European Journal of Human Movement, 2015: **34**, 52-74

A REVIEW OF RISK FACTORS FOR HAMSTRING INJURY IN SOCCER: A BIOMECHANICAL APPROACH

Enrique Navarro; David Chorro; Gonzalo Torres;
Carlos García; Archit Navandar; Santiago Veiga

Faculty of Physical Activity and Sport. Technical University of Madrid (Spain).

Abstract

The aim has been to review the literature about the risk factors of hamstring injury in soccer from a biomechanical point of view. METHODOLOGY. Data bases of bibliography references were Medline, Scopus and SportDiscuss. RESULTS AND DISCUSSION. Many prospective studies have shown that the previous injury is the greatest risk factor of sustaining the injury. However the primary causes of the injury are unclear in soccer. A lack of hamstring flexibility has been one of the main injury risk factors with controversies on the results. Imbalance of isokinetic force is a risk factor but electrical coactivation of all muscles participating during knee flexion and extension are unknown in football. While the importance of lumbopelvic-hamstrings muscles synchronization during running seems to be crucial for understanding the risk of injury, no research has been developed in this topic in football. CONCLUSIONS. More research using new data recording procedures as Dynamic Scanners, Surface EMG, Inverse Dynamic Analysis are needed. The analysis of more specific movements as running, kicking or jumping is clearly required. Managers, coaches, physical trainers, physiotherapists, sport physicians and researchers should work together in order to improve the injury prevention and rehabilitation programs of football players.
Key Words: sports biomechanics, soccer, hamstring injury, risk factors

Resumen

El objetivo de este estudio, ha sido revisar la bibliografía sobre la lesión de isquiotibiales desde un punto de vista biomecánico. METODOLOGÍA. Las bases de datos utilizadas fueron Medline, Scopus y SportsDiscuss. RESULTADOS Y DISCUSIÓN. Muchos estudios prospectivos han demostrado que el principal factor de riesgo es haber tenido la lesión previamente. Sin embargo, las causas primarias de la lesión en fútbol son desconocidas. Una falta de flexibilidad ha sido uno de los principales factores de riesgo pero existen controversias en los resultados de la literatura. Desequilibrio de la fuerza isocinética es un factor de riego pero la participación de cada músculo por separado durante la flexo-extensión de rodilla en fútbol no ha sido considerado en los estudios. Mientras que la sincronización de los músculos lumbopélvicos parece ser clave para entender el riesgo de lesión, no se ha desarrollado investigación al respecto. CONCLUSIONES. Por tanto, son necesarios más estudios prospectivos y nuevos procedimientos como el escaner dinámico, la electromiografía de superficie o el análisis dinámico inverso. El análisis de gestos más específicos del fútbol es necesario. Gestores, entrenadores, preparadores físicos, fisioterapeutas, médicos deportivos e investigadores deberían trabajar juntos para mejorar los sistemas de prevención y de recuperación de la lesión.
Palabras clave: biomecánica deportiva, fútbol, lesión de isquiotibiales, factores de riesgo

Correspondence:
Enrique Navarro Cabello
Faculty of Physical Activity and Sport Technical University of Madrid
Campus Ciudad Universitaria
Avenida Martín Fierro, 7
28040 Madrid (Spain)
enrique.navarro@upm.es
Submitted: 12/12/2014
Accepted: 08/06/2015

INTRODUCTION

What is the importance of hamstring injury?

Hamstring muscle injury (Mueller, 2013) is the most prevalent muscular damage presented in sport, according to Mendiguchia (2012). Epidemiology research studies (Hawkins et al., 1999, Wood, 2004, Arnason et al., 2004; Waldén et al., 2005, Hägglund et al.,2005, 2006, 2013, Ekstrand et al., 2011) have reported that the frequency of hamstring injury is still the same as thirty years ago (Mendiguchia, 2012), which suggests that risk factors examined until now have not prevented injuries properly. Hawkins (1999) reported 8.5 injuries/1000 hours (training and competition) and 27.7 injuries/1000 hours of competition in four English football teams. Arnason (2004) found a similar injury incidence (24.6 injuries/1000 competition hours) in 306 Icelandic football players. Walden (2005) observed 30.5 injuries/1000 competition hours in 266 players of eleven teams of the European elite. Hägglund (2006) examined two complete seasons of twelve Swedish football teams and he observed between 25.7 and 22.7 injuries/1000 competition hours. In women's professional football, the incidence of injuries is lower than male players with 13 injuries/1000 competition hours, according to Nilstand (2014). In view of these data, it can be stated that incidence of hamstring injury in football is around 25 injuries/1000 competition hours, being half of the incidence in women's football as compared to that of the men's.

