, the biomechanical, neuromuscular, anatomical, and hormonal differences between males and females.

One important difference is that females tend to show quadriceps dominance relative to the hamstrings due to different muscle size and an altered activation pattern, meaning the quadriceps are stronger and the quadriceps are activated first and more intensely than the hamstrings. The hamstrings and quadriceps work together to decrease the strain on the ligaments of the knee. Therefore, without this balance, excess strain is placed on the ACL.

Another important difference discovered between males and females is that females demonstrate decreased proprioception at the knee. This results in delayed detection of extension and rotation which leads to delayed activation of the muscles which are necessary in order to decrease ACL strain.

Treatment

The treatment of ACL tears in athletes is dependent on the severity of the tear. If the tear is not severe, physicians opt for a conservative approach involving physical therapy. If the tear is severe, ACL reconstructive surgery is the best option for athletes to make a full recovery.

Prevention

The focus of prevention methods are on the biomechanical and neuromuscular differences between males and females because these are far more modifiable than the anatomical and hormonal differences.

The first characteristic component of ACL prevention methods is hamstring strengthening exercises in order to decrease the quadriceps dominance exhibited by females. Lunges are a great example.

The second characteristic component is proprioceptive training, such as using a balancing board to improve muscle activation in response to ACL stretching. Plyometric exercises (example shown right) are a great way to improve muscle strength and proprioception.