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ANTERIOR CRUCIATE LIGAMENT STRUCTURE AND FUNCTION. INJURIES AND PREVENTION PLAN

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ABSTRACT:

The main goal of this revision is to make a proposal of a prevention plan for non-contact Anterior Cruciate Ligament (ACL) injuries in soccer players. In order to achieve this, the first thing to do is to analyse the current evidence around the ACL from its anatomy and structure to its injuries, deepening in the injury mechanisms and risk factors. Additionally, a revision of the current knowledge about prevention protocols and exercises should be also done. After having reviewed the most important evidence and bearing in mind the factors that might affect the schedule of the programme, the proposed intervention plan may be useful to soccer players to reduce the risk of sustaining a non-contact ACL injury during both practice and competition. With the aim of developing an evidence-based protocol, the training components and the specific exercises are supported on the analysed studies as well.

KEY WORDS: Anterior Cruciate Ligament, ACL, anatomy, biomechanics, injury, risk factors, prevention, soccer, sport.

ANTERIOR CRUCIATE LIGAMENT STRUCTURE AND FUNCTION. INJURIES AND PREVENTION PLAN.

1) INTRODUCTION

The anterior cruciate ligament (ACL) is one of the most commonly injured ligaments of the knee, in fact, more than 2 million ACL injuries are reported worldwide (Dargo et al., 2017)

It is estimated that about 100.000 ACL reconstructions are performed each year in the USA (National Centre for Health Statistics, 1996). Additionally, an epidemiology study in the United Kingdom saw an incidence of about 30 cases of ACL injury per 100.000 people per year. (Bollen, 2000)

Rehabilitation after surgery seems to be possible since, Mai et al (2017) analysed 344 professional athletes who had sustained an ACL injury and saw that 298 (86,6%) returned successfully to their previous level. Nonetheless, a study carried out in 2016 among females with a previous ACL injury demonstrated that 28% of them had a second ACL tear, what is more, among those who did return to soccer, the ratio was even higher, 34% (Allen et al, 2016). Taking this evidence into account, not only rehabilitation programs seem to be important but also subsequent prevention programs may be paramount to avoid a second ACL injury.

In order to emphasize even more the importance of following an adequate prevention and rehabilitation plan, evidence shows some of the associated effects of sustaining an ACL injury. In 2014, Myer et al analysed the evolution of Body Mass Index (BMI) and %fat during 1 year in 71 people with knee injuries. Conclusions taken said that athletes with knee injuries increase on average their BMI on 5 units and their %fat on 1,5% compared to non-injured.

Another of the associated consequences after suffering an ACL injury is the development of Osteoarthritis, a retrospective study evaluates 109 patients who had sustained an ACL rupture 11 years before, with a mean age of 30,7 years. Results showed a 24% of Osteoarthritis incidence (Kessler et al., 2008). Furthermore, a research conducted by Lohmander, Östenberg, Englund & Roos in 2004 concluded that a very high prevalence of Osteoarthritis, pain and functional limitations exists among young women who sustained an ACL injury 12 years earlier. These effects makes the prevention of ACL even more important because when an athlete suffers an ACL injury is not only the injury in itself and the recovery time but also all the sequels that it may have in both a short-term and a long-term period.

2) JUSTIFICATION:

The justification of this review is based in the fact that there are uncountable evidence relative to the ACL and its injury, therefore, a brief schematic summary of this evidence may be interesting to facilitate the access to the information. Furthermore, propose an intervention protocol based on the current evidence may be interesting and as well. The reason for choosing this theme for my final degree project resides on a combination of factors. In first place, my personal interest in the areas of anatomy, biomechanics, physiology and how they are related to sports performance and sports injuries. Secondly, my lifelong relation with soccer makes me have a special interest in those injuries that have our soccer idols out of the fields for a long period of time, and one of the most feared injuries among soccer players and fans are the knee injuries, specifically, those of the Anterior Cruciate Ligament. Combining this two points, I found very interesting to understand personally how this ligament works and the different injury risks and mechanisms it may have and then be able of transferring that knowledge to the day a day of the soccer players and how could I help them to reduce the risk of injury by giving them a protocol to follow based on the evidence I have read.

3) OBJECTIVES:

The objective of this work is to review and make a brief summary of the current evidence relative to ACL structure, function, injuries and the latest protocols about reducing and preventing the possibility of sustaining a non-contact Anterior Cruciate Ligament injury. The second objective is to make a proposal of an easily understandable prevention protocol that could be applicable to any soccer team or individual player based on the latest researches about prevention strategies and protocols.

4) MATERIAL AND METHODS

The carried out review is a bibliographical review of the current evidence about the Anterior Cruciate Ligament (ACL) of the knee with the objective of analysing its structure and function and aspects related to its injuries such as injury mechanisms and risks with the second objective of proposing a prevention intervention protocol based on the current evidence. To do so, the search strategies has been based in the use of two databases: PubMed and ResearchGate.

In order to increase the accuracy of the search and find the appropriate information, some key words and Boolean operators has been used. The Key Words used are: Anterior Cruciate Ligament, ACL, anatomy, biomechanics, injury, risk factors, prevention, soccer, sport. Additionally, Boolean operators such as AND, OR and NOT have been used to facilitate the process. The Boolean operator NOT with the word reconstruction (ACL NOT Reconstruction) had a paramount role during the search in order to avoid all the studies and information relative to the surgical techniques of ACL reconstruction and the medical part of the ACL injury.

Notwithstanding, it must be remarked that after obtaining the results with the search established parameters, many valuable information may have been lost due to restricted access to numerous studies and articles that required a subscription. Another fact to bear in mind is that, the vast majority of the studies found in the databases guide me to other studies that were referenced on them.

Relative to figures, it must be considered that photos and illustrations used in this review have been taken from free distribution sites or filtering google images with the creative commons license option, that is a tool that allows openly licensed and public domain works to be discovered and used. Furthermore, graphs and tables represented has been remade in order to respect the copyright policies.

