

Posterior Thigh Pain

WITH ANTHONY SCHACHE

CHAPTER 26

Anatomy

The hamstring muscle group (Fig. 26.1) consists of three main muscles: biceps femoris, semimembranosus and semitendinosus. Biceps femoris has two heads,

with the short head originating from the linea aspera and thus only acting on the knee joint.

Biceps femoris has a dual innervation, with the long head being innervated by the tibial portion of the sciatic nerve (L5, S1–3), whereas the short head

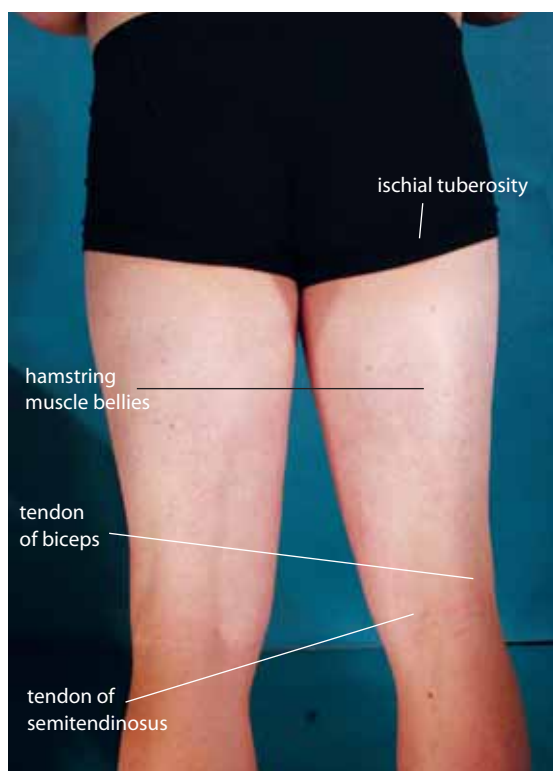
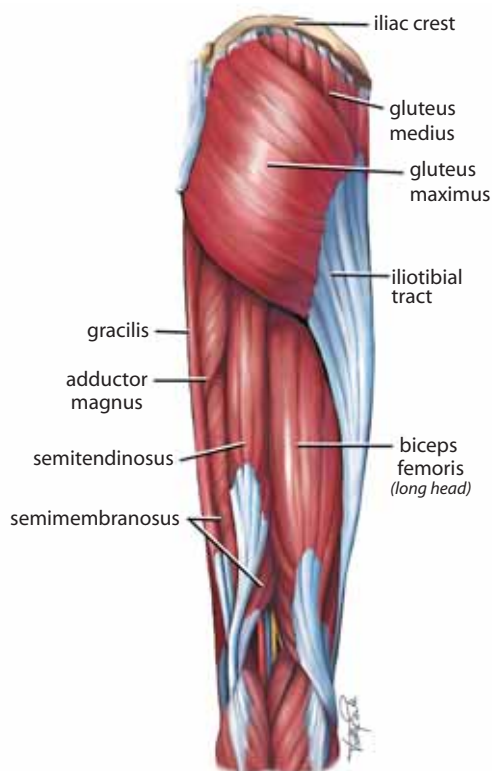


Figure 26.1 Anatomy of the posterior thigh

(a) Surface anatomy



(b) Muscles of the posterior thigh

is innervated by the common peroneal division (L5, S1–2).

The posterior portion of the adductor magnus is sometimes considered functionally as a hamstring due to its anatomical alignment. Adductor magnus is involved in hip extension and adduction and has innervation from the tibial portion of the sciatic nerve, like the majority of the hamstring group.

Clinical perspective

The effective management of posterior thigh pain is dependent upon correct diagnosis. Initially, the practitioner must determine whether the injury to the posterior thigh is a muscle strain or pain referred from elsewhere. This is not always a simple process. However, if not established, the athlete, practitioner and coach may be frustrated by a recurrent injury that hinders a successful return to sport.

