Available online at www.sciencedirect.com

SciVerse ScienceDirect

Journal of Sport and Health Science 1 (2012) 92–101

www.jshs.org.cn

Review

Injury rate, mechanism, and risk factors of hamstring strain injuries in sports: A review of the literature

Hui Liu [a], William E. Garrett [b], Claude T. Moorman [b], Bing Yu [c,*]

[a] Sports Biomechanics Laboratory, College of Human Movement Science, Beijing Sport University, Beijing 100084, China
[b] Sports Medicine Center, Duke University, Durham, NC 27710, USA
[c] Center for Human Movement Science, The University of North Carolina at Chapel Hill, Chapel Hill, NC 27599, USA

Received 6 April 2012; revised 25 May 2012; accepted 14 June 2012

Abstract

Hamstring strains are one of most common sports injuries. The purpose of this literature review is to summarize studies on hamstring strain injury rate, mechanism, and risk factors in the last several decades with a focus on the prevention and rehabilitation of this injury. Hamstring injury commonly occurs in sporting events in which high speed sprinting and kicking are frequently performed, such as Australian football, English rugby, American football, and soccer. Basic science studies have demonstrated that a muscle strain injury occurs due to excessive strain in eccentric contraction instead of force, and that elongation speed and duration of activation before eccentric contraction affect the severity of the injury. Hamstring strain injury is likely to occur during the late swing phase and late stance phase of sprint running. Shortened optimum muscle length, lack of muscle flexibility, strength imbalance, insufficient warm-up, fatigue, lower back injury, poor lumbar posture, and increased muscle neural tension have been identified as modifiable risk factors while muscle compositions, age, race, and previous injuries are non-modifiable risk factors. The theoretical basis of some of these risk factors, however, is lacking, and the results of clinical studies on these risk factors are inconsistent. Future studies are needed to establish the cause-and-effect relationships between those proposed risk factors and the injury.

Keywords: Hamstring injury; Mechanism; Prevention; Rehabilitation; Sport medicine

1. Introduction

Hamstring strain injury is one of the most common injuries in sports, and causes significant loss of training and competition time and significantly affects the quality of life of injured athletes. This indicates a need to prevent this injury. Hamstring muscle injury also has a high re-injury rate, which frustrates the injured athletes as well as the clinicians and increases cost of the treatment. This indicates a need to improve current prevention and treatment strategies for hamstring strains. To prevent hamstring strain injury and improve the treatment for this injury, understanding the injury rate, mechanisms, and risk factors is essential. Significant research efforts have been made to understand hamstring muscle strain injury and re-injury over the last several decades. These research efforts provided further insight into prevention, treatment and clinical practice. The purpose of this literature review is to summarize studies on hamstring strain injury rate, mechanism, and risk factors with a focus on the prevention and rehabilitation of this injury.

* Corresponding author.
E-mail address: uncbyu@gmail.com (B. Yu)
Peer review under responsibility of Shanghai University of Sport

ELSEVIER Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jshs.2012.07.003

2. Injury rate

A hamstring muscle strain injury is defined as posterior thigh pain, where direct contact with the thigh is excluded as a cause of the injury, with hyperintense within the hamstring muscle(s) that can be detected in magnetic resonance imaging (MRI).[1] Hamstring injuries are often diagnosed based on clinical and/or ultrasound examinations. They commonly occur in the athletes of many popular sport events in which high speed sprinting and kicking are frequently performed, including Australian football, English rugby, soccer, and American football.

Hamstring muscle strain injury is the most common and prevalent injury in Australian football. Verrall et al.[2] reported that 30% of Australian football players in two clubs had posterior thigh pain over one season. Orchard and Seward[3] reported a hamstring muscle strain injury rate of six injuries per club per season in Australian football between 1997 and 2000. Hoskins and Pollard[4] reported the same injury rate between 1987 and 2003. Gabbe et al.[5] found that 16% of Australian football players sustained hamstring muscle strain injuries during the 2000 season alone with an incidence of four injuries per 1000 player hours.

Hamstring injuries are also very common in English rugby. Brooks et al.[6] reported an incidence of 0.27 hamstring muscle strain injuries per 1000 player training hours and 5.6 injuries per 1000 player match hours, respectively, between 2002 and 2004. They also reported that, on average, hamstring muscle strain injuries resulted in 17 days of lost training/playing time. Their results indicate that the hamstring muscle strain injury was the second most commonly seen injury in English rugby.

Woods et al.[7,8] found that hamstring strain injury accounted for 11% of the total injuries in preseason trainings, and 12% of the total injuries in competition seasons in English professional soccer. A total of 13,116 days and 2029 matches were missed because of these injuries with an average of 90 days and 15 matches missed per club per season and 18 days and three matches missed per injury. Arnason et al.[9] and Dadebo et al.[10] also reported that hamstring strain injuries represented 11% of all injuries in professional soccer in England, 13% in Norway, and 16% in Iceland, respectively. Ekstrand and Gillquist[11] revealed that hamstring strain injury represented 17% of all injuries and presented in 12% of players in soccer in Europe. The results of these studies demonstrate that hamstring strain injury is among the most common acute injuries in European soccer.

Hamstring muscle strain injury is also common in American football. A review of the medical database of the National Football League (NFL) between 1987 and 2000 indicated that 10% of all injuries in American college football players likely to play in the NFL were hamstring strain injuries.[12] Feeley et al.[13] reported that 12% of all injuries in NFL training camps were hamstring strain injuries, making it the second most commonly seen injury. Elliott et al.[14] reported that the average hamstring strain injury rate of NFL players during a 10-year period was 0.77 per 1000 athlete-exposure and represented 13% of all injuries among NFL players.

Many studies have also reported that hamstring muscle strain injury frequently occurs in many popular individual sports, such as track and field, waterskiing, cross-country skiing, downhill skiing, judo, cricket, and bull riding.[15−21] Besides sports, dancing is another physical activity that has a high risk for hamstring muscle strain injury. Askling et al.[22] reported that 34% of dancers have experienced acute hamstring strain injuries and 17% had overuse injuries of hamstring muscles.