According to Ekstrand (2011), muscular injuries represented 31% of the total injuries that occurred in 51 European football teams between 2001 and 2009 and they were the cause of 27% of the time absence of activity. Mallo et al. (2012) found that 25% of injuries of Spanish sub-elite football players were muscle strains and that these injuries caused 32% of lost games due to injury. From all the muscular damage, those affecting the hamstrings are the most incident and important because they usually represent between one and four weeks of absence to play (Heiderscheit et al. 2010). Recently, Hagglund (2013) reported that 42% of injuries affecting lower limbs of 26 European teams between 2001 and 2010 were hamstring injuries and that they occurred more frequently on the kicking leg. From all injuries produced due to football practice, those affecting hamstring represent approximately 12% (Woods et al. 2004, Ekstrand et al.,2011) and constitute an average of five injuries per season in a football team (Woods, 2004).

How are hamstring injuries produced?

Between 1997 and 1999 Woods (2004) examined injuries of 91 English league clubs and they found that 57% of hamstring injuries occurred during running. Injuries occur at the end of the swing phase and at the beginning of the stance which coincide when hamstring musculature are acting to decelerate both hip flexion and knee extension (Schache et al. 2009, Chumanov, 2011, Yu, 2009). The muscle strain occurs when the hamstring muscle complex contracts eccentrically at the same time as lengthening at high velocities followed by a concentric contraction. Several researches have analyzed the lengthening of hamstring muscles and the internal forces during normal walking and running by the means of an inverse dynamic analysis (Chumanov, 2007, 2011, Schache et al. 2009, Yu, 2009; Riley, 2009; Frank, 2009). They demonstrated that maximal hamstring muscular tension is produced at the end of the swing phase being the muscular damage suffered normally at the proximal part (intramuscular tendon of aponeurosis) of biceps femoris and semitendinosus muscles (Heiderscheit, 2010). In other movements when leg elevation occurs at slower velocities but with a higher height (for example, during ball controlling), the muscular damage usually suffered in semitendinosus and it results in longer recovery times.

Why do hamstring injuries occur and what are the risk factors?

According to the "Munich" classification (Mueller, 2013), injuries are divided in structural (fiber damage) and functional (alterations due to fatigue or neurological issues). Recently, it has been demonstrated that 2/3 of hamstring injuries are structural, which imply longer recovery periods (Ekstrand, 2013). Structural injuries are due to a mechanical failure during eccentric contraction (lengthening and muscular activation simultaneously). In this situation muscular fibers, which are activated to contract at the same time of lengthening, support internal forces greater than the breaking point of the muscular structure (Whiting and Zernicke, 1998, Garret et al. 1990). Risk factors are often determined by a reductionist model based on linear and univariant relationships without considering the relation between variables (Mendiguchia, 2012). According to (Beijsterveldt et al. 2014), in order to obtain valid and reliable risk factors in an epidemiological study, the research must be prospective, the sample must be composed by football players and statistical methods employed should be multivariant. Beijsterveldt (2014) classified risk factors as: 1) intrinsic unmodifiable, like gender, age or to have been previously affected by injury; 2) intrinsic modifiable, like the lack of flexibility, imbalance of muscular force, unstable pelvis and spine, problems of motor control (poor running technique) or fatigue; and 3) extrinsic like the kind of playing surface or the footwear.

The majority of research studies consider that the most important risk factor is having been previously injured (Opar et al., 2013, Arnason et al., 2004; Hägglund et al., 2006; Engebretsen et al., 2010). However, to our knowledge any study have examined real causes of this risk. There are some research studies that demonstrated that flexibility constitutes a risk factor (Witvrouw,

2003) but there are some discrepancies about (Henderson et al., 2010). The imbalance of muscular force, examined through the ratio hamstrings:quadriceps, (H:Q) has also been considered as an injury risk (Aagaard, 1998, Croisier, 2008) although its role it is still unclear (Henderson et al. 2010, Eleftherios 2015, Fousekis 2011). Other factors related to the motor control during running or kicking are considered important to some authors (Heiderscheit, 20120, Mendiguchia, 2012, Beijsterveldt, 2014), however, only one work has been found in football with that point of view (Navandar, 2013). Despite primary causes of injury being biomechanical or neurophysiological, most of the research studies in football are descriptive and limited to evaluate external force or flexibility without further analyzing causes. As a consequence, there is an existing lack of knowledge about the primary causes of hamstring injury which would allow anticipating, predicting and recovering injuries individually. Therefore, the main aims of the present systematic review are: 1) analyze injury risk factors from a biomechanical perspective and 2) to propose new lines of research.