In healthy individuals, a strain to a large muscle group such as the hamstrings is the result of a substantial force. The athlete should recall a particular point in time that the incident occurred and whether a significant force was applied to the muscle. Practitioners should be reticent to diagnose a muscle strain in the absence of these findings. Often this fundamental but common mistake will lead to inappropriate treatment. Tethering of neural structures or fascial strains in the posterior thigh can also occur as an incident, however, appropriate examination will reveal whether the injury has a fascial or neural component. The causes of posterior thigh pain are shown in Table 26.1.



The challenge in patients with posterior thigh pain is to distinguish between a hamstring muscle strain and referred pain from the lumbar spine or gluteal muscle trigger points.

History

Posterior thigh pain that is not the result of a hamstring strain will require skilful clinical reasoning to determine the cause. This involves not only an intricate knowledge of the local anatomy and possible abnormalities but also an understanding of the structures that can refer pain into this region. Practitioners should be aware of the wide variety of assessment and treatment techniques used around the pelvis in order to make an accurate diagnosis. Systems of treatment often are associated with a specific diagnosis. Therefore, a common fault in manual medicine is to make the diagnosis based on what best fits with the treatment technique of choice.

The inability to utilize alternative techniques leads a practitioner to the inevitable conclusion that the presenting injury can only be a result of a diagnosis that fits in with the technique they are most competent in using. For example, a practitioner unskilled in sacroiliac management is unlikely to ever diagnose referred pain from the SIJ as a cause of hamstring pain.

History taking has the same goals and objectives as any other area in sports medicine. However, because there are so many causes of posterior thigh pain, the clinician, having taken the history, must be able to formulate a definite set of goals for the subsequent examination. Otherwise, time will limit the examination or there will be confusion with the vast amount of information collected.

Table 26.1 Causes of posterior thigh pain

Common	Less common	Not to be missed
Hamstring muscle strains	Referred pain	Tumors
Acute	Sacroiliac joint	Bone tumors
Recurrent	Tendinopathy	Vascular
Hamstring muscle	Bursitis	Iliac artery endofibrosis
contusion	Semimembranous	
Referred pain	Ischiogluteal	
Lumbar spine	Fibrous adhesions	
Neural structures	'Hamstring syndrome' (Chapter 22)	
Gluteal trigger points	Chronic compartment syndrome of the posterior thigh	
	Apophysitis/avulsion fracture of the ischial tuberosity (in adolescents)	
	Nerve entrapments	
	Posterior cutaneous thigh	
	Sciatic	
	Adductor magnus strains	
	Myositis ossificans, hamstring muscle	

The important points to consider in the history of the patient with posterior thigh pain are listed below. Note that this is a guide only and is not comprehensive.

1. Level of activity
 - (a) Has a change in training caused injury?
 - (b) Is there an adequate base of training?
2. Occupation/lifestyle
 - (a) What factors outside of sport could be aggravating the condition (e.g. prolonged sitting at work, bending over with young children)?
3. Incident
 - (a) Yes: consider strain, fascial/neural trauma.
 - (b) No (not a strain!): consider overuse, referred pain, alternative abnormality.
4. Progress since injury
 - (a) Slow: indicates a more severe injury.
 - (b) Erratic: strain is being aggravated by activity or injury is not a strain.
5. Aggravating factors
 - (a) Incident related: useful for specificity of rehabilitation (e.g. acceleration injuries require acceleration in the rehabilitation program).
 - (b) Non-incident related: eradication or modification for recovery and prevention (e.g. sitting at a computer causing back/hamstring pain requires ergonomic modification).
6. Behavior with sport
 - (a) Warms up with activity, worse after—inflammatory pathology.
 - (b) Starts minimal or with no pain, builds up with activity but not as severe after—claudicant, either neurological or vascular.
 - (c) Sudden onset: mechanical (e.g. strain).
7. Night pain
 - (a) Sinister pathology.
 - (b) Inflammatory condition.
8. Site of pain
 - (a) Posterior thigh and lower back: lumbar referral or neuromotor/biomechanical mediator.
 - (b) Buttock, SIJ without lower back symptoms: trigger points.
 - (c) Ischial: tendinopathy/bursitis.
9. Presence of neurological symptoms
 - (a) Nerve involvement.
10. Recurrent problem
 - (a) Extensive examination and rehabilitation required.

