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SPECIAL ARTICLE

Proposal of a protocol for the primary prevention of hamstring strains in football players

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KEYWORDS
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Abstract Hamstring strains, mainly in the femoral biceps, are the most common football injury. In spite of all the studies carried out on preventing these injuries, their incidence has not fallen. One of the possible causes of this is incorrect choice of strength exercises and the traditional reductionist vision that fails to consider the interrelation between risk factors. The aim of this article is to review the risk factors presented in the literature and propose a correct choice of exercises for prevention based on the location of muscle activation, as well as offering a multifactor description of risk factors.

PALABRAS CLAVE
Protocolo;
Factores de riesgo;
Distensión muscular;
Fuerza excéntrica

Propuesta de protocolo de prevención primaria para distensiones en los isquiosurales en futbolistas

Resumen La distensión en la musculatura isquiosural, principalmente en el bíceps femoral, es la lesión más común en el fútbol. A pesar de todos los estudios realizados sobre su prevención, la incidencia no se ve reducida. Las posibles causas son la incorrecta elección de los ejercicios para el desarrollo de la fuerza y la no consideración de las interrelaciones entre los factores de riesgo. El objetivo de este artículo es revisar los factores de riesgo que expone la literatura y hacer una propuesta específica de ejercicios para su prevención en esta modalidad deportiva, en función de la localización de la activación muscular.

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Introduction

The chief cause of being unable to play in professional footballers is muscle injuries, approximately eight of which occur for every 1000 h of practice. They occur more often in matches than they do in training sessions. In the past two decades, the most common injuries in elite football have varied, and now the most common ones are injuries to the hamstring muscles, which cause more loss of playing time than any other group of muscles.[1]

Up to 50 injuries of all types will occur per season in a football team composed of 25 players.[2] Muscle injuries represent 20–37% of all the lesions which cause a loss of playing time.[3] 65% of these muscle injuries occur during competitive play, while the remaining 35% occur during training sessions.[4]

Rear thigh lesions are one of the most important types in footballers, and hamstring muscle lesions amount to 12–16% of injuries.[2,3,5–7]

The prevalence of injuries to different portions of the hamstring muscles is not uniform. Thus, biceps femoris injuries are more common than those to the semitendinosus and semimembranosus muscles.[8–10] 34.2% of lesions affect more than one part,[8] and the most common groups are both portions of the biceps femoris muscle (13.1%) and the long portion of the biceps femoris together with the semitendinosus muscle (23.6%). Additionally, four proximal portions are involved in 10.5% of the lesions recorded.

Differences also arise in terms of the location of injuries, as myotendinous injuries can be differentiated from intramuscular ones. The myotendinous junction of the biceps femoris is the most commonly injured.[9]

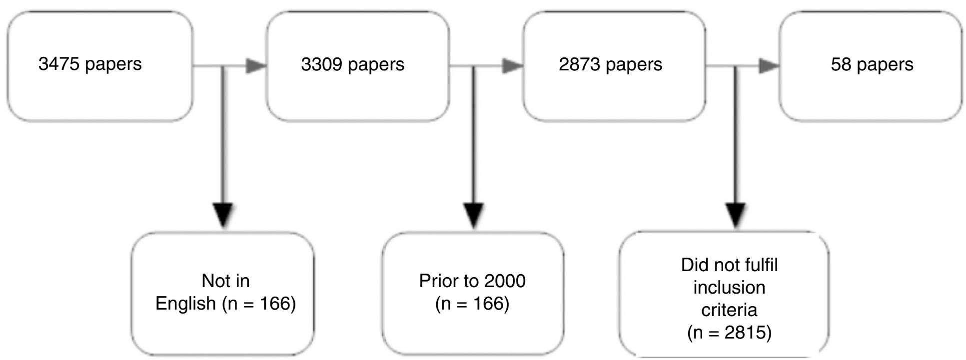
The typical type of injury is the result of excessive stretching of the myotendinous junction, which normally occurs when moving at speed or jumping, both of which are explosive actions.[8,10]

The main risk factors mentioned in the literature[11] are age, a previous injury, flexibility, strength, core stability, fatigue and the anatomy of the muscle itself. However, controversies have arisen about several factors. Moreover, independent factors such as previous injuries and age cannot be influenced.[1]

This study aims to analyse the risk factors in football hamstring muscle strains and how to correctly select strength exercises to prevent these injuries, examining their incidence in different portions of the muscles and their location.

