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SPECIAL COMMUNICATION

Is There a Potential Relationship Between Prior Hamstring Strain Injury and Increased Risk for Future Anterior Cruciate Ligament Injury?

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Abstract

Hamstring strain injuries (HSIs) are the most prevalent injury in a number of sports, and while anterior cruciate ligament (ACL) injuries are less common, they are far more severe and have long-term implications, such as an increased risk of developing osteoarthritis later in life. Given the high incidence and severity of these injuries, they are key targets of injury preventive programs in elite sport. Evidence has shown that a previous severe knee injury (including ACL injury) increases the risk of HSI; however, whether the functional deficits that occur after HSI result in an increased risk of ACL injury has yet to be considered. In this clinical commentary, we present evidence that suggests that the link between previous HSI and increased risk of ACL injury requires further investigation by drawing parallels between deficits in hamstring function after HSI and in women athletes, who are more prone to ACL injury than men athletes. Comparisons between the neuromuscular function of the male and female hamstring has shown that women display lower hamstring-to-quadriceps strength ratios during isokinetic knee flexion and extension, increased activation of the quadriceps compared with the hamstrings during a stop-jump landing task, a greater time required to reach maximal isokinetic hamstring torque, and lower integrated myoelectrical hamstring activity during a sidestep cutting maneuver. Somewhat similarly, in athletes with a history of HSI, the previously injured limb, compared with the uninjured limb, displays lower eccentric knee flexor strength, a lower hamstrings-to-quadriceps strength ratio, lower voluntary myoelectrical activity during maximal knee flexor eccentric contraction, a lower knee flexor eccentric rate of torque development, and lower voluntary myoelectrical activity during the initial portion of eccentric contraction. Given that the medial and lateral hamstrings have different actions at the knee joint in the coronal plane, which hamstring head is previously injured might also be expected to influence the likelihood of future ACL. Whether the deficits in function after HSI, as seen in laboratory-based studies, translate to deficits in hamstring function during typical injurious tasks for ACL injury has yet to be determined but should be a consideration for future work.

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Hamstring strain injuries (HSIs) are the most common injury sustained by elite athletes in a number of sports. For example, during the 2011 season of the elite Australian football competition, the average incidence of HSIs per club was 4.8 per season, resulting in 16.5 player games missed per club in the same season.[1] Similar data have been reported in the professional rugby league and rugby union.[2,3] In contrast, the incidence of new anterior cruciate ligament (ACL) injuries per club was significantly lower at 0.9 for Australian football and 0.4 for the professional rugby union per season.[1,3] However, the consequences of ACL injury are potentially much more serious because they can result in prolonged absences from training and competition as well as an increased risk of developing osteoarthritis in later life.[4,5] Therefore, both HSIs and ACL injuries present a considerable burden and risk to the success of both sporting clubs and athletes, making them key targets for prevention programs. Evidence exists that points to a relationship between ACL injury and HSI.[6,7] Verrall et al[7] reported that Australian footballers with a past history of severe knee injury (including injury to the ACL) displayed an odds ratio for future HSI of 5.6 (95% confidence interval, 1.1−28.1). The authors postulated that

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these injuries, the subsequent rehabilitation program, or both could result in altered biomechanics of the lower limbs with a resultant increase in the risk of HSI.

To our knowledge, however, very little attention has been given to the potential for previous HSI to increase the risk of sustaining an ACL injury. HSIs are known for high rates of injury recurrence; therefore, recent research has focused on the impact of HSI on neuromuscular hamstring function.[8-15] If neuromuscular hamstring function is altered after injury, this may offer a possible explanation as to why HSIs are so prone to reinjury.[16] Furthermore, given that hamstring function is important for "unloading" the ACL from ground reaction force and subsequent anterior tibial translation during foot plant, it is feasible that neuromuscular dysfunction of the hamstring muscles after HSI may also lead to an increased risk of ACL injury. This theory is supported by research that has reported neuromuscular deficits in the female hamstring, and the fact that ACL injuries are far more prevalent in women athletes compared with men athletes.[17] As such, this clinical commentary aims to present a neuromuscular case that suggests previous HSI could increase the risk of future ACL, by drawing parallels in hamstring dysfunction in previously hamstring strain–injured athletes and women athletes. The known mechanisms for ACL injury, the pertinent neuromuscular deficits reported in the female hamstring, and the reported maladaptations associated with prior HSI will be discussed briefly. The impact of these maladaptations after HSI will then be integrated with the known deficits in neuromuscular function of the female hamstring and the reported mechanisms for ACL injury to suggest a link between prior HSI and the likelihood of future ACL injury. Finally, the impact of which specific hamstring muscle is injured and how that may influence the likelihood of future ACL injury will be discussed, along with what future questions need to be pursued.