Examination

All examinations should commence with observation and palpation. The remainder of the examination will depend on information gathered in the history. It is beneficial to have several quick tests to screen for various factors that commonly cause hamstring pain. However, once the most likely cause of pain has been identified, the most appropriate technique of assessment should be implemented to identify the exact nature of the problem. The initial examination should be thorough but not excessive. Contributing factors or alternative sources of pain in the hamstring group can be evaluated in subsequent examinations.

1. Observation
 - (a) standing (Fig. 26.2a)
 - (b) walking
 - (c) lying prone
2. Active movements
 - (a) lumbar movements
 - (b) hip extension
 - (c) knee flexion
 - (d) knee extension
3. Passive movements
 - (a) hamstring muscle stretch (Fig. 26.2b)
4. Resisted movements
 - (a) knee flexion
 - (b) hip extension
 - (c) eccentric hamstring contraction (Fig. 26.2c)
5. Functional tests
 - (a) kicking
 - (b) running
 - (c) sprint starts
6. Palpation
 - (a) hamstring muscles (Fig. 26.2d)
 - (b) ischial tuberosity
 - (c) gluteal muscles (Fig. 26.2e)
7. Special tests
 - (a) neural tension: slump test (Fig. 26.2f)
 - (b) lumbar spine examination (Chapter 21)
 - (c) sacroiliac joint (Chapter 22)
 - (d) assessment of lumbopelvic stability (Chapter 11)
 - (e) biomechanical analysis (video)

Investigations

Investigations of posterior thigh pain may be useful in defining the source of pain but practitioners must not take these findings in isolation from the rest of the examination. Both ultrasound and MRI can be used to confirm the presence of a muscle tear in cases where the diagnosis is in doubt clinically.



Figure 26.2 Examination of the patient with posterior thigh pain

(a) Observation. Look for wasting, bruising or swelling of the posterior thigh. Observation of gait is also important. Observation of the lumbar spine may show the presence of an excessive lordosis or relative asymmetry. A lateral view may demonstrate excessive lumbar lordosis or anterior pelvic tilt



(b) Passive movement—hamstring muscle stretch. The leg is raised to the point where pain is first felt and then to the end of range, pain permitting. Movement should be compared to the uninjured side



(c) Resisted movement—eccentric hamstring contraction. If pain is not produced by concentric contraction, an eccentric hamstring contraction should be performed as shown. This can be performed by rapid extension and catch or resistance against the force of the examiner's hand, which slowly extends the knee



(d) Palpation. Commence with the belly of the hamstring muscle with the knee in partial flexion. Palpation should also be performed during muscle contraction and with the muscle on stretch. The hamstring origin should also be palpated



(e) Palpation—gluteal muscles. Palpate the gluteal muscles for trigger points that are taut bands, which are usually exquisitely tender locally and may refer pain into the hamstring muscle



(f) Special tests—slump test. The slump test is an essential part of the examination of the patient with posterior thigh pain (Chapter 8). The slump test plays an important role in differentiating between hamstring muscle injuries and referred pain to the hamstring region from the lumbar spine

Hamstring muscle strains

Acute, moderate or severe hamstring strains are common injuries among sprinters, hurdlers and long jumpers. They also occur in other sports involving sprinting, especially football and field hockey. There is a tendency towards an increased incidence with increasing age. Hamstring injuries occur frequently despite the prevalence of stretching and strengthening programs.