5) STRUCTURE AND FUNCTION

5.1) ACL ANATOMY:

The anterior cruciate ligament (ACL) is an intraarticular but extra synovial band of dense connective tissue which courses from the femur to the tibia (Duthon et al., 2006).

As to anatomy of the ACL, it can be divided into two subcategories, macroanatomy, which makes reference to distal and proximal insertions, length or width among others and microanatomy which refers to the microstructure, tissues and composition of the ACL.

5.1.1) MACROANATOMY

The bony attachment is located at the posterior part of the inner surface of the lateral femoral condyle (Duthon et al., 2006). Proximally it attaches to fossa on the posteromedial edge of the lateral femoral condyle. Distally attaches to the anterior intercondylar fossa on the tibial plateau (Bicer et al., 2010). The femoral attachment site is covered with synovial membrane (Bicer et al., 2010).

In 1991, a study was carried out where 27 cadaveric knees anatomy where analysed. The authors observed that from the femoral attachment, the ACL goes anteriorly, medially and distally to the tibial attachment (*Figure1*). The length of the ACL is between 22mm and 41mm with a mean of 32mm and its width ranges from 7 to 12mm (Amis & Dawkins, 1991). Anterior to the tibial insertion, ACL passes beneath the transverse meniscal ligament.

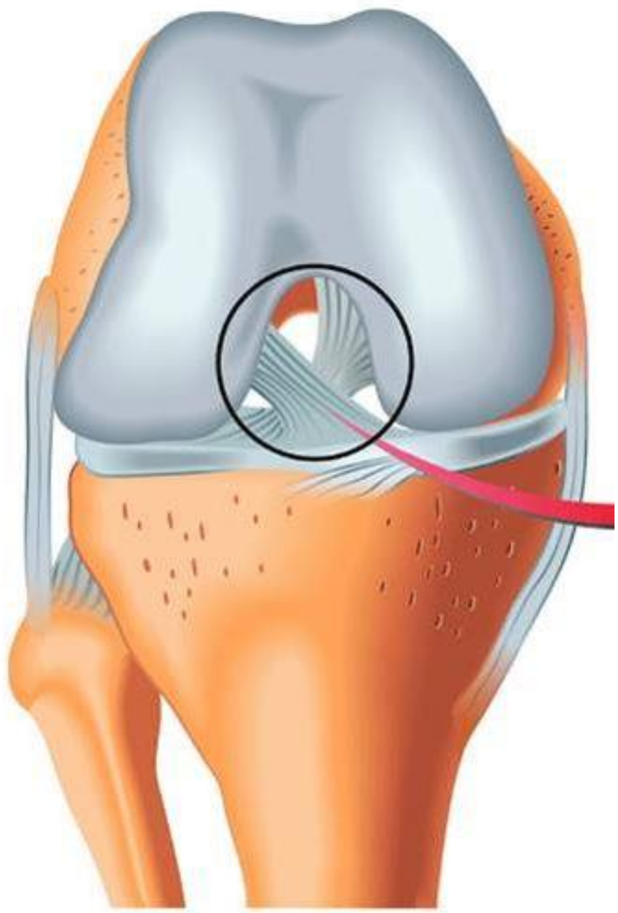


Figure 1 ACL anatomy.

The cross-sectional shape of the ACL is irregular, not circular nor any other geometric form (Duthon et al., 2006). There are two components of the ACL, the anteromedial bundle (AMB) and the posterolateral bundle (PLB) (Duthon et al., 2006). The AMB is originated at the most anterior and proximal aspect of the femoral attachment and is inserted at the anteromedial zone of the tibial attachment. Conversely, the PLB is originated at the postero-distal aspect of the femoral attachment and insert at the posterolateral aspect of the tibial attachment (Amis & Dawkins, 1991)

Amis & Dawkins found that during extension, both bundles elongated, whereas during flexion AMB tightened and the PLB slackened. In relation with this, the authors also found a reciprocal action between AMB and PLB since each bundle provides stability to the knee as a result of their tensioning patterns throughout the full range of motion (ROM). Authors discovered that the contribution of PLB to anterior tibial translation resistance decreases as knee flexion angle increases, conversely, the contribution of AMB increases as knee flexion does (Amis & Dawkins, 1991). In 2004, Gabriel et al backed up these findings adding that under combined rotatory loads the force made by the AM bundle were significantly greater than that of the PL bundle. In relation with this movement-dependent patterns, in the femoral attachment, the orientation of the two bundles alters with motion (Bicer et al., 2010)

In conclusion, both the PLB and the AMB are responsible for maintaining anterior and rotational stability varying the degree of tension of each one depending of the position of the knee.

5.1.2) MICROANATOMY

ACL could be divided into three zones (Duthon et al., 2006). The proximal part is the less solid and it is highly cellular. The middle part has a high density of collagen fibers and it is a special zone of cartilage and fibrocartilage. Finally, the distal part is the most solid of all and has a low density of collagen.

According to Duthon et al (2006) the matrix of the ACL consists of four different systems.

- Collagen (There are different types)
  - Type I: Major collagen of ligaments and tendons responsible of the tensile strength. Indeed, according to Markatos et al (2013) Type I collagen represents 90% of the collagen of the ACL
  - Type II: Typical collagen of cartilage, only found in the tibial and femoral sites of attachment.
  - Type III: Divides the type I collagen bundles and it is important for the pliability of the ligament.
  - Type IV: Mainly in the proximal and distal parts.
  - Type VI: It is present in higher amounts in the attachment regions due to these regions normally suffers higher strains.
- Glycosaminoglycans: Water comprises 60-80% of the total wet weight of the ACL. Alters the viscoelastic properties of the ACL giving it an additional shock-absorbing capacity.
- Glyco-conjugates.
- Elastic components: Permit the ACL extreme distance changes during motion.