METHOD

Literature Search

The articles selected for review were obtained via the "Ingenio" searcher of Technical University of Madrid. This tool uses Medline, Scopus and SportDiscuss data bases. The keywords were Sports Biomechanics, Soccer, hamstring injury and risk factors. The review was expanded between 2000 and 2015.

Biomechanical Model of Hamstring Injury

Fiber tear occurs when the internal forces exceed the mechanical limits of the tissue (Garret, 1996,). The biarticular character of hamstrings justifies the big elongations produced during the flexion and extension of the hip and knee joints respectively.

In order to understand the hamstring injury from a biomechanical point of view, a model based on Newton's Second Law (Force= mass x acceleration) has been developed. The Biceps Femoris (BF) has been chosen as the reference of the model. The mechanical model expresses the forces involved in the deceleration of the shank during the late swing phase of running:

$F_{ib} + F_{ext} = F_{total}$ (1)

$F_{total} > 0$ (2)

$F_{ib} > F_{ext}$ (3)

$F_{ext} < 0$ => this force elongates the muscle

$F_{ib} > 0$ => this force shortens the muscle

Positive Force implies the force tries to shortens the muscle

Negative Force implies the force tries to lengths the muscle

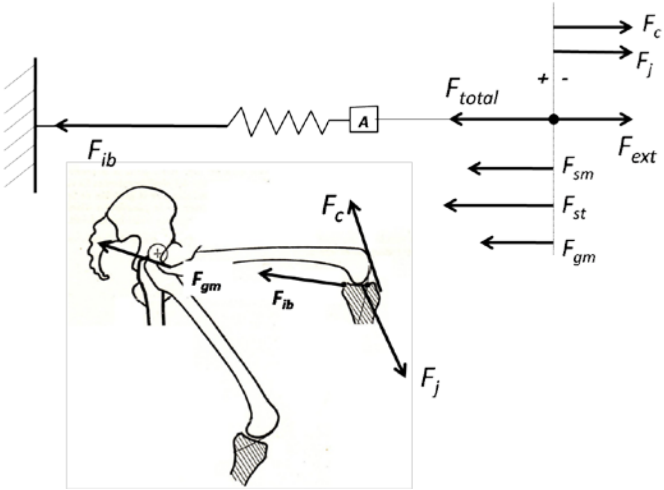

FIGURE 1: Forces applied in the shank during knee extension.

In order to understand this model is necessary to define properly the effects produced by all the forces involved in the process. The external force (F_{ext}) is applied in the negative direction what it means is that it produces the knee extension and muscle elongation. On the contrary, the internal force of Biceps Femoris (F_{ib}) is applied in the positive direction and therefore it contributes to the shortening of the muscle (Figure 1). In order to decrease the angular velocity of shank, the total force (F_{total}) has to be applied with a positive sense (equation 2). Therefore, if total force (F_{total}) has to positive, the amount of force which is shortening the muscle (F_{ib}) will have to be greater than the amount of force (F_{ext}) lengthening it (equation 3).

It has to be observed (equation 4), that the external force is the summation of the forces acting on the same sense that Biceps Femoris force (F_{ib})and those applied on the contrary sense, that is, trying to elongate the BF.

$$F_{ext} = (F_{st} + F_{sm} + F_{gm}) - (F_c + F_j) \qquad (4)$$

Finally, the mechanical model expressing the risk of strain injury of one of the hamstring muscles (BF), is presented as it follows:

$F_{ib}+(F_{st}+F_{sm}+F_{gm})-(F_c+F_j)>0$ (5)

F_{ib} (l,v)> F_F=> injury (6)

F_{ib}: Biceps Femoris Force

F_{st}: Semiotendinosus Force

F_{sm}: Semimembranosus Force

F_c: Quadriceps Force

F_j: Tibia Knee Joint Force

F_F: Failure mechanical limit

Taking into account this mechanical model, the strain injury occurs when the internal force opposing the muscle elongation of BF is greater than the tissue mechanical limit to failure (F_F). Several reasons could be involved:

1. The mechanical limit (F_j) is smaller than the expected due to the formation of the scar of a previous injury.
2. The forces (F_c, F_j) producing the acceleration of shank during the knee extension are very big, and therefore, greater internal forces (F_{ib}) are needed in order to decelerate the shank. Therefore, the strain injury risk is increased (Whiting and Zernicke, 1998).
3. The internal force (F_{ib}) is smaller than expected and the total force (F_{total}) decreases producing less deceleration of shank and a greater elongation of the muscle. If the elongation reaches the mechanical limit, the tissue failure is possible (Whiting and Zernicke, 1998).

