Advanced management of hamstring muscle strains in athletes with return to sport considerations: A review

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Table of Contents

Purpose

Hamstring injuries are an incredibly common part of sport, with some incident rates reported at 3 to 4.1 per 1000 competition hours.1 There are multiple risk factors that can predispose an athlete to hamstring injury or reinjury. For this reason, the rehabilitative strategy needs to be multifactorial. Currently, many physical therapists treat hamstring injuries as they would any other muscle strain in the body, failing to appreciate the incredibly dynamic and rigorous stress placed on the hamstring during athletic activity. This can result in too early return to sport, diminished performance, and even reinjury. The purpose of this project is to synthesize the available literature pertaining to hamstring injury, risk factors, rehabilitation, and return to sport considerations. Using that information, a standardized protocol can be established to assist physical therapists with hamstring rehabilitation, including recommendations for useful metrics/outcome measures and evidence-based interventions.

Literature Review

Hamstring Biomechanics in Running

It is important to appreciate the differences between the 3 individual hamstring muscles; the semimembranosus (SM), semitendinosus (ST), and biceps femoris (BF). Although this group of muscles work as synergists to flex the knee and extend the hip, EMG research has revealed they work in complex neuromuscular coordination patterns.2 During running, both the BF and ST engage in maximal eccentric contraction during the swing phase.2 However, the BF is predominantly activated during the middle to late swing phase before the ST takes over during the terminal swing phase.2 This is an important consideration, as it has been proposed that hamstring muscles are at greatest risk of injury during late or terminal swing phase.3

As running speed increases, several changes occur in the hamstrings that influence biomechanics and injury risk. First, hip flexion increases while hip extension decreases with increasing speed.4 Second, the complexity of neuromuscular control between the hamstrings increases, revealing even more significant differences with individual hamstring muscle activation at various points throughout the running cycle.5 Finally, with high speed running, kinematic studies have revealed the BF specifically is subject to the highest levels of stretch through the terminal swing phase, predisposing this muscle to higher potential risk of injury.2

Mechanism of Injury

There are currently 2 proposed scenarios in which hamstring muscle strain occurs; (1) active lengthening during high speed running or (2) excessive stretching movements.3 Injury with high speed running typically affects the long head of the BF, while the SM is commonly affected during stretch injury.[3] The BF and ST are subject to the greatest eccentric loads during high speed running.[3] The ST plays a predominant role in force production while running, but the BF will compensate for the ST following fatigue or failure, making the BF particularly susceptible to injury.[2] The hamstring muscles collectively are most susceptible to injury during active lengthening which is most significant during the late swing phase of running gait.[6] A recent systematic review concluded that the majority of hamstring strain injuries occur during the late swing phase.[3] It is estimated that only 3% of hamstring strains occur during the excessive stretching mechanism, and that these almost always involve the SM and a much longer recovery time.[7] Therefore, the focus of this review will be on the active lengthening mechanism.

In a review of 2761 hamstring injuries, the most frequently injured hamstring muscle was the long head of the BF, accounting for 70% of all injuries.[7] This would align with the biomechanical role the BF plays in late swing. Further, the most frequent tissue location of injury was the myotendinous junction (MTJ) at 52% of all injuries.[7] The proximal MTJ of the long head of the BF specifically appears to be most commonly injured.[8] Mid-substance lesions were relatively homogenous, with an equal percent occurring distally, centrally, or proximally.[7] Significant shear stress across the MTJ would seem to account for the increased risk of injury at that location.[9]

Risk Factors

There are several factors that predispose an athlete to develop a hamstring strain injury. First, it is important to note that there may not be a significant correlation between hip ROM (including hip flexion) and hamstring injury. Recent evidence seems to suggest that there are no significant differences in hip ROM between injured and uninjured athletes.[10]