Mechanisms of ACL injury

ACL injury typically occurs at foot plant with concurrent low knee flexion angle, knee joint rotation, and valgus collapse.[17] This kinematic profile is thought to elongate the ACL and also result in increased shear forces of the femur over the tibia, resulting in greater anterior tibial translation.[17] In noncontact ACL injuries in field sports, this kinematic profile is most commonly seen when changing direction while running—specifically, when executing a sidestep cutting maneuver.[17-19] The balance of activation between the hamstring and quadriceps groups plays an integral role in the avoidance or realization of the aforementioned injurious kinematic extremes.[18,20,21] Electromyography studies have shown that when executing sidestep cutting maneuvers, both hamstring and quadriceps myoelectrical activity and joint loading increase significantly.[18,21] Not surprisingly, these studies have also shown that the kinematic extremes observed when noncontact ACL injuries occur are more easily reached when total hamstring activity relative to quadriceps activity is reduced.[18,20,21] The reduced activity of the hamstrings relative to the quadriceps is likely to reduce the knee flexion angle; therefore, increased ground reaction force will pass through the knee joint, and greater shear force of the femur over the tibia will ensue and, subsequently, anterior tibial translation. Thus, the strength and neuromuscular function of the hamstring muscle group is critical for the prevention of noncontact ACL injury.[17] Of further interest are the changes in activation and loading patterns of the medial (semitendinosus [ST], semimembranosus [SM]) and lateral (biceps femoris [BF]) hamstring muscles. When changes of direction are executed during running, the medial and lateral hamstrings contribute differently to knee stability; ST and SM are responsible for internal rotation and varus stress about the knee, and BF is responsible for external and valgus rotation.[18,20,21] Compromised function of the medial or the lateral hamstrings will reduce net hamstring activation relative to quadriceps activation and may lead to elongation of the ACL and the potential for injury.

List of abbreviations:

ACL	**anterior cruciate ligament**
BF	**biceps femoris**
HSI	**hamstring strain injury**
SM	**semimembranosus**
ST	**semitendinosus**

Neuromuscular characteristics of the female hamstring

Numerous studies have identified divergence in neuromuscular hamstring function of the woman and man athlete, particularly after puberty.[22] Relevant to the proposed hypothesis, from a neuromuscular perspective, these studies have examined the coactivation of the hamstrings and quadriceps, the hamstrings-to-quadriceps strength ratio, the preactivation of the hamstrings before potentially injurious tasks, and the difference in lateral-to-medial hamstring activation patterns. Compared with men athletes, women have been found to display lower hamstring-to-quadriceps strength ratios during isokinetic knee flexion and extension,[23] which corroborates with observations of increased activation of the quadriceps compared with the hamstrings during a stop-jump landing task,[24] a greater time required to reach maximal isokinetic hamstring torque,[25] and lower integrated electromyographic hamstring activity during a sidestep cutting maneuver.[26]

Maladaptation after HSI

Previous HSI has consistently been identified as the primary risk factor for future HSI,[27,28] and while this has been classified as a nonmodifiable risk factor, several functional deficits have been identified in athletes with a history of HSI.[16] These neuromuscular maladaptations include but are not limited to the following: lower eccentric knee flexor strength (10%–24%)[9,10]; lower voluntary myoelectrical activity during maximal knee flexor eccentric contraction (18%–20%)[11,15]; lower knee flexor eccentric rate of torque development (39%–40%)[12]; lower voluntary myoelectrical activity during the initial portion of eccentric contraction (19%–25%)[12]; and lower functional hamstrings-to-quadriceps ratio (19%).[9] Many of these factors, if left unattended, are purported to increase the likelihood of hamstring strain reinjury. However, only lower levels of eccentric strength have been identified as a risk factor for future injury.[29,30] Although these findings do not allow for the determination of whether these deficits are the cause of or the result of previous injury, they suggest that a previously injured limb exhibits alterations in hamstring muscle function compared with a contralateral uninjured limb. Of note, all of these deficits have been assessed during single-joint isokinetic dynamometry, and more work needs to be done assessing the impact of previous HSI on activity types with greater degrees of freedom.

Is there potential for an increased risk of noncontact ACL injury because of hamstring maladaptation after HSI?

