Opinion

Mechanism of hamstring muscle strain injury in sprinting

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Hamstring muscle strain injury is one of the most common injuries in sports involving sprinting and kicking. Hamstring muscle strain injuries occur at a high rate and have a high re-injury rate, which results in loss of training and competition time, which has a significant impact on the quality of life of the injured athletes.[1] Preventing and rehabilitating hamstring muscle strain injury is an important task for clinicians and scientists in sports medicine.

Understanding the mechanisms underlying hamstring injury is critical for developing appropriate strategies to prevent and rehabilitate hamstring injuries. Understanding the general mechanism of muscle strain injury is essential for understanding the specific mechanisms of hamstring muscle strain injury. Many studies using animal models have been conducted in the past 2 decades to determine the general mechanisms of muscle strain injury. The results of these studies point to excessive muscle strain in eccentric contraction or stretching as the primary mechanism of muscle strain injury.

Garrett et al.[2] studied the biomechanics of muscle strain injury using rabbit extensor digitorum longus and tibialis anterior models. They randomly assigned each muscle to a passive stretching group, an eccentric contraction group stimulated at 16 Hz, or an eccentric contraction group stimulated at 64 Hz. Each muscle was stretched to the point of injury. The results showed that all injuries occurred at the distal muscle-tendon junctions with minimum deformation in the tendon. The results further indicated that there was no significant difference in muscle strain at which injury occurred among the 3 experimental groups. However, the force at which injury occurred was significantly greater in the eccentric contraction compared to the passive stretch group muscles. The results also showed the eccentric contraction groups absorbed significantly more mechanical energy prior to injury, and 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 excessive muscle strain is the primary cause of muscle strain injury regardless of the muscle activation level and the force generated by the muscle. These results further suggest that the higher the activation level of a muscle during eccentric contraction, the more mechanical energy the muscle absorbs prior to strain injury.

The results of the study by Garrett et al.[2] were subsequently supported by Lieber and Friden.[3] In their study, rabbit tibialis anterior muscles were strained by 25% of the muscle fiber length at identical rates but different timing of length change relative to muscle activation, thereby producing different muscle forces. They found that maximum tetanic force and other contractile parameters measured after 30 min of cyclic activity were identical for the 2 groups, suggesting that muscle damage was equivalent despite the different forces. In a second experiment, Lieber and Friden[3] used the same protocol, but the muscles were only strained by 12.5% of muscle fiber length. A two-way analysis of variance of both experiments revealed a significant effect of strain magnitude on muscle damage but no significant effect of stretch timing. The investigators concluded that the observed muscle damage after eccentric contraction was due to strain not force, which was similar to the conclusion drawn by Garrett et al.[2]

Lovering et al.[4] studied the effect of muscle activation before eccentric contraction on the severity of muscle strain injury using a rat tibialis anterior model. The loss of maximum isometric force after the injury protocol was used as a measure of the degree of injury. They found a significant negative correlation between the duration of muscle activation prior to the eccentric contraction and the loss of maximum isometric force after the injury protocol, particularly when the duration of muscle activation was less than 50 ms before the onset of the eccentric contraction. These results indicate that a sudden activation during an eccentric contraction causes more severe muscle injury.

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Nikolaou et al.[5] studied the effects of elongation speed on muscle strain injury by comparing the strain injury sites and muscle strain at failure in eccentric contractions among rabbit tibialis anterior, extensor digitorum longus, rectus femoris, and gastrocnemius muscles. These muscles represent 4 architectures: fusiform, unipennate, bipennate, and multipennate. They found that more than 97% of strain injuries in the tibialis anterior, 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% of injuries in the gastrocnemius occurred in the distal and proximal muscle-tendon junctions. The stretch speed did not affect where an injury occurred.

Best et al.[6] studied the effects of elongation speed on muscle strain injuries in rabbit tibialis anterior muscles. They found that muscle failure occurred at the distal muscle-tendon junction when the elongation speeds were 4 cm/s and 40 cm/s, but occurred at the distal muscle belly when the elongation speed was 100 cm/s. They also found that the external loading at failure was sensitive to the stretch speed: greater speed was associated with greater external load at failure. These results suggest that the injury site moves from distal to proximal as muscle elongation speed increases and that greater elongation speeds are associated with greater muscle force at injury occurrence. This study further suggests that muscle axial deformation and strain at failure were not dependent on the speed of elongation. However, there was a trend showing that muscle axial deformation and strain at failure decreased as the elongation speed increased.

