Injury Mechanism of Bi-articular Muscle Hamstring during Sprint Running

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Many mechanisms and risk factors of hamstring injury were implicated. In sprinting, the greatest length of the hamstring muscle occurs during later swing phase. However, maximal muscle torque at knee joint and consequent stress on muscle occurs during stance phase. In present paper, we apply the intersegmental dynamics and the optimization model combined with kinematics, ground reaction force (GRF) and Electromyography （EMG） measurement to study the injury mechanisms of hamstring muscle. The findings of intersegmental dynamics analysis revealed that the GRF produced a large extension torque at knee joint during the initial stage of stance phase, meanwhile, the hamstring muscle was required to generate a flexion torque in order to counteract the effect of GRF, this may contribute to the occurrence of hamstring injury. This kind of analysis provides a new approach for understanding the mechanisms of hamstring injury.

KEY WORDS: Hamstring, Injury Mechanism, Sprint Running

INTRODUCTION:

Muscle strain injury is amongst the most common injuries in sprint athletes. The most common strains are to the multi-joint muscles of the lower limb, particularly the hamstring muscle group (De Smet and Best, 2000; Orchard, 2001). The hamstring is a bi-articular muscle comprised of the semimembranosus (SM), simitendinosus (ST) and biceps femoris (BF) and predominantly made up of Type II fast-twitch muscle fibres (Tortora & Grabowski, 2003; Foreman et al, 2006).

Although hamstring muscle strains are a more common injury, researches have disagreed about whether strains occur during late swing or early stance phase during sprinting (Orchard, 2002; Thelen et al., 2006). Current understanding of hamstring injury mechanisms is largely based on biomechanical analyses of injury-free running trials (Mann and Sprague, 1980; Wood, 1987; Thelen et al., 2006) and subjective evidence (Askling et al, 2000; 2006) from injury cases. However, both sources of information carry inherent uncertainties when used to interpret injury mechanisms.

Hamstring injuries are fairly evenly distributed (Orchard, 2001) and previous muscle strain injury is a strong risk factor for future strain injury to the same muscle group. Recent research suggests that hamstring strains often occur due to over-striding when at fast speed, and the mechanism of hamstring strain is probably when the body is leaning forward trying to achieve extra speed and the foot lands too far in front of the center of mass (Orchard, 2002). Foreman et al. (2006) completed prospective studies relating to risk factors associated with hamstring injury, in which a number of potential risk factors, namely; hamstring muscle weakness and thigh muscle imbalance, poor lumbar posture and poor neuromuscular control, decreased muscle flexibility, other previous hamstring injury, anthropometric factors, and muscle fatigue were identified. However, research evidence to substantiate these associations is limited and findings are often conflicting. In this paper we will discuss some of the possible and likely biomechanical factors that contribute to a hamstring strain injury and present a new approach, namely intersegmental dynamics analysis to provide a new perspective to the mechanisms of hamstring injury.

The time of occurrence of hamstring strain injury during sprinting

Although the rate of recurrence of hamstring strains during sprinting, it remains uncertain when in the gait cycle the muscle is injured. It has been suggested that injuries may occur during late swing, when the hip is flexed and the knee is extended. Clinical sports medicine teaching asserts that two-joint muscles strain during sprint activities when undergoing eccentric contractions, which is well summarized in the works of Garrett (1990; 1996).

However, Garrett admits in these reviews that he is merely summarizing popular opinion of the clinical sports medicine literature rather than stating proven fact, which suggests that hamstring muscles are prone to strain injury in late swing phase (eccentric phase) rather than early ground contact (when the hamstring contraction is concentric).

Thelen and co-workers (2005a) used a three-dimensional, 14-segment, 29 degree-of-freedom musculoskeletal model to compute joint angles and hamstring muscle-tendon lengths during sprinting. They conclude that intermuscle differences in hamstring moment arms about the hip and knee may be a factor contributing to the greater propensity for hamstring strain injuries to occur in the biceps femoris (BF) muscle. Their results suggest that peak hamstring muscle-tendon lengths occur during late swing before foot contact, tend to be larger in the BF than in the ST and SD muscles, but do not vary significantly as sprinting speed is increased from submaximal to maximal. The authors found that peak hamstring stretch occurs during the late swing phase of sprinting before foot contact. Electromyography data indicate that the hamstrings are active at this same phase of the gait cycle. Thus, the hamstrings are undergoing an active lengthening contraction during late swing, creating the potential conditions for a strain injury to occur. In addition, through unexpected circumstances, Heiderscheit et al (2005) completed an analysis of whole-body kinematics obtained at the time of an acute hamstring injury. Combined information from statistical techniques in identifying when individual marker trajectories deviated from a periodic pattern with estimates of neuromuscular latencies and electromechanical delay, they concluded that the BF was likely injured as a result of a lengthening contraction during the late swing phase of the running gait cycle. Although providing interesting information, it is difficult to directly assess when an injury occurs based on the kinematic analysis.