Methodology

The bibliography was reviewed using the PubMed database with the following search strategy: (hamstring OR Hamstrings) AND (''injury'' OR ''injuries'' OR ''prevention'' OR ''MRI'' OR ''Magnetic resonance imaging'' OR ''risk factor'' OR ''eccentric strength''), in entries prior to 01/01/2018. Of the 3475 files found, 166 were rejected as they were not written in English and 436 were rejected as they were from before the year 2000. The title and abstract of the final 2873 were read, after which 2811 were eliminated as they did not fulfil the inclusion criteria, so that 58 were finally selected.



Results

Risk factors

A set of modifiable and non-modifiable factors were proposed for hamstring muscle strains, including age, a previous injury, race, strength imbalances, flexibility, ROM and fatigue.[1,10–14]

Non-modifiable risk factors

Age

Age is a risk factor for hamstring muscle injuries.[1,15,16] The possibility of suffering an injury in the hamstring muscles increases by 1.8 times with every year that we age.[17] Increasing age leads to degeneration in the lumbar spinal column (L5-S1), causing trapping of the hamstring nerve that innervates it and results in a loss of strength in its muscles.[16] Additionally, increasing age is associated with a loss of strength causes by a reduction in muscle mass and type II fibres.[14,15]

Race

Three studies found that belonging to an aboriginal, black African or Caribbean race is a risk factor for suffering strains in the hamstring muscles.[10,18,19] Nevertheless, only the study by Varrel[19] reported a significant increase in the number of injuries in this group.

Muscle anatomy

Different types of hamstring muscle injuries are associated with specific lesion locations.[20–22] The studies in question report that lesions associated with fast running mainly affect the proximal part of the biceps femoris, while over-stretching injuries involve the proximal portion of the semimembranosus muscle. Proximal lesions occur when there is high hip flexion parallel to extension of the knee.[22]

The prevalence of biceps femoris lesions is higher than is the case in the other portions.[9] Peak biceps femoris elongation occurs in the final moment of the oscillation phase and with greater magnitude, with the increase in velocity compared with the rest of the hamstring musculature.[23] Aponeurosis of the biceps femoris is narrower than the distal part, and this may explain the increase in fascicle length during contraction.[24]

Previous injury

Several studies[1,25,26] state that a previous injury and inappropriate rehabilitation are the major risk factors for future lesions. From 12 to 31% of injuries are caused by previous lesions, and they are more severe than the initial ones.[5,10] A player with a lesion in the hamstring muscle increases the probability of suffering another injury in the same muscles of the same leg by 2/3.[25] Players with previous injuries are 3.6 times more likely to suffer another injury.[27] Injuries last longer if there has been a previous lesion, at 24 days in comparison with 18.[2] One study of a repeat injury group found very low levels of muscular strength in comparison with the group without a repeat lesion.[28]

Moreover, previous lesions in other muscles are also a risk factor, as they will probably cause biomechanical changes in running technique.[16]

Modifiable risk factors

Flexibility and ROM

In the bibliography, it is currently possible to find controversies on the relationship between flexibility, ROM and the risk of injury.