Certain alterations in running form certainly influence risk of injury. Previous biomechanical studies revealed that anterior trunk sway and contralateral pelvic drop while in single leg stance increased the load on the hamstrings.[11] Theoretically, weak hip abductors would predispose the hamstring to greater load in the running cycle as well. This is supported by recent findings that suggest a forward trunk lean elongates the hamstrings during high speed running and increases overall strain.3 Other factors that seem to predispose an athlete to injury include greater thoracic lateral flexion, greater hip extension moment (which is seen with forward trunk lean), and greater knee power absorption between peak hip flexion and peak knee extension during late swing phase.[12] Although the majority of injuries occur during terminal swing, excessive work of the hamstrings due to biomechanical inefficiency through stance phase may fatigue the hamstrings and increase risk of injury during the swing phase.

Previous injury presents a clear risk for factor for future injury. One study estimates that previous hamstring injury increases risk of reinjury 11-fold compared to uninjured athletes.[13] This might be explained by alterations in neuromuscular control that occur following the initial/prior injury including more symmetrical muscle activation across the hamstring(s) which potentially implicates a less efficient hamstrings contraction.2 Injury can also results in non-functional scar formation, muscle atrophy, and persistent eccentric strength reductions all impacting hamstring function.[13]

Both chronic and acute fatigue seem to increase risk of injury. Acutely, injury rates have been shown to increase during later stages of soccer games, suggesting an association between fatigue and increased risk of injury.[14] It has been proposed that fatigue leads to alterations in neuromuscular control, effectively diminishing the efficiency of the hamstrings and predisposing the muscles to injury when subjected to intense physical demands.[15] There is also evidence to suggest that chronic training loads over training and competition periods results in an accumulation of fatigue that is associated with increased risk of injury.[16] This may be explained by the persistent presence of inflammatory proteins and exercise-induced muscle damage not given sufficient time to heal.[15] Prevention of chronic fatigue appears to be mitigated with a long-term, graduated training protocol. For example, athletes that completed more than 18 weeks of training prior to initial injury were at reduced risk of injury recurrence.[16] Since both over-training and under-training can increase injury risk, finding the appropriate balance of training intensity over weeks and months is vital.[16]

Several key factors specifically in the acute window are associated with longer recovery times and should influence the rehabilitative strategy; greater ROM deficit, increased maximal pain score on VAS, time to first consultation >1 week, and >1 day to return to pain-free walking following injury.[17]

Goals of Rehabilitation

Hamstring strength

Improving hamstring strength is an essential component of an effective rehabilitation plan because it is known that well-developed physical qualities protect against injury.[18] Wan et al, 2021 found participants undergoing hamstring strengthening significantly increased the optimal musculotendinous lengths of all 3 hamstring muscles in addition to significantly decreasing the peak musculotendinous strain during sprinting.[19] A series of prospective studies established that eccentric strength training reduces the risk of hamstring injury if compliance to the program is high.[20] In addition to reducing strain, improved hamstring strength (especially eccentric strength) was correlated with improved sprint performance.[21] A sample of elite soccer players undergoing 27 sessions of hamstring strengthening improved in 5-meter, 10-meter and countermovement jump performance compared to a control group.[22]

Gluteus strength

While no study has established a direct connection between gluteal strength and hamstring injury, it would be expected that strengthening gluteal musculature is important for assisting with hip extension and hip stability, which should decrease the load on the hamstrings while running. Authors, et al reported that anterior trunk sway and contralateral pelvic drop while standing on one leg increased the load on the hamstrings, emphasizing the importance of lateral and posterior hip strengthening.[11] Further, fatigue of the gluteus maximus, which plays an important role in eccentrically absorbing ground reaction force during landing, places an increased eccentric load on the hamstrings and predisposes them to injury.[23]

Gender differences are also an important consideration in runners. EMG studies reveal that females tend to run with higher gluteus maximus activation.[24] This may contribute to earlier gluteus maximus fatigue over time (especially considering its high proportion of type II muscle fibers) placing greater hip extension load and ground reaction force on the hamstrings.[24] Thus, endurance of the gluteal muscle group must be considered as well as strength. Finally, isometric hip strength does not appear to have a clear influence on hip kinematics during the stance phase of running.[25] This would seem to imply that gluteal strengthening needs to be performed in functional positions and that neuromuscular coordination of the gluteal muscles is more important than strength alone in maintaining hip stability.