RESULTS AND DISCUSSION

Injury Risk factors.Previous injury

In the opinion of Mendiguchia (2012), and Beijstrveldt (2014), prospective studies of soccer players using multivariate analysis are offering the more valid data about hamstring injury risk factors. Many prospective studies have been found showing that the previous injury is the greatest risk factor (Orchard, 2001, Arnason et al., 2004; Hägglund et al., 2006; Engebretsen et al., 2010, Hagglund et al. 2013). Orchard (2001) followed 1607 Australian football players during several seasons and found that the main risk factor is a combination of three variables: having been previously injured in the last eight weeks, having had a previous hamstring injury and Age. Authors have assessed the injury risk of hamstring injury on European footballers differently. While, Arnasson (2004) have considered that a player suffering previously the injury has 11.5 times more risk, recently, Hagglund (2013) found a risk of 1.4 in relation with players without a previous injury history. However, some discrepancies exist about it; Henderson (2010) and Fousekis (2011) didn´t find that previous injury is a risk factor both based on a prospective methodology.

Other authors (Brockett, 2004, Opar, 2012, Lees, 2009, Warren, 2008, Askling, 2010) using retrospective methods, have compared athletes and Australian Football players previously injured with those who hadn´t had it. They showed that after sustaining the injury, some adaptations appear on the muscle 1) a decrease of the eccentric force of hamstrings (Lee, 2009, Opar, 2013), 2) a reduction of the knee joint angle of maximum eccentric force (Brockett, 2004, Lee, 2009), 3) a decrease of hamstrings to quadriceps concentric ratio (Lee, 2009) and 4) a decrease of hamstring flexibility (Askling, 2010). Another important finding is that, after suffering a hamstring injury some changes are produced in the biomechanics of the running and kicking. Lee et al. (2009) found that elite sprinters with a history of hamstring injury decrease the maximum hip flexion angle during the swing leg in order to reduce the muscle elongation. Navandar et al. (2013) was the only study found analyzing the influence of previous hamstring injury on the kicking technique of soccer players. They found that some adaptations are produced on the kicking technique as a consequence of having had the injury.

Therefore, the prospective studies on soccer have showed that previous injury is the main risk but they have not determined the causative factors which produce the hamstring strain injury until now. On the other hand, the retrospective studies have found that muscle adaptations are produced as a consequence of a previous injury but this finding doesn´t mean that the modifications were the original causes of the injury (Gabble et al., 2006). A lack of information exists about the real causes of the hamstring strain injury in soccer. Possibly a new approach based on the biomechanical factors involved on the injury is needed.

Taking into account the proposed model (equation 6), we observe that when the tissue limit is decreased (F_F) the risk of the internal force (F_{ib}) overcoming this limit is higher. The scar generated after the injury has a reduced mechanical limit to failure in relation with the rest of the muscle, therefore the risk of a new strain in this zone is logically bigger. In a work with Australian Football players (Orchard, 2002) it has been shown that 12.6% of subjects were re-injured one week after the “return to play” moment and 30.6% on anytime during the same season. In accordance with these authors, the scar appeared after the healing of the injury, increased the stiffness of this muscle area and reduced the elongation capacity of this tissue zone.

Implementing in vivo analysis of the mechanical modifications on the scar tissue is very complicated. Some alterations on the Magnetic Resonance Images (MRI) of the muscle after the injury have been related with an increase of the risk of a new tissue failure (Silder et al. 2008). These authors (Silder et al. 2010) used a new technique of Dynamic MRI and scan the muscle during a flexion-extension of the knee; they observed that subjects previously injured had bigger deformations on the scar zone than in the healthy tissue area as a mechanical response to muscle stress.

Paying new attention to the equation (5) we can observe that if the internal force on the analyzed muscle (F_{ib}) is smaller than expected, the resultant force (F_{total}) will be smaller and the angular velocity of the shank during the knee extension will not be properly reduced.

$$F_{ib} + (F_{st} + F_{sm} + F_{gm}) - (F_c + F_j) > 0 \qquad (5)$$

If this one occurs, the muscle reaches bigger deformations and the risk of a new strain of hamstrings is clearly enhanced (Equation 6). This is in accordance with the findings showing that hamstring eccentric force is reduced after sustaining the injury (Lee et al. 2009, Opar et al. 2013). Yu et al. (2008) studied the sprint in elite athletes and found that the biggest hamstring elongations were produced during the late leg swing. If the sprint velocity is higher, the muscle internal tension is also higher (Chumanov, 2012). Therefore, when the football player is sprinting, the muscular tension is higher and bigger forces on hamstring are needed in order to decrease the shank angular velocity; If one of the hamstring muscles is weaker than the required force, the risk of reaching the stress tissue limit is also higher.