Epidemiology

Hamstring muscle injuries are a common injury in sports that involve high-speed running and kicking. They are the most common and most prevalent injury in Australian football, constituting 15% of all injuries, with the average professional Australian Football League (AFL) club having six injuries per club (40 players) and 21 missed matches per club per season.¹ Similarly, in British soccer, hamstring injuries make up 12% of all injuries^{2,3} with an average of five per club per season, resulting in 15 matches and 90 days missed. The average injury caused the player to miss an average of 18 days and three matches.⁴

Hamstring muscle injuries have the highest recurrence rate of all injuries with a recurrence rate of 34% in AFL football¹ and 12% in British soccer.⁴

Biomechanics of hamstring injury

The majority of hamstring muscle injuries occur in the biceps femoris muscle, mainly at the muscle–tendon junction.^{4–6} They are usually a non-contact injury and mostly occur during sprinting.

During maximal sprinting the hamstrings become highly active in the terminal swing phase as they work eccentrically to decelerate the swinging tibia and control extension of the knee. The hamstrings then remain active into the initial stance phase, whereby they work concentrically as an extensor of the hip joint.^{4,7–9} Recent studies have demonstrated that during unperturbed sprinting the point of failure is most likely to occur during the terminal swing phase just prior to foot strike.^{10,11} It is at this point that the hamstrings are maximally activated and are approaching peak length.¹²

Factors that predispose to hamstring strain

Predisposing factors are generally divided into intrinsic (person-related) and extrinsic (environment-related) factors.

Intrinsic predisposing factors

Age

Several studies have shown that increasing age is a risk factor for hamstring muscle injury,^{4, 13–16} even when the confounding factor of previous injury is removed.⁸ Community level Australian footballers over 23 years old were four times as likely to sustain a hamstring strain than those younger than 23.

This relationship may be related to decreased strength (see below). This may be due to an age-related reduction in muscle fiber size and number, leading to a loss of mass and strength. Thus age-related denervation of muscle fibers may lead to increased risk.¹⁵ It has also been suggested that it may be due to age-related lumbar spinal degeneration, leading to L5 and S1 nerve impingement, thus resulting in hamstring and calf muscle fiber denervation, which then leads to decreased muscle strength.¹⁶

Previous injury

Previous hamstring injury is a major risk factor,^{8, 14, 17, 18} but past history of injury is associated with reduced strength so this may be a confounder.¹⁶ Previous calf muscle,¹⁶ knee or groin injuries have also been associated with an increased likelihood of hamstring injury.⁸

Race

There is an increased incidence of hamstring injury in those of black⁴ or Aboriginal⁸ ethnic origin.

Flexibility

Prospective studies have shown either a significant association between pre-season hamstring muscle tightness and subsequent development of a hamstring muscle injury,¹⁹ or a tendency towards a statistical relationship.^{15, 20}

Retrospective studies are of less value as any associated muscle weakness may be the result, rather than the cause, of the muscle injury. The retrospective studies have shown mixed results.^{21–23}

A survey of stretching practises among professional football teams in the United Kingdom found that more hamstring strains occurred in those teams that did not stretch regularly and/or hold their stretches for long periods.²⁴

One study suggested that decreased quadriceps flexibility (<52° knee flexion) had an increased risk of hamstring injury.¹⁵

Strength

Low hamstring strength has been shown in most studies to be a significant predictor of hamstring

muscle strain injury.^{23, 25–28} However, this has been contradicted by other studies.^{29, 30} Retrospective studies have shown that those with a history of hamstring injury have significantly weaker hamstrings.^{21, 31, 32}

It may be that the actual length at which peak torque in the muscle is developed is most important rather than the magnitude of the peak torque itself. Footballers with a history of hamstring strain develop peak torque at angles representing shorter muscle length, which therefore makes them vulnerable to load in the muscle under lengthened situations.³³

Neuromyofascial

A number of authors have suggested a relationship between increased neural tension and posterior thigh pain.^{34, 35} The presence of myofascial trigger points in the gluteal and hamstring muscles appears to be associated with decreased flexibility and possible increased motor firing of the muscle.