3. Recurrence rate

Hamstring strain injury has a very high recurrence rate. In English professional soccer, hamstring strain injury reoccurred in between 12% and 48% of the players.[8,10,23,24] The recurrence rate of hamstring strain injury has been reported to be two times higher than that of other injuries in English professional soccer.[8] In Australian football, 34% of the players reinjured their hamstring muscles within a year of returning to play after their initial hamstring strain injuries.[3] Australian football players had the highest risk (13%) of recurrence of hamstring muscle strain injury during the first week of returning to play.[25] In addition, the persistence of the recurrence was reported to continue for many weeks after returning to play with a cumulative recurrence risk of 31% over the entire season in comparison to 15%, 12%, 11%, and 5% of recurrence risks for ankle sprain, thigh contusion, medial collateral ligament strain, and concussion, respectively.[25] Recurrent hamstring muscle strain injuries are generally more severe and result in significantly more lost time in comparison to the initial injury.[25]

4. Consequences of the hamstring muscle strain injury

The consequences of a hamstring muscle strain depend on the severity of the injury. There is no standardized classification system for the severity of muscle strain injuries; however, different classification systems share a common categorization. Combining anatomical diagnosis, physical examination, ultrasound, and imaging, the severity of muscle strain injuries is generally categorized as Grade I: mild strain injury with minimum tear of the musculotendinous unit and minor loss of strength, Grade II: moderate strain injury with a partial tear of the musculotendinous unit and a significant loss of strength that results in significant functional limitations, and Grade III: severe strain injury with a complete rupture of the musculotendinous unit and is associated with severe functional disability.[26,27] The precise definitions of different grades may vary among specific classification systems. The averaged time losses for different grades of hamstring muscle strain injuries in European professional soccer are 17 ± 10 days for Grade I, 22 ± 11 days for Grade II, and 73 ± 60 days for Grade III.[28]

The majority (97%) of all hamstring strains in soccer are classified as grade I and grade II.[29] The complete tear of the hamstring muscle is rare, occurring in roughly 1% of all hamstring injuries, however, the consequences are usually much more severe.[8] Grade III injuries can result in an avulsion fracture of the ischium, an avulsion of the ischial apophysis, or a pure avulsion of the hamstring tendons themselves, depending on the patient's age.[30] The rare incidence of complete rupturing of the hamstring is often misdiagnosed as a simple "hamstring pull", resulting in improper treatment thereby leading to the development of chronic pain and potential disability.[30]

Because the symptoms of a grade I and grade II muscle strain injuries may be negligible or entirely absent at rest or in activities of daily living, the patient may prematurely return to activity. This may lead to repeatedly unsuccessful efforts to return to sports, resulting in re-injuries or a development of chronicity of the injury and symptoms, even longer rehabilitation times, and, in worst cases, the end of an athletic career.[31] Muckle[32] pointed out that recurrent hamstring injuries may cause lumbar spine abnormalities, meniscal problems in the knee, adhesion of the lateral popliteal nerve, abnormal quadriceps power, and enthesopathies. Hernesman et al.[33] reported a case of motor dysfunction of the sciatic nerve from a chronic hamstring strain injury. Petersen et al.[34] reported 46 new and eight recurrent injuries resulting in a total of 1163 days of absence from football (ranging from 3 to 136 days with a mean of 21.5 days and a median of 16 days per injury) among 374 elite Danish soccer players over a 12-month period.

5. General mechanism of muscle strain injury

Understanding the general mechanism of muscle strain injury is essential for understanding the specific mechanisms of hamstring muscle strain injury. Tremendous research efforts have been made in the last two decades to understand the general mechanism of muscle strain injury. The results of previous studies demonstrate that muscle strain in eccentric contraction is the primary cause of the muscle strain injury affected by muscle strength and contraction velocity.

Garrett et al.[35] studied the biomechanics of muscle strain injury using rabbit extensor digitorum longus and tibialis anterior models. They compared the strain, force, and energy absorbed at the time the muscle was stretched to the point of injury in three experimental groups: passive stretching group, eccentric contraction group stimulated at 16 Hz, and eccentric contraction group stimulated at 64 Hz. Muscle strain injury was defined as the increase of muscle length from the muscle resting length divided by the muscle resting length. Muscle resting length was defined as the muscle length at which the muscle parallel element starts to generate force as muscle length increases. All injuries occurred at the distal muscle-tendon junctions with minimum deformation in the tendons. The results of this study showed no significant differences in muscle strain among the three groups when muscle strain injury occurred. The results of this study also showed that the force generated by the eccentric contraction groups when muscle strain injuries occurred was significantly greater than that by the passive stretch group, and that the forces generated by the two eccentric contraction groups were not significantly different. The results of this study further showed that the eccentric contraction groups absorbed significantly more mechanical energy before injury occurred, and that the eccentric contraction group at the higher activation level absorbed significantly more mechanical energy than the eccentric contraction group at the lower activation level. These results suggest that muscle strain is the primary cause of the injury regardless of the muscle activation level. These results also suggest that a muscle generates greater force in eccentric contraction than in passive stretch when a muscle strain injury occurs, and that the force a muscle generated in eccentric contraction when a muscle strain injury occurs is not affected by the muscle activation level. These results further suggest that the higher the activation level of a muscle during eccentric contraction, the more mechanical energy the muscle would absorb before a muscle strain injury occurs. A later study by Lieber and Friden[36] also demonstrated that lower grade muscle strain injury similar to that of delayed onset muscle soreness was sensitive to the strain not the force.

As a continuation of their previous study, Nikolaou et al.[37] compared the strain injury sites and muscle strain at failure among rabbit anterior tibialis, extensor digitorum longus, rectus femoris, and gastrocnemius muscles that represent four architectures: fusiform, unipennate, bipennate, and multipennate. The results of this study showed that more than 97% of strain injuries in the anterior tibialis, extensor digitorum longus, and rectus femoris occurred at the distal muscle-tendon junction while only 55% of the injuries in the gastrocnemius occurred in this region. The other 45% involved distal as well as proximal muscle-tendon junctions. The elongation speed did not affect where an injury occurred.

Best et al.[38] studied the effects of elongation speed on the biomechanical characteristics of the muscle strain injury using a rabbit anterior tibialis model. The results of this study showed that muscle material failure occurred at the distal muscle-tendon junction when the elongation speeds were at 4 and 40 cm/s, and that failure occurred at the distal muscle belly when the elongation speed was at 100 cm/s. The results of this study also showed that the external loading at failure was sensitive to elongation speed, and that the greater the elongation speed was, the greater the external loading at failure. These results suggest that the muscle strain injury site moves toward proximal from distal muscle-tendon junction while muscle elongation speed is increasing, and that the greater the elongation speed is, the greater the muscle contraction force when injury occurs. This study further showed that the total muscle axial deformation and strain at failure were not elongation speed sensitive. This result was likely due to a low statistical power in the data analysis. The data showed a trend that the total muscle axial deformation and strain at failure decreased as the elongation speed increased, which indicates that muscle strain injury may occur with less muscle strain as elongation speed increases.

