

Hamstring injury occurrence in elite soccer players after preseason strength training with eccentric overload

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The primary purpose of this study was to evaluate whether a preseason strength training programme for the hamstring muscle group – emphasising eccentric overloading – could affect the occurrence and severity of hamstring injuries during the subsequent competition season in elite male soccer players. Thirty players from two of the best premier-league division teams in Sweden were divided into two groups; one group received additional specific hamstring training, whereas the other did not. The extra training was performed 1–2 times a week for 10 weeks by using a special device aiming at specific eccentric overloading of the hamstrings. Isokinetic hamstring strength and maximal running speed were measured in both groups before and

after the training period and all hamstring injuries were registered during the total observational period of 10 months. The results showed that the occurrence of hamstring strain injuries was clearly lower in the training group (3/15) than in the control group (10/15). In addition, there were significant increases in strength and speed in the training group. However, there were no obvious coupling between performance parameters and injury occurrence. These results indicate that addition of specific preseason strength training for the hamstrings – including eccentric overloading – would be beneficial for elite soccer players, both from an injury prevention and from performance enhancement point of view.

Hamstring muscle strains are common injuries in sports with high demands on speed and power, such as soccer (Ekstrand & Gillquist, 1983a; Inklaar, 1994a). Ekstrand & Gillquist (1983a) showed that 80% of all muscle strains encountered by soccer players during training and/or matches occurred in the lower extremity and that 47% of those were injuries to the hamstrings. In a later study, Morgan & Oberlander (2001) reported that about 10% of Major League Soccer players encountered a hamstring injury during a season.

Muscle strength deficiency has been proposed as one of several risk factors for hamstring injury (Yamamoto, 1993; Worrell, 1994), although earlier studies attempting to establish relationships between muscle strength parameters and occurrence of hamstring injuries have shown diverging results (Orchard et al., 1997; Bennell et al., 1998).

Strength training has been advocated as a preventive measure in order to avoid hamstring muscle injuries (Stanton & Purdam, 1989). This recommendation has been based on experiments on animal muscle, where it has been shown that a stronger muscle can absorb more energy prior to failure than a weaker muscle (Garrett, 1990, 1996). To our knowledge, no prospective study concerning the possible preventive effect of specific

strength training of the hamstrings has so far been performed.

Increasing amounts of evidence point to the advantages of including eccentric muscle actions in strength training regimes to achieve optimal effects (Colliander & Tesch, 1990; Dudley et al., 1991). This has been demonstrated both in studies of changes in maximal strength performance (Hather et al., 1991) and in rehabilitation studies (Alfredson et al., 1998; Croisier et al., 2002). Eccentric training appears also to be motivated from a functional point of view as eccentric actions are an integral part of the functional repertoire of this muscle group (Nilsson et al., 1985; Mann et al., 1986). Furthermore, there are theories, which state that the strain injury would occur during eccentric hamstring actions. Proved valid, this could be another incentive for eccentric training as a preventive measure.

The aim of this study was to evaluate whether a preseason hamstring strength training programme – emphasising eccentric overloading – could affect the occurrence and severity of hamstring injuries during the subsequent competition season in elite soccer players. Additional attention was paid to the effects of the training on strength and speed performance and their possible relationship with hamstring injury prevention.

Materials and methods

Subjects

Thirty male soccer players from two of the best premier-league division teams in Sweden were recruited as subjects. All players remained in their respective team during the entire study period. Fifteen players from each team participated; goalkeepers, injured players and players with chronic hamstring problems were excluded. The participating players in each team (7 + 8 and 8 + 7, respectively) were randomly assigned to either a training group ($n = 15$) or a control group ($n = 15$). A similar number of defenders and forwards were included in each group. All subjects gave their informed consent to participate. Before the study period started, there were no significant differences between the training and the control groups with respect to anthropometric measures (Table 1), muscle strength, maximal running speed, or hip flexibility (range of motion, ROM) (Table 2).

Study design

Before the start of the study, the players, coaches and medical personnel of the two teams were informed about the purpose and the design of the study. The coaches, physical therapists and physicians agreed to supervise the training and to register and report all hamstring injuries.