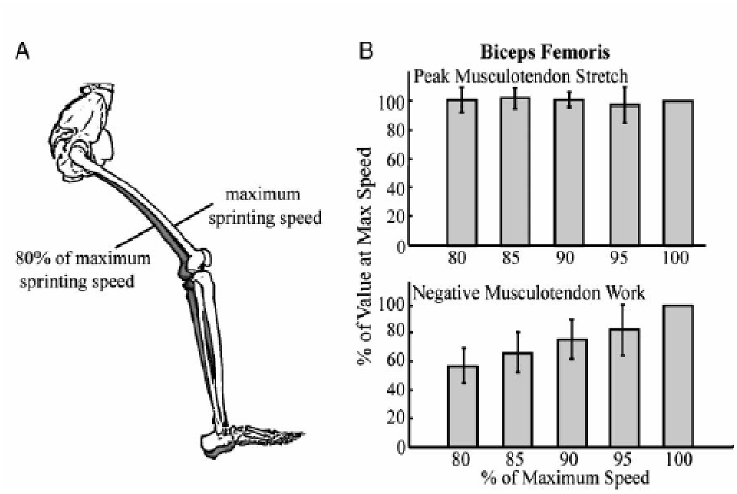

Figure 1. A. Shown is the lower extremity posture at the time of peak hamstring musculotendon stretch. B. Peak stretch is invariant with speed. In contrast to the peak stretch, the negative musculotendon work increases substantially with printing speed (mod. from: Thelen , 2006).

Thelen et al (2005b) had used neuromusculoskeletal model of sprinting to analyze potential hamstring injury mechanisms. The model describes the relationship among muscle excitations, activation dynamics, musculotendon contraction mechanics, and segmental accelerations. The model they used investigated the effects of sprinting speed, musculotendon properties, and coordination on hamstring mechanics during sprinting. Their results revealed that the BF musculotendon complex underwent a stretch-shortening cycle over the later half of swing phase. Peak hamstring musculotendon was found to be invariant across the range of speed, however, the negative musculotendon work done by the hamstring increased considerably with speed (Fig. 1). Stretch and negative work requirements may couple together at high speed to contribute to injury risk. It must be pointed out that the series studies on hamstring injury by Thelen and coauthors were limited

to the swing phase of sprinting. They haven't applied the models to the ground contact phase of sprinting.
However, others have speculated that the potentially large loads associated with ground contact may cause injury during the stance phase of sprinting. The first author to measure muscle moments during sprinting and declare a period in the gait cycle where the hamstrings were prone to tear was Ralph Mann (Mann and Sprague, 1980; Mann, 1981). He measured muscle moments for hip, knee and ankle during sprinting and found that knee flexion moment and hip extension moment were both highest in the early ground contact phase of sprinting. This establishes that the hamstring muscle group is generating the most force during this phase of gait (initial ground contact), and Mann concluded from these that hamstring strains are most likely to occur at this moment.
The model of Mann based on kinetics suggests that the hamstring muscle is most prone to failure when they are most stressed and also generating the most force, when opposing external forces during ground contact.