Lumbopelvic stability

Neuromuscular control of the lumbopelvic region, including anterior and posterior pelvic tilt, may be needed to create optimal function of the hamstrings in sprinting and high-speed skilled movement. Changes in pelvic position could lead to changes in length–tension relationships or force–velocity relationships.³⁶ Improvements in lumbopelvic stability appear to assist in the rehabilitation program.³⁶

Joint dysfunction

As mentioned above, age-related lumbar spinal degeneration leading to L5 and S1 nerve impingement may lead to hamstring and calf muscle fiber denervation, which then leads to decreased muscle strength.¹⁶

An increased incidence of lumbar lordosis was also noted in a group of players who had a history of hamstring strain in the previous 12 months when compared to an uninjured group.²²

In those with hamstring strains the innominate bone at the sacroiliac joint ipsilateral to the hamstring strain was found to be tilted anteriorly.³⁷ A bilateral anterior pelvic tilt has been associated with weakness of the transversus abdominis, which may make the hamstrings functionally tighter.

Extrinsic predisposing factors

Warm-up

A physiological warm-up consisting of isometric contractions increases the amount of force and length of stretch that the muscle can absorb prior to tearing.³⁸ There appears to be clinical evidence that

muscle strain injuries, in general, are more likely to occur without adequate warm-up.^{39–41}

Fatigue

Fatigued muscles are able to absorb less energy.⁴² Hamstring injuries are more common at the end of matches and training sessions in soccer,⁴ have a higher incidence in the fourth quarter of Rugby union,⁴³ and occur infrequently during warm-up of the first quarter in Australian football.⁴⁴

Fatigue may induce physiological changes within the muscle, as well as altered coordination, technique or concentration, predisposing the player to injury.⁴³ The dual innervation of biceps femoris could lead to asynchrony in the activation of separate parts of the muscle and result in inefficiencies. Abnormalities in running style may be the consequence of fatigue, increasing the workload of the stabilizing biarticular muscles around the pelvis.⁴⁵ When footballers become fatigued during sprinting there is an earlier activation of the biceps femoris and semitendinosus muscles.⁴⁶

Fitness level

Inadequate pre-season training resulting in low fitness levels may contribute to an increased hamstring injury rate.^{2, 47}

Training modalities

Too much emphasis on aerobic training instead of more high-intensity running/acceleration drills has been suggested as a causative factor.⁴⁸ Abrupt increases in training volume and intensity may also contribute to injury risk.⁴⁹

Additional specific predisposing factors in recurrent hamstring injuries

- Inadequate rehabilitation: this may lead to deficits in strength and/or flexibility.
- Angle of peak torque: as mentioned above, footballers with a history of hamstring strain develop peak torque at angles representing shorter muscle length, which therefore makes them vulnerable to load in the muscle under lengthened situations.³³
- Neural tension: injury may result in increases in neural tension.^{34, 35}

Prevention of hamstring muscle injuries

Stretching

A warm-up stretching program was found to statistically reduce the number of hamstring injuries in a military population.⁵⁰

Strengthening program

Correcting strength deficits can lower injury to the hamstrings.^{27, 31} Pre-season hamstring muscle strengthening using an open chain weight machine reduced the number of minor hamstring injuries but not the number of significant injuries.⁵¹ Specific eccentric training (see below) may be more important in view of the mechanism of injury.