The study was divided into two phases. Phase 1 (preseason) was the first 10 weeks (January 7–March 15) and phase 2 (competition season) was the period between weeks 11 and 46 (March 16–November 15). Both the training and control groups followed the same protocols, the only exception being that the training group received additional specific hamstring training during phase 1. During the 8 days directly preceding and 3–12 days following the training period, tests for hamstring strength and maximal running speed were performed in both groups. The incidence of hamstring injuries was registered over the whole

Table 1. Background data, mean values and standard deviations (SD), for the training group ($n = 15$) and the control group ($n = 15$). There were no significant differences between the two groups

	Training group	Control group
Age (years)	24 (2.6)	26 (3.6)
Body mass (kg)	78 (5)	77 (6)
Body height (m)	1.82 (0.06)	1.81 (0.07)
Body mass index (kg/m ²)	23.5 (0.6)	23.3 (0.9)

Table 2. Mean values and standard deviations (SD) in the training and control groups for concentric (con) and eccentric (ecc) strength (peak torque; $n = 13$ for both groups) and maximal running speed (time for 30-m-sprint; $n = 14$ for both groups) before and after the preseason-training period. Values for the range of motion (ROM; $n = 15$ for both groups) for each leg in passive hip flexion measured before the training period are also presented

	Training group			Control group		
	Before	After	After-Before	Before	After	After-Before
Strength						
Peak torque con (Nm)	131 (21)	151 (26)	20* (12)	130 (25)	133 (19)	2 (14)
Peak torque ecc (Nm)	148 (24)	176 (22)	28* (28)	158 (25)	156 (23)	0 (16)
Speed						
Time 30 m (s)	3.36 (0.10)	3.28 (0.09)	0.074* (0.052)	3.38 (0.11)	3.38 (0.12)	0.002 (0.05)
ROM						
Hip flexion dx (°)	70 (6)			75 (10)		
Hip flexion sin (°)	71 (6)			74 (9)		

*Significant difference After-Before ($P < 0.05$).

study period. After the training period, the training group was interviewed concerning their subjective experience of the specific hamstring training – for example, discomfort, muscle soreness, effects on performance and attitude towards this type of training.

Training programme

The training group performed a total of 16 sessions of specific hamstring strength training, every fifth day for the first 4 weeks and every fourth day during the last 6 weeks (total training period 10 weeks, all players completed all sessions). The hamstring training was performed in a non-fatigued state, after a standardised warm-up period (15 min jogging/cycling). Four individually supervised sessions over a 2-week period were allowed for familiarisation before the start of the study. Thereafter each player was responsible for his own training, including keeping track of times, days, training intensity, muscle soreness and other symptoms in his training diary. Midway through the training period, one training session for each player was again controlled by the project leader. Apart from the extra training, all players in both groups followed the ordinary training of each team. There was no further detailed registration of exposure.

The specific hamstring training consisted of both concentric and eccentric actions and was performed on a YoYo™ flywheel ergometer (YoYo Technology AB, Stockholm, Sweden) (Berg & Tesch, 1994). The working principle of this device is based on setting a flywheel into rotational motion via concentric muscle action and then decelerating the motion via eccentric muscle action. By performing the eccentric action over a smaller angular displacement and hence with a greater muscle torque than the concentric one, an eccentric overload is accomplished.

The subjects performed bilateral knee flexor actions in the prone position (fig. 1), accelerating the flywheel by concentric hamstring action and subsequently decelerating it with eccentric action of the same muscle group. The instruction was to apply maximal effort from a straight knee position until full knee flexion (130–140°), then start braking upon passing the 90° position on the way back and continue braking with maximal effort until the knees were straight. Once the flywheel had come to a stop, the next cycle was initiated. The average angular velocity was approximately 60° s⁻¹ (estimated with an electro-goniometer in one subject) – that is, the concentric and eccentric muscle actions lasted about 2.2 and 1.5 s, respectively. Every training session consisted of four sets with eight repetitions; the first set serving as specific warm-up. The rest period between sets was approximately 1 min.