Intersegmental dynamics analysis of hamstring strain injury

Although the series studies of Thelen and Co-workers, including kinematic analysis and simulation of neuromusculoskeletal models, are very comprehensive and perspective, their analyses were limited to the swing phase of sprinting. The models they developed were solely applied in the swing phase. The reason for this could be that during swing phase, the forward dynamic simulation could be easily applied based on internal force/torque information to predict kinematic data. However, during stance phase of sprinting, the internal force/torque, kinematic of the body and the ground reaction force are interrelated and co-varied synchronously. It is complicated to obtain the relationship among the interacted parameters and thus, the neuromusculoskeletal models and their simulation have not been conducted for study of the support phase of sprinting.
Clinical teaching that stretch (strain) is most responsible for muscle strain injuries (Garrett, 1996), suggests that the hamstring muscle is most prone to failure when most stretched which is when they are contracting eccentrically during the swing phases. Even though we suppose that the hamstring strain injury occurs during eccentric lengthening, it is also the effect of force acting on the muscle. Thus force is the ultimate cause for muscle injury. It is also known that strain injury is the result of excessive forces, which can be either externally applied or passive internal forces, due to strain (Brooks, 2001). However, there are few established models to determine the external force (or stress) that individual muscle is subject to at any given time of the sprinting gait cycle, making it very hard to assess why strain injury actually occurs; and few optimal biomechanical models can be used to understand the underlying mechanisms of multi-joint muscle injuries (Orchard, 2002).
Mann's speculation that muscle and external torque are acting in opposite directions and are tending to neutralize each other is thought to be reasonable. However, Mann and other authors, when publishing their papers, have not quantified the external torque.
During movement, the multiple, interconnected links of human body are affected not only by muscle forces, but also by external forces, as well as motion-dependent forces generated by the moving body segments. The modified formulation of limb dynamics allows quantification of those forces/torques, and thus it is called "intersegmental dynamics" (Zernicke, 1996). At each of the joints of the linked segments, the torques can be divided into five categories - net joint torque (NET), muscle torque (MUS), gravitational torque, motion-dependent torques (MDT) and contact torques (EXT):

$$NET = MUS + GRA + MDT + EXT$$

At the moment of submitting this paper, a research project is being conducted to investigate the neuromechanical limitation factors to sprint speed, in which intersegmental dynamics is quantified and optimal biomechanical model is used combining with kinematics, ground reaction force and EMG analysis during stance and flight phase of maximal sprinting. In a pilot study, we found that the motion-dependent torque (MDT) was less important, and the active muscle torque (MUS) was acting to counterbalance the contact torque (EXT) produced by GRF during initial ground contact phase. Figure 2 shows that the GRF vector passed through in front of knee joint and produced a torque (T_{EXT}) acting to extend the knee joint; meanwhile, the muscle torque (T_{MUS}) must counteract generating a flexion torque at the knee. Since the impact of GRF at this stage is very large, the required counteraction and hence the stress loading on knee flexor was extraordinarily large as well. If the strength of hamstring muscle is not sufficient, it is likely susceptible to strain injury.

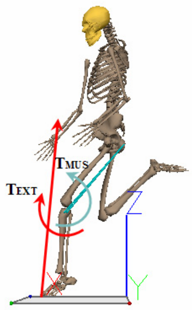

Fig. 2: Diagram of sprinting during the initial contact phase. GRF vector passes through in front of knee joint and produces an extension torque T_{EXT}, hamstring muscle generates a flexion torque T_{MUS} to counteract T_{EXT}.

The EMG results revealed also that the hamstring was most active during the later swing phase and the totally stance phase. Previous studies reported that greater speeds of running were associated with longer periods of hamstring activity during the support phase (Mann et al, 1986; Weimann and Tidow, 1995). The authors believed this further validated the role of the hamstring as hip extensor during the stance phase of sprinting.

The intersegmental dynamics analysis and the optimization model combined with kinematics, GRF and EMG measurement can help us to identify forces that individual muscle undergo and to understand the dynamic loading on knee flexors, to predict the stress loading on hamstrings and furthermore to get insights into the potential mechanisms of hamstring injury during stance phase of sprinting.

Concluding remarks

Many mechanisms and risk factors of hamstring injury could be implicated. In sprinting, the greatest length of the hamstring muscle occurs during later swing phase. However, maximal muscle torque at knee joint and consequent stress on muscle occurs during stance phase. Although Mann and co-authors were the first to measure muscle torques during sprinting and speculated that the hamstring muscle strains are most likely to occur during the initial contact phase due to large external force, they haven't quantified the interrelationship between the muscle torque and the torque produced by external force. Others have used sophisticated neuromusculoskeletal models to provide insights into the mechanisms of hamstring strain, however, the studies focused solely on the swing phase. The findings of intersegmental dynamics analysis revealed that the GRF produced a large extension torque at knee joint during the initial stage of stance phase, meanwhile, the hamstring muscle was required to generate a flexion torque in order to counteract the effect of GRF, this may contribute to the occurrence of hamstring injury. This kind of analysis provides a new approach to understand the mechanisms of hamstring injury.

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