5.2) ACL BIOMECHANICS

ACL plays a crucial role in joint stability. It is the primary restraint to anterior translation of the tibia relative to the femur (Amis, 2017)

The ACL also functions as a major secondary restraint to internal rotation, particularly when the joint is near full extension. In addition, the ACL functions as a minor secondary restraint to external rotation and varus–valgus angulation, particularly under weightbearing conditions (Beynnon, Johnson & Fleming, 1997, as cited in Duthon et al., 2006)

Twisting is resisted by a combination of capsular shearing, slanting collateral ligament action, joint surface, and meniscal geometry, while ACL plays only a secondary role (Amis, 1985, as cited in Duthon et al., 2006)

The ACL bundles are, according to Markatos et al (2013), functional structures rather than anatomic structures. The maximum tensile strength of the ACL is approximately 1725 ±270N, which is less than the maximum force occurred during some vigorous athletic activities (Markatos et al., 2013)

Focusing in sex differences, females have smaller hip flexion angular velocity, knee flexion angle and maximum knee flexion angle during landing in comparison to males (Yu et al., 2006)

6) INJURIES

6.1) ACL INJURY AETIOLOGY

In 2019, Takahashi et al made a retrospective study in order to classify the ACL injuries mechanisms in high school students, 1000 cases were analysed (500 males and 500 females). The results of these study are shown in *figure 2.*

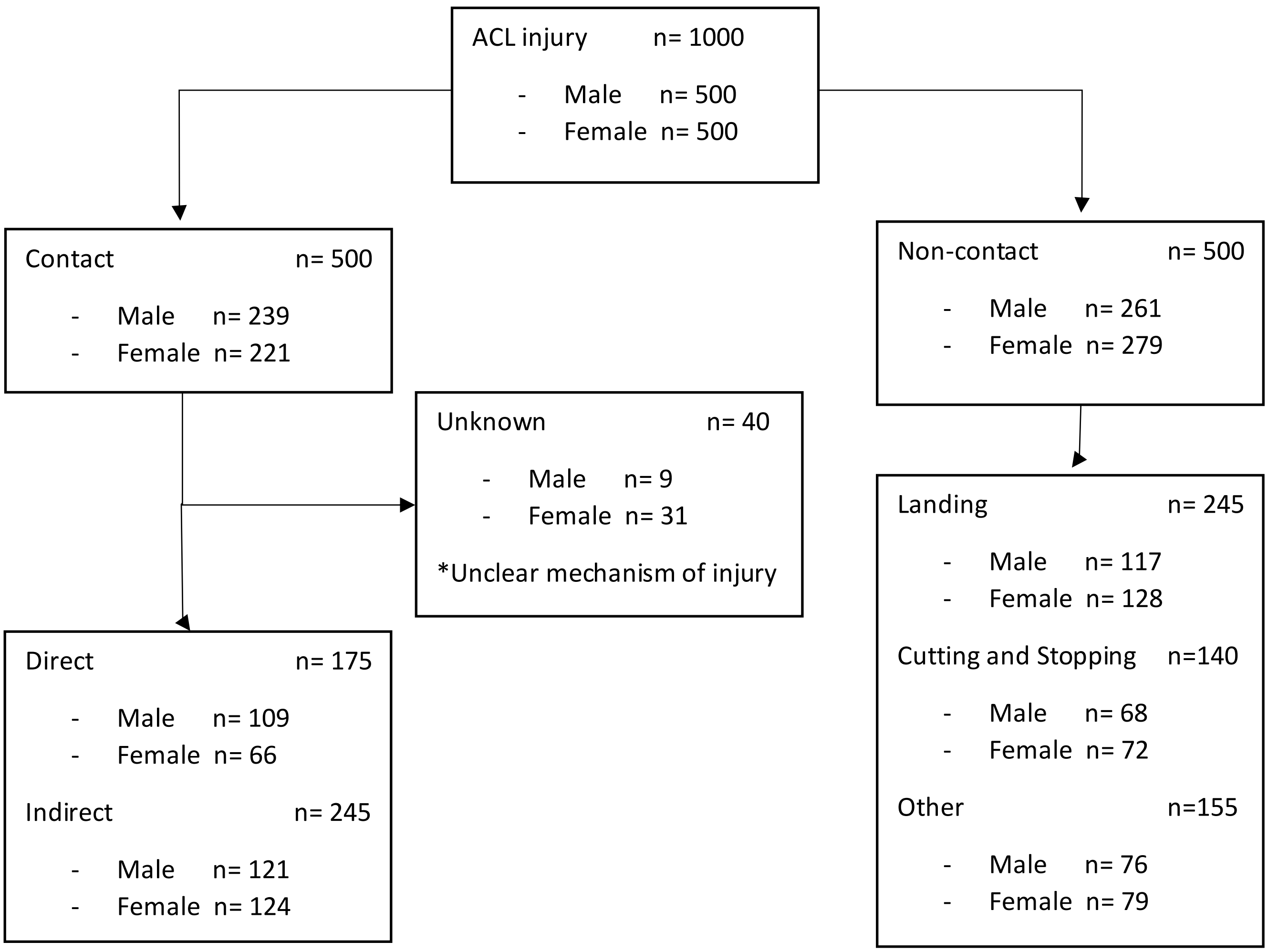


Figure 2 Inclusion and exclusion flowchart based from the one seen in Takahashi et al (2019)

Focusing on non-contact injuries, since are the ones that can be better prevented and avoided, it can be regarded that nearly half of ACL injuries occurred after a landing (n=245) and almost all injures occurred after a landing or a cutting and stopping manoeuvre Takahashi et al (2019). This study can give a general vision of the mechanisms that tend to provoke a big ACL strain and therefore a greater risk of ACL injury.

Bearing in mind that the vast majority of ACL injuries happened during landing, cutting and stopping manoeuvres, the prevention strategies may be focused on the improvement of technique, neuromuscular and biomechanical control during these movements.

After running a questionnaire to injured people, more than 70% of ACL injuries observed were non-contact ACL injuries (Bodet et al., 2000)

ACL is one of the most injured structures during high impact or sporting activities (Duthon et al., 2006).