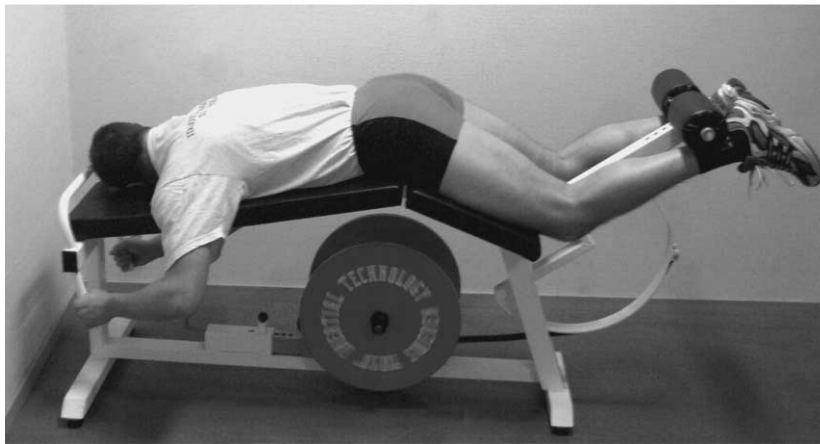


Fig. 1. The set-up for specific hamstring training (for description, see Methods).

Isokinetic muscle strength

The isokinetic concentric and eccentric hamstring muscle strength was measured, for each leg separately, in a seated position by using a Kinetic Communicator (KIN-COM[®] 500 H, Chattecx Corp., Chattanooga, TN, USA) at an angular velocity of $60^{\circ} \text{ s}^{-1}$. A 10-min warm-up period on a cycle ergometer at 50 W preceded the test. The subject was sitting with the thigh supported, hip flexed at 90° , and arms folded; secured to the apparatus with straps across the chest, pelvis, thigh and ankle. The rotational axis of the knee was aligned with that of the dynamometer. The range of motion of the knee joint was $5\text{--}90^{\circ}$ (0° = straight knee). The test protocol consisted of two submaximal repetitions followed by three maximal trials, first concentrically then eccentrically. About half a minute rest was allowed between the muscle actions. Gravity-corrected peak torque (PT) was registered and the trial giving the highest PT value was used for statistical analysis.

Running speed

A test of maximal running speed, a so-called flying-30-m-test, was performed before and after the training period. The subjects were allowed to accelerate over a distance of 20 m and the time for running the next 30 m at full speed was measured using photocells (Time-it, Eleiko, Sweden, resolution 0.01 s). The fastest of three trials was used for analysis. A standardised warm-up programme preceded the tests and a 2-min recovery period was given between runs. The tests were performed on an indoor all-weather-track and conventional training shoes were used.

Range of motion

Range of motion was measured for passive hip flexion of each leg on all 30 players during the week prior to the start of the training period. No warm-up exercises were performed and strength training of the thigh muscles was prohibited during the 2 days preceding the test. The angular displacement during passive leg raising with straight knee was measured with a flexometer (Myrin, Follo A/S, Norway) according to Ekstrand et al. (1982).

Injury registration

All hamstring injuries were registered during the entire study period. An injury was included if it occurred during scheduled matches or practices and caused the player to, at least, miss the next game or practice session (Ekstrand & Gillquist, 1983a). All injuries were diagnosed after a clinical examination and were defined as pain in connection with palpation as well as with

isometric contraction and stretching. None of the injured players had any diffuse lumbar region problems that could be related to the hamstring symptoms. The number of matches or practices missed was decided, recorded and reported by the respective team physician. The medical personnel of each team were not part of the study, thus avoiding bias. The severity of the injuries was classified into three categories, according to Ekstrand & Gillquist (1983a): (i) minor injuries (absence from practice/match less than a week), (ii) moderate (absence more than 1 week to 1 month), or (iii) major (absence more than 1 month). Both groups were treated identically and a finer gradation of the number of matches or practice sessions was not performed in any of the groups. Each injured player was interviewed in connection with the injury occasion according to a standardised questionnaire, including a description of the injury situation and an attempt to analyse the possible cause of the injury.

Statistics

Differences between groups and between values before and after the training period were tested for significance by using the two-tailed paired Student's *t*-tests. Statistical significance was accepted at the $P < 0.05$ level with Bonferroni adjustment for multiple *t*-tests. In order to test for statistical significance between groups with respect to the occurrence of hamstring injuries, Fisher's Exact test with a Yates correction was employed (Agresti, 1992). The level of significance was set at $P < 0.05$.