Brooks and Faulkner[39] investigated the effects of muscle elongation speed during eccentric contraction on the severity of muscle strain injury using a mouse extensor digitorum longus model. The severity of a muscle strain injury was quantified by the deficit in maximum isometric contraction after the injury. Their results showed that the deficit in the maximum isometric contraction force after a muscle strain injury could be predicted from the muscle strain and elongation speed during the eccentric contraction that induced the injury. The role of muscle elongation speed in predicting the deficit in maximum isometric contraction force after a muscle strain injury depended on the muscle strain. The contribution of the muscle elongation speed to the prediction of the severity of strain injury increased as the muscle strain increased when muscle strain was large. These results suggest that the greater the muscle elongation speed in an eccentric contraction is, the more severe the muscle strain injury will be when the muscle strain is large.

Lovering et al.[40] studied the effect of muscle activation before eccentric contraction on the severity of muscle strain injury using a rat tibialis anterior model. The degree of injury was also determined by the loss of the maximum isometric contraction force after the injury. The results showed a significant negative correlation between the duration of the muscle activation before eccentric contraction and the amount of loss of the maximum isometric contraction force after the injury, particularly when the duration of muscle activation was less than 50 ms before the eccentric contraction. These results indicate that a suddenly activated eccentric contraction is more likely to cause severe muscle strain injury.

6. Mechanism of hamstring strain injury

The majority of hamstring muscle strain injuries occur in sports that require high speed running such as American football, Australia football, basketball, soccer, rugby, and track and field.[41] Verrall et al.[42] reported that 65 out of 69 confirmed hamstring muscle strain injuries during two playing seasons of Australia football occurred during running activities. Gabbe et al.[5] reported that over 80% of the confirmed hamstring muscle strain injuries in community level Australia football occurred in running or sprinting. Woods et al.[8] reported that over 60% of the hamstring injuries occurred during running in English professional soccer. Brooks et al.[6] reported that over 68% of hamstring muscle strain injuries in English rugby occurred during running, not including turning and scrimmaging which are similar to running. Askling et al.[31] identified 18 athletes who had first time hamstring muscle strain injuries from major track and field clubs in Sweden. All 18 athletes were sprinters, and their injuries all occurred during competition when the speed was maximum or close to maximum.

Besides running, kicking is another activity in which hamstring muscle strain injury frequently occurs. Gabbe et al.[5] reported that 19% of the confirmed hamstring muscle strain injuries in community level Australian football occurred during kicking while over 80% in running or sprinting. Brooks et al.[6] reported that about 10% of the hamstring muscle strain injuries in English rugby occurred during kicking. Brooks et al.[6] also found that the hamstring muscle strain injuries occurred in kicking were more severe than those occurred in other activities in terms of lost play time.

Several studies have been conducted on the biomechanics of running to better understand the mechanism of hamstring muscle strain injury. Mann and Sprague[43,44] comprehensively described sagittal plane joint resultant moments in sprinting. The results of their studies demonstrated a peak knee flexion moment and a peak hip extension moment immediately after foot strike, which was suggested as a factor related to the incident of hamstring muscle strain injury. However, previous studies on the general mechanism of muscle strain injury demonstrated that great muscle force was not a necessary condition for a strain injury.

Wood[45] presented joint resultant moments and power, electromyography (EMG), and hamstring muscle lengths in sprinting. These data confirmed the finding of a peak knee flexion moment and a peak of hip extension moment immediately after the foot strike by Mann and Sprague.[43,44] These data, however, also demonstrated that knee and hip joint resultant powers were all positive when the peak knee flexion moment and peak hip extension moment occurred immediately after the foot strike. This suggests that the hamstring muscle group is in a concentric contraction after the foot strike, in which a hamstring muscle strain injury is not likely to occur.[45] The hamstring muscle length and EMG data demonstrated that hamstring muscles were in eccentric contractions during the late swing phase before foot strike and late stance phase before takeoff.[45] These data suggest that hamstring muscle strain injury may occur before foot strike and before takeoff.

Two recent studies confirmed the data in the previous study.[45] Thelen et al.[46] also found a hamstring muscle eccentric contraction during the late swing phase of treadmill sprinting, and suggested that the potential for hamstring muscle strain injury existed during the late swing phase. Their results, however, did not show a hamstring muscle eccentric contraction during the stance phase as Wood[45] did. Yu et al.[47] analyzed the biomechanics of ground sprinting, and also found that the hamstring was in eccentric contraction during the late swing phase as well as during the late stance phase as reported by Wood. Yu et al.[47] suggested that hamstring muscles were at the risk for strain injury during the late stance phase as well as during the late swing phase. However, hamstrings may have higher risk for strain injury during the late swing phase than during the late stance phase because the lengths of the hamstring muscles were significantly longer during the late swing phase than during the late stance phase.[47]

7. Risk factors

Understanding risk factors for hamstring strain injury is critical for developing prevention and rehabilitation strategies. Many risk factors for hamstring muscle strain injury have been identified in the literature, however, only a few of these are evidence-based while the majority are theory-based. These risk factors can be categorized as modifiable factors and non-modifiable factors.[48] Modifiable risk factors include shortened optimum muscle length, lack of muscle flexibility, strength imbalance, insufficient warm-up, fatigue, low back injury, and increased muscle neural tension (Table 1). Non-modifiable risk factors include muscle compositions, age, race, and previous injuries (Table 1).

7.1. Shortened optimum muscle length

Optimum muscle length is defined as the muscle length at which the muscle contractile element generates maximum force, which is similar to the muscle resting length.[49,50] Brocket et al.[51] demonstrated that legs with hamstring muscle strain injury histories have a significantly greater knee flexion angle for the maximum knee flexion torque in comparison to legs without hamstring muscle strain injury histories. This means that legs with hamstring muscle strain injury histories may have shorter optimum hamstring muscle lengths and thus higher muscle strains in comparison to legs without injury histories for the same range of motion. This suggests that shortened optimum hamstring muscle length is a risk factor for hamstring strain injury. However, a recent prospective study on risk factors of hamstring injuries in sprinters did not show a significant difference in the knee flexion angle for the peak knee flexion torque in preseason test between injured and uninjured athletes.[52]

