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**Hamstring Strains: Etiology, Treatment, and Prevention**

 Hamstring strains are one of the most common lower extremity musculotendinous injuries in sport1. Athletes that are involved in a sport that includes sprinting demands are particularly susceptible to this injury2,3,4, as well as dancers due to the extreme stretch withstood by the hamstrings3,5. Hamstring strains are challenging due to the lack of agreement on rehabilitation protocols and the common recurrence rate associated with this injury2. It is important to have an understanding of the anatomy of the musculotendinous junction, where the injury tends to occur6, as well as the etiological factors involved in a hamstring strain to determine an optimal rehabilitation program.

 The hamstrings are comprised of three muscles: semimembranosus, semitendinosus, and biceps femoris, which is comprised of a long and short head6. Except for the short head of the biceps femoris, these muscles all originate at the ischial tuberosity6 and span the hip and knee joint. Excessive anterior tilt of the pelvis places the hamstring muscles at increased length due to their common origin, which some have suggested may increase the risk of hamstring strain injuries10.

The two heads of the biceps femoris comprise the lateral hamstring and insert on the fibular head2. The hamstring muscle group is comprised of mostly type II muscle fibers2. The most commonly injured area from indirect trauma is in the musculotendinous junctions of these muscles6, which are attachment sites between skeletal muscle and tendon7. The muscle cell membranes at these junctions have folds that extend from the muscle cell toward the tendon, creating interdigitations and a stronger interface between the two surfaces8. This folding places the membrane at very low angles relative to the force vector, creating an increase in contact area and placing the membrane predominantly under shear forces7. If the cell membrane was not folded and instead approached the extracellular matrix at a right angle, the junction would experience tensile loading7 and would be at greater risk for strain injuries8.

 Disuse atrophy causes an increase in the approach angle between the basement membrane of the muscle cell folds and extracellular matrix8. Changes caused by atrophy affect the magnitude and the type of stress seen at the myotendinous junction, meaning it will greatly increase the tensile component of membrane loading by reducing membrane folding13. Increasing the tensile component of loading caused by atrophy may reduce the adhesive strength of the junction, leading to failure13. Decreased surface area at the junction also corresponds to the increased failure due to disuse atrophy13.

Changes that occur at the myotendinous junction from disuse or immobilization can be reversed when activity is increased8. Progressive increases in magnitude, duration, and frequency8 are important when intensifying activity in order to benefit from these changes and reduce risk of injury. Muscle strain injuries often occur near rather than directly at the musculotendinous junction, due to the structurally stiffer terminal sarcomeres remaining attached to the tendon8.

Indirect muscle strain injuries often occur from excessive force or stress on the muscle7. This may be from passive stretching, active tension in the muscle, or both8. Both of these factors are involved when eccentric muscle action causes the muscle to be contracting internally while the external environment is stretching the muscle-tendon unit8. These opposing actions cause a high level of tensile stress within the muscle-tendon unit8. In rapid knee extension during sprinting or kicking, a protective eccentric action is solicited by the hamstring muscles to decelerate the lower leg, causing tension development while simultaneously lengthening9. During increasing speeds of running, the hamstrings must contract faster and absorb more force during a shorter period of time2. The hamstrings are predominantly biarticular (spanning the hip and knee joint) and incur significant lengthening during simultaneous hip flexion and knee extension, as with running and kicking10. Lengthening demands may exceed the mechanical limits of the hamstrings or lead to accumulation of muscle damage over time10.

There is debate over which hamstring muscle is most often involved in strain injuries as well as which phase of the sprinting cycle most hamstring strains occur. During sprinting, it is thought that the biceps femoris is the most commonly injured muscle due to its musculotendinous junction incurring the greatest stretch3. It has also been stated that generally in running, jumping, hurdling, and kicking sports the biceps femoris is the most commonly single strained muscle in the hamstring group6. It is believed that this muscle is most prone to injury during foot take-off phase while the swing phase produces more stress on the semimembranosus and semitendinosus6. Movements placing the hamstrings at extreme stretch as with dancing or high kicking cause the most commonly injured muscle to be the semimembranosus3.

During terminal swing phase in sprinting, the hamstrings are lengthening and eccentrically contracting to absorb the energy and decelerate the leg in preparation for foot contact with the ground3. There is a general belief that because of this, it is during the second half of swing in the gait cycle when the majority of hamstring strains occur3. This perception was confirmed in a study by Schache et al, which found that most of the inertial force acting on the knee joint was imparted onto the hamstrings during terminal swing of sprinting4. The gastrocnemius is the only other major muscle about the knee joint capable of providing support to the hamstrings in the effort to decelerate the limb4.