Results

Isokinetic muscle strength

The training group showed a significant increase ($P < 0.05$) after the training period in both eccentric and concentric knee flexor strength (peak torque), whereas there were no differences in the control group (Table 2). The increases in eccentric and concentric strength in the training group were of similar magnitude, 19 and 15%, respectively. Concentric strength constituted, on the average, about 85% (82–89%) of the eccentric strength in both groups, before and after the study period.

Running speed

The time for 30-m maximal speed running (flying-30-meters) was significantly ($P < 0.05$) shorter (2.4%)

in the after-test as compared to the before-test in the training group, whereas it remained unchanged in the control group (Table 2).

Injury occurrence

During the study period of 10 months, a total of 13 (43%) hamstring injuries were reported among the 30 players, all occurring during the competition season (March–October) (Table 3). A significantly ($P < 0.05$) lower number of injuries occurred in the training group (3/15) as compared to the control group (10/15). Seven of the 10 injuries in the control group were classified as 'minor'. Overall, eight of the injuries (62%) were classified as 'minor', four (31%) as moderate and one (7%) as major. Six (46%) of the injuries happened during matches and seven (54%) during training sessions. Eight of the nine acute injuries were reported by the subjects as having occurred during sprint-like activities and one (the only major injury) when performing a glide-tackle. The number of traumatic injuries – that is, injuries with a sudden onset – was nine (69%), whereas the remaining four (31%, all minor injuries) were classified as overuse injuries, having an insidious onset of symptoms.

In a questionnaire completed by both groups before the study period, 10 players – six in the training group and four in the control group – reported previous injuries to the hamstrings during the preceding season. Among the 13 players injured during the current season, six (46%) had had a hamstring injury during the previous season, five (all minor) in the same leg and one (the only major injury) in the contralateral leg. Of the six re-injured players, two belonged to the training group and four to the control group.

In the first test before the training protocol started, there were no differences in performance variables – that is, isokinetic strength or running speed, or ROM in passive hip flexion – between the group of players ($n = 13$) that were later to be injured and the group that remained uninjured ($n = 17$). Similarly, there were no significant differences in any of these variables within the injured group – that is, between the legs that were to be injured and those that remained healthy.

Interview

In the interview after the training period, 11 players in the training group stated that they had experienced muscle soreness of varying intensity 1–3 days after the training sessions – particularly, during the first half of the training period. A majority of the players (11/15) considered the extra hamstring training meaningful and were positive towards a continuation; five players would prefer whole season extra training, whereas six recommended that it be a part of the preseason schedule only.

Discussion

The main finding of the present study was that a group of elite male soccer players performing extra preseason training specifically directed towards overloading the hamstring muscles eccentrically had a lower occurrence of hamstring strain injuries than a matched group performing ordinary training. The training also had a positive effect on the concentric and eccentric maximal voluntary strength of the hamstrings, as well as on maximal running speed. The players came from two of the highest ranked male teams in the Swedish premier-league division, which should be borne in mind when attempting to extrapolate the findings. Although the teams may not represent the highest absolute level of soccer, the majority of the players are full-time employees, undertaking frequent training sessions and matches. Therefore, the significant effects of the extra training were even more remarkable.

Previous studies have suggested that hamstring strain is one of the most common soft tissue injuries in athletes (Garrett et al., 1984; Kujala et al., 1997; Clanton & Coupe, 1998; De Smet & Best, 2000). Earlier injury surveys in male elite soccer players have, however, not been able to identify the hamstrings as a particularly injury-prone muscle group (Árnarson et al., 1996; Lüthje et al., 1996). The prevalence of hamstring injuries in the present study was particularly high in the control group (67%), which is clearly higher than in earlier studies (Ekstrand & Gillquist, 1983a; Morgan & Oberlander, 2001). It should be noted that

Table 3. Distribution of hamstring injuries ($n = 13$), in relation to subject groups, severity (minor, moderate, major), occurrence, type and time (month) of the year