7.2. Lack of muscle flexibility

Poor muscle flexibility has been repeatedly suggested as a modifiable risk factor for muscle strain injury. A recent study provided theoretical support for this suggestion from a point of view of the effect of hamstring flexibility on isometric knee flexion angle—torque relationship.[53] This study demonstrated that subjects with poor hamstring flexibility had a greater knee flexion angle for the maximum knee flexion torque in an isometric contraction test in comparison to subjects with normal hamstring flexibility. This result indicates that an athlete with poor hamstring flexibility may have shorter optimum hamstring muscle lengths in comparison to athletes with normal hamstring flexibility. As previously discussed, shorter optimum muscle length may result in higher muscle strain for the same range of motion, and thus increase the risk for hamstring strain injury. However, the results of clinical studies on the effect of hamstring flexibility on the risk for hamstring muscle strain injury are inconsistent. Worrell et al.[54] conducted a case-control study in which 16 athletes who had hamstring strain injuries within the past 18 months and 16 sports and dominant leg matched controls without injury were tested for their hamstring flexibility and concentric and eccentric strength at 60°/s and 180°/s. The results showed a significant difference in hamstring flexibility between injured and matched control groups. Two prospective studies indicated that English soccer players who sustained a hamstring muscle injury had significantly less hamstring muscle flexibility measured before their injuries compared to their uninjured counterpart.[55,56] These studies support poor hamstring flexibility as a risk factor for hamstring muscle strain injury. However, several other studies showed no significant difference in hamstring flexibility prior to hamstring muscle strain injuries between injured and uninjured athletes.[52,57−59] A study by Gabbe et al.[60] showed that elite Australian football players who had recurrences of hamstring muscle strain injury appeared to have better hamstring flexibility in comparison to their counterpart without recurrence of the injury. The inconsistency among these studies may be due to differences in control group, control of other risk factors, and injury risk measures in study designs. Further studies with improved research designs are needed to determine the effects of flexibility on the risk of hamstring muscle strain injury.

Table 1
Proposed risk factors for hamstring muscle strain injury in the literature.

Category	Proposed risk factor	Evidence	
		Basic science	Clinical
Modifiable	Shortened optimum muscle length	Yes	Lacking
	Lack of muscle flexibility	Yes	Controvert
	Strength imbalance	Lacking	Controvert
	Insufficient warm-up	Yes	Lacking
	Fatigue	Yes	Lacking
	Low back injury	Lacking	Controvert
	Increased muscle neural tension	Lacking	Association
Non-modifiable	Muscle compositions	Yes	Lacking
	Age	Lacking	Controvert
	Race	Yes	Yes
	Previous injuries	Yes	Yes

7.3. Hamstring strength imbalance

Hamstring strength imbalance is a commonly proposed modifiable risk factor. Two hamstring strength measures have been used to quantify hamstring strength imbalance: bilateral hamstring strength asymmetry and hamstring to quadriceps strength ratio. Hamstring strength imbalance quantified by either of these two measures is considered a risk factor for hamstring muscle strain injury. Many prevention programs have been designed in attempt to prevent hamstring muscle strain injury through strength training. This review, however, found that the research results on the role of hamstring strength imbalance played in the risk of hamstring strain injury are inconsistent.

Orchard et al.[59] predicted hamstring muscle strain injuries for 62 legs of Australian football players using hamstring strength measures as independent variables. The results showed that the injured legs had significantly lower concentric isokinetic hamstring strength and hamstring to quadriceps strength ratio tested at a speed of 60°/s compared to uninjured legs. In addition, injured athletes had significantly lower injured to uninjured concentric isokinetic hamstring strength tested at 60°/s compared to uninjured athletes. However, the sensitivity and specificity of the prediction of hamstring strain injury from hamstring strength were 28% and 98%, respectively, which means that the hamstring strength had a better prediction of no injury than injury. Croisier et al.[61] reported a significant difference in the ratio of hamstring eccentric strength tested at 30°/s to quadriceps concentric strength tested at 240°/s between a hamstring strain injury recurrence group and a non-recurrence group of soccer, track and field, and martial arts athletes. Croisier et al.[62] found that soccer players with uncorrected preseason hamstring strength imbalance had a significantly higher rate of hamstring strain injury in comparison to those without preseason hamstring strength imbalance, and to those with confirmed correction of preseason hamstring strength imbalance. Sugiura et al.[63] reported similar results for sprinters as those by Orchard et al.[59] for Australian football players. Yeung et al.[52] reported that the hamstring-to-quadriceps concentric strength ratio tested at 180°/s was the best predictor of hamstring strain injury. Fousekis et al.[64] reported that bilateral hamstring eccentric strength asymmetry was the best predictor of hamstring strain injury for soccer players. Askling et al.[65] and Petersen et al.[66] reported that hamstring specific eccentric strength training significantly reduced hamstring injury in Sweden soccer players.

While these studies support hamstring strength imbalance as being a risk factor for hamstring strain injury, several other studies showed otherwise. A retrospective case-control study showed no significant difference in hamstring and quadriceps concentric and eccentric strengths, bilateral strength asymmetries, and hamstring to quadriceps strength ratios at 60°/s and 180°/s.[54] Similar results were reported in another retrospective study.[51] Although the effects of rehabilitation on the strength of those injured athletes were unknown in these two studies, the results were consistent with a prospective study.[67] Two randomized controlled trial studies reported that a hamstring strengthening intervention did not significantly reduce the risk for hamstring strain injury.[30,60] Although investigators of both studies blamed low compliance as the reason for negative results, neither of the studies reported on any other outcome measures of their intervention programs. It is unclear if the negative results in injury rates were due to lack of effect of their intervention program on injury rate or on strength.

Future studies are needed to better understand the effects of strength imbalance and strength training on risk of hamstring strain injury. Basic science studies on the general mechanism of muscle strain injuries demonstrate that muscle strain is the primary cause of muscle strain injury, and have established theoretical connections between muscle strain and flexibility and between flexibility and muscle strain injury. However, the theoretical connection between muscle strength and muscle strain injury still needs to be established. Future studies should consider multiple factors instead of hamstring strength alone, and emphasize the cause-and-effect relationship between strength and injury. Comparisons of hamstring strength between injured and uninjured groups provide little information on this relationship. The time when hamstring strength is tested may need to be carefully arranged in future studies. Schache et al.[68] found that the bilateral hamstring strength asymmetry significantly increased 5 days prior the hamstring strain injuries.

7.4. Insufficient warm-up

Insufficient warm-up has also been suggested as a modifiable risk factor for hamstring muscle strain injury due to early observations that many hamstring muscle strain injuries occurred during the early portions of practices or competitions.[11] This is supported by a study by Safran et al.[69] that demonstrated that increasing muscle temperature increases the muscle length and force at failure of rabbit hind limb muscles. However, a study by Gillette et al.[70] demonstrated that a 20-min warm-up increased body core temperature but did not increase hamstring flexibility. This review failed to find any clinical studies, which showed that an insufficient warm-up results in an increased hamstring muscle strain injury rate.

