Hamstring Muscle Injury: The Influence of Strength, Flexibility, Warm-Up, and Fatigue

By: Teddy W. Worrell, EdD, PT, ATC* and David H. Perrin, PhD, ATC†

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Abstract:
Hamstring muscle injury is a complex problem for athletes, physicians, physical therapists, and athletic trainers. This injury tends to recur and to limit participation in athletic competition. The etiology of hamstring muscle injury continues to be confusing and incomplete for clinicians and researchers. The purposes of this paper are: I) to review briefly hamstring muscle group anatomy and function, 2) to review the clinical and animal research literature concerning the role of strength, flexibility, warm-up, and fatigue in hamstring muscle injury, 3) to present an evaluation and rehabilitation scheme for hamstring muscle injury, 4) to describe a theoretical multiple factor hamstring injury model, and 5) to offer recommendations concerning prevention of hamstring muscle injury. During preseason screening and rehabilitation following hamstring muscle injury, clinicians should consider the influence of hamstring strength, flexibility, warm-up, and fatigue on muscle performance. Additional research concerning these factors is recommended.

Article:
Hamstring muscle injury represents a significant portion of lower extremity musculotendinous injury in athletic competition (5, 11, 25, 28). Often, the athlete describes a sharp pain during sprinting, kicking, or jumping. Occasionally, only tightness develops in the posterior thigh after activity. Physicians, physical therapists, and athletic trainers are well aware of the frequent occurrence of this noncontact injury. Furthermore, hamstring muscle injury tends to recur (1, 6, 7, 16, 17).

While initial treatment of rest, ice, compression, and elevation is generally accepted by physicians, physical therapists, and athletic trainers (2, 32), rehabilitation protocols vary considerably (8, 10, 20, 22, 31, 34). Lack of agreement concerning rehabilitation may reflect absent or conflicting scientific information regarding the etiology of hamstring muscle injury.

The literature supports more than a single etiological factor as the cause of hamstring muscle injury (1, 6, 7, 9, 16, 20, 24, 27, 36, 37, 39). Moreover, contradiction exists concerning many of these factors. For example, some authors have reported that lack of hamstring strength (6, 7, 20) and flexibility (24, 39) are more common in the hamstring-injured athlete while other authors have reported no relationship between lack of hamstring strength (24, 30, 39) and flexibility (6, 11, 24) in the hamstring-injured athlete (Table I). Adequate evidence exists, however, in both the

* Assistant professor, physical therapy, Krannert Graduate School of Physical Therapy, University of Indianapolis, Indianapolis, IN
† Associate professor and director, Sports Medicine/Athletic Training Education Research Laboratory and Graduate Athletic Training Education, University of Virginia, Charlottesville, VA

clinical and animal research literature to support the relationship of several factors to hamstring muscle injury: strength, flexibility, warm-up, and fatigue.

The purposes of this paper are: /) to review briefly hamstring muscle group anatomy and function, 2) to review the clinical and animal research literature concerning the role of strength, flexibility, warm-up, and fatigue in hamstring muscle injury, 3) to present an evaluation and rehabilitation scheme for hamstring muscle injury, 4) to describe a theoretical multiple factor hamstring injury model, and 5) to offer recommendations concerning prevention of hamstring muscle injury.

HAMSTRING MUSCLE GROUP ANATOMY

The biceps femoris, semitendinosis, and semimembranosus muscles comprise the hamstring muscle group, which is primarily composed of type 11 muscle fibers (16). Two heads compose the biceps femoris, or lateral hamstring. The long head originates from the distal portion of the sacrotuberous ligament and the posterior aspect of the ischial tuberosity; the short head, which does not cross the hip joint, originates from the femur at the lateral lip of the linea aspera, the proximal two-thirds of the supracondylar line, and the lateral intramuscular septum. Both heads form the muscle belly and pass distally to insert on the lateral side of the head of the fibula, the lateral condyle of the tibia, and the deep fascia of the lower leg. The biceps femoris has a dual innervation: the long head is innervated by the tibial portion, and the short head by the peroneal portion of the sciatic nerve (19).