Stretching

Although there is not a clear correlation between hip flexion ROM and injury risk,[10] biomechanical data has revealed that static stretching may reduce strain on the long head of the BF during the late swing phase.3 Danielsson et al explain by stating: "static stretching results in subsequent reduced peak values of joint torque at the hip and knee and increased force productions of the biceps femoris at longer muscle lengths, which demonstrates that stretching may reduce the risk of hamstring injuries."3 One RCT found that participants in the flexibility intervention group significantly increased the optimal musculotendinous lengths of the hamstrings and decreased peak musculotendinous strains in all 3 bi-articulate hamstring muscles.[19] Both a warm-up and static stretching of the hamstrings in previously injured athletes increased hamstring flexibility whereas dynamic stretching had no effect.[26] Consistent hamstring stretching post-exercise was shown to increase 30-meter sprint performance after 7 weeks.[27] Athletes that performed hamstring static stretching 4x/day had a shorter rehabilitation duration than athletes that only stretched 1x/day.[17] While there is some evidence to suggest that static stretching may reduce muscular performance and power, chronic stretching (especially after exercise) does not negatively impact muscle performance.[28] In short, it appears that there is some merit to performing stretching exercises in athletes recovering from hamstring injury to decrease strain, restore ROM limitations, and even improve performance long-term.

Exercise selection

Hamstring strengthening

A large body of research has supported the use of eccentric muscle strengthening for the hamstrings in injury prevention and improved performance. Specifically, the Nordic hamstring exercise (NHE) has been used in a variety of protocols. The NHE "activates the hamstrings at high levels and at angles similar to the joint angles at which peak hamstring activation occurs during sprinting."[29] EMG data has shown that the NHE recruits greater hamstring MVIC than popular exercises such as the straight-leg deadlift (RDL), single leg straight-leg deadlift (SL RDL), and physio ball curl (PB curl). The SL RDL did have a higher recruitment ratio of BF to SM and ST, and was recommended for use earlier in rehab by this group of researchers.[30] One NHE protocol reduced the incidence of hamstring strain injuries by up to 51%.[31] A second protocol combining the NHE with hip bridges, prone hamstring curls and physio ball curls reduced hamstring strain after 8 weeks.[19] There is more global activation in the hamstrings with the SL RDL exercise and higher distal BF activation with the NHE, indicating that a progression from the SL RDL to the NHE may be appropriate as a focus on the strength of the BF becomes important.[32] However, under heavy load conditions like the barbell deadlift, it is possible to achieve over 100% MVIC of the BF.[33] The BF becomes the more dominant hamstring in hip extension exercises like the SL RDL and standing hip extension.[34] Straight-knee bridges and OKC leg curls exhibit the highest % MVIC in BF and ST during concentric phase (up to 85% MVIC).[34]

A Swedish rehab protocol utilized the following 3 exercises: 90/90 active stretch performed 2x/day for 3 sets of 12, SL RDL performed every 2 days for 3 sets of 6, and gliders (involving an eccentric slide into a split stance hamstring stretch) performed every 3 days for 3 sets of 4.[35] This protocol demonstrated faster time to return to sport than a more traditional protocol utilizing the following 3 exercises; standing hip extension, SL hip bridge, and standing hamstring stretch.[35] It should be noted that popular exercise selections including the squat and lunge only elicit 40% and 11% MVIC of the hamstrings, respectively.[33,36]

Core and hip strengthening

It is accepted that very high muscle activation on EMG is considered >60% MVIC. When targeting hip musculature for strengthening, it is important to select exercises that elicit the greatest gluteal activation possible. Per an extensive systematic review, the step-up exercise and its variations present the highest levels of gluteus maximus (GMAX) activation (>100% of MVIC) followed by several loaded exercises and its variations, such as deadlifts, hip thrusts, lunges, and squats that all present with very high levels of GMAX activation (>60% of 1RM).[37] These exercises should be incorporated for emphasis on gluteal strengthening and not as a primary mode of strengthening the hamstrings, as discussed previously.