A rupture in the fibres or a soft-tissue mass in the notch with high-signal characteristics resulting from edema and haemorrhage indicates an ACL tear (Markatos et al., 2013)

Isolated rupture of the ACL causes very small increase of internal rotation, therefore, a great increase of internal rotation may indicate damage in other structures. (Amis,2017)

6.2) ACL INJURY MECHANISM

Knowledge and identification of both intrinsic and extrinsic risk factors associated with ACL injury mechanisms may be paramount in order to develop prevention programs to high-risk individuals.

Both ACL injury plus anterolateral structures injury leads to increased tibial anterior translation and tibial internal rotation when compared to ACL injuries alone (Amis, 2017)

The main mechanisms for an ACL injury are an unsuccessful adjustment to postural and centre of gravity rapid changes (Griffin et al., 2005)

A research conducted by Fleming et al (2000) compared the ACL strain between weight bearing and non-weight bearing conditions combined with three external loads: anterior-posterior shear forces, internal-external torques and varus-valgus moments. The results concluded that anterior shear loads and internal torques increased the anteromedial ACL strain. Furthermore, external torque and varus-valgus moments only increased the ACL strain under-weight bearing conditions.

Another research concluded that this ACL loading mechanisms reported by Fleming et al (2000) showed that the anterior shear force is the major contributor to ACL loading (Yu et al., 2006), therefore, conditions such as a strong quadriceps contraction or a great posterior ground reaction force may increase ACL loading (Yu & Garrett, 2007).

According to the results of the research conducted by Yu et al (2006), peak knee extension moment and peak proximal tibia anterior shear force are correlated to each other. Additionally, these two measures are indicators of ACL loading and are, as well, correlated to peak posterior ground reaction forces. These results suggested that peak ground reaction forces can be used to predict ACL loading and estimate the risk of non-contact ACL injury (Yu et al., 2006)

According to Yu&Garrett (2007), ACL injury occurs when an excessive tension force is applied on the ACL. Furthermore, non-contact ACL injury occurs when a person generates great forces at the knee.

Hewett et al (2005) results showed that knee abduction angles at landing were 8.4º greater in ACL injured compared to uninjured athletes and that the ACL-injured athletes had a 2.5 times greater knee abduction moment and 20% higher ground reaction force. What is more, the results obtained support that knee abduction moment predicted ACL injury with 73% specificity and 78% sensitivity. Furthermore, the authors remarked that an improvement in neuromuscular control may contribute to reducing knee valgus and therefore ACL injury risk.

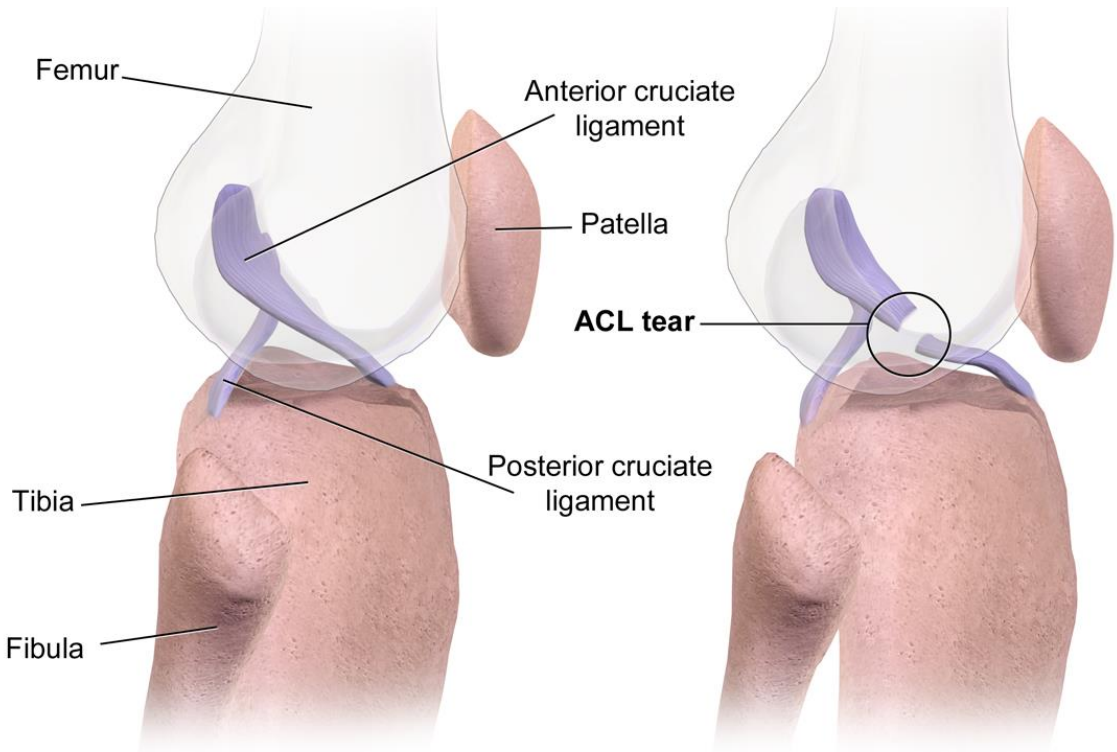


Figure 3 ACL tear lateral view (creative commons license)

6.3) RISK FACTORS

In terms of risk factors, it must be considered that women have a significantly greater risk of suffering an ACL tear than men (Dienst et al., 2007; Gans et al., 2018; Hashemi et al., 2008; Montalvo et al., 2019**...).** Therefore, in the following subcategories the main ACL injury risk factors will be presented bearing in mind the differences between males and females within most of the factors. It must be remarked that according to the following evidence, there is not an isolated risk factor that appears in all ACL injury cases, conversely, it looks like a combination of different risk factors is the main reason for the vast majority of injuries.

6.3.1) EXTRINSIC

Practice vs competition:

A research conducted by Gans et al (2018) analysed from a database of the National Collegiate Athletic Association Injury Surveillance System the differences in ACL rupture risk on different sports between 2004 and 2014. Relative to soccer, they found that women were more likely than men to suffer an ACL injury. Furthermore, they observed that both male and female were more likely to suffer an ACL rupture during competition than during practice. According to the author, this may be due to a less predictable environment, greater speed and greater intensity during competition.