Etiology	Literature	
	Supports	Refutes
Hamstring fatigue	Dorman 1971	
Insufficient hamstring flexibility	Liemohn 1978, Worrell et al 1991	Burkett 1970, Ekstrand & Gillquist 1982
Insufficient hamstring strength	Burkett 1970, Christenson & Wiseman 1972, Heiser et al 1984	Liemohn 1978, Patton et al 1989, Worrell et al 1991
High hamstring forces	Mann & Sprauge 1980, Woods et al 1984	
Insufficient warm-up	Dorman 1971, Ekstrand et al 1983	
Sciatic nerve entrapment	Puranen & Orva 1988	

TABLE 1. *Proposed etiologies of hamstring injuries that have been subjected to scientific inquiry.*

The semitendinosis and semimembranosus muscles comprise the medial hamstrings. The semitendinosis has a common origin with the long head of the biceps femoris from the ischial tuberosity and derives its name from its long tendon of insertion. This tendon forms the medial wall of the popliteal fossa. It inserts proximally into the medial surface of the tibia and the deep fascia of the lower leg and distally to form a member of the pes anserinus with the gracilis and sartorius. The semimembranosus originates via a thick tendon from the ischial tuberosity proximal and medial to the biceps femoris and the semitendinosis and inserts into the medial-posterior aspect of the tibia via fibrous expansions. The semitendinosis and semimembranosus muscles are innervated by the tibial portion of the sciatic nerve (19).

HAMSTRING MUSCLE GROUP FUNCTION

In order to fully appreciate the role of the hamstring muscle group in athletic activities, a brief review of the gait cycle in both walking and running is necessary. The gait cycle in walking is divided into a stance phase (60%) and a swing phase (40%). The stance phase consists of heel strike, foot flat, and toe off. The swing phase is described as the period from toe off to heel strike. One complete gait cycle is described as heel strike to heel strike of the same leg. During walking, one limb is always in contact with the ground (21).

During running, a period of noncontact with the ground occurs that is called nonsupport or float. With increasing running speeds, the length of time in stance phase decreases while the amount of time in float phase increases. Thus, with increasing speeds of running and sprinting, the period of time in which the muscles of the lower extremity must work is shortened. Therefore, these muscles must contract faster and absorb more force during a shorter period of time (26).

Mann and Sprague (27) describe the function of the hamstrings in walking as active at the end of the swing phase until foot flat has been completed. The hamstrings contract eccentrically to control knee extension in the swing phase. At heel strike, they provide stability and initiate flexion of the knee. During running, the hamstring muscles become active during the last third of the swing phase, at which time the tibia is being decelerated eccentrically and the hip flexes concentrically. Just prior to foot contact, the hamstrings continue to be active for hip extension and knee flexion (26).

During sprinting, Woods et al (37) reported high eccentric forces (150 J) by the hamstring muscle group in the late swing phase in an attempt to decelerate the lower leg prior to ground contact. The authors also reported simultaneous proximal hamstring activity for hip extension.

EVALUATION OF HAMSTRING MUSCLE INJURY

The athlete with an acute hamstring muscle injury (noncontact) will most often describe a sudden sharp pain in the posterior thigh. Occasionally, the athlete will describe a gradual onset of symptoms, such as dull ache, burning, and/or tightness. These vague symptoms are usually seen after several clays or weeks of strenuous workouts. Generally, evaluation of hamstring muscle injuries reveals point tenderness in the proximal hamstring region near the ischial tuberosity, painful active knee flexion, and painful restricted passive knee extension. Garrett et al (17) reported that Computerized Axial Tomographies (C.A.T.) of 10 subjects with acute hamstring muscle injury revealed that eight of the 10 injury sites were detected by C.A.T. The most common site of injury was proximal in the lateral portion of the hamstring. Ecchymosis and swelling may be observed extending distally to the midposterior thigh or, in some cases, to the popliteal space.

PROPOSED ETIOLOGIES OF HAMSTRING MUSCLE INJURY

Hamstring Muscle Strength

Several authors have discussed the importance of hamstring strength and the hamstring/quadriceps (ham/quad) ratio in relation to hamstring muscle injury (6, 7, 20, 24, 30, 39). Burkett (6) and

Christenson and Wiseman (7) were the first to document the importance of hamstring strength using cable tensiometers. The authors predicted that predisposition to hamstring muscle injury exists when bilateral deficits in isometric hamstring strength or ham/quad ratios exceed 10%. Burkett (6) correctly predicted four of six (66%) hamstring muscle injuries in professional football players who presented with at least a 10% deficit in hamstring strength. Christenson and Wiseman (7) predicted two of five (40%) hamstring injuries in collegiate track athletes who had at least a 10% deficit in hamstring strength. It should be noted that both studies, which established a 10% deficit in hamstring strength indices between extremities as predictive of hamstring injury, were performed approximately 20 years ago. There has been only one replication of these studies. Liemohn (24) prospectively reported isometric hamstring strength and ham/quad ratios of 27 track athletes. During the following track season, six athletes sustained hamstring muscle in jury. Liemohn did not find a significant difference in isometric hamstring strength or ham/quad ratios ("not substantial enough to elucidate specific precipitators of hamstring strain") between hamstring-injured and noninjured athletes.