Thermal pants

The use of thermal pants has been suggested to have a role in reducing the recurrence of hamstring injuries.⁵²

Combined programs

A number of multifactorial programs appear to have been effective in reducing the number of hamstring injuries. The programs have included:

- increasing the amount of anaerobic interval rather than aerobic training, stretching while muscle is fatigued, sport-specific training drills, and closed chain rather than open chain leg weights⁴⁸
- a program combining general interventions such as improved warm-up, regular cool down, and a series of exercises to improve stability of ankle and knee joints, flexibility and strength of the trunk, hip and leg muscles, as well as to improve coordination, reaction time and endurance—this was found to be effective in reducing injuries in soccer players, including thigh injuries⁵³
- a pre-season conditioning program consisting of sport-specific cardiovascular conditioning, plyometric work, sport cord drills, strength training and flexibility exercises in a group of soccer players.⁴⁷

Clinical features

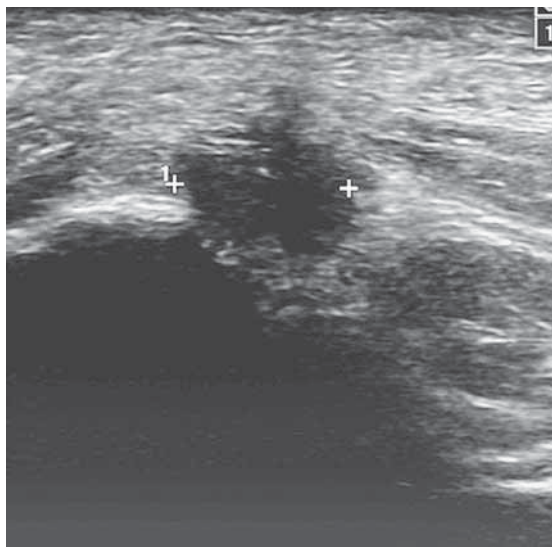
The main aim of the clinical history, examination and investigations is to differentiate between the significant hamstring tear and neuromyofascial referred pain primarily from gluteal trigger points but also from lumbar spine and SIJ structures. The clinical features of the two are shown in Table 26.2.

Imaging

Ultrasound and MRI have both been found to be effective in depicting hamstring injuries (Fig. 26.3). Ultrasound may be the preferred imaging technique due to lower costs, however, MRI is more sensitive

Table 26.2 Clinical features of hamstring muscle tear and referred hamstring pain

Hamstring muscle tear	Referred hamstring pain
Sudden onset	May be sudden onset or gradual feeling of tightness
Moderately severe pain	Usually less severe, may be cramping or 'twinge'
Disabling—difficulty walking, unable to run	Often able to walk/jog pain-free
Markedly reduced stretch	Minimal reduction in stretch
Markedly reduced contraction against resistance	Full or near to full muscle strength against resistance
Local hematoma, bruising	No local signs
Marked focal tenderness	Variable tenderness, usually non-specific
Slump test negative	Slump test frequently positive
May have gluteal trigger points	Gluteal trigger points that reproduce hamstring pain on palpation or needling
May have abnormal lumbar spine/SIJ signs	Frequently have abnormal lumbar spine/SIJ signs
Abnormal ultrasound/MRI	Normal ultrasound/MRI

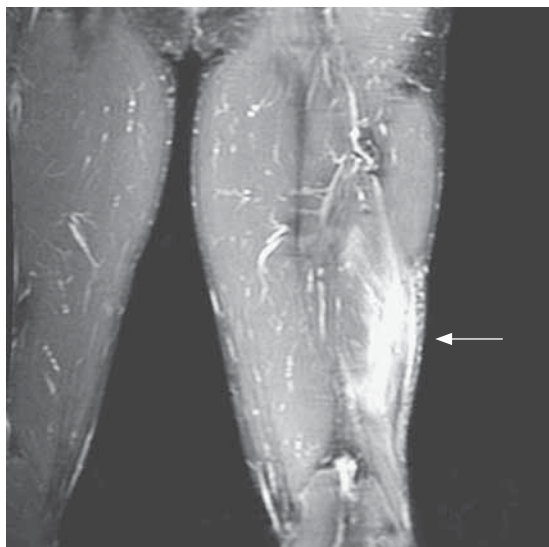
**Figure 26.3** Imaging of hamstring injuries