On the other hand, if the extensor knee muscle forces are very big, the required hamstring force has to be bigger in order to decelerate the lower leg (equation 5). When this occurs, the risk of muscles internal Force (F_{ib}) surpassing the failure threshold (F_F) is also bigger. Therefore, a decrease of the H:Q ratio in subjects previously injured justify the former argument (Lee et al., 2009). Until now, a reduction on the H:Q ratio of previously injured football players is unclear.

In accordance with Equation 5, if the muscular forces (Semitendinosus Force, Semimembranosus Force and Gluteal muscle Force) helping the Biceps Femoris, are smaller than the expected, the eccentric force of this muscle will have to be bigger, reducing the injury tolerance to failure. Chumanov et al. (2011) have found that semimembranosus internal loads were bigger than Biceps Femoris and Semitendinosus forces during the late leg swing phase and these loads increased with the velocity or running. Unfortunately, this lack of muscle synchronization during running in soccer players with recurrence of the injury has not been studied until now.

Motor Control alterations of running technique due to the injury have been studied on sprinters and Australian Football players but not in soccer (Lee, 2009). In accordance with Orchard et al. (2002), one of the better strategies for understanding the injury recurrence is to study the running biomechanics in relation with the hamstring strain injury. In order to prevent a new injury the player adapts automatically his running technique as a defense mechanism which can negatively influence his performance on the field of play (Orchard et al. 2002).

In conclusion, the adaptations produced after the injury can be justified via the mechanical model and the retrospective studies on the literature. However the most important thing it is to find the causes which produced the injury the first time. Therefore, prospective studies are needed analyzing the biomechanical variables which produce the injury in football players with and without a previous injury history. More research is required about the muscle and running technique adaptations (loads elongations, synchronization muscle activation) after the injury using 3D dynamic analysis.

Injury Risk Factors. Flexibility

A lack of hamstring flexibility has been considered in the literature as one of the main injury risk factors (Witvrouw et al. 2003, Arnasson et al. 2004, Henderson et al. 2010, Engebretsen et al. 2010, Askling et al. 2010, Fousekis et al. 2011). However, the results obtained with football players are non-conclusive. Witvroum et al. (2003) analyzed the flexibility of 146 professional players of the Belgian league. They applied a passive flexibility test during the season (the hip flexing angle was measured using a goniometer while the subject was in a supine position with the knee extended fully) and found that players who had suffered the injury previously recorded lesser hamstring flexibility during the preseason test. Henderson et al. (2010) have analyzed 36 English football league players and obtained that for each decreased degree in hamstring flexibility, the risk of injury increased a 1.78%. On the contrary, other researchers (Engebretsen et al., 2010; Arnasson et al. 2004) with bigger samples of players and using similar methods didn´t find the former results. A lack of internal and external validity on the procedures could be the reason for these discrepancies. To our knowledge, the flexibility of the joints or the elasticity of the muscles in soccer has been measured usually during a static position of the subject.

Applying the mechanical model proposed (equation 6) it can be observed that internal forces in the Biceps Femoris (F_{ib} (l,v)) depends on the length and the shortening-lengthening velocity o muscle fibers. The muscle is a viscoelastic system, that is, the tension opposing deformation increases when the velocity of muscles elongation also increases (Hamill and Knutzen, 1995). The amount of force produced by a muscle is also related to the length at which the muscle is held (Tension-Length relationship). The Tension/length ratio defines the material´s stiffness. When the stiffness increases, the slope of the curve

Tension-Length become steeper and greater tensions with smaller deformations are produced. That is, the failure tension (F_F) is reached at shorter deformations of the muscle fiber. As stiffness of tendon is bigger than that of the muscle, the fiber tear occurs normally near the proximal muscle-tendon union especially in the Biceps Femoris (Heiderscheit et al. 2010). Therefore, elevated levels of the muscle stiffness associated with a lack of flexibility, increases the risk of hamstring injury. The instants of the running cycle when poor levels of flexibility can lead to muscular damage have been described as the late support phase and at the late swing phase (Chumanov et al. 2011, Yu et al. 2008). At these instants, great deformations of hamstrings are produced and maximum levels of eccentric force can be exerted by sprint athletes previously injured (Lee et al. 2009). In opinion of Yu et al. (2008) the risk of hamstring injury exists also during the late support phase. In conclusion, the mechanical analysis shows that increase of muscles stiffness increases the risk of injury. Therefore, it is necessary to implement more realistic methods for measuring the flexibility of soccer players and its relation with the risk of injury. Possibly, 3D kinematic based methods should be the more appropriate for this task.