Heiser et al (20) reported a significant reduction ($p < 0.005$) of hamstring muscle injury after implementing a minimum isokinetic concentric ham/quad ratio of .60 at 60°/sec as a prerequisite to participation in a collegiate football program. However, the authors stated that the effects of a simultaneously initiated hamstring stretching and strengthening program may have confounded their results.

In contrast, Worrell et al (39) reported in a retrospective study that 16 hamstring-injured athletes matched by position, sport, and motor dominance to a control group did not reveal a statistically significant difference ($p > 0.05$) between the two groups in hamstring strength indices of isokinetic concentric and eccentric peak torque at 60 and 180°/sec. Paton et al (30), in a retro-spective study, reported that seven professional soccer players with a previous history of hamstring muscle injury matched by position and motor dominance to a control group did not reveal a statistically significant difference ($p > 0.05$) between the two groups in hamstring strength indices of isokinetic concentric ham/ quad ratios at 30, 60, and 120°/sec. Both of these studies agree with Liemohn (24), who prospectively re ported that no significant difference existed in isometric ham/quad ratios between hamstring-injured and non- injured track athletes. Thus, the relationship between hamstring muscle injury and hamstring strength is not clear.

Mann and Sprague (27) studied 15 collegiate and world class sprinters to determine lower extremity muscle moment patterns. They utilized a force platform to record horizontal and vertical component forces combined with high speed filming. The hamstring muscles developed the greatest force of any lower extremity muscles at ground contact. At ground contact, the hamstrings are switching from maximal eccentric to concentric force production. The authors postulated that this is the period of hamstring muscle injury (closed kinetic chain). Of particular interest in this study was the fact that the fastest sprinters were those who could control the forces at the hip and knee by generating the largest hamstring forces (hip extension and knee flexion). A high magnitude of hamstring force at ground contact was significantly correlated to a history of hamstring injury ($r = 0.70$, $p = 0.01$).

Wood et al (37) reported electromyographic, kinematic, and kinetic analyses of nine sprinting athletes while using a force platform and two high-speed cameras. As a result of their findings, the authors postulated that hamstring muscle injury occurs during the late swing phase of running. Thus, the hamstring muscles are subjected to high forces during both open and closed kinetic chain activities of sprinting.

Since the ability of connective and muscle tissue to absorb force is directly proportional to both passive and active components (18, 33), it seems logical that a stronger hamstring muscle group can absorb greater forces. This concept is supported by studies indicating that muscle strength imbalances are related to muscle injuries (6, 7). The inability of research (24, 30, 39) to consistently demonstrate a significant relationship between hamstring strength and injury may be due to methodological differences (for example, small sample size and retrospective type analyses) or confounding variables (for example, hamstring fatigue, flexibility, and warm- up). Further research clarifying the relationship of hamstring strength to hamstring muscle injury is needed. Specifically, prospective research comparing hamstring and quadriceps concentric and eccentric strength indices to one another and to body weight measures is needed.

Flexibility

Several authors have investigated the relationship between hamstring flexibility and hamstring injury (6, 11, 24, 39). Worrell et al (39) and Liemohn (24) reported hamstring-injured subjects were less flexible than noninjured subjects. In contrast, Burkett (6) reported no difference in hamstring flexibility between hamstring-injured and noninjured subjects. In addition, Ekstrand and Gillquist (11) reported no relationship between hamstring flexibility and hamstring injury. Burkett (6) utilized the Wells sit-and-reach method to determine hamstring flexibility. Liemohn (24) and Ekstrand and Gillquist (11) utilized the straight-leg-raise method. Worrell et al (39) utilized the passive-knee-extension test.

Only two authors have reported reliability data to support their method of assessing hamstring muscle length (13, 39). Worrell et al (39) reported the use of a passive-kneeextension test (N = 20, test-retest Pearson product moment coefficient of r = 0.98). During the passiveknee-extension test, each subject is placed supine with the hip positioned at 90° of flexion. The hip is then stabilized in this position by the sub ject placing both hands around the distal thigh just proximal to the knee joint with the fingers interlocked while maintaining the foot in plantarflexion. The opposite leg is maintained in 0° of hip flexion. The universal goniometer is utilized to determine the hip position. To determine hamstring flexibility, the knee is passively extended by the tester while the hip is maintained at 90° of flexion by the subject. The stationary arm of the goniometer is then placed parallel to the midline of the femur and the movable arm is placed parallel to the midline of the fibula. The point in the knee range of motion where resistance is encountered while maintaining the hip at 90° is determined as the end of hamstring range of motion. This evaluation technique is similar to the active-knee-extension method recommended by Gajdosik and Lusin (15) for determining hamstring flexibility. Ekstrand et al (I 3) reported the use of the straight-leg-raise (SLR) method for assessing hamstring muscle length (N = 22, coefficient of variation = 1.9 ± .07%). The SLR test for hamstring flexibility assessment may be confounded by pelvic rotation (3, 4) and foot position (14). The Wells sit-and-reach test for hamstring flexibility assessment may be confounded by the flexibility of the upper extremity and lumbar and thoracic spines.