	Training group			Control group		
	Minor	Moderate	Major	Minor	Moderate	Major
Frequency	1	1	1	7	3	0
During match		1	1	2	2	
During training	1			5	1	
Acute injury		1	1	4	3	
Insidious injury	1			3		
Month (#) of the year	6	7	10	3, 4, 8, 8, 10, 10, 10	4, 7, 8	

the majority of these injuries were categorised as 'minor'. There are several possible explanations for the apparent discrepancy between the current and earlier findings, although a conclusive explanation is still lacking. One plausible explanation might be related to the method of data collection (Östenberg & Roos, 2000). This can be critical, particularly in studies using large subject numbers where the coach/player is to report the injury to the investigator. The size of the present cohort was small enough to allow for a very careful collection procedure, where the team physician made an acute clinical diagnosis and the main investigator followed up with an interview. Another explanation could be that the present study was focused on injuries to the hamstring muscles, whereas the previous studies have attempted to survey the overall injury pattern. As mentioned, many of the present injuries (62%) were 'minor' – that is, causing absence from practice/match for less than a week – and they may have escaped attention in surveys of larger format. Furthermore, the category of players studied is most likely critical – that is, the actual definition of a player's proficiency and thus the classification as 'elite'. The risk of injury may increase with the level of play as discussed by Heidt et al. (2000).

In the training group, the number of hamstring injuries was significantly lower as compared to the control group. At the same time, the performance in the strength and speed tests improved. However, no direct coupling between the two was observed on an individual level. It was not within the scope of this study to determine whether preseason strength and speed tests were predictive of injury risk. This is in line with the general notion that hamstring strains are complex injuries with several potential predisposing factors – for example, muscle weakness and imbalance, lack of flexibility, fatigue, etc. (Agre, 1985; Worrell, 1994). There are studies showing that low muscle strength measured isokinetically during the preseason can be related to a higher risk of hamstring injuries during the ensuing competition season (Orchard et al., 1997). Yet, other investigations were not able to show such a relationship (Bennell et al., 1998).

The injured legs did not demonstrate any difference in flexibility before the observation period started. This is in accordance with a previous study, which showed no relationship between passive hip flexion measured during preseason and subsequent occurrence of hamstring muscle injury (Ekstrand & Gillquist, 1983b). It may be noted in this context that excessive flexibility training *per se* may lead to hamstring strain injuries (Askling et al., 2000, 2002).

The low number of subjects is a limitation with the present study and there is a need for large-scale multi-factorial prospective studies in order to clarify possible relationships between potential risk factors and subsequent occurrence of hamstring injury. One

important factor to consider in such studies would be the occurrence of previous hamstring injuries. In the control group that just received conventional soccer training during the preseason, all four of those who reported that they had suffered a hamstring strain injury during the preceding season were re-injured during the current season. Accordingly, several earlier studies have clearly indicated that a previous injury constitutes a severe risk for re-injury at the same location (Inklaar, 1994b; Bennell et al., 1998; Orchard, 2001; Verrall et al., 2001).

In this study, none of the 13 players – who were injured during the actual observational period – did, however, experience a second injury to the same leg during that particular period. This could possibly be related to the special attention that each injury received from the investigators. Every injured player was carefully followed up until the time of return to full activity. Immediate treatment and a rehabilitation programme closely integrated with the healing process have been emphasised as critical factors for minimising the risks for re-injury (Taylor et al., 1993; Thorsson, 1996; Järvinen et al., 2000; Kannus, 2000). This is essential even if the first injury is characterised as 'minor' (Ekstrand & Gillquist, 1983a).

The training group showed improvements both in isolated strength of the hamstrings and in a coordinated activity – that is, short-term maximal speed running. The ordinary training performed by the control group did not cause any such changes. The hamstring training was performed as a combination of heavy concentric and eccentric overloading. Such a combination of concentric and eccentric training has been shown to cause larger strength improvements than concentric training alone (Colliander & Tesch, 1990; Dudley et al., 1991; Hather et al., 1991). There are studies demonstrating that eccentric training may cause more pronounced strength gains than pure concentric training (Hortobagyi et al., 1996b; Seger et al., 1998). However, in the present study it could not be determined whether the preventive effect on hamstring injuries could be attributed to the extra eccentric overloading as such. It is worth noting that eccentric training is receiving increased recognition as a rehabilitation tool, especially in connection with tendon injuries (Alfredson et al., 1998).