Injury Risk Factors. Strength Imbalances

The imbalances (Aagaard et al, 1998, Croisier et al., Crosiser et al. 2002, Croisier et al. 2008) of strength related with the hamstring strain injury are classified as: 1) Deficit of concentric and eccentric muscle force of knee flexors and extensors, 2) hamstrings-quadriceps imbalance and 3) bilateral differences of force. The force imbalances have been measured normally by means of isokinetic machines (Balzopoulos, 2008). Retrospective and prospective researches have studied the influence of muscle force on the hamstring strain injury incidence in soccer. In the following paragraphs, the review will focus in the prospective works mainly. We have found studies applied to Track and Field, Australian Football, American Football and Soccer. In accordance with Aagard et al., (1989) two types of hamstrings to quadriceps ratios exists, H:Q Conventional Ratio (the maximum concentric force of hamstrings divided by the maximum concentric force of quadriceps) and H:Q Functional Ratio (the maximum eccentric force of hamstrings divided by the maximum concentric force of quadriceps).

In Australian Football, some authors (Orchard et al., 1997) have shown that deficit of the hamstring eccentric force and smaller Conventional Ratio implied more injury probability. However, Benell (1998) published a paper named "Isokinetic strength testing does not predict hamstring injury in Australian Rules footballers". Zvijac et al. (2013) in a prospective work on American

Football in New Zealand obtained results that showed that the Conventional Ratio (60 deg/sec) is not useful for predicting the hamstring strain injuries.

In track and field velocity events, Croisier et al. (2002) found that athletes injured on the hamstrings had less concentric and eccentric forces in these muscles and a small mixed functional ratio. Croisier used an original mixed functional ratio where the performance of flexor muscles was measured at 30 deg/sec and the performance of extensors at 240 deg/sec. Similar to the former study, a prospective work (Sugiura et al. 2008) with elite sprinters found that the subject who sustained a hamstring injury had smaller records of the eccentric force of the hamstrings and smaller functional ratio at 60 deg/second than those athletes who hadn't suffered the injury during the season. Yeung et al. (2009) also studying elite sprinters obtained results that showed a Conventional Ratio at 180 deg/sec less than 0.6 meant a greater risk of hamstring strain injury by 17 times.

In soccer, we have found several studies comparing the force of players of different performance levels with diverse results. There have been shown that elite professional players had a greater concentric force of hamstrings and bigger H:Q ratios than professionals with a lesser performance level (Cometti et al., 2001). Similarly, Tourny-Chollet et al., 2002 found that amateur players presented higher functional ratios than non players. Recently, Eleftherios et al. (2015) obtained that the functional ratios of amateur players were not different from those of the control group. Iga et al. (2009) have shown that junior players who followed a training program with resistant loads had better results of conventional and functional ratios.

The influence of fatigue on hamstring force has been also considered (Rahnama et al, 2003, Rahnama et al. 2006, Thorlund et al. 2009). Some authors have simulated the fatigue during a soccer match by means of a treadmill obtaining that hamstring eccentric force decreased along with the match time (Greig et al. (2009, Small et al. 2010). Recently, Greco et al. (2013) observed that on 21 professional players the conventional ratio decreased from 0.6 to 0.58 and the functional ratio from 1.29 to 1.16 due to fatigue.

In a prospective study in soccer, Henderson et al. (2010) didn’t find any differences for any of the isokinetic measures of leg strength between the injured and the uninjured limb for knee flexion and extension. On the other hand, Fousekis et al. (2011) measured the concentric and eccentric force of knee flexors and extensors and found that 47% of players have bilateral imbalances of hamstring eccentric force (60-180 deg/sec). He also obtained results that showed players with bilateral imbalances of hamstring eccentric strength, anthropometric asymmetries and no previous injury had a greater risk of sustaining a hamstring strain injury.

Possibly, the most conclusive work in soccer about muscle thigh imbalances and injury risk is that of Croisier et al. (2008). These authors followed the isokinetic force of 462 soccer players during 9 months. The preseason test was composed of the next measurements: 1) concentric (60-240 deg/sec) and eccentric force (30-120 deg/sec) of knee flexors and extensors, 2) conventional ratio at 60-240 deg/sec and 3) mixed functional ratio (hamstring eccentric at 30 deg/sec and extensor eccentric at 240 deg/sec). Players with imbalances were those that accomplished with at least two of following asymmetries: 1) bilateral difference of more than 15% on the hamstring concentric force at 60-240 deg/sec, 2) bilateral difference of more than 15% on the hamstring eccentric force at 60-120 deg/sec, 3) conventional ratio smaller than 0.45 (Biodex) and 4) functional ratio smaller than 0.89 (Biodex). The players with imbalances represented 47% of the sample. They found that players without imbalance sustaining a lesser number of injuries and players with imbalances who didn't follow the injury prevention training, had 4-5 times greater risk as compared to the rest of the players.