The researchers also confirmed this hypothesis by indicating peak hamstring myographic activity occurred during terminal swing in sprinting4. They discuss the common theme of the hamstring muscle-tendon unit undergoing an eccentric muscle action, or an active lengthening contraction, during terminal swing4. Eccentric contractions are capable of producing muscle fiber damage, which may be attributable to the starting point for muscle strain injuries4. An additional theory is that once the hamstrings have accomplished deceleration of knee extension during terminal swing of running, they must then become an active extensor of the hip joint11. It is suggested that during this quick change from eccentric to concentric contraction, the hamstring muscle group is most susceptible to being injured11.

 In order to prevent hamstring strains, it is important to understand how they occur as well as risk factors that can be avoided or altered. Risk factors for initial hamstring strains are comprised of modifiable and non-modifiable factors9. These factors, in addition to modifications from the initial strain, questionable treatment options, and premature return to sport are linked to recurrent injuries9. Risk factors may also be divided into intrinsic (player-related) factors and extrinsic (environment-related) factors9,14.

Non-modifiable risk factors include age3,9,10, prior history of a hamstring strain3,11, and black or aboriginal ethnic origin10,11. A study by Orchard found that age-related increases in hamstring injuries may be related to low lumbar degeneration leading to L5 and S1 nerve impingement14. This would cause denervation of the hamstrings and would lead to loss of muscle strength14. Strength of the quadriceps would be unaffected by L5 and S1 nerve impingement, potentially causing strength imbalance in the hamstring to quadriceps ratio9. High proportions of type II muscle fibers and excessive anterior pelvic tilt in the black and aboriginal ethnic populations have been proposed as factors for why these populations have higher incidence of hamstring strains10.

Previous history of a hamstring strain has been suggested as the most important risk factor for future injury14. Risk of recurrence has been shown to increase two to six times when there has been a prior hamstring strain1. Athletes often return to sport sooner than recommended and the injury does not have time to properly heal. Athletes and rehabilitation specialists must understand this initial injury as a major risk factor for recurrence. If full recovery of flexibility, strength, endurance, and coordination is not attained then there is a risk of injury recurrence or an even more severe injury than the initial strain6. Reduced tensile strength of scar tissue at the site of the previous injury may also contribute to increased risk for recurring strains9.

Modifiable risk factors for hamstring strains have been reported as a wide array of influences. These factors commonly include reduced flexibility, fatigue, hamstring strength deficits, and inadequate warm-up2. Other modifiable factors that potentially increase the risk of hamstring injuries includestrength and coordination deficits of the pelvic and trunk muscles3 and poor lumbar posture1,12. The concept of strength imbalance between hamstrings (eccentric) and quadriceps (concentric)3 also known as low hamstring to quadriceps ratio (H:Q)10,11 is viewed as a modifiable risk factor.

Flexibility, fatigue, strength, and warm-up are mentioned with clinical evidence in many studies and reviews as factors relating to hamstring muscle injury2. The effect of flexibility is highly debated, but many believe it should not be overlooked. The greater the resting length, the greater the ability to absorb forces and avoid strain, making flexibility have an important role in reducing these injuries2. Verrall et al also suggests that stretching results in reduction of load on the muscle-tendon unit for any given length, improving force absorption and making the muscle more resistant to stretch injury15. Small changes in hip joint kinematics have been shown to have a large effect on hamstring injury risk17. It has been suggested that every degree of hip flexor flexibility lost increases hamstring strain risk by 15%17. Fatigue has the potential to not only create physiological changes within the muscle, but also decrease coordination or technique in the athlete, increasing the risk for strain6. Fatigued muscles are less able to absorb energy when undergoing stretching, making them more susceptible to injury15. Flexibility and strength are both reported as being reduced when muscle becomes fatigued6.

Return to sport after a hamstring injury with decreased strength is a risk factor for a recurrent injury. Sanfilippo et al found that athletes discharged and released to return to sport after an average of 26 days presented with strength deficits (60% peak torque compared to uninjured side) and 20% of the cross-sectional area continuing to show signs of injury on MRI16. The authors found it took up to six months after return to sport for full strength recovery16. They also discovered the injured side to have consistently lower H:Q than the uninvolved side, which has been proposed as a predictor of recurrent injury16. A lower H:Q ratio suggests the hamstrings are less able decelerate the flexing hip and extending knee joint during terminal swing. This allows forceful contraction of the stronger quadriceps to produce momentum at the knee joint that exceeds the hamstring’s mechanical limits10. It is recommended that athletes should undergo isokinetic testing before return to sport to detect any residual muscle performance dysfunction9.

Greater strain at failure within a functional range of motion incurred by the muscle and myotendinous junction can be accomplished by increased ultimate strength8 and extensibility9 through proper warm-up. An animal study has shown that cold muscles tear at shorter lengths6. In sports that require the athlete to be strong as well as flexible to perform required tasks such as kicking and leaping, the warm-up is essential to prevent hamstring strains. The knee is often fully extended while the hip joint is flexed to an extreme range of motion in these movements, causing the hamstring muscles to be more vulnerable to strain if not appropriately warmed up.