Injured players have an average of 6.5° less range of movement.[29] Another study showed the difference in active as well as passive ROM between players who had suffered an injury and those who had not, and the ROM of the injured ones was smaller.[17] It has recently been shown that footballers with a shorter fascicle length of the long part of the biceps are at greater risk of suffering a muscle injury.[30]

On the other hand, they found no differences in terms of the number of injuries between teams that apply a preventive flexibility protocol and those that do not, although there were differences in lesion severity.[31]

Fatigue

The highest number of hamstring injuries occur in the final minutes of the first and second halves. This suggests that fatigue is a risk factor for muscle injuries.[3,10] Other studies also classify fatigue as a risk factor for the hamstring muscles.[11]

The peak force that arises in the eccentric phase is reduced when a match ends and during half time.[32] The reduction in the eccentric hamstring: concentric quadriceps ration is caused because the peak concentric force of the knee extensors occurs at a longer muscle length, while the peak in eccentric force of the knee flexors occurs at a shorter muscle length.[32]

Fatigue also changes the technique used in high-speed running, shortening the stride, which increases the risk of injury.[33]

Lumbar weakness and core stability

Lesions in the hamstring muscles while sprinting may be associated with the performance of major negative efforts in repeated strides and/or as the result of a disorder in the coordination of the pelvic muscles leading to excessive stretching of the hamstring muscles.[34]

Warming-up

Another suggestion is that an insufficient warm-up is also a risk factor for suffering a hamstring muscle injury. One study determined that warming-up increases the length of the hamstring muscles.[35] Warming-up also increases the speed of stretching after a nerve transmission. A warm-up composed of stretching and eccentric exercises is an effective means of preventing hamstring muscle injuries, while exercises that centre solely on flexibility do not seem to have preventive effect.[31]

Strength imbalance

Hamstring muscle weakness in concentric or eccentric contractions has been suggested as a risk factor by several authors.[5,13,36] Strength imbalances include hamstring muscle weakness, asymmetry between the hamstring muscles and low ratios in the hamstrings:quadriceps.

Strength

It has recently been shown that footballers with less eccentric strength in the knee flexor muscles have a higher risk of suffering a muscle injury.[30] Another study showed that eccentric knee flexor strength work plays a protective role by preventing hamstring muscle injuries.[37] This eccentric work leads to lengthening of the muscle fascicles, an increase in muscle density and an better pennation angles.[38,39]

The peak moment of maximum force

Regarding the length−tension ratio, the phase when the leg is descending is inherently unstable, so that as peak maximum force is produced later there is less risk of injury.[40] Their study showed that legs with previous hamstring muscle injuries have a greater angle of flexion when peak maximum force is produced than is the case with legs without a history of injury.[40] This means that legs with previous hamstring muscle injuries generate more tension than uninjured legs at the same range of movement.

Training is therefore suggested as a means of increasing the angle of the knee at which peak maximum force of the hamstring muscles is produced, as this would lead to a reduction in the eccentric load of the same during the descending phase of the leg.[41]

Table 1 The most commonly injured portions of the hamstring muscles.

Study	Year	Participants	*N*	BF	SMT	SMM	BF + SMT	ALL	Not spec.
[10]	2004	Footballers	749	396	116	98	—	—	139
[8]	2011	Footballers	38	30	12	13	9	4	—
[9]	2013	Footballers	31	18	9	—	—	—	4

Table 2 Location of hamstring muscle injuries.[9]

Injury	Total	Proximal MTJ	Distal MT	Intramuscular
Biceps femoris	18	6	9	10
Semitendinosus	9	—	—	9
Semimembranosus	—	—	—	—
Undetermined	4	—	—	4

Bilateral asymmetry

It has been suggested that a hamstring muscle in one leg that is significantly weaker than the one in the other leg, denominated bilateral hamstring asymmetry, may predispose the weaker hamstring muscle to a high risk of lesion.[42] This comparison between the legs of a sportsman may be a better marker than comparison with the standardised average of a group.

Hamstrings:quadriceps ratio

Muscle strength imbalance between the hamstring muscles and the quadriceps is a good predictor of hamstring muscle injuries.[43] Low eccentric capacity of the hamstring muscle to reduce the concentric action of the quadriceps during the end of the balancing phase is a risk factor.[12] Eccentric strength exercises of the hamstring muscles during the pre-season and season reduce the risk of suffering a muscle injury.[31] A study that analysed the relationship between the hamstring muscles, the quadriceps and the risk of injury found that uncorrected strength imbalances in football players is a risk for a muscle injury.[13] The smaller the functional ratio between the eccentric hamstring muscles (excI) and the concentric quadriceps (conC), the greater the risk of injury.[27] Bilateral deficits of 20% or more between excI (30°/s) and conC (240°/s) increase the risk of lesion by up to four times in comparison with a normal strength profile.[13]