Taking into account these findings, we conclude that: 1) Data about force imbalances and risk of hamstring injury depends on the sport analyzed and procedures employed (concentric-eccentric, isokinetic angular velocity, conventional-functional ratio), 2) The variables influencing the risk of injury are: hamstring eccentric force deficit, functional H:Q ratio deficit and bilateral differences and 3) The variables are dependent of fatigue and performance level.

In accordance with the mechanical model (Equation 5) proposed in the present study, when the eccentric force of the muscle (F_{ib}) is under the required standard, the capacity of decreasing the angular velocity of the shank decreases. When this occurs, the muscle reaches excessive elongations and the risk of tissue failure is higher (F_{ib} (l,v)> F_F). It is important to remark that biomechanical response of the muscle is produced by means of the elastic components and by means of activation of actine-miosine proteins of sarcomere. Experimental studies with animals have shown that, during eccentric contraction, an activated muscle produced more stress and accumulated more elastic energy than muscles without electrical activation (Garret, 1990). Therefore, a lack of force during the eccentric activity of hamstring can be due to an inappropriate activation of the muscle.

On the other hand, we can conclude from equation 5 that coativation of all the body muscles of the hamstrings group is essential in order to share the internal loads among them properly. The researches on running using inverse dynamic analysis (lee, 2009, Chumanov, 2011) have found internal loads of 83 k, 150 k and 44 k in biceps femoris, semimembranosus and semitendinosus respectively. These data would correspond to a subject with a weight of 80 k running at 80% of his maximum velocity. It is obvious from Equation 5, that activation of quadriceps and the synchronization with the hamstrings are also crucial for the loads supported by each of the hamstring body muscles. However, a lack of information exists in the scientific literature about hamstrings and quadriceps activation during isokinetic tests in soccer (Oliviera et al. 2009). However, the muscle forces have been studied using simultaneously isokinetic and electromyography measures in sports as Australian Football or Track and Field but not in soccer (Opar et al., 2013, Kellis et al., 1998, Onishi et al., 2002, Hassani, et al. 2006, Sole et al. 2011, Oliveria, et al. 2012). It has been found that electromyographic activation of biceps femoris during eccentric contraction was smaller in the previously injured leg (Opar et al., 2013). A reduction on the electrical activity means a decrease in the recruitment number of motor units and/or a decrease in the stimulation frequency of fiber(Opar et al. 2013). More research is needed to demonstrate that a reduction on the electric activity of the muscle represents more risk of hamstring injury (Opar, 2012). Oliveira et al (2009) studied the force and electromyographic response of hamstrings and quadriceps during isometric contraction in 10 professional players. They found a strong relationship between the H:Q ratios calculated from the isometric force and from EMG records. The isometric force H:Q ratio reached values of 0.6 while EMG ratios ranged between 0.8 and 1.0. In accordance with Oliviera et al. (2009), the EMG activation patterns should be taken into consideration when the rehabilitation and prevention exercises are being designed.

Many researchers have studied the activation of quadriceps and hamstrings during the exercises used during injury rehabilitation therapies (Farrokhi et al., 2008 et al., Irish et al., 2010 et al., Begalle et al., 2012, Harput et al., 2014). The information about this topic applied to soccer is almost null. Recently it has been shown that the ratio H:C can be measured in football players using wireless electromyography (Torres, 2014 et al. 2014, Navarro et al. 2015). These authors have shown that hamstring and quadriceps muscles coativation is bigger on the monopod squat than in the forward lunge.

Summarizing; the hamstring: quadriceps force imbalance is one of the main risk factors of suffering a hamstring strain injury in soccer; however results found in the literature are not totally conclusive. These results have been obtained from isokinetic test without taking into consideration the forces of the muscles involved. While a lot of information exists in the literature about EMG coativation of knee muscles during isokinetic test, rehabilitation exercises and during running in track and field and Australian Football almost nothing has been found applied to soccer. Therefore, prospective studies combining isokinetic, EMG and 3D Inverse Dynamics Analysis measures in football players are needed in order to study muscles forces in relation with the risk of injury.

The effect of fatigue and performance level of players should be taken into account in the researches.

Injury Risk Factor. Lumbo pelvic muscles syncronization

In accordance with Heischeit (2010), some of the most important risks factors of hamstring injury are: 1) alterations of biomechanics and motor patterns of movements, 2) force imbalance of lumbopelvic muscles and 3) motor control alterations between hamstrings and lumbopelvic muscles. Core stability has been linked with hamstring strain injury but there are no prospective studies on the topic (Mendiguchia et al. 2012, Beijstrveldt et al. 2014).