 Poor lumbar posture was a component found to be significantly different between injured and uninjured players in a study by Hennessy et al12. It has been found that lumbar lordosis increases in players secondary to strengthening of the iliopsoas through kicking exercises and straight-leg abdominal strengthening, creating a postural defect12. This is certainly an area that should be examined along with other potential risk factors for athletes, with corrective postural exercises to decrease the effects of increased lumbar lordosis.

 Hamstring strains can be placed into three classifications: mild/first degree11/grade I6, moderate/second degree11/grade II6, or severe/third degree11/grade III6. Mild strains are characterized by a stretching of the musculotendinous junction with resulting tear of a few muscle fibers, minor swelling and minimal loss of strength6,11. Moderate strains consist of greater damage to the muscle with an obvious decrease in strength, but without complete disruption of the musculotendinous unit6,11. Severe strains are a complete rupture of the musculotendinous unit, resulting in complete lack of muscle function and the potential need for surgical treatment6,11.

 Grade I and II strains are often treated conservatively, beginning immediately after the injury occurs with rest, ice, compression, and elevation to minimize inflammation11 and injury-induced bleeding into the muscle tissue18. The use of NSAIDs can control inflammation and edema, which may reduce excessive scar tissue formation8. It is not recommended to take NSAIDs past the acute phase of injury, as the short-term benefits are clear while long-term usage may have detrimental effects leading to functional loss9.

A short period of immobilization should be considered to allow the injured muscle stumps to attain strength needed to withstand muscle contraction forces without re-rupturing18. Immobilization should not last longer than a few days to minimize any adverse effects and controlled, early mobilization should follow directly after this period of rest8. This is to avoid muscle atrophy9 and facilitate formation of strong scar tissue8. Early mobilization within pain tolerance has been shown to best enhance the regeneration phase of injured muscle tissue18. Controlled movement after the inflammation phase also promotes proper orientation of regenerating muscle fibers and decreases adhesions within the connective tissue9.

Progression of activity after early mobilization should be initiated after proper warm-up of the muscle tissue and exercises should be performed pain-free. Adequate warming-up has been shown to reduce muscle viscosity, allowing the stimulated muscles to absorb more energy and better withstand loading18. Protection is needed during this phase from too much magnitude, frequency, and duration of loading while the tissue continues to be mechanically weaker8. Once full passive range of motion as been attained, it is suggested to begin with gentle concentric and eccentric muscle contractions after warm-up8. A major goal of any rehabilitation program is to prevent hamstring strain recurrence by promoting the development of strong and flexible tissue. Cardiovascular fitness should also be considered and maintained through controlled resistance activities such as stationary bike riding or swimming11,18.

Neuromuscular control of the lumbopelvic region is required to enable optimal function of the hamstrings during challenging activities in sports3. An RCT by Sherry and Best supported the hypothesis that gaining control in the lumbopelvic region during high speed skilled movements prevents hamstring injury19. Two groups were provided different exercise programs, one concentrated on strengthening and stretching (STST) while the other focused on progressive agility and trunk stabilization exercises (PATS). The PATS group’s program required neuromuscular control and limited end range tension on the hamstrings19. A significant reduction in injury recurrence was found at 2 weeks (STST, 55%; PATS 0%) and at 1 year (STST, 70%; PATS, 8%). Specific neuromuscular factors responsible for the decrease of recurrence in the PATS group are unclear, but one thought is that improved lumbopelvic control allows the hamstrings to function at safe lengths and loads during movement19.

Muscle atrophy, an important factor in injury recurrence, can be reduced through early loading at a protected muscle-tendon length19. The controlled direction of movement in the PATS group allowed early retraining of rapid changes in agonist and antagonist muscle contractions that control hip and pelvic movement19. Drills in this group involved early combinations of concentric, eccentric, and isometric contractions of the hamstrings in a controlled environment, which has potential to reduce weakness and prevent muscle imbalances without adversely affecting scar tissue19.

One area of main focus is eccentric training, with evidence supporting it to be an important protective factor after hamstring strains20. This is related to the previously discussed topic on the majority of hamstring strains occurring during terminal swing phase in sprinting, when the hamstrings are eccentrically contracting to decelerate the leg3. During this phase, it has been suggested that athletes who produce peak torque at shorter length are more prone to injury because the hamstrings are functioning in a risk range of the length tension relationship21. Optimum length of the hamstring muscles has been identified as a risk factor for strains21. Recurrence of hamstring injuries thus may be reduced if this optimum length can be increased through eccentric training, a common approach being the Nordic hamstring exercise21.