Of the training parameters, volume and intensity are normally subjects of debate (Tables 1–3).[44]

The selection of strength-developing exercises

Hamstring muscle injuries may occur at the end of the flight phase or at the start of the oscillation phase on the ground[23,45–47] when running. This means that it is relevant to include open and closed kinetic exercises in actions to prevent injuries. The different locations where an injury may occur (proximal, medial distal) must be trained at the moment when it may arise. On the other hand, as the hamstring muscles portions are not activated uniformly during different exercises,[48,49] this suggests that a range of exercises should be used.

Exercises that involve flexion or resistance against the extension of the knee involve the participation of the semitendinosus and biceps femoris muscles.[50,51] The exercises that consist of extension or resistance against flexion of the hip involve the semitendinosus muscle, the long portion of the biceps femoris and the semimembranosus muscle.[50,52]

This activation in each one of the exercises may be varied depending on the position of the feet. Thus, active external rotation of the feet activates the lateral hamstring muscles (biceps femoris) to a greater extent, while internal rotation

Figure 1 Eccentric Leg Curl (initial position).

Figure 2 Eccentric Leg Curl (final position).

Table 3 Exercises that work on hamstring muscle strength as a primary means of prevention.

Exercise	Portion	Proximal	Medial	Distal	Kinetic hip	Evidence
Eccentric Leg Curl	BFl	+	++	++	Open	48,50,54
	BFs	++	++	++		
	ST	++	++	++		
	SM		++			
Nordic Hamstring	BFl			+	Closed	50,54–56
	BFs	++	++	++		
	ST	++	++	++		
	SM					
Russian Belt Deathlift	BFl	+	+	+	Closed	50,52,54
	BFs	+		+		
	ST	++	++	+		
	SM	++	+	+		
Hamstring Catapult (conic–pulley)	BFl	++	+		Open	50,54
	BFs					
	ST	+	++			
	SM	+	+	+		

of the feet gives rise to greater activation of the medial hamstring muscles (semitendinosus and semimembranosus).[53]

The main moments when hamstring muscle strains occur are during running, prior to the foot landing on the ground and when kicking.[10,15]

Practical application

The reviewed literature recommends the following exercises to work on the strength of the hamstring muscles as a primary prevention method.

The eccentric Leg Curl (Figs. 1 and 2) was selected due to its activation of the biceps femoris and semitendinosus at the distal level together with proximal activation of the short portion of the biceps femoris and semitendinosus muscles. The Nordic hamstring (Figs. 3 and 4) was selected as it works at the proximal and distal levels of the short head of the biceps femoris and semitendinosus. The Russian Belt

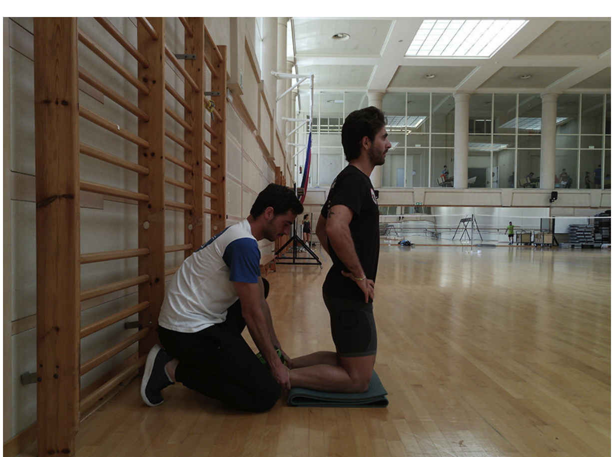


Figure 3 Nordic Hamstring (initial position).

Figure 4 Nordic Hamstring (final position).

Deathlift (Figs. 5 and 6) was selected for its proximal working of the semitendinosus and semimembranosus muscles. Lastly, the Hamstring Catapult (Figs. 7 and 8) was chosen mainly for its proximal activation of the long head of the biceps femoris.