Ekstrand and Gillquist (11) reported that 180 soccer players had greater hamstring flexibility (SLR) than a group of 86 nonplayers. They reported no correlation between past injury and muscle tightness. In contrast, Worrell et al (39) reported that the hamstring-injured group's injured extremity was significantly less flexible than the noninjured extremity ($p < 0.05$). Also, the authors reported that both of the injured group's hamstring muscles were less flexible than the noninjured group's hamstring muscles ($p < 0.05$). It is plausible that a less flexible extremity existed prior to hamstring injury. Evidence demonstrates that areas of inflammation and adhesion occur following muscle injury (18, 29). Furthermore, calcification within the hamstring muscles following muscle strain has been documented on C.A.T. (17). Therefore, it seems possible that loss of hamstring flexibility is a possible sequelae to hamstring muscle injury.

Since the ability of connective and muscle tissue to absorb force is related to its resting length, the greater the resting length, ie., flexibility, the greater the ability to absorb forces and avoid strain (33). Therefore, the importance of hamstring flexibility can not be overemphasized.

Warm-Up

Dorman (9) reported on 140 hamstring injuries that occurred during a 3-year period. Ile stated that hamstring muscle injuries occurred either early or late in practice or game situations. Dorman suggested inadequate warm-up and fatigue were the precipitating factors for injury.

Ekstrand and Gillquist (12) prospectively reported the injury rates of 180 male soccer players in Sweden. The authors found strains were most common in the lower extremity and occurred most often at the beginning of practice and game sessions in teams not utilizing warm-ups < 0.058) or specific stretching exercises *(t* = 2.1).

Safran et al (33) demonstrated in an *in vivo* rabbit model that an exercised muscle (preconditioned) required significantly more force to failure [tibialis anterior *(p* < 0.01), extensor digitorum longus < 0.05), flexor digitorum longus< 0.001)1 than the contralateral muscles that were not exercised. The authors concluded that a warm-up period prior to participation may prevent injury to the musculotendinous unit by increasing its elasticity and force absorption capability.

Fatigue

As mentioned previously, Dorman (9) reported hamstring injuries were more common early or late in game or practice situations. Dorman did not report any statistical analysis of his data, only general observations and conclusions. The role of muscle fatigue and injury is extremely difficult to study in the field. In an animal model (an in vivo anterior tibialis muscle of the rabbit), Lieber and Friden (23) demonstrated the role of muscle fatigue and eccentric muscle contraction in muscle injury. The anterior tibialis muscle was electrically stimulated (40 Hz for 400 cosec) under isometric, concentric, and eccentric contractions (1,800 contractions over 30 minutes). The authors reported tears in myofibrils (Z-band streaming and A-band damage) only in the eccentric exercised group. During the fatigue protocol, the authors reported that no significant muscle injury occurred in the concentric or isometric exercised groups. The Z-band and A-band damage reported is similar to that seen in human muscle following exhaustive eccentric contraction (35). It is clear that further work is needed concerning fatigue and hamstring muscle injury in athletic population studies.

Theoretical Hamstring Injury Model

The etiology of hamstring muscle injury continues to be an enigma for clinicians and researchers. After reviewing the literature concerning hamstring muscle injury, it appears that several authors support a single cause for hamstring muscle injury. These include lack of strength (6, 7, 20), lack of flexibility (24, 39), improper warm-up (9, 12), or fatigue (9). Figure 1 represents an interpretation of these factors. Confusion exists, however, concerning strength and flexibility, and there is limited information concerning fatigue and warm-up. Therefore, the authors of this paper have developed a theoretical, multiple factor model of hamstring injury (Figure 2). It seems plausible that these factors are related rather than singularly responsible for this injury. For example, muscle fatigue reduces the force capabilities of a muscle (23), and a less flexible muscle or insufficiently warm muscle absorbs less force to failure (18, 33). Therefore, it seems possible that a relationship exists between strength, warm-up, fatigue, and flexibility. Obviously, this is speculative and further research is needed.