The model used for eccentric overload in this study builds upon fundamental mechanics – that is, the utilisation of inertia – and the training equipment was introduced by Berg & Tesch (1994). The apparatus has a simple construction and is easy to use. It is important, however, that a careful introduction and familiarisation is given for the equipment to be used optimally. The extra training was applied relatively seldom in the present study, every fifth day for the first 4 weeks and every fourth day during the remaining 6 weeks. Still, muscle soreness was experienced by

most of the players. The number of players complaining about soreness gradually decreased over the training period (11/15 after the first session, 9/15 after the eighth session, 7/15 after the last session).

Specific muscle training involves training of muscles in isolated movements. The aim of this type of training is to increase the performance of a muscle group to a higher level than can be attained by soccer activity alone and then to be able to use this enhanced capacity in an integrated movement. This appears to be the case here as maximal running speed increased after the specific hamstring training protocol. The hamstring muscles have a complex anatomy and the function of the four individual muscle portions, three of which span both the knee and hip joints, is not fully understood. The activation pattern, documented primarily with surface electromyography (Nilsson et al., 1985; Simonsen et al., 1985), shows two major periods of activation in fast running – one at the end of swing, the other during support. The hamstrings are involved in braking and stabilisation of the hip and knee joints and they contribute to propulsion primarily through hip extension (Mann et al., 1986). The hamstring muscle group is likely to have an essential role also in

other parts of the soccer game, such as jumping and cutting.

Perspectives

Specific training of the hamstring muscle group is an integral part of the training protocol for many athletes in individual sports, but is probably not common among team sports, such as soccer. The positive results from the present study should give an incentive for it to be utilised more systematically within elite soccer, both from an injury prevention and from performance enhancement point of view. However, a larger scale study would be desirable as a basis for more definite recommendations.

Key words: eccentric overload; hamstring strain; range of motion; running speed; soccer players; strength training.

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References

- Agre JC. Hamstring injuries: proposed aetiological factors, prevention and treatment. *Sports Med* 1985; 2: 21–33.
- Agresti A. A survey of exact inference for contingency tables. *Statist Sci* 1992; 7: 131–153.
- Alfredson H, Pietilä T, Jonsson P, Lorentzon R. Heavy-load eccentric calf-muscle training for the treatment of chronic Achilles tendinosis. *Am J Sports Med* 1998; 26: 360–366.
- Árnarson Á, Gudmundsson Á, Dahl HA, Jóhansson E. Soccer injuries in Iceland. *Scand J Med Sci Sports* 1996; 6: 40–45.
- Askling C, Lund H, Saartok T, Thorstensson A. Self-reported hamstring injuries in student-dancers. *Scand J Med Sci Sports* 2002; 12: 230–235.
- Askling C, Tengvar M, Saartok T, Thorstensson A. Sports-related hamstring strains – two cases with different etiologies and injury sites. *Scand J Med Sci Sports* 2000; 10: 304–307.
- Bennell K, Wajswelner H, Lew P, et al. Isokinetic strength testing does not predict hamstring injury in Australian Rules footballers. *Br J Sports Med* 1998; 32: 309–314.
- Berg HE, Tesch PA. A non-gravity dependent ergometer to be used for resistance training in space. *Aviat Space Environ Med* 1994; 65: 752–756.
- Clanton T, Coupe K. Hamstring strains in athletes: diagnosis and treatment. *Am J Orthop Surg* 1998; 6: 237–248.
- Colliander EB, Tesch PA. Effects of eccentric and concentric muscle actions in resistance training. *Acta Physiol Scand* 1990; 140: 31–39.
- 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* 2002; 30: 199–203.
- De Smet A, Best T. MR imaging of the distribution and location of acute hamstring injuries in athletes. *AJR* 2000; 174: 393–399.
- Dudley GA, Tesch PA, Miller BJ, Buchanan P. Importance of eccentric actions in performance adaptations to resistance training. *Aviat Space Environ Med* 1991; 62: 543–550.
- Ekstrand J, Gillquist J. Soccer injuries and their mechanisms: a prospective study. *Med Sci Sports Exerc* 1983a; 15: 267–270.
- Ekstrand J, Gillquist J. The avoidability of soccer injuries. *Int J Sports Med* 1983b; 4: 124–128.
- Ekstrand J, Wiktorsson M, Öberg B, Gillquist J. Lower extremity goniometric measurements: study to determine their reliability. *Arch Phys Med Rehabil* 1982; 63: 171–175.
- Garrett WE, Califf JC, Bassett FH III. Histochemical correlates of hamstring injuries. *Am J Sports Med* 1984; 2: 98–103.
- Garrett WE. Muscle strain injuries. *Am J Sports Med* 1996; 24: 2–8.
- Garrett WE. Muscle strain injuries: clinical and basic aspects. *Am J Sports Med* 1990; 22: 436–443.
- Hather BM, Tesch PA, Buchanan P, Dudley GA. Influence of eccentric actions on skeletal muscle adaptations to resistance training. *Acta Physiol Scand* 1991; 143: 177–185.
- Heidt RS, Sweeterman LM, Carlonas RL, Traub JA, Tekulve FX. Avoidance of soccer injuries with preseason conditioning. *Am J Sports Med* 2000; 28: 659–662.
- Hortobagyi T, Hill JP, Houmard JA, Fraser DD, Lambert NJ, Israel RG. Adaptive responses to muscle lengthening and shortening in humans. *J Appl Physiol* 1996b; 80: 765–772.
- Inklaar H. Soccer injuries II. Aetiol and prevention. *Sports Med* 1994b; 18: 81–93.
- Inklaar H. Soccer injuries I. Incidence and severity. *Sports Med* 1994a; 18: 55–73.
- Järvinen T, Kääriäinen M, Järvinen M, Kalimo H. Muscle strain injuries. *Curr Opin Rheumatol* 2000; 12: 155–161.