Brooks and Faulkner[7] investigated the effects of muscle elongation speed on the severity of muscle strain injury in mouse extensor digitorum longus. The severity of injury was quantified by the deficit in maximum isometric contraction after the injury protocol. They found that the deficit in maximum isometric force could be predicted from the muscle strain and elongation speed. The contribution of the muscle elongation speed to the prediction of the severity of strain injury increased as the muscle strain increased. These results suggest that greater elongation speeds cause more injury for similar muscle strains.

The majority of hamstring muscle strain injuries occur in sports that require high speed running, such as American football, Australian football, basketball, soccer, rugby, and track and field.[8] Verrall et al.[9] reported that 65 out of 69 confirmed hamstring muscle strain injuries during 2 playing seasons of Australian football occurred during running activities. Gabbe et al.[10] reported that more than 80% of confirmed hamstring muscle strain injuries in community-level Australian football occurred during running or sprinting. Woods et al.[11] reported that more than 60% of the hamstring injuries occurred during running in English professional soccer. Brooks et al.[12] reported that more than 68% of hamstring muscle strain injuries in rugby occurred during running, not including turning and scrimmaging, which are similar to running. Askling et al.[13] 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 injuries occur frequently. Gabbe et al.[10] reported that 19% of the confirmed hamstring muscle strain injuries in community-level Australian football occurred during kicking. Brooks et al.[12] reported that about 10% of the hamstring muscle strain injuries in English rugby occurred during kicking. They also found that hamstring muscle strain injuries during kicking were more severe than those occurring in other activities in terms of lost play time.

Several studies have been conducted on the biomechanics of running to understand the specific mechanism of hamstring muscle strain injury. Wood[14] presented joint resultant moments and power, electromyography, and hamstring muscle lengths in sprinting. These data demonstrated that hamstring muscles contract eccentrically in the late swing and late stance phase of sprinting. Considering the results of previous studies with animal models, these data indicate that hamstring muscle strain injuries may occur in late swing before foot strike and in late stance before takeoff.

Two recent studies supported the results of Wood.[14] Thelen et al.[15] found that the hamstring muscles worked eccentrically in the late swing phase of treadmill sprinting and suggested that a 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[14] did. Yu et al.[16] determined hamstring muscle-length changes and activations in sprinting. They found that the hamstrings worked eccentrically in the late swing phase and the late stance phase, as reported by Wood.[14] Yu et al.[16] suggested that the hamstring muscles were at risk of strain injury in the late stance phase and the late swing phase. However, the hamstring muscles are at a much longer length at the end of swing compared to stance, and thus presumably are also at a higher risk for strain injury in late swing compared to late stance.[16] Yu et al.[16] attributed the eccentric contraction during late stance as a possible characteristic of sprinting.

The studies on the general mechanism of muscle strain injury and the specific mechanism of hamstring muscle strain injury set the basis for further studies on prevention of hamstring muscle strain injuries in sprinting. Studies on the general mechanisms of muscle strain injury implicated excessive muscle strain as the direct cause of injury. The key for reducing the risk of hamstring injuries is to reduce maximum muscle strains. Muscle strain is defined as the ratio of muscle length deformation relative to the muscle resting length,[2,3] which suggests that muscle strain can be reduced by either reducing muscle deformation or increasing the resting length. For hamstring strain injuries in sprinting, reducing muscle deformations can be achieved by reducing trunk forward lean and increasing knee flexion, which may not be practical for maximizing performance. This leaves us with the second mechanism: increasing muscle resting length. Two studies in this special section demonstrate that hamstring muscle resting length is positively correlated to hamstring muscle flexibility and that maximal hamstring muscle strain in sprinting is negatively correlated to hamstring muscle flexibility.[17,18] Further studies are needed to determine the effects of flexibility training on hamstring muscle

resting length, maximal hamstring muscle strain in sprinting, and risk for hamstring strain injury.

Authors' contributions

BY drafted the manuscript; HL performed literature searches and helped to draft and revise the manuscript; WEG helped to perform literature search and draft and revise the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

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