These exercises should be applied on the basis of the following common parameters, and they should be adapted individually to each player while paying attention to the specific risk factors described above. The exercise programme consists of two routines per week. Routine 1 consists of gym work with the Leg Curl and the Hamstring Catapult, while routine 2 takes place in the field with the Nordic Hamstring and Russian Belt Deathlift. The workload consists of two series of six repetitions (2×6) per exercise.[57,58] Both routines will be used during periods of increasing workload (pre-season), while during competitive periods (the season) only routine 2 will be used, with the aim of avoiding high-intensity or long-lasting eccentric strength exercises during periods of competition, due to the fact that their side effects of muscle pain and strength deficit may reduce performance.[44] These routines should be included in a multifactor protocol[57] and completed by CORE and ROM stability exercises.

Figure 5 Russian Belt Deathlift (initial position).

Figure 6 Russian Belt Deathlift (final position).

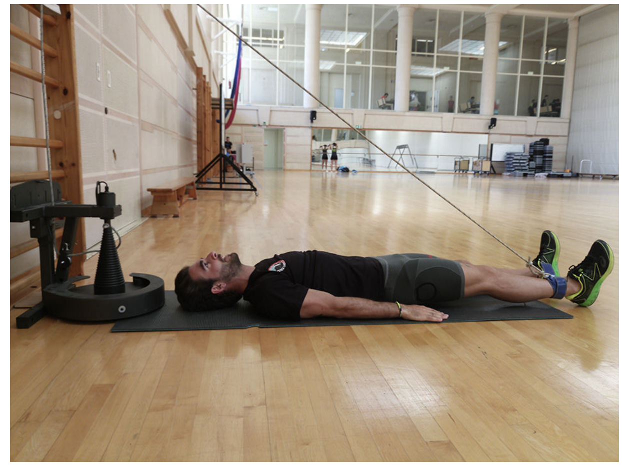


Figure 7 Hamstring Catapult (conic–pulley) (initial position).

Figure 8 Hamstring Catapult (conic–pulley) (final position).

Conclusions

Hamstring muscle strains are multifactor as they have more than one cause, although strength may be a highly important factor.[5] This means that an effective programme to prevent injuries to the hamstring muscles in football has to act specifically on all of the factors that can be modified in an individualised way.

Conflicts of interest

The authors declare that they do not have any conflict of interests.

References

1. Arnason A, Sigurdsson SB, Gudmundsson A, Holme I, Engebretsen L, Bahr R. Risk factors for injuries in football. Am J Sports Med. 2004;32:5–16.
2. Ekstrand J, Hägglund M, Waldén M. Injury incidence and injury patterns in professional football: the UEFA injury study. Br J Sports Med. 2009;45:553–8.