Period of season

In the aforementioned study, data analysis revealed that men are more likely to sustain ACL rupture during regular season and postseason than during preseason (Gans et al, 2018).

Weather conditions

Weather may take an important role as an extrinsic risk for sustaining an ACL injury. A study conducted in Australia concluded that wet conditions significantly reduce the risk of ACL injuries, this was explained by the effect that water has on the ground, softening it and therefore reducing the shoe-surface traction (Orchard et al., 1999)

6.3.2) INTRINSIC

6.3.2.1) MODIFIABLE

NEUROMUSCULAR

Relative strength and recruitment

Although there are multiple risk factors explaining ACL injury risk, neuromuscular control seems to be important to injury risk and the most modifiable factor (Hewett, Myer & Ford, 2006)

An experiment conducted by Withrow et al (2008) demonstrated that a higher hamstrings muscles contraction during landing reduces the peak strain in the ACL. Therefore, it was concluded that both strengthening hamstrings and increasing hip flexion during landing may reduce the strain in the ACL and, as a consequence, the injury risk. (Withrow et al., 2008)

Quadriceps are the major contributor to the anterior shear force through its attachment to the patella. (Yu et al., 2006)

The aforementioned investigation carried out by Hewett et al (2005) concluded that knee loading and knee motion during a landing tasks is a predictor of ACL injury risk, focusing on knee valgus as a strong predictor of ACL injury risk.

Initial ground contact flatfooted or with the hindfoot during landing increase the ACL injury risk by reducing the absorptive capacity of the foot, moreover, knee abduction and increased hip flexion may be risk factors for ACL injury too. (Boden et al., 2009). What is more, knee-flexion angles alone were not found to significantly increase the ACL injury risk.

Reduced hip internal rotation also was identified as a risk factor for sustaining an ACL injury (Bedi et al., 2016). In their studio, it was found that a 30º reduction in left hip internal rotation was associated with 4.06- and 5.29-times greater odds of ACL injury in the ipsilateral and contralateral leg respectively. Having found that, it was suggested that interventions focused in increasing hip internal rotation may reduce the chances of ACL injury. Furthermore, measurement of hip internal rotation may be useful to identify those athletes with higher possibilities of getting injured.

A research that analysed risk factors for leg injuries saw that all the ACL injured subjects participating in the studio had lower H/Q ratio in the injured leg compared to the uninjured one (Söderman et al., 2001). Based on this found, the authors concluded that increasing hamstrings strength in order to reduce the quadriceps dominance in the H/Q ratio may be helpful in the prevention of ACL injury. Nonetheless, further research may be crucial to confirm these findings since the sample size was not big enough.

This finding agrees the aforementioned ideas that quadriceps are the major contributor to anterior shear force and that increasing hamstring strength may reduce the strain in the ACL as it counteract the quadriceps action.

Furthermore, fatigue appears to increase anterior tibial translation and therefore, increase ACL injury risk (Wojtys et al., 1996). This is as a result of the fatigue in both quadriceps and hamstrings and produces a slowed muscle reaction and a slowed muscle restraint to anterior tibial translation.

Focusing on the neuromuscular control of the trunk, Zazulak et al (2007) found that trunk displacement was greater in ACL injured athletes than uninjured. Furthermore, lateral displacement demonstrated to be the strongest predictor of knee ligament injury. The investigation concluded that all trunk displacements, low back pain history and trunk proprioception predicted ACL injury among females with 91% accuracy. Notwithstanding, among male athletes only low back pain history was a significant predictor of ACL injury.

NEUROCOGNITIVE

In 2007, Swanik et al investigated the link between neurocognitive function and non-contact ACL injury, neurocognitive parameters such as verbal memory, visual memory, processing speed or reaction time were measured among both injured and uninjured athletes. Results showed that ACL injured athletes had a significantly slower reaction time and processing speed as well as a worse performance on visual and verbal memory compared to uninjured control group. Thus, the authors concluded that a lower neurocognitive function may be associated with coordination errors and a loss of neuromuscular control, therefore predisposing these athletes to a greater ACL injury risk.

6.3.2.2) NON-MODIFIABLE

ANATOMICAL

Even though anatomic risk factors are not easily modifiable, the need of understanding their effects on knee joint health and how to best counteract these risks still exists.

An experiment developed by Shen et al in 2019 by which knee joint magnetic resonances were made to 50 subjects tried to discover the main anatomical risk factors for sustaining an ACL injury. 50 ACL injured subjects were chosen and matched with 50 control subjects. After analysing the magnetic resonances several conclusions were made by the authors. Increased tibial tubercle-trochlear groove (TT-TG), medial tibial slope (MTS) and smaller notch width index (NWI) were significantly associated with ACL injury risk. Furthermore, injured subjects also demonstrated to have smaller cross-sectional area (CSA) but this was not associated to ACL injury according to the posterior multivariable analysis. Notwithstanding, intercondylar notch depth, femur condylar width and notch depth index (NDI) were not significantly different between these two groups (Shen et al., 2019).

Some of the following studies have also found relevant results in order to explain the main anatomical ACL injury risk factors.

ACL volume:

A smaller ACL volume is an independent predictor of ACL injury (Whitney et al, 2014). Furthermore, in a research conducted by Chaudhari et al in 2009, the authors concluded that participants with ACL injuries had less ACL volume on their uninjured leg than did non-injured subjects. This may indicate that the smaller the ACL volume is, the higher the risk of sustaining an ACL injury is. Relative to ACL volume, according to Anderson et al (2001) females showed to have a smaller ACL in comparison to males, authors also concluded suggesting these factor increases the injury risk in females.

Knowing these, further investigation is required in order to determinate the extent to which ACL size and strength are modifiable through training.

Joint laxity:

Tibial Plateau: An experiment made by Hashemi et al (2008) demonstrated that the tibial slopes were greater in females than in males. This may play an important role in ACL risk differences within sexes due to a greater tibial slope may decrease resistance to displacement of the tibia relative to the femur, placing the knee at increased risk for ACL injury. (Hashemi et al., 2008).