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- Kannus P. Immobilization or early mobilization after an acute soft-tissue injury? *Phys Sportmed* 2000; 28: 55–63.
- Kujala UM, Orava S, Järvinen M. Hamstring injuries. *Am J Sports Med* 1997; 23: 397–404.
- Lüthje P, Nurmi I, Kataja M, et al. Epidemiology and traumatology of injuries in elite soccer: a prospective study in Finland. *Scand J Med Sci Sports* 1996; 6: 180–185.
- Mann RA, Morgan GT, Dougherty SE. Comparative electromyography of the lower extremity in jogging, running and sprinting. *Am J Sports Med* 1986; 14: 501–510.
- Morgan BE, Oberlander MA. An examination of injuries in major league soccer. The inaugural season. *Am J Sports Med* 2001; 29: 426–430.
- Nilsson J, Thorstensson A, Halbertsma J. Changes in leg movements and muscle activity with speed of locomotion and mode of progression in humans. *Acta Physiol Scand* 1985; 123: 457–475.
- Orchard J. Intrinsic and extrinsic risk factors for muscle strains in Australian football. *Am J Sports Med* 2001; 29: 300–303.
- Orchard J, Marsden J, Lord S, Garlick D. Preseason hamstring muscle weakness associated with hamstring muscle injury in Australian footballers. *Am J Sports Med* 1997; 25: 81–85.
- Östenberg A, Roos H. Injury risk factors in female European football. A prospective study of 123 players during one season. *Scand J Med Sports* 2000; 10: 279–285.
- Seger JY, Arvidsson B, Thorstensson A. Specific effects of eccentric and concentric training on muscle strength and morphology in humans. *Eur J Appl Physiol* 1998; 79: 49–57.
- Simonsen EB, Thomsen L, Klausen K. Activity of mono- and biarticular leg muscles during sprint running. *Eur J Appl Physiol* 1985; 54: 524–532.
- Stanton P, Purdam C. Hamstring injuries in sprinting – the role of eccentric exercise. *J Orthop Sports Phys Ther* 1989; 10: 343–349.
- Taylor DC, Dalton JD Jr, Seaber AV, Garrett WE Jr. Experimental muscle strain injury. Early functional and structural deficits and the increased risk for re-injury. *Am J Sports Med* 1993; 21: 190–194.
- Thorsson O. Muscle injuries in athletes. (Thesis) Medical faculty, Lund University, 1996.
- 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: 435–440.
- Worrell T. Factors associated with hamstring injuries. *Sports Med* 1994; 17: 338–345.
- Yamamoto T. Relationship between hamstring strains and leg muscle strength. *J Sports Med Phys Fitness* 1993; 33: 194–199.