3. Ekstrand J, Hägglund M, Waldén M. Epidemiology of muscle injuries in professional football (soccer). Am J Sports Med. 2011;39:1226–32.
4. Ekstrand J, Waldén M, Hägglund M. Hamstring injuries have increased by 4% annually in men's professional football, since 2001: a 13-year longitudinal analysis of the UEFA Elite Club injury study. Br J Sports Med. 2016;50:731–7.
5. Croisier J. Factors associated with recurrent hamstring injuries. Sport Med. 2004;34:681–95.
6. Dauty M, Collon S. Incidence of Injuries in french professional soccer players. Int J Sports Med. 2011;32:965–9.
7. Hägglund M, Waldén M, Ekstrand J. Risk factors for lower extremity muscle injury in professional soccer: the UEFA injury study. Am J Sports Med. 2013;41:327–35.
8. Cohen SB, Towers JD, Zoga A, Irrgang JJ, Makda J, Deluca PF, et al. Hamstring injuries in professional football players: magnetic resonance imaging correlation with return to play. Sports Health. 2011;3:423–30.
9. Petersen J, Thorborg K, Nielsen MM, Skjødt T, Bolving L, Bang N, et al. The diagnostic and prognostic value of ultrasonography in soccer players with acute hamstring injuries. Am J Sports Med. 2013;42:399–404.
10. Woods C, Hawkins RD, Maltby S, Hulse M, Thomas A, Hpdson A. The football association medical research programme: an hamstring injuries in professional football—analysis of hamstring injuries. Br J Sports Med. 2004;38:36–41.
11. Mendiguchia J, Alentorn-geli E, Brughelli M. Hamstring strain injuries: are we heading in the right direction? Br J Sports Med. 2011;46:1–6.
12. Croisier J-L, Forthomme B, Namurois M-H, Vanderthommen M, Crielaard J-M. Hamstring muscle strain recurrence and strength performance disorders. Am J Sports Med [Internet]. 2002;30:199–203. Available from: http://www.ncbi.nlm.nih.gov/pubmed/11912088
13. Croisier J-L, Ganteaume S, Binet J, Genty M, Ferret J-M. Strength imbalances and prevention of hamstring injury in professional soccer players: a prospective study. Am J Sports Med [Internet]. 2008;36:1469–75. Available from: http://www.ncbi.nlm.nih.gov/pubmed/18448578
14. Gabbe BJ, Bennell KL, Finch CF, Wajswelner H, Orchard JW. Predictors of hamstring injury at the elite level of Australian football. Scand J Med Sci Sport. 2006;16:7–13.
15. Gabbe BJ, Finch CF, Bennell KL, Wajswelner H. Risk factors for hamstring injuries in community level Australian football. Br J Sports Med. 2005;39:106–10.
16. Orchard JW. Intrinsic and extrinsic risk factors for muscle strains in Australian football. Am J Sports Med. 2001;29:300–3.
17. Henderson G, Barnes CA, Portas MD. Factors associated with increased propensity for hamstring injury in English Premier League soccer players. Sports Medicine Australia. J Sci Med Sport [Internet]. 2010;13:397–402. Available from: https://doi.org/10.1016/j.jsams.2009.08.003
18. Brooks JHM, Fuller CW, Kemp SPT, Reddin DB. Incidence, risk, and prevention of hamstring muscle injuries in professional rugby union. Am J Sports Med. 2006;34:1297–306.
19. Verrall GM, Slavotinek JP, Barnes PG, Fon GT, Spriggins AJ. Clinical risk factors for hamstring muscle strain injury: a prospective study with correlation of injury by magnetic resonance imaging. Br J Sports Med. 2001;35:435–40.
20. Askling CM, Tengvar M, Saartok T, Thorstensson A. Acute first-time hamstring strains during slow-speed stretching: clinical, Magnetic Resonance Imaging, and Recovery Characteristics. Am J Sports Med [Internet]. 2007;35:197–206. Available from: http://ajs.sagepub.com/lookup/doi/10.1177/0363546507303563
21. Askling C, Saartok T, Thorstensson A. Type of acute hamstring strain affects flexibility, strength, and time to return to pre-injury level. Br J Sports Med [Internet]. 2006;40:40–4. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2491922/pdf/40.pdf [cited 13-04-17].