Furthermore, another research made by Simon, Everhart, Nagaraja & Chaudhari (2010) compared the tibial slopes and notch dimensions between two groups, the first one was of people who had sustained an ACL injury and the other was a control group matched by gender, age, height and weight. Results showed that the difference in lateral tibial slope was significant with the injured group having values of 1,8º and the uninjured values of -0,3º (p=0,02). Additionally, the notch dimensions were found to be smaller in the injured group. Having found that, the authors concluded that both a higher tibial slope and a smaller notch dimension are likely to be risk factors for sustaining an ACL injury.

Notch width:

A study demonstrated a correlation between the intercondylar notch width and the width of the ACL (Davis, Shelbourne & Klootwky, 1999). Furthermore, a research conducted by Dienst et al (2007) showed not only the correlation between notch width and ACL width but also the correlation between a thinner ACL and the increased ACL injury risk and the fact that women have a thinner ACL compared to male with the same weight. According to the authors this may be one of the key factors of the greater ACL injury rates among women.

HORMONAL

Shultz et al (2005) studied the hormonal influences on sex differences in knee joint laxity. The results showed that differences were menstrual cycle dependent. Sex differences were greater when females were in the early luteal phase. Therefore, the author concluded that female hormone levels are paramount to explain the sex differences in knee joint laxity. Notwithstanding, further research is required in order to clarify the relation of this finding with the greater ratio of ACL injuries among females.

SEX DIFFERENCES IN RISK FACTORS AND INJURY MECHANISM

According to a research conducted by Montalvo et al (2019) female football players had 2.2-fold increase in the ACL injury risk comparing to male. The sex differences founded were independent of participation level. This conclusion supports the aforementioned researches (Dienst et al., 2007; Gans et al., 2018; Hashemi et al., 2008...) which also found a significant greater ACL injury risk among females.

What is more, deepening into injury mechanism differences, a research studied the role of leg dominance in ACL injury between gender in soccer players. The authors found that for non-contact injuries there was a significant difference in the leg distribution since 74,1% of males were injured on the dominant kicking leg compared to 32% of females (Brophy et al., 2010). With these results, the authors concluded that females are more likely to injure the ACL in their supporting leg whereas males tend to injure their preferred kicking leg. These findings may result from anatomical and neuromuscular differences between sexes and may be one of the factors that explains the greater rate of non-contact ACL injuries among females.

7) PREVENTION PLAN

The aim of a non-contact ACL injury prevention programme is to influence the neuromuscular system via plyometrics, strength and stretching exercises, balance, agility and technique in order to reduce the ACL injury risks (Grindstaff et al., 2006; Mandelbaum et al., 2005; Caraffa et al., 1996; Hewett et al., 1999; Hewett et al., 2017). Furthermore, these strategies may be focused on the prevention of non-contact injuries since contact injuries are caused by an external impact that is not avoidable and its risk is not controllable. Nonetheless, enhancing the knee kinematics and mechanisms and strengthening the key muscles may also help the ACL to endure certain impacts.

By following the aforementioned components of training, the objective of the following intervention is to improve the modifiable risks and to help those with anatomical and hormonal non-modifiable risks to develop secure mechanisms in landings, decelerations and other risky movements in order to minimize the chances of sustaining an ACL injury.

A Meta-Analysis carried out by Donnell-Fink et al (2015) evaluated 24 studies about the effectiveness of ACL injury prevention plans. The results of the meta-analysis indicated that neuromuscular and proprioceptive interventions significantly reduced knee injury by 26,9% and ACL injuries by 50.7%. Furthermore, the authors did not found any specific training component directly related with ACL injury prevention, conversely, they did found that interventions in the pre-season were better than interventions during the season. Therefore, they suggested that not the training components, but the timing of the intervention is crucial.

This agrees with the conclusions made by Dargo et al (2017) who suggested that specific components of training are not as key as the time of implementation. Furthermore, they reported that interventions started in the preseason were better than those started during the season. Additionally, the researchers also concluded that neuromuscular and proprioceptive training prevented ACL injuries.

Among all the scientific research, there are plenty of investigations analysing the effects of ACL injury prevention protocols. Here there are some of the most significative investigations, most of them applied to soccer specifically.

In 1996, Caraffa et al conducted an investigation with soccer players during 3 seasons where the experimental group followed a special proprioceptive training program in addition to their standard training program and were after compared to the control group. The routine consisted of 20 min per day during the preseason and at least 3 times per week during the season. The exercises done were proprioceptive exercises with different balance and wobble boards. Results obtained shown an incidence of 0.15 ACL injuries per team/season in the experimental group while control group had an incidence of 1.15 ACL injuries per team/season. Authors concluded that proprioceptive training is a useful tool to reduce the number of ACL injuries and recommend introducing these exercises both during pre-season and regular season.

Focusing in neuromuscular training, Mandelbaum et al (2005) carried out an investigation where more than 1000 females from 95 soccer teams participated in an intervention 20-minute program followed during 2 seasons that consisted of stretching, strengthening, plyometrics and agility. The results showed clearly the effects of the training program towards ACL injury. During the first season there was a decrease of 88% in ACL injuries among the intervention group compared to control, in the second season, the reduction was of 74%. These data clearly demonstrate the effectiveness of the aforementioned training components when it comes to reduce the ACL injury ratios among female soccer players.

Additionally, other research studied the effect of neuromuscular training programme on the incidence of knee injury in female soccer, basketball and volleyball players. The programme consisted of 6-week preseason flexibility, plyometrics and weight training. At the end of the programme the control group demonstrated a knee injury risk 3.6 times higher than the trained group (Hewett et al., 1999). The recommendation of introducing a preseason neuromuscular programme in order to improve strength, flexibility and proprioception in young females practising sports which involves jumping, pivoting and cutting movements is made by the authors.