7.5. Fatigue

The suggestion that fatigue is a modifiable risk factor for hamstring muscle strain injury was also based on the clinical observation that many hamstring muscle strain injuries occurred during the late portions of practices and competitions.[6,8,11] This suggestion was supported by a study by Mair et al.[71] in which the investigators found that although fatigued and non-fatigued muscles failed at the same length, the non-fatigued muscles absorbed significantly less energy before failure. These results indicate that a fatigued athlete may have to increase the elongation to absorb a given amount of energy and thus increased muscle strains in the movement and the risk for muscle strain injury. The study by Small et al.[72] also provides support for fatigue as being a risk factor. They found that fatigue significantly increased the knee flexion angle at which peak knee eccentric flexion torque occurred. This result combined with the results of those studies on the general mechanism of muscle strain injury and optimum hamstring muscle length indicate that hamstring muscle strain may be increased in a given movement when fatigued. To a certain degree, this result also supports increasing hamstring flexibility as a prevention strategy for hamstring strain injury.

7.6. Lumbar disorders

Hamstring strain injury may be associated with low back pain in the zygapophyseal origin area.[73] Mooney and Robertson[74] found increased electrical activities and decreased flexibility of hamstring muscles for patients with low back pain. These results indicate that low back pain may provoke hamstring responses such as increased tension and result in muscle damage.[73] In a retrospective study, Hennessey and Watson[75] found a significant increase of lumbar lordosis among hamstring injured athletes in comparison to their uninjured counterparts, which indicates a possible association between hamstring strain injury and lumbar posture. However, a study by Verrall et al.[2] found that a past history of back injury did correlate with an increased risk of posterior thigh pain, which did not necessarily mean a hamstring strain injury.

7.7. Neural tension

Abnormal neural tension was another proposed modifiable risk factor for the recurrence of hamstring strain injuries.[76] Abnormal neural tension is defined as abnormal physiological and mechanical responses in the neuromuscular system when the normal range of movement and stretch capabilities is exceeded.[77,78] Neural tension can be evaluated using the Slump test.[77,78] Branches of the sciatic nerve can be tethered to the scar after a hamstring injury, and create increased neural tension with or without local irritation, which may result in local damage to the hamstring muscle.[73] Turl and George[76] reported that more than 50% of athletes had abnormal neural tension after non-repetitive grade I hamstring strain injuries. However, as previous studies on the mechanism of muscle strain injury demonstrated, muscle strain injuries are caused by strain, not by force.[35,36] As the relationship between muscle strain injury and abnormal neural tension is still speculative in nature, the relevance of incorporating special mobility techniques including “neural tension positions” in rehabilitation programs has not yet been scientifically established.[29]

7.8. Muscle fiber composition

Several basic science studies have demonstrated that Type II (fast) muscle fibers were more prone to strain injury than Type I (slow) muscle fibers. Garrett et al.[79] noticed that muscles prone to strain injury have more Type II fibers than muscles not prone to strain injury, and that hamstring muscles have a relatively high percentage of Type I fibers compared to other lower extremity muscles. They hypothesized that muscles comprised of a high percentage of fast fibers were prone to strain injury. This hypothesis has been supported by basic science studies. Friden and Lieber[80] demonstrated that eccentric contraction-induced strain injuries predominantly occurred in fast fibers with low oxidative capacity. They hypothesized that oxidative capacity was an important factor that affects the eccentric contraction induced muscle injury. Macpherson et al.[81] demonstrated that fast fibers had more severe strain injury with less strain in comparison to slow fibers. These results combined together indicate that athletes with a higher percentage of type I fibers may be prone to hamstring strain injury as well as other muscle strain injuries. No clinical studies have been found to support this hypothesis.

7.9. Age

Many retrospective and prospective studies have identified age as a risk factor of hamstring strain injury. Orchard et al.[82] found that Australian football players older than 23 years had a significantly higher risk for hamstring strain injuries than players younger than 23 years. Woods et al.[8] and Ekstrand et al.[24] reported similar results for English and European soccer players. Gabbe et al.[5,60] reported that Australian football players older than 25 years sustained more hamstring strain injuries than did their younger counterparts. Verrall et al.[2] estimated that an increase of 1 year in age increased hamstring strain injury rate by 1.3 times for Australian football players, while Henderson et al.[83] estimated that the odds for sustaining hamstring injury increased 1.78 times for each 1 year increase in age for English soccer players. The studies on the hamstring strain injury in rugby and Australian football did not show significantly effect of age on hamstring strain injury rate.[6,84]

Orchard et al.[82] attributed the association between age and the risk for hamstring strain injury to the decrease in hamstring strength induced by hamstring muscle fiber denervation due to L5 and S1 never impingement caused by age-related low lumbar degeneration. He argued that the decrease in hamstring strength as quadricep strength remained unchanged would result in a hamstring strength imbalance relative to the quadricep strength, and thus increased the risk for hamstring strain injury.[82] Orchard et al.’s explanation of the mechanism of the age effect on the risk of hamstring strain injury was based on the theory that muscle strength is a risk factor for muscle strain injury, which has not been validated by basic science and clinical studies. In addition, Orchard et al.’s study[82] did not demonstrate any difference in hamstring strength between their old and young subjects. Gabbe et al.[60] found age related differences in body weight, hip flexor flexibility, and ankle plantarflexor flexibility, but could not explain the connections between these age-related differences and age-related differences in hamstring strain injury rate.

7.10. Race

Different hamstring injury rates in athletes of different races have been repeatedly reported in the literature. Verrall et al.[2] found that Australian football players who were of aboriginal descent had a significantly higher risk of hamstring injuries in comparison to players of other races. Woods et al.[8] reported that English professional soccer players of African descent have a significantly higher risk of hamstring strain injury in comparison to players of other races. Brooks et al.[6] noticed that, although not statistically significant, the incidence of hamstring strain injury among African and Caribbean descents was almost four times that of Caucasian players. These results suggest that individuals of difference races may have different muscle fiber compositions. Ama et al.[85] demonstrated that individuals of African descent have more fast fibers than Caucasians. As previously mentioned, athletes who have more fast fibers may be prone to muscle strain injury. Woods et al.[8] also argued that the increased pelvis anterior tilt of African descents might be another explanation of their elevated hamstring strain injury risk. However, a study by Mosner et al.[86] found no difference in actual pelvis anterior tilt between African and Caucasian individuals.