Optimal hamstring function may be crucial to the protection of the ACL. When compared with uninjured hamstrings or men athletes, both previously strained and female hamstrings have been shown to have lower hamstring-to-quadriceps strength ratios during isokinetic or handheld dynamometry,[9,23] lower knee flexor rate of force development during either eccentric isokinetic contractions[12] or isometric contractions,[25] and lower electromyographic hamstring activity during isokinetic eccentric knee flexion[11,15] or a sidestep cutting maneuver.[26] If these functional differences are responsible for the elevated risk of ACL injury in women, then an argument may also be made that previously strained hamstrings, and the subsequent associated functional deficits, might also increase the risk of ACL injury in athletes with a previous HSI.

From a mechanistic perspective, low levels of knee flexor strength (either absolute or relative to quadriceps strength) could result in a reduced flexion angle at the knee joint at foot plant and, consequently, an increase in vertically directed ground reaction force and shearing force of the femur over the tibia (Figure 1). Elongation of the ligament itself from the reduced flexion angle, combined with knee joint rotation and valgus collapse often observed with change-of-direction running, is also likely to be greater. Greater force going through the knee joint, combined with a taut ligament, will likely expose the ACL to a greater risk of injury.[17]

Does the specific hamstring muscle injured affect the risk of ACL injury?

One further consideration is that while HSI can lead to general alterations in sagittal knee joint function, the medial and lateral hamstrings have different roles in coronal knee joint control. As such, the specific hamstring muscle injured may have a direct influence on the potential increase in ACL injury risk. The BF is the hamstring muscle most commonly afflicted by strain injury.[31] The BF is responsible for knee valgus,[32] and excessive knee valgus, reached through compression of the lateral aspect and distraction of the medial portion of the knee joint, has been reported as a major contributing factor to increases in loading on the ACL.[33] It might therefore be hypothesized that strain injury to the BF and the associated reductions in neuromuscular function to this muscle might actually be beneficial if it reduces the active valgus loading that the knee joint is exposed to. Indeed, compared with men, women display far greater activation of their lateral hamstrings during deceleration from a jump-landing task,[32] supporting the suggestion that greater BF activation, and by extension, greater knee joint valgus loading, is a particularly injurious biomechanical profile. Contrary to this, during an unanticipated sidestep cutting