22. Askling CM, Tengvar M, Saartok T, Thorstensson A. Proximal hamstring strains of stretching type in different sports: injury situations, clinical and magnetic resonance imaging characteristics, and return to sport. Am J Sports Med. 2008;36:1799–804.
23. Thelen DG, Chumanov ES, Hoerth DM, Best TM, Swanson SC, Li L, et al. Hamstring muscle kinematics during treadmill sprinting. Med Sci Sports Exerc. 2005;37:108–14.
24. Rehorn MR, Blemker SS. The effects of aponeurosis geometry on strain injury susceptibility explored with a 3D muscle model. J Biomech. 2010;43:2574–81.
25. Hägglund M, Waldén M. Previous injury as a risk factor for injury in elite football: a prospective study over two consecutive seasons. Br J Sports Med. 2006;40:767–72.
26. Mendiguchia J, Brughelli M. A return-to-sport algorithm for acute hamstring injuries. Phys Ther Sport [Internet]. 2010:1–13. Available from: https://doi.org/10.1016/j.ptsp.2010.07.003
27. Lee JWY, Mok K, Chan HCK, Yung PSH, Chan K. Eccentric hamstring strength deficit and poor hamstring-to-quadriceps ratio are risk factors for hamstring strain injury in football: a prospective study of 146 professional players Justin. Sports Medicine Australia. J Sci Med Sport [Internet]. 2017;1:1–5. Available from: https://doi.org/10.1016/j.jsams.2017.11.017
28. Schuermans J, Van Tiggelen D, Danneels L, Witvrouw E. Susceptibility to hamstring injuries in soccer: a prospective study using muscle functional magnetic resonance imaging. Am J Sports Med. 2016;20:1–10.
29. Witvrouw E, Danneels L, Asselman P, Have TD, Cambier D. Muscle flexibility as a risk factor for developing muscle injuries in male professional soccer players: a prospective study. Am J Sports Med. 2003;31:41–6.
30. Timmins RG, Bourne MN, Shield AJ, Williams MD, Lorenzen C, Opar DA. Short biceps femoris fascicles and eccentric knee flexor weakness increase the risk of hamstring injury in elite football (soccer): a prospective cohort study. Br J Sports Med [Internet]. 2015;1:1–12. Available from: http://bjsm.bmj.com/lookup/doi/10.1136/bjsports-2015-095362
31. Arnason A, Andersen TE, Holme I, Engebretsen L, Bahr R. Prevention of hamstring strains in elite soccer: an intervention study. Scand J Med Sci Sport. 2008;18:40–8.
32. Small K, Mcnaughton L, Greig M, Lovell R. The effects of multidirectional soccer-specific fatigue on markers of hamstring injury risk. J Sci Med Sport. 2010;13:120–5.
33. Small K, Mcnaughton LR, Greig M, Lohkamp M, Lovell R. Soccer fatigue, sprinting and hamstring injury risk. Int J Sports Med. 2009;30:573–8.
34. Chumanov ES, Heiderscheit BC, Thelen DG. The effect of speed and influence of individual muscles on hamstring mechanics during the swing phase of sprinting. J Biomech. 2007;40:3555–62.
35. O'Sullivan K, Murray E, Sainsbury D. The effect of warm-up, static stretching and dynamic stretching on hamstring flexibility in previously injured subjects. BMC Musculoskelet Disord [Internet]. 2009;10:1–9. Available from: http://bmcmusculoskeletdisord.biomedcentral.com/articles/10.1186/1471-2474-10-37
36. Yeung SS, Suen AMY, Yeung EW. A prospective cohort study of hamstring injuries in competitive sprinters: preseason muscle imbalance as a possible risk factor. Br J Sports Med. 2009;43:589–95.
37. Askling CM, Tengvar M, Tarassova O, Thorstensson A. Acute hamstring injuries in Swedish elite sprinters and jumpers: a prospective randomised controlled clinical trial comparing two rehabilitation protocols. Br J Sport Med [Internet]. 2014;48:532–9. Available from: https://doi.org/10.1136/
38. Alonso-Fernandez D, Docampo-Blanco P, Martinez-Fernandez J. Changes in muscle architecture of Biceps Femoris induced