7.11. Previous hamstring injury

Many studies have demonstrated that a history of hamstring strain injury is a significant risk factor for the recurrence of the injury.[2,4,6,60,67,87–89] Engebretsen et al.[58] suggested that previous injury was the only significant risk factor for new hamstring strain injury for a group of Norwegian soccer players. Based on an animal experiment, Nikolaou et al.[37] suggested that scarring and fibrosis seen in the muscle 7 days after initial strain injury may explain the elevated risk of the injury. As previously mentioned, Brockett et al.[51] demonstrated that the legs with hamstring muscle strain injury histories had a significantly greater knee flexion angle for the maximum knee flexion torque in comparison to the legs without hamstring muscle strain injury histories. This indicates a possibility that previous strain injury resulted in shortened optimum lengths of hamstring muscles and thus increased the risk for injury. However, a recent prospective study by Fousekis et al.[64] reported that previous hamstring injury significantly decreased the odds of injury. A possible explanation for this result is that rehabilitation programs might have eliminated some risk factors or reduced the effects of risk factors for the subjects involved.

Besides the above mentioned risk factors, a study by Sherry and Best[90] showed that poor agility and trunk stabilization may be risk factors for hamstring muscle strain injury while a study by Cibulka et al.[91] showed that sacroiliac joint dysfunction may also be a risk factor. However, similar to many previously discussed risk factors, the scientific basis of these proposed risk factors is not clear.

8. Summary

Hamstring strain injury is one of the most common sports injuries that have significant effects on patients' quality of life and sports career. The high recurrence rate and serious consequences of this injury have not been fully recognized.

Basic science studies have demonstrated that the excessive strain during an eccentric contraction is the general mechanism of muscle strain injury, and that the severity of the injury is affected by the eccentric contraction speed when the muscle strain is large and by the duration of activation before the eccentric contraction. *In vivo* studies demonstrated that hamstring injury is likely to occur during the late swing phase of sprinting when the knee is extending and the hip is flexed and during the late stance phase before takeoff when knee is extending and the trunk is leaning forward.

Many risk factors including poor flexibility, strength imbalance, insufficient warm-up, and fatigue have been proposed as risk factors for hamstring strain injury. Basic science studies have established the connections between muscle strain and strain injury, muscle optimum length and muscle strain, and flexibility and muscle optimum length, which support poor flexibility and insufficient warm-up as risk factors for hamstring strain injury. However, the theoretical basis of hamstring strength imbalance and other proposed risk factors for hamstring strain injury is lacking.

Many clinical studies have been conducted in attempts to provide clinical evidence to support the proposed risk factors. However, the results of those clinical studies are descriptive and controversial. Clinical evidence for current prevention and rehabilitation programs for hamstring injury is lacking.

Future studies are needed to improve the prevention and rehabilitation of hamstring strain injury, particularly randomized controlled trials, in order to establish the cause-and-effect relationships between those proposed risk factors and hamstring strain injury. Future clinical research should consider the interaction effects of multiple risk factors on the risk of hamstring strain injury. Clinical studies on risk factors and prevention and rehabilitation programs should be based on the injury mechanisms established in basic science studies. Evidence-based prevention and rehabilitation programs for hamstring strain injuries can be developed only after risk factors of the injury have been scientifically identified, confirmed, and understood through well-designed basic science and clinical studies.

References

1. Verrall GM, Slavotinek JP, Barnes PG. The effect of sports specific training on reducing the incidence of hamstring injuries in professional Australian rules football players. *Br J Sports Med* 2005;**39**:363−8.
2. 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**:435−9. discussion 440.
3. Orchard J, Seward H. Epidemiology of injuries in the Australian football league, seasons 1997−2000. *Br J Sports Med* 2002;**36**:39−44.
4. Hoskins WT, Pollard H. Injuries in Australian rules football. A review of the literature. *Australas Chiropr Osteopat* 2003;**11**:49−56.
5. 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.
6. Brooks JH, Fuller CW, Kemp SP, Reddin DB. Incidence, risk, and prevention of hamstring muscle injuries in professional rugby union. *Am J Sports Med* 2006;**34**:1297−306.
7. Woods C, Hawkins RD, Hulse M, Hodson A. The football association medical research programme: an audit of injuries in professional football − analysis of preseason injuries. *Br J Sports Med* 2002;**36**:436−41.
8. Woods C, Hawkins RD, Maltby S, Hulse M, Thomas A, Hodson A. The football association medical research programme: an audit of injuries in professional football − analysis of hamstring injuries. *Br J Sports Med* 2004;**38**:36−41.
9. Arnason A, Andersen TE, Holme I, Engebretsen L, Bahr R. Prevention of hamstring strains in elite soccer: an intervention study. *Scand J Med Sci Sports* 2008;**18**:40−8.
10. Dadebo B, White J, George KP. A survey of flexibility training protocols and hamstring strains in professional football clubs in England. *Br J Sports Med* 2004;**38**:388−94.
11. Ekstrand J, Gillquist J. The frequency of muscle tightness and injuries in soccer players. *Am J Sports Med* 1982;**10**:75−8.
12. Brophy RH, Chehab EL, Barnes PG, Lyman S, Rodeo SA, Warren RF. Predictive value of orthopedic evaluation and injury history at the NFL combine. *Med Sci Sports Exerc* 2008;**40**:1368−72.
13. Feeley BT, Kennelly S, Barnes RP, Muller MS, Kelly BT, Rodeo SA, et al. Epidemiology of national football league training camp injuries from 1998 to 2007. *Am J Sports Med* 2008;**36**:1597−603.
14. Elliott MC, Zarins B, Powell JW, Kenyon CD. Hamstring muscle strains in professional football players: a 10-year review. *Am J Sports Med* 2011;**39**:843−50.
15. Chakravarthy J, Ramisetty N, Pimpalnerkar A, Mohtadi N. Surgical repair of complete proximal hamstring tendon ruptures in water skiers and bull riders: a report of four cases and review of the literature. *Br J Sports Med* 2005;**39**:569−72.
16. Connell DA, Schneider-Kolsky ME, Hoving JL, Malara F, Buchbinder R, Koulouris G, et al. Longitudinal study comparing sonographic and MRI assessments of acute and healing hamstring injuries. *AJR Am J Roentgenol* 2004;**183**:975−84.
17. De Smet AA, Best TM. MR imaging of the distribution and location of acute hamstring injuries in athletes. *AJR Am J Roentgenol* 2000;**174**:393−9.
18. Koulouris G, Connell D. Evaluation of the hamstring muscle complex following acute injury. *Skeletal Radiol* 2003;**32**:582−9.
19. Kurosawa H, Nakasita K, Nakasita H, Sasaki S, Takeda S. Complete avulsion of the hamstring tendons from the ischial tuberosity. A report of two cases sustained in judo. *Br J Sports Med* 1996;**30**:72−4.