Due to the influence of anterior pelvic tilt and lateral trunk sway on hamstring load, incorporating trunk stability and core strengthening exercises are considered important. EMG data would suggest that an exercise like the side bridge(plank), which elicits 74% MVIC of the gluteus medius (GMED), is an effective way of engaging both core and hip.[36] This same EMG study revealed that the birddog exercise elicits, on average, 56% MVIC of GMAX but lower levels of core activation, and that the prone bridge elicits on average 43% MVIC of the rectus abdominis.[36] Strength and tension in the rectus abdominis helps resist anterior pelvic tilt. The roll-out and pike exercises specifically elicit strong EMG signals (up to 84% MVIC) in the rectus abdominis, internal obliques, and external obliques.[38]

Loading parameters

The American College of Sports Medicine (ACSM) provides guidelines for effective loading parameters to achieve strength and power improvements.[39] It should be noted that these recommendations are made for healthy individuals, and minor adjustments may be necessary for an injured athlete. The ACSM indicates that improvements in lower extremity power can occur by a combination of training at 0-60% of 1RM for high velocity repetitions and less overall volume. [39] For improvements in strength, the ACSM recommends beginning with 8 to 12 repetitions per set and using failure or near failure at the end of a set as an indicator of appropriate load. Higher volume, multiple set schemes emphasize hypertrophy and typically only require 1-2 mins rest.[39] Later stages of strength training should progress to 1 to 6 repetitions per set at 2-3x/week for each muscle group.

Because eccentric exercise can be more isolated and supramaximal, traditional recommendations would be <6 repetitions per set at 85% of the 1-rep maximum (1RM) with a progressive increase in volume over 4 weeks.[40] One study suggests that higher volumes of eccentric exercise is not necessary, indicating that as few as 21 repetitions per week may be necessary to see improvements.[40]

Return to running

Running is associated with highly individualized hamstring activity patterns, however these patterns remain consistent across speeds. Therefore, it is recommended that running at submaximal speeds be implemented early after hamstring injury for restoration of normal neuromuscular function.[41] Most hamstring specific strength exercises achieve only 60% of the maximal hamstring activation used while sprinting.[42] This indicates that a slow progression to full sprinting over time is important to avoid excessive strain on the injured tissue early in the rehabilitation process. Running and sprinting are important components to any hamstring rehabilitation program, as they represent activity-specific movements that are difficult to replicate with other forms of exercise. For example, an experimental group of athletes performing only a NHE protocol reported trivial improvements in sprint performance, whilst a sprint training group experienced a moderate improvement in maximum speed.[43] Sprint training also produced greater perceptions of soreness than the NHE following a four-week training intervention, indicating greater stress placed on the hamstrings.[43] Sprint training should therefore incorporate appropriate rest intervals relative to the sprint distance. For example, one group of researchers established rest intervals of 30 seconds were sufficient for maintaining sprint performance over 15-meter repetitions.[44] However, 30 seconds was not sufficient rest to maintain sprint performance over a 40-meter distance, and that 60-120 seconds was required.[44]

Sprint interval training (SIT) is becoming a popular way of improving aerobic endurance, lower extremity power, and sprint performance. Various studies have shown that SIT allows for similar or greater endurance, strength, and power performance improvements than traditional endurance training but demands less time and volume.[45] One protocol consisted of 4-7 bouts of 30 seconds sprinting at maximal intensity followed by 4 minutes of recovery, performed 3x/ week. This sample of predominantly distant runners saw significant improvements in 3000-meter time, time to exhaustion, and peak power after only 2 weeks.[45]