Another study analysed the effects of a neuromuscular programme in knee loading. The intervention consisted of 10 weeks of core neuromuscular training 2-3 times per week (Hewett et al., 2017). Results showed significant increasement in trunk flexion and reduction in extension angles during different types of jumps. Hip external rotation angles also were improved significantly. What is more, greater improvements were seen in high-risk profile subjects. Authors concluded that core training improves biomechanical factors that are related to ACL injury risk.

A study carried out by Olsen et al in 2005 analysed 120 handball teams, with 1837 players. The aim of the experiment was to investigate the effect of a structured warm-up in the reduction of knee and ankle injuries in young athletes. Intervention consisted of warm-up exercises, technique (cutting movements, jump shot landings…), balance (passing, bouncing…), strength and power (squats, jump shots, Nordic hamstrings…).

The conclusions made by the authors were that a structured warm-up programme reduces significantly knee injuries, therefore, the authors recommend the introduction of preventive training as a routine for sports that involves pivoting, jumping and cutting manoeuvres.

Gilchrist et al (2008) also analysed the effects of both neuromuscular and proprioceptive training in female soccer players. The PEP programme was the intervention followed. It consists of 5 groups of exercises. Warm-up, including shuttle and backwards running. Stretching, including calf, quadriceps, hip flexor and inner thigh stretching. Strengthening, including lunges, Russian hamstrings and leg raises. Plyometrics, including lateral, forward, backward, single leg and vertical jumps. Finally, agility, including diagonal runs and bounding run. The protocol was made 3 times per week during one season. Results showed that ACL injury ratios were 3.3 times lower in the intervention group, that is to say, a 70% reduction in ACL in juries compared to control group. In conclusion, the followed intervention programme significantly reduces the ACL injury among female soccer players.

Other of the reported risk factors for sustaining an ACL injury is having a disbalance between hamstrings and quadriceps strength, that is to say, having a low H/Q ratio. Focusing on this, Mendiguchia et al (2015) analysed the effects of a 7-week neuromuscular program with 2 sessions of 30-35 mins per week. The sessions consisted of eccentric strength, plyometrics and acceleration exercises. The authors reported an increase in the hamstring's strength and a higher H/Q ratio. These results may suggest that, as long as a low H/Q ratio is known to be a risk factor for ACL injury (Söderman et al., 2001), this increment in the H/Q ratio may help in reducing the injury risk. Notwithstanding, further evidence may confirm the direct relationship between the proposed training program and the ACL injury ratio.

Indeed, strengthening hamstrings could be one of the paramount tasks when facing a intervention plan for reducing non-contact ACL injury risk since quadriceps is the major contributor to the anterior shear force(Yu et al., 2006), anterior shear force is the main mechanism of ACL injury (Yu et al., 2006) and hamstrings are the main antagonist to quadriceps action. This goes in the same line than the aforementioned studies that suggested that the stronger the hamstrings are, the lower the ACL injury risk is (Söderman et al., 2001; Withrow et al., 2008).

An already existing protocol for reducing soccer injuries among male players is FIFA 11+, Silvers-Granelli et al (2017) tried this programme in order to evaluate its effectiveness. The FIFA11+ is based on a 20 minutes warm-up which includes running, strength, plyometrics and balance exercises. The protocol is followed during the season 2 times per week. The studio was made with 64 soccer teams. Results showed that at the end of the season there was a higher injury rate among the control group compared to the intervention group, indeed, the intervention group showed a 75% decrease in non-contact ACL injuries compared to control group. The FIFA11+ protocol was also tested by Daneshjoo et al (2012), in this case the conclusions were also positive demonstrating that this intervention plan improved the strength ratio and the dynamic control ratio of the intervention group compared to control. In this case the protocol was followed for 8 weeks, 3 days per week in 20-25 minutes workouts. Further research to discover the ideal duration, volume and intensity of programs is needed.

7.1) PROPOSAL OF INTERVENTION

Following the aforementioned studies strategies, in order to maximize the benefits, the proposed prevention plan will consist of 5 sessions per week in a 6-week intervention during the preseason and a maintenance phase of 2 sessions per week during the hole season. Each session will be of 20 minutes previous to the training session. As have been shown in the analysed studies, there is not a single way of facing these interventions and there are not a closed group of exercises that shown better results than others, in consequence, the following intervention plan is not the one and only or the best strategy to reduce the ACL injury risk. This protocol has been designed following the current evidence and taking interesting aspects of different protocols used in the analysed studies such as the PEP program (Prevent injury and Enhance Performance) or the FIFA11+ (developed in 2009 by the FIFA Medical Assessment and Research Centre, also known as F-MARC) among others, notwithstanding, the protocol must be carried out and its effects analysed to have the enough knowledge to conclude whether it reduce the injury ratios significantly or not. Furthermore, analysing its effects on both male and female groups may be interesting to see if a difference in the response to this training program exists and if it should be applied to one specific sex athletes or not.

The protocol has the main objective of strengthening hamstrings. Strengthening core and improvements in balance, coordination, neuromuscular control and proprioception in tasks such as jumping and decelerating are also pursued.

It must be remarked that the selection of exercises is based on the exercises and protocols followed in the analysed studies (Mandelbaum et al., 2005; Caraffa et al., 1996; Hewett et al., 1999; Hewett et al., 2017; Olsen et al., 2005; Gilchrist et al., 2008; Mendiguchia et al., 2015; Silvers-Granelli et al., 2017; Daneshjoo et al., 2012). Furthermore, in order to develop the protocol in the field prior to the training session and do not need going to the gym, the exercises will not require special gym machines, most of them will not need material and in the case they do, the material needed will be cheap and lightweight material accessible to every football team or player such as elastic bands or wobble boards, notwithstanding, the needed material will be indicate in the description of each exercise The basic components of the developed intervention protocol are warm-up, plyometrics, strength and stretching exercises, balance agility and technique. It must be considered that some of them will be combined in the same exercises, for example some balance exercises done with a ball will require of technique and agility as well. This means that there will not be a block of technique alone, but it will be worked inherently in other exercises that have a specific soccer component.