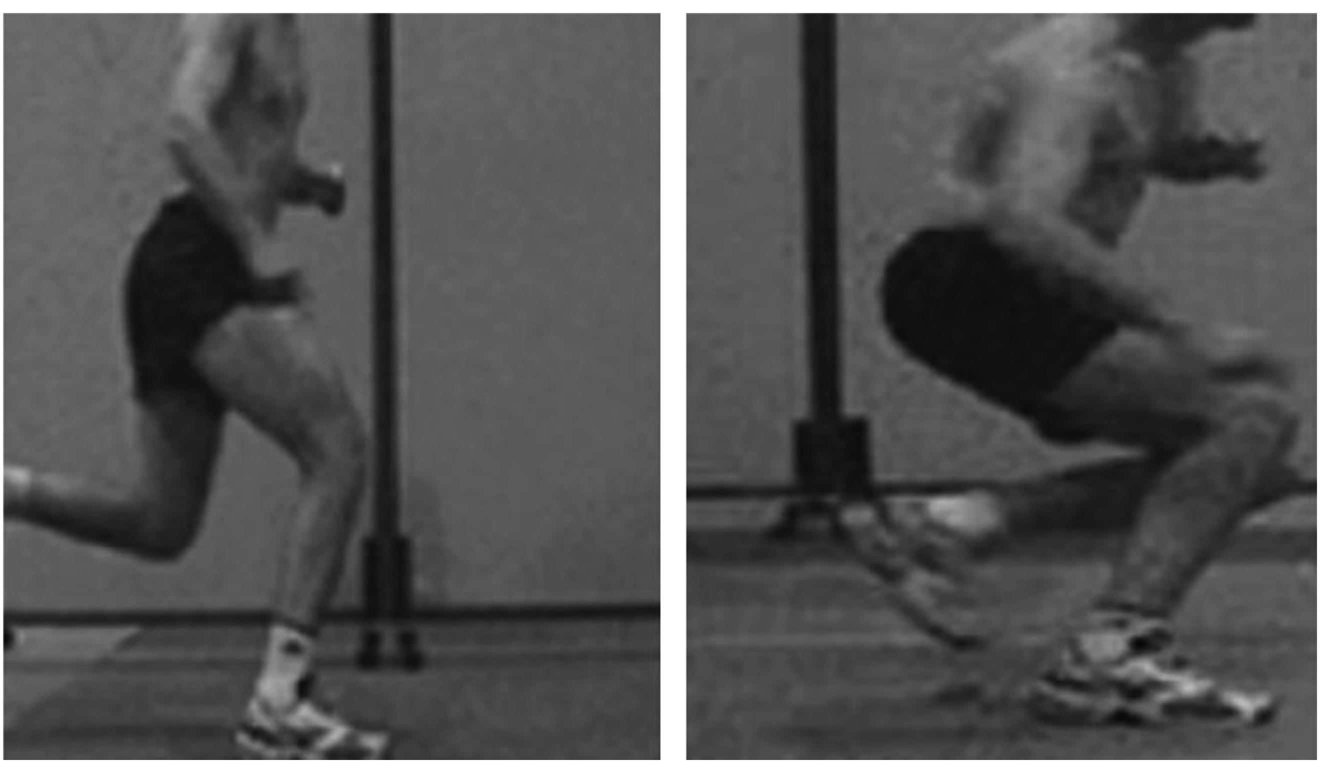

Fig 1 The change-of-direction maneuver likely to lead to noncontact ACL injury is seen in the athlete on the left. The athlete on the right changes direction with greater knee flexion angle compared with the athlete on the left. This suggests a smaller quadriceps-to-hamstring moment ratio (ie, greater quadriceps strength and activation relative to hamstring strength and activation). Thus, hamstring torque relative to quadriceps torque in the athlete on the left would not be as great as that for the athlete on the right. For the athlete on the left, this is likely to lead to increased anterior tibial translation when the foot/lower limb is fixed, consistent with findings in the literature.[34] (Courtesy of Dempsey et al, 2007.[35] Reproduced with permission.)

maneuver, compared with anticipated changes of direction, which is considered less injurious, the ratio of lateral-to-medial hamstring activation decreases by nearly 30%.[18] This reduction in lateral-to-medial hamstring activation would be achieved by a greater decrease in BF activity compared with ST and SM activity, a greater increase in ST and SM activity compared with BF activity, or a concurrent decline in BF activity and an increase in ST and SM activity. Because an unanticipated sidestep cutting maneuver has been identified as an action that places the ACL at high risk of injury,[18,20] the reduction in the lateral-to-medial activation ratio might be indicative of an injurious activation pattern. After HSI to the BF, a reduction in the activity of this muscle has been reported during isokinetic eccentric knee flexor contractions, while the activation of the medial hamstrings is unaffected.[11] This ultimately reduces the lateral-to-medial activation ratio. Whether such a neuromuscular deficit after HSI to the BF also translates to multiple joint and multiple degrees-of-freedom movements, such as sidestep cutting, remains to be seen and should be considered in future work. Furthermore, while the BF is the most commonly strained hamstring, the SM and ST can also be exposed to strain injury.[31] Because of the varus knee force applied by the medial hamstrings,[32] any deficits in neuromuscular function might be expected to increase the likelihood of a knee valgus kinematic profile and augment the risk of ACL injury. However more work needs to be done to determine whether activation of the medial hamstrings is impacted on by previous strain injury, and whether this leads to more injurious kinematic profiles during potentially harmful tasks (ie, stop landing, sidestep cutting, etc).

Future direction

Previous severe knee injury is known to increase the likelihood of future HSI.[7] We have suggested the possibility that prior HSI may increase the risk of future ACL injury. Evidence indicating that a limb that has sustained a previous HSI is more susceptible to ACL injury would strengthen the proposed hypothesis. Furthermore, whether the specific hamstring muscle that was previously injured influences the risk of sustaining an ACL injury is worthy of consideration. While a number of retrospective studies have examined neuromuscular knee joint function after ACL injury rehabilitation during injurious tasks that involve multiple joints and degrees of freedom, studies examining hamstring function after HSI have been largely performed using a single-joint isokinetic model. Retrospective studies involving individuals with previously strained hamstrings, examining hamstring function during tasks that pose an inherent risk of injury to the ACL, should be investigated further.

Conclusions

The prevention of HSIs and ACL injuries is of great concern in elite sporting environments; however, consideration of the effect of HSI on potential ACL injury has not been investigated. We propose that the maladaptation associated with a prior HSI could result not only in an increased risk of HSI recurrence, but also in an elevated risk of ACL injury. Future work should consider the examination of athletes with a history of hamstring injury to determine whether functional deficits related to the previously injured hamstring affect markers considered important for ACL injury risk. If an interrelationship is found between these 2 injury types, it would warrant further research into the prevention and optimization of rehabilitation for HSI as a means of reducing the risk of ACL injury. This could potentially be beneficial at both the elite and community level and lessen the burden of secondary outcomes of ACL injury (ie, knee osteoarthritis) on the community.

Keywords

Injuries; Knee joint; Rehabilitation; Trauma

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