Pain is also a very important outcome, as higher pain scores at injury and with activity are associated with longer recovery and increased injury risk.[17] Therefore, a numeric pain score or visual analogue scale (VAS) should be used frequently during any running activity to determine safe progression. Several studies propose either a pain threshold (i.e. ≤2/10) or no pain during activity to determine if that activity is appropriate.[17]

Return to Sport

Outcome measures

Hamstring muscle strength directly impacts sprint performance and injury risk.[46] Isokinetic strength testing is the gold standard but is often infeasible for most clinicians.1Handheld dynamometry (HHD) is considered a reliable method of measuring hamstring muscle strength, demonstrating strong intertester reliability in a recent study.[47] Hamstring strength is measured with the patient in prone and the HHD device positioned at the posterior ankle. Measurements are taken with the knee flexed at 15 degrees and 90 degrees.[7,47]

Hamstring extensibility, measured in the 90/90 position with the individual supine, has been shown to have an important impact on functional performance and injury risk.1 Using goniometry to assess progress in hamstring extensibility is a valid and effective way to track progress in ROM.

Performance on various functional measures including sprinting, hopping, agility, and sport-specific movement tasks should inform clinical decision-making.1 Some of the most researched and utilized measures include the single leg hop for distance, triple hop, vertical jump, and T-agility tests.[48] The shuttle run test may have even more utility for this population because it involves rapid acceleration/deceleration, change of direction, and progressive speed increases .[48] There are multiple forms of this test, but the 20-meter shuttle run test is used very often and has validity as a measure of cardiorespiratory fitness as well.[49] This becomes relevant as fatigue is thought to be a risk factor for muscle strain.[14]

Training loads

There is a strong relationship between training loads and injury rates. In one cohort of players over a 3-year period, reduced training loads markedly reduced injury rates.[16] Another study of Australian football players revealed that 40% of injuries were associated with a rapid change (10%) in weekly training load in the preceding week.[50] Researchers generally track load by multiplying the rate of perceived exertion (RPE) by session minutes, then sum the RPE-minutes for that week.[16,50] The RPE scale is a patient-reported outcome that is considered simple to use and valid.[44] The RPE-based method of measuring training load is correlated with various HR-based methods and demonstrates that RPE is a good indicator of internal load during sport activities.[51] One study identified that "players were 50–80% likely to sustain a preseason injury within the weekly training load range of 3000 to 5000 arbitrary minutes (RPE-minutes).These training load 'thresholds' for injury were considerably lower (1700–3000 session-RPE units/week) in the competitive phase of the season."[18]

Once players enter the rehabilitation process, the challenge for clinicians is to appropriately load and enhance physical qualities that will provide a protective effect against injury in addition to preventing the 'spike' in loads when players return to full training.[16] The rehabilitation design should incorporate as many of the above factors as is necessary to return the athlete/individual to the pre-injury level of activity, while protecting them against future injury. Gabbett et al. explain that well-developed physical qualities can protect against injury,[16] emphasizing the importance of building hip and hamstring strength during rehabilitation. The goal should be to foster the following conditions for the rehabilitation environment: “If the acute training load is low (i.e., the athlete is experiencing minimal ‘fatigue’) and the rolling average chronic training load is high (i.e., the athlete has developed ‘fitness’), then the athlete will be in a well-prepared state.”[16]

Elite athlete considerations

Keep in mind that at the time of return to sport, although all athletes may show a near-complete resolution of pain and return of muscle strength, no athlete will show complete resolution of injury as assessed on MRI.[52] Regardless of how effective the rehabilitation strategy is, the tissue will lack some integrity several months for injury. Further, returning to play does not mean returning to pre-injury sprint performance for nearly half of the high-level professional football players examined in a recent study. This suggests that successful return to play metrics should be expanded from simple time to recover and injury recurrence to include specific performance parameters .[53]

Authors et al performed a study on injured elite soccer players finding that those who had less than 10 training sessions before they participated in a competitive match after an injury period had an increased risk of subsequent injury.[54] Even more importantly, for every additional training session before returning to a match, the odds for an injury were 7% lower, indicating that following a period of reduced activity, loading the hamstrings in a controlled practice environment should occur for a “reasonable length of time” before full activity is resumed.[54]