RECOMMENDATIONS

Prevention

A comprehensive approach should be utilized in the prevention and rehabilitation of hamstring muscle injury. This approach should be incorporated into preseason screening and evaluation procedures. Athletes involved in sprinting, jumping, and kicking sports are considered high risk and should be selected for hamstring strength and flexibility assessment. When deficits are identified, physical therapists and athletic trainers should monitor the remedial rehabilitation program to ensure progress and compliance.

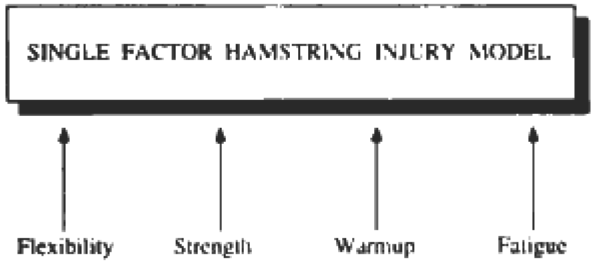

FIGURE 1. *Single factor hamstring injury model.*

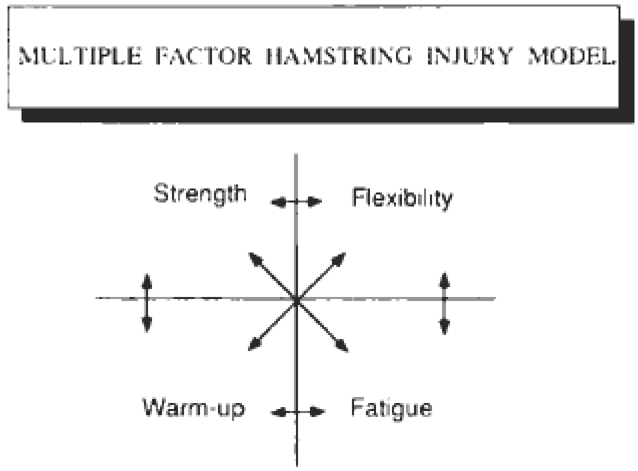

FIGURE 2. *Multiple factor hamstring injury model.*

Assessment of Hamstring Flexibility

An accurate and reliable method of assessing hamstring flexibility is of utmost importance. It is recommended that clinicians establish their accuracy and reliability using the method recommended by Gajdosik and Lusin (15) or Worrell et at (39). Use of the straight leg raise (3, 4, 14) and Wells sit-and-reach technique in assessing hamstring flexibility should be discontinued.

Hamstring Stretching

During the rehabilitation process, many of the hamstring injured subjects in one investigation utilized the hamstring stretching technique of bringing the head/chin toward the knee in a seated or standing position (Figure 3) (39). The results of that study suggest this technique was inadequate for increasing hamstring flexibility. Perhaps, reevaluation of this stretching technique is required. Regardless of the stretching technique, the clinician should monitor hamstring flexibility as recommended to ensure that improvement is occurring in hamstring muscle length. Further research is needed concerning the most effective hamstring stretching technique.

FIGURE 3. Head/chin toward knee hamstring *stretching technique.*

Isokinetic Strength Assessment

Strength assessment following hamstring muscle injury while pain is present will inevitably indicate weakness. Therefore, strength assessment should be performed after the athlete has completed the established rehabilitation protocol, which includes a functional progression of activities in his/her sport. Bilateral assessment of hamstring strength prior to return to maximal sport activity is recommended. Concentric and eccentric strength indices should be documented. Preseason hamstring strength assessment may be beneficial in high risk athletes. This would allow prospective analysis of data concerning these athletes and might be useful in clarifying the relationship between strength and hamstring muscle injury.

Rehabilitation

Any protocol that addresses hamstring rehabilitation should consider the dynamic role of the hamstring muscle group during sprinting. The proximal concentric and distal concentric and eccentric function can be best replicated in the prone position. The length-tension relationship of this position is similar to that of sprinting (38). Both concentric and eccentric progressive resistive exercises should be utilized. If available, high speed isokinetic concentric and eccentric protocols may also be used. Hamstring stretching should be performed before and after activity. An adequate warm-up period of functional activities prior to maximal sport activities is highly recommended.

CONCLUSION

Hamstring muscle injury is a complex injury that probably involves more than one etiological factor. There is evidence to support the influence of strength, flexibility, warm-up, and fatigue on hamstring injury in both clinical and animal research studies. Evaluation and rehabilitation of hamstring muscle injuries should include strength and flexibility assessment. Use of the passive-knee-extension or active-knee-extension test is recommended for assessing hamstring muscle length. Stretching techniques should be monitored to ensure improvement in flexibility measures. Hamstring muscle strengthening should include both concentric and eccentric exercises. Further clinical research in these areas is recommended.

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