by eccentric strength training with Nordic hamstring exercise. Scand J Med Sci Sport. 2017;28:88–94.
39. Bourne MN, Williams MD, Opar DA, Al Najjar A, Kerr GK, Shield AJ. Impact of exercise selection on hamstring muscle activation. Br J Sports Med. 2016;51:1–9.
40. Brockett CL, Morgan DL, Proske U. Predicting hamstring strains injury in elite athletes. Med Sci Sports Exerc. 2004;36:379–87.
41. Clark RA, Hons B. Hamstring injuries: risk assessment and injury prevention. Ann Acad Med Singapore. 2008;37:341–6.
42. Zakas A. Bilateral isokinetic peak torque of quadriceps and hamstring muscles in professional soccer players with dominance on one or both two sides. J Sport Med Phys Fit. 2006;46:28–35.
43. Carvalho A, Brown S, Abade E. Evaluating injury risk in first and second league professional Portuguese soccer: muscular strength and asymmetry. J Hum Kinet. 2016;50:19–26.
44. Malliaropoulos N, Mendiguchia J, Pehlivanidis H, Valle X, Malliaras P, Maffulli N. Hamstring exercises for track and fi eld athletes: injury and exercise biomechanics, and possible implications for exercise selection and primary prevention. Br J Sports Med. 2012;46:846–51.
45. Heiderscheit BC, Hoerth DM, Chumanov ES, Swanson SC, Thelen BJ, Thelen DG. Identifying the time of occurrence of a hamstring strain injury during treadmill running: a case study. Clin Biomech. 2005;20:1072–8.
46. Schache AG, Wrigley TV, Baker R, Pandy MG. Biomechanical response to hamstring muscle strain injury. Gait Posture. 2009;29:332–8.
47. Yu B, Queen RM, Abbey AN, Liu Y, Moorman CT, Garrett WE. Hamstring muscle kinematics and activation during overground sprinting. J Biomech. 2008;41:3121–6.
48. Mendiguchia J, Garrues MA, Cronin JB, Contreras B, Los Arcos A, Malliaropoulos N, et al. Nonuniform changes in MRI measurements of the thigh muscles after two hamstring strengthening exercises. J Strength Cond Res [Internet]. 2013;27:574–81. Available from: http://journals.lww.com/nsca-jscr/Fulltext/2013/03000/Nonuniform_Changes_in_MRI_Measurements_of_the.3.aspx
49. Bourne MN, Williams MD, Opar DA, Al Najjar A, Kerr GK, Shield AJ. Impact of exercise selection on hamstring muscle activation. Br J Sports Med. 2017;51:1021–8.
50. Fernandez-Gonzalo, Tesch Linnehan, Kreider, Salvo D, Suarez-Arrones, et al. Individual muscle use in hamstring exercises by soccer players assessed using functional MRI. Int J Sports Med. 2016;37:559–64.
51. Schuermans J, Van Tiggelen D, Danneels L, Witvrouw E. Biceps femoris and semitendinosus—teammates or competitors? New insights into hamstring injury mechanisms in male football players: a muscle functional MRI study. Br J Sports Med. 2014;48:1599–606.
52. Ono T, Higashihara A, Fukubayashi T. Hamstring functions during hip-extension exercise assessed with electromyography and magnetic resonance imaging. Res Sport Med [Internet]. 2011;19:42–52. Available from: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=21253975
53. Lynn SK, Costigan PA. Changes in the medial-lateral hamstring activation ratio with foot rotation during lower limb exercise. J Electromyogr Kinesiol [Internet]. 2009;19:e197–205. Available from: https://doi.org/10.1016/j.jelekin.2008.01.007
54. Mendez-Villanueva A, Suarez-Arrones L, Rodas G, Fernandez-Gonzalo R, Tesch P, Linnehan R, et al. MRI-based regional muscle use during hamstring strengthening exercises in elite soccer players. PLoS ONE. 2016;11:1–15.
55. Mendiguchia J, Arcos AL, Garrues MA, Myer GD, Yanci J, Idoate F. The use of MRI to evaluate posterior thigh muscle activity and damage during nordic hamstring exercise. J Strenght Cndition-ing Res. 2015;27:3426–35.
56. Bourne MN, Opar DA, Williams MD, Najjar A Al, Shield AJ. Muscle activation patterns in the Nordic hamstring exercise: impact of prior strain injury. Scand J Med Sci Sport. 2016;26:666–74.
57. Mendiguchia J, Martinez-Ruiz E, Edouard P, Morin J-B, Martinez-Martinez F, Idoate F, et al. A multifactorial, individualized, criteria-based progressive algorithm for hamstring injury treatment. Med Sci Sports Exerc. 2017;49:1482–92.
58. Petersen J, Thorborg K, Budtz-Jørgensen MBNE, Hölmich P. Preventive effect of eccentric training on acute hamstring injuries in men's: a cluster-randomized controlled trial. Am J Sports Med. 2011;39:2296–303.