Platelet-rich plasma injections (PRP) are becoming an increasingly popular intervention for the treatment of acute muscle strains at the collegiate and professional sports levels. It has been proposed as an adjunct for tissue repair strategies and involves the injection of the individuals platelet growth factors into the tissue lesion for accelerated recovery.[55] As noted in one study, PRP does appear to hasten soft tissue healing at the injured site.[56] Authors et al study identified the average time to return to play was 26.7 days and 42.5 days for the PRP and control groups, respectively.[57] More recently, a study of 55 athletes with hamstring strains reported an average return to sport at 23.5 days and 32.4 days in the PRP and control groups, respectively.[58] Similarly, 69 NFL players having MRI evidence of grade II hamstring strains were divided into a PRP and control groups, with both groups receiving standard physical therapy as well. In the PRP group, average time missed included 22.5 days, 18.2 practices, and 1.3 games.[59] In the control group, average time missed included 25.7 days, 22.8 practices, and 2.9 games.[59] While there was no statistically significant difference in days or practices missed, there was a very statistically significant difference in the number of games missed. Considering the weight of each individual game at the NFL level, this is an important consideration.

Injury recurrence should be another consideration when assessing the influence of PRP interventions. In the aforementioned study of 55 athletes, injury recurrence over 6 months was reported at 4% (1/27) in the PRP group and 28.6% (8/28) in the control group.[58] In contrast, a systematic review of 6 studies and 374 patients (predominantly male athletes <30 years old) found no statistical difference in injury recurrence rates (ranging from 0-30% and 0-27% across studies) between the control and PRP groups.[60] In 2021, another systematic review analyzed 10 studies including a total of 207 hamstring injuries(cite). Authors concluded that PRP resulted in a non-significant reduction in time to return to sport and injury recurrence when compared to physical therapy alone.[61] A complication rate of 5.2% in the PRP group was also reported, and this included post injection discomfort, pain, or sciatic nerve irritation.[61]

In conclusion, there seems to be somewhat inconclusive evidence to suggest PRP improves hamstring recovery in higher-level athletes as assessed by return to sport and injury recurrence outcomes.

Key Points

- The BF demonstrates a strong eccentric contraction through the middle to late swing phase of high-speed running
- Hip flexion position increases and hip extension decreases with increasing speed
- The majority of hamstring injuries occur during high-speed running as the hamstring is actively lengthening in swing phase, with an estimated 70% off all injuries occurring to the long head of the BF
- Previous injury may increase risk of re-injury almost 11-fold
- Chronic and acute fatigue seems to be correlated with injury rates
- Greater hip flexion ROM deficit, greater maximal pain score, and >1 day to return to pain-free walking at the time of injury are associated with longer recovery times
- Eccentric strength training of the hamstrings reduces injury risk
- There may be sprint performance and re-injury risk benefits with regular static stretching after exercise
- The NHE should be a staple in any rehabilitation program
- It is important to load muscle per the ACSM guidelines to achieve the desired effect of increasing muscle strength and power
- A gradual return to running program is safest and most effective
- Running involves very individualized hamstring activity patterns, but these remain consistent as speed increases, so slower running should begin early in the rehabilitation program to restore neuromuscular function
- Appropriate rest is important for maintaining sprint performance in any interval or training regimen
- Pain scores are important to track and can be an indicator of readiness to progress in rehabilitation
- Utilize multiple outcome measures including strength, pain, ROM, and functional tasks such as, the single lep hop for distance, T-agility, and shuttle run tests to determine readiness for return to sport
- Monitoring acute and chronic training loads may help identify when an athlete is at increased risk for hamstring injury
- Re-injury risk may be reduced by up to 7% for every additional training session past 10 sessions that an athlete completes prior to return to full competition
- PRP injections may improve hamstring recovery and decrease time to return to sport, but may only be merited in professional and collegiate sports where time away from sport is costly

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