The Nordic hamstring exercise, as explained by Schmitt et al, is performed by placing the patient in tall kneeling while the clinician holds their feet1. The patient slowly falls forward while maintaining neutral hip posture without use of the upper extremities until they can no longer control descent1. The patient is extending at the knee while contracting the knee flexors eccentrically to maintain a slow descent10. The patient then pushes back to the starting position with the use of their arms1. (Figure 1)24

An RCT by Petersen et al demonstrated the ability to reduce the incidence of hamstring injuries with a training program focused on eccentric exercises, particularly the effects of the Nordic hamstring exercise22. The authors found the overall hamstring injury rates were significantly lower in the intervention group versus the control group. The only adverse effect during the first weeks in the training group was delayed onset muscle soreness (DOMS), which is common with eccentric exercise22. Investigators found the number needed to treat (NNT) to prevent 1 overall hamstring strain, new or recurrent, is 13 in elite and amateur male soccer players22. This training program reduced the rate of new hamstring injuries by 60%, and significantly reduced recurrent strains by approximately 85%. No beneficial effect on the severity of hamstring injuries was documented22.

Optimal eccentric training would not exceed three times a week in the presence of DOMS, as it may overall promote the occurrence of strain9. DOMS behaves like fatigue and can give rise to re-injury if precautions are not taken during eccentric training9. Magnitude, frequency, and duration of eccentric exercise have been recommended to remain low during early rehabilitation to provide a protective effect against DOMS, increasing progressively throughout the therapy sessions9.

Sport-specific training is also highlighted in literature to prevent hamstring strain recurrences. A prevention program designed by Verrall et al for Australian Rules football players began with a 2-year analysis of factors related to hamstring strains15. The authors implemented an intervention program the following two years, emphasizing an increase in the amount of anaerobic interval training. The study incorporated specific football training drills with the athlete running while in a position of trunk flexion. This was determined to be when most injuries occurred, while the athlete was sprinting and simultaneously reaching down to grab the ball15. Stretching at a time when the muscle was fatigued was encouraged and the players were advised to perform closed chain leg weight exercises only if they were previously using leg weights15. Verrall et al found the incidence and consequences of hamstring injuries can be reduced by implementing a sport-specific training program that reflects the conditions where most injuries occur15. The clinical commentary by Schmitt et al also suggests eccentric training in the lengthened state, plyometrics, sports-specific training, and advanced balance exercises being initiated in the final phase of rehabilitation for hamstring strains1.

There are many consequences to the athlete returning to play prematurely, which unfortunately is often the case. A proper rehabilitation program reduces the number of recurrences and is often prolonged, in the attempt to diminish all lingering symptoms9. The pressure of coaches and teams as well as an athlete’s impatience contributes to an early return to play, increasing the risk of major re-injury9. There continues to be need for objective criteria to determine the appropriate time for return to sport, although severity of strains are individualized as well as a patient’s compliance to a rehabilitation program. With an average return to sport (RTS) of 26 days, Sanfilippo et al found residual edema and decreased isokinetic knee flexion strength that did not resolve completely until six months after RTS16. Strength can be assessed by the athlete’s ability to complete 4 consecutive repetitions of maximum pain-free effort in prone position with knee flexed to 15° and 90°, as well as isokinetic strength being tested in eccentric and concentric conditions3. The athlete should present with < 5% bilateral deficit in the ratio of eccentric hamstring strength to concentric quadriceps strength3 prior to RTS.

Askling et al performed a study on the comparison of hamstring injuries incurred between sprinters (during high speed sprinting) and dancers (performing slow stretching exercises) and the timing differences for return to sport5. Self-estimated time for RTS at pre-injury level was an average of four weeks for sprinters and one week for dancers. The actual time back was significantly longer, an average of 16 weeks for sprinters and 50 weeks for dancers5. There were clear deficits in flexibility and strength in both groups initially. Sprinters had more severe functional deficits initially which appeared not to correlate with time to return to pre-injury level, as the sprinters recovered more quickly5. The location of the strain may also have effect on the time for recovery, as the strains in sprinters primarily involved muscle tissue while the dancers’ injuries involved significantly more proximal tendinous tissue5.

Rehabilitation programs for hamstring strains must be individualized to each patient. Severity of the strain, location of injury, and required activity performed by the individual should influence the development of an exercise program. Protected mobilization is crucial after the inflammation period to gain full passive range of motion and reduce muscle atrophy in the early phase of rehabilitation. Slow progression of magnitude, frequency, and duration of concentric and eccentric exercises, lumbopelvic control, and sport-specific training drills should be strongly considered when creating an individualized program. Return to sport should not be recommended until the tissue has fully recovered flexibility, strength, and endurance to decrease the risk of a recurring hamstring injury.



Figure 1. Nordic hamstring exercise

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