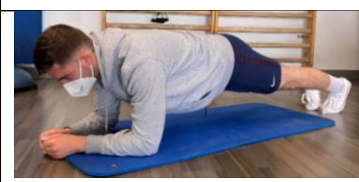
The protocol will consist of around 20 minutes (17 minutes of exercise and 3 minutes to prepare the materials, position etc) previous to the regular training session. The structure will consist of 4 blocks with a warm-up in first place, followed by stretching, balance and strengthening & plyometrics in that order. It must be outlined that this protocol is focused on preventing the ACL injury and therefore it can be previously complemented with other warming up exercises if wanted.

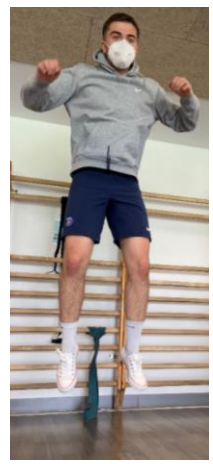
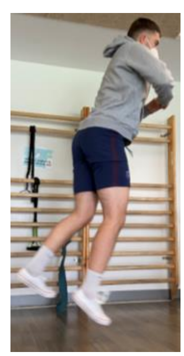
In the following table, the order of exercises will be explained as well as a brief description of each exercise and an image (when needed) in order to help understanding the technique and execution.

GENERAL WARM-UP (6 minutes)			
EXERCISE	DESCRIPTION	TIME	IMAGE
Jogging		4 min	
Backwards running with sidesteps		30 sec	
Running with knee lifts		30 sec	
Running with heel kicks		30 sec	
Sideways running with crossovers	Running laterally to the left crossing the right foot ahead and behind the left foot alternatively and then running laterally to the right crossing the left foot ahead and behind the right foot in the same way.	30 sec	
STRETCHING: Stretch to a point of tension and hold. Breath normally. (Based on the the PEP protocol used by Mandelbaum et al (2005) (3 min)			
EXERCISE	DESCRIPTION	TIME	IMAGE
Calf stretch	Stand leading with the right leg. Bend forward at the waist and place both hands on the ground. Keep the left knee slightly bent and your right leg straight. Make sure the left foot is flat on the ground. Do not bounce during the stretching. Switch sides and repeat.	40 sec	
Hamstring stretch	Sit on the ground with the right leg extended out in front of you. Bend the left knee and rest the bottom of your foot on your right inner thigh. Try to bring the chest toward the knee touching your toes with the fingers. Switch leg.	40 sec	

Hip flexor stretch	From the first picture position, incorporate on your knees and push your hips forward contracting the gluteal muscles. Maintain the position.	40 sec	 
Inner thigh stretch	Seated on the ground, flex both legs and put the sole of the right foot against the left foot one. Try to touch the ground with the knees.	40 sec	

BALANCE: (3 min)			
EXERCISE	DESCRIPTION	TIME	IMAGE
Isometric balance with wobble board. (Caraffa et al., 1996)	Maintain an isometric single-leg balance on a wobble board. 20 seconds each leg.	40 sec	
Soccer passing during an isometric single-leg balance with wobble board. (Based on Olsen et al (2005))	Holding the same position than in the previous exercise, soccer passes should be done maintaining balance. 20 seconds with each leg.	40 sec	
Isometric landing on wobble board.	Make 3 or 4 steps running and jump landing on the wobble board. Try to flex the knee during the landing and maintain that position during 3-5 seconds before losing balance. Make one repetition with each leg until the time is ended.	1 min	

Isometric balance under imbalance conditions. (Based on Olsen et al (2005))	Isometric balance with the knee slightly flexed should be maintained on a wobble board while other person pushes with a fit ball adding an external imbalance. 20 seconds each leg.	40 sec	
STRENGHTENING & PLYOMETRICS: (5 min)			
EXERCISE	DESCRIPTION	TIME	IMAGE
Walking lunges (Based in Hewett et al (2017))	Lunge forward leading with the right leg. Push off with your right leg and lunge forward with your left leg. Drop the back knee straight down. Control the motion and avoid the front knee from caving inward.	1 min	
Core planks (Based in FIFA11+ protocol used by Silvers-Granelli et al (2017))	Lift your body supported on your forearms, pull your stomach in and hold the position. The body should be in a straight line. Do not sway or arch your back. 2 sets of 25 seconds with 10 seconds to rest in between.	1 min	
Nordic hamstrings (Olsen et al., 2005; Mandelbaum et al., 2005)	With the body completely straight from the shoulder to the knee. Lean forward as far as you can, controlling the movement with your hamstrings and gluteal muscles. When you can no longer hold the position, take your weight on your hands falling into a push-up position. Do 15 repetitions	1 min	

Hamstring curl with elastic bands.	Anchor the ends of a resistance band to a sturdy object. Lie down on your stomach with your feet hip-width apart. Place the band around one heel and flex your ankle. Bend your knee to pull your heel toward your butt, keeping your thighs and hips on the mat. Stop when you can't pull any further. Return to starting position. Do 15 repetitions with each leg.	1 min	 
Box jumps (Taken from the FIFA11+ protocol used by Silvers-Granelli et al (2017)	Stand with your feet hip-width apart, alternate between jumping forwards, backwards, side to side and diagonally. Jump as explosively as possible.	30 sec	
Scissor jumps (Based on Hewett et al (1999))	Lunge forward with the right leg. Push off with the right leg and jump landing into a left leg lunge. Repeat it 20 times.	30 sec	  

8) CONCLUSIONS

The conclusion of this review is that, according to the evidence analysed, the ACL is a key structure for the motion of the knee and its rupture is one of the most common and serious injuries among team sports in general and soccer in particular. Furthermore, it can be concluded that with a correct preventive protocol its incidence can be significantly reduced. The proposed protocol may be a useful tool for the soccer players and teams to reduce the ratios of the ACL injuries. Nonetheless, further scientific research may be needed in order to determine the practical effectiveness of this protocol and if its effects are better or worse than other existing protocols.

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