20. Sallay PI, Friedman RL, Coogan PG, Garrett WE. Hamstring muscle injuries among water skiers. Functional outcome and prevention. *Am J Sports Med* 1996;**24**:130−6.
21. Sarimo J, Lempainen L, Mattila K, Orava S. Complete proximal hamstring avulsions: a series of 41 patients with operative treatment. *Am J Sports Med* 2008;**36**:1110−5.
22. Askling C, Lund H, Saartok T, Thorstensson A. Self-reported hamstring injuries in student-dancers. *Scand J Med Sci Sports* 2002;**12**:230−5.
23. Hawkins RD, Hulse MA, Wilkinson C, Hodson A, Gibson M. The association football medical research programme: an audit of injuries in professional football. *Br J Sports Med* 2001;**35**:43−7.
24. Ekstrand J, Hagglund M, Walden M. Epidemiology of muscle injuries in professional football (soccer). *Am J Sports Med* 2011;**39**:1226−31.
25. Orchard J, Best TM. The management of muscle strain injuries: an early return versus the risk of recurrence. *Clin J Sport Med* 2002;**12**:3−5.
26. Clanton TO, Coupe KJ. Hamstring strains in athletes: diagnosis and treatment. *J Am Acad Orthop Surg* 1998;**6**:237−48.
27. Petersen J, Holmich P. Evidence based prevention of hamstring injuries in sport. *Br J Sports Med* 2005;**39**:319−23.
28. Ekstrand J, Healy JC, Walden M, Lee JC, English B, Hagglund M. Hamstring muscle injuries in professional football: the correlation of MRI findings with return to play. *Br J Sports Med* 2012;**46**:112−7.
29. Croisier JL. Factors associated with recurrent hamstring injuries. *Sports Med* 2004;**34**:681−95.
30. Gidwani S, Bircher MD. Avulsion injuries of the hamstring origin − a series of 12 patients and management algorithm. *Ann R Coll Surg Engl* 2007;**89**:394−9.
31. Askling CM, Tengvar M, Saartok T, Thorstensson A. Acute first-time hamstring strains during high-speed running: a longitudinal study including clinical and magnetic resonance imaging findings. *Am J Sports Med* 2007;**35**:197−206.
32. Muckle DS. Associated factors in recurrent groin and hamstring injuries. *Br J Sports Med* 1982;**16**:37−9.
33. Hernesman SC, Hoch AZ, Vetter CS, Young CC. Foot drop in a marathon runner from chronic complete hamstring tear. *Clin J Sport Med* 2003;**13**:365−8.
34. Petersen J, Thorborg K, Nielsen MB, Holmich P. Acute hamstring injuries in Danish elite football: a 12-month prospective registration study among 374 players. *Scand J Med Sci Sports* 2010;**20**:588−92.
35. Garrett WE, Safran MR, Seaber AV, Glisson RR, Ribbeck BM. Biomechanical comparison of stimulated and nonstimulated skeletal muscle pulled to failure. *Am J Sports Med* 1987;**15**:448−54.
36. Lieber RL, Friden J. Muscle damage is not a function of muscle force but active muscle strain. *J Appl Physiol* 1993;**74**:520−6.
37. Nikolaou PK, Macdonald BL, Glisson RR, Seaber AV, Garrett WE. Biomechanical and histological evaluation of muscle after controlled strain injury. *Am J Sports Med* 1987;**15**:9−14.
38. Best TM, McElhaney JH, Garrett Jr WE, Myers BS. Axial strain measurements in skeletal muscle at various strain rates. *J Biomech Eng* 1995;**117**:262−5.
39. Brooks SV, Faulkner JA. Severity of contraction-induced injury is affected by velocity only during stretches of large strain. *J Appl Physiol* 2001;**91**:661−6.
40. Lovering RM, Hakin M, Moorman CT, De Deyne PG. The contribution of contractile pre-activation to loss of function after a single lengthening contraction. *J Biomech* 2005;**38**:1501−7.
41. Garrett Jr WE. Muscle strain injuries. *Am J Sports Med* 1996;**24**:S2−8.
42. Verrall GM, Slavotinek JP, Barnes PG, Fon GT. Diagnostic and prognostic value of clinical findings in 83 athletes with posterior thigh injury: comparison of clinical findings with magnetic resonance imaging documentation of hamstring muscle strain. *Am J Sports Med* 2003;**31**:969−73.
43. Mann R, Sprague P. A kinetic analysis of the ground leg during sprint running. *Res Q Exerc Sport* 1980;**51**:334−48.
44. Mann RV. A kinetic analysis of sprinting. *Med Sci Sports Exerc* 1981;**13**:325−8.
45. Wood GA. Biomechanical limitations to sprint running. *Med Sport Sci* 1987;**25**:58−71.
46. Thelen DG, Chumanov ES, Best TM, Swanson SC, Heiderscheit BC. Simulation of biceps femoris musculotendon mechanics during the swing phase of sprinting. *Med Sci Sports Exerc* 2005;**37**:1931−8.
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. Clark RA. Hamstring injuries: risk assessment and injury prevention. *Ann Acad Med Singap* 2008;**37**:341−6.
49. Hatze H. *Myocybernetic control models of skeletal muscle*. Pretoria: University of South Africa; 1981.
50. Kaufman FR, An KN, Chao EY. Incorporation of muscle architecture into muscle length−tension relationship. *J Biomech* 1989;**22**:943−8.
51. Brocket CL, Morgan DL, Proske U. Predicting hamstring strain injury in elite athletes. *Med Sci Sports Exerc* 2004;**36**:379−87.
52. Yeung SS, Suen AM, 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**:589−94.
53. Alonso J, McHugh MP, Mullaney MJ, Tyler TF. Effect of hamstring flexibility on isometric knee flexion angle-torque relationship. *Scand J Med Sci Sports* 2009;**19**:252−6.
54. Worrell TW, Perrin DH, Gansneder BM, Gieck JH. Comparison of isokinetic strength and flexibility measures between hamstring injured and noninjured athletes. *J Orthop Sports Phys Ther* 1991;**13**:118−25.
55. Bradley PS, Olsen PD, Portas MD. The effect of static, ballistic, and proprioceptive neuromuscular facilitation stretching on vertical jump performance. *J Strength Cond Res* 2007;**21**:223−6.
56. Witvrouw E, Danneels L, Asselman P, D'Have T, 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.
57. Burkett LN. Causative factors in hamstring strains. *Med Sci Sports* 1970;**2**:39−42.
58. Engebretsen AH, Myklebust G, Holme I, Engebretsen L, Bahr R. Intrinsic risk factors for hamstring injuries among male soccer players: a prospective cohort study. *Am J Sports Med* 2010;**38**:1147−53.
59. 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**:81−5.
60. 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 Sports* 2006;**16**:7−13.
61. Croisier JL, Forthomme B, Namurois MH, Vanderthommen M, Crielaard JM. Hamstring muscle strain recurrence and strength performance disorders. *Am J Sports Med* 2002;**30**:199−203.
62. Croisier JL, Ganteaume S, Binet J, Genty M, Ferret JM. Strength imbalances and prevention of hamstring injury in professional soccer players: a prospective study. *Am J Sports Med* 2008;**36**:1469−75.
63. Sugiura Y, Saito T, Sakuraba K, Sakuma K, Suzuki E. Strength deficits identified with concentric action of the hip extensors and eccentric action of the hamstrings predispose to hamstring injury in elite sprinters. *J Orthop Sports Phys Ther* 2008;**38**:457−64.
64. Fousekis K, Tsepis E, Poulmedis P, Athanasopoulos S, Vagenas G. Intrinsic risk factors of non-contact quadriceps and hamstring strains in soccer: a prospective study of 100 professional players. *Br J Sports Med* 2011;**45**:709−14.
65. Askling C, Karlsson J, Thorstensson A. Hamstring injury occurrence in elite soccer players after preseason strength training with eccentric overload. *Scand J Med Sci Sports* 2003;**13**:244−50.
66. Petersen J, Thorborg K, Nielsen MB, Budtz-Jørgensen E, Hölmich P. Preventive effect of eccentric training on acute hamstring injuries in men's soccer: a cluster-randomized controlled trial. *Am J Sports Med* 2011;**39**:2296−303.
67. Bennell K, Wajswelner H, Lew P, Schall-Riaucour A, Leslie S, Plant D, et al. Isokinetic strength testing does not predict hamstring injury in Australian rules footballers. *Br J Sports Med* 1998;**32**:309−14.
68. Schache AG, Crossley KM, Macindoe IG, Fahrner BB, Pandy MG. Can a clinical test of hamstring strength identify football players at risk of hamstring strain? *Knee Surg Sports Traumatol Arthrosc* 2011;**19**:38−41.