In accordance with the mechanical model (Equation 5), the total force applied with a positive direction (Figure 1), is the summation of the forces of three hamstring muscles (F_{ib}, F_{st}, F_{sm}) and the force of gluteal muscles. Hamstrings and gluteal muscles work with the same mechanical objective, to decrease knee extension. A lack of synchronization between them can produce the overloading of the muscles. The synergism of hamstring-gluteus is crucial in order to prevent the strain injury of hamstrings. Only a few authors have payed attention to imbalance hamstrings: hip flexors (Sugiura et al. 2008, Lee et al. 2009) in sprint athletes. On the other hand, the function of Gluteus muscles is dependent of the pelvis position (Kapandji, 1977); when a lack of abdominal muscles exists and/or the psoas muscle stiffness is high, the pelvic anteversion and hyperlordosis occur. A proper pelvis stability produced via a good activation of abdominal muscles prevents the pelvic anteversion and decreases the excessive elongation of hamstrings during running (Oh, et al. 2007, Kuszewski et al., 2009, Frank, et al. 2009, Mendiguchia et al. 2012). A subject with strain hamstring injury history recorded a decrease of hip extension during running (Brughelli, 2010) associated with force deficit of hip extensor and/or excessive activation of psoas muscle. The decreasing force of gluteal muscle can produce the hamstring overload (Wagner, et al. 2010). In accordance with Chumanov et al. (2007), the maximum elongation of biceps femoris occurs at 90% of running cycle (late leg swing) and is independent of velocity. Therefore, the biomechanical assessment of running can be crucial in order to examine the possible alterations in the motor control of muscles. However, some discrepancies exit about this issue; Silder et al. (2008) showed morphological differences via MRI of a previously injured muscle but they didn't find any differences on the kinematic and EMG recordings during running in a treadmill. Fatigue is an important injury risk factor (Mendiguchia et al. 2012) due its influence on the neurologic response. Several researchers have found that fatigue affects the running kinematics of football players (Pinninger et. Al 2000, Small et al. 2009). Small (2009) used 90' Test for simulating the effort of a football match and observed that fatigue provoked a decrease of maximum hip flexion and knee extension angles during running.

In relation to the rehabilitation and prevention injury programs, authors give lumbopelvic-hamstring synergism a relevant role (Sherry et. al, 2004, Verral et al. 2005; Cameron et al. 2009, Heirscheit et al. 2010, Petersen et al. 2011, Mendiguchia, et al. 2012). In the opinion of some authors, the use of drills training programm on lower limb neuromuscular control can prevent risk of hamstring strain injury (Cameron et at. 2003, Cameron et al. 2009). During rehabilitation program, it has been proven that smooth exercises working lumbopelvic muscles produced indirect activation of the hamstrings, which improved the mechanical response of the sustained hamstring injury scar (Heiderscheit et al. 2010).

While the importance of lumbopelvic-hamstring muscles synchronization seems to be crucial for understanding the risk of injury, no research has been developed in this topic in football.

CONCLUSIONS

In relation to the first objective of the current work, a biomechanical analysis of the scientific results about the risk factors affecting the hamstring strain injury, have been developed by means of a simple mechanical model. The main conclusions have been:

1. There is a lot of information about the risk factors from an epidemiological point of view but little is known about the real causes of the injury in soccer.
2. The biggest risk factor is to have sustained the injury previously but no conclusive results exist about other factors of the injury in soccer.
3. The majority of studies have been based on the use of isokinetic machine and static flexibility.
4. There is a lack of information about muscle elongations, muscle loads and electrical activity during specific movements such as running or kicking in soccer.
5. There is a lack of information about the coativation of hamstring and quadriceps muscles during rehabilitation exercises of the injury in soccer.

In relation with the second objective of the current study, new research approaches have been proposed:

1. To develop prospective studies following up soccer players during several seasons analyzing the multivariate risk factors from a biomechanical point of view. While, to have suffered the injury

previously, the fatigue and the performance level would have to be considered as independent variables.

2. To develop new scanner based procedures for studying the mechanical response of the scar produced after the injury.
3. To measure the elongations, the internal loads, and the synchronization of muscles using a combination of isokinetic machines, surface EMG and 3D Inverse Dynamic Analysis during running and kicking.
4. To research about the rehabilitation and injury prevention programs in relation with the EMG of hamstrings-quadriceps coactivation, the motor control of lumbopelvic muscles and the running technique.

The incidence of hamstring strain injury in the professional European football nowadays is rampant. Managers, coaches, physical trainers, physiotherapists, sport physicians and researchers, should work altogether in order to improve the injury prevention and rehabilitation programs of football players.

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