69. Safran MR, Garrett WEJ, Seaber AV, Glisson RR, Ribbeck BM. The role of warmup in muscular injury prevention. *Am J Sports Med* 1988;**16**:123−9.
70. Gillette TM, Holland GJ, Vincent WJ, Loy SF. Relationship of body core temperature and warm-up to knee range of motion. *J Orthop Sports Phys Ther* 1991;**13**:126−31.
71. Mair SD, Seaber AV, Glisson RR, Garrett WE. The role of fatigue in susceptibility to acute muscle strain injury. *Am J Sports Med* 1996;**24**:137−43.
72. 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.
73. Devlin L. Recurrent posterior thigh symptoms detrimental to performance in rugby union: predisposing factors. *Sports Med* 2000;**29**:273−87.
74. Mooney V, Robertson J. The facet syndrome. *Clin Orthop Relat Res* 1976;**115**:149−56.
75. Hennessey L, Watson AW. Flexibility and posture assessment in relation to hamstring injury. *Br J Sports Med* 1993;**27**:243−6.
76. Turl SE, George KP. Adverse neural tension: a factor in repetitive hamstring strain? *J Orthop Sports Phys Ther* 1998;**27**:16−21.
77. Newsham K. The role of neural tension in minor and recurrent hamstring injury, part 1: evaluation. *Athl Ther Today* 2006;**11**(4):54−6.
78. Newsham K. The role of neural tension in hamstring injury, part 2: treatment and rehabilitation. *Athl Ther Today* 2006;**11**(9):66−9.
79. Garrett Jr WE, Califf JC, Bassett 3rd FH. Histochemical correlates of hamstring injuries. *Am J Sports Med* 1984;**12**:98−103.
80. Friden J, Lieber RL. Structural and mechanical basis of exercise-induced muscle injury. *Med Sci Sports Exerc* 1992;**24**:521−30.
81. Macpherson PC, Schork MA, Faulkner JA. Contraction-induced injury to single fiber segments from fast and slow muscles of rates by single stretches. *Am J Physiol* 1996;**271**:C1438−46.
82. Orchard J, Steet E, Walker C, Ibrahim A, Rigney L, Houang M. Hamstring muscle strain injury caused by isokinetic testing. *Clin J Sport Med* 2001;**11**:274−6.
83. Henderson G, Barnes CA, Portas MD. Factors associated with increased propensity for hamstring injury in English premier league soccer players. *J Sci Med Sport* 2010;**13**:397−402.
84. Koulouris G, Connell DA, Brukner P, Schneider-Kolsky M. Magnetic resonance imaging parameters for assessing risk of recurrent hamstring injuries in elite athletes. *Am J Sports Med* 2007;**35**:1500−6.
85. Ama PF, Simoneau JA, Boulay MR, Serresse O, Theriault G, Bouchard C. Skeletal muscle characteristics in sedentary black and Caucasian males. *J Appl Physiol* 1986;**61**:1758−61.
86. Mosner EA, Bryan JM, Stull MA, Shippee R. A comparison of actual and apparent lumbar lordosis in black and white adult females. *Spine (Phila Pa 1976)* 1989;**14**:310−4.
87. Orchard JW. Intrinsic and extrinsic risk factors for muscle strains in Australian football. *Am J Sports Med* 2001;**29**:300−3.
88. Upton PA, Noakes TD, Juritz JM. Thermal pants may reduce the risk of recurrent hamstring injuries in rugby players. *Br J Sports* 1996;**30**:57−60.
89. Warren P, Gabbe BJ, Schneider-Kolsky M, Bennell KL. Clinical predictors of time to return to competition and of recurrence following hamstring strain in elite Australian footballers. *Br J Sports Med* 2010;**44**:415−9.
90. Sherry MA, Best TM. A comparison of 2 rehabilitation programs in the treatment of acute hamstring strains. *J Orthop Sports Phys Ther* 2004;**34**:116−25.
91. Cibulka MT, Rose SJ, Delitto A, Sinacore DR. Hamstring muscle strain treated by mobilizing the sacroiliac joint. *Phys Ther* 1986;**66**:1220−3.