(a) Ultrasound showing hypoechoic area (between electronic calipers, +)

for follow-up imaging of healing injuries. The longitudinal extent of the strain as measured on MRI is a strong predictor of the amount of time needed until an athlete can return to competition.⁵

Management of hamstring strain

There is very little scientific evidence on which to base one's management of hamstring injuries. Only



(b) MRI demonstrating area of edema in hamstring consistent with muscle tear

one study has compared the efficacy of two treatment regimens,³⁶ so much of the regimen described below is on the basis of our clinical experience. Clearly, further research needs to be performed in this area.

The management of hamstring muscle injuries is summarized in Table 26.3.

Acute management

Acute injuries should always be assessed before any treatment, including ice, is administered.

Table 26.3 Management of hamstring injury**First 48 hours**

RICE

Early mobilization

Pain-free, active knee extension while sitting
(Fig. 26.4) following 10–15 minutes of ice

Subsequent

Stretching

Hamstrings (Fig. 26.5)

Antagonist muscles

Quadriceps

Iliopsoas

Strengthening

Hamstrings

Concentric (Fig. 26.8a)

Eccentric (Fig. 26.8b)

Gluteals and adductor magnus (Fig. 26.9)

Soft tissue treatment

Hamstrings (Fig. 26.6a, b)

Gluteal trigger points (Fig. 26.6d)

Neural stretching (Fig. 26.7)

Spinal mobilization

Cross-training bike

Running program (below)

Stability program (Figs 26.10, 26.11; Chapter 11)

**Figure 26.4** Active pain-free knee extension in the acute phase

The RICE program should be commenced. Pain-free, active knee extension may be performed while sitting following 10–15 minutes of ice (Fig. 26.4). This active stretching of the hamstring is conducted for 5 minutes and the whole process may be repeated every hour in the initial phase. The athlete may actually wake every few hours to use this technique in order to ensure inflammation settles as quickly as possible. This process normally takes place over two to three days or until inflammation has settled.

Medication

The role of NSAIDs in the treatment of acute muscle injuries such as the hamstring is controversial. The most common recommendation in the literature is short-term use (three to seven days) starting immediately after injury.^{9, 17} The intended aim of using NSAIDs is to keep the inflammatory process under control and to provide analgesia.⁵⁴ However, the normal healing process could be blunted as a result and the repair response delayed.⁵⁵ There is a case to delay treatment with NSAIDs until two to four days after injury because the drugs interfere with chemotaxis of cells, which is necessary for the repair and remodeling of regenerating muscles.⁹

Only one study has examined the use of NSAIDs in hamstring injuries and found no additional benefit

with NSAIDs over physiotherapy alone for the treatment of acute hamstring injuries.⁵⁶

We do not believe there is sufficient evidence to justify the use of NSAIDs in hamstring injuries. It makes more sense to use simple analgesics (paracetamol [acetaminophen]) in the first 48 hours for pain relief. The only situation where we recommend that a short course of NSAIDs may be helpful is if there is an excessive inflammatory response in the muscle as a result of early mobilization and aggressive exercise therapy (see below).⁵⁷

One study showed favorable results with intramuscular corticosteroid injection in American football players with acute hamstring injuries.⁵⁸ Previously, the use of corticosteroids in acute muscle strains had been clearly contraindicated because they were thought to lead to a delayed elimination of hematoma and necrotic tissue, as well as retardation of muscle regeneration.⁵⁷ There are concerns regarding the retrospective nature of the National Football League (NFL) study and lack of control group, so we caution against the use of corticosteroids in this situation until further clinical trials are conducted.

Stretching

In the acute phase, pain-free range of motion should be achieved as soon as possible. If there is long-term

loss of range of motion, then specific stretching should be undertaken to focus on the affected area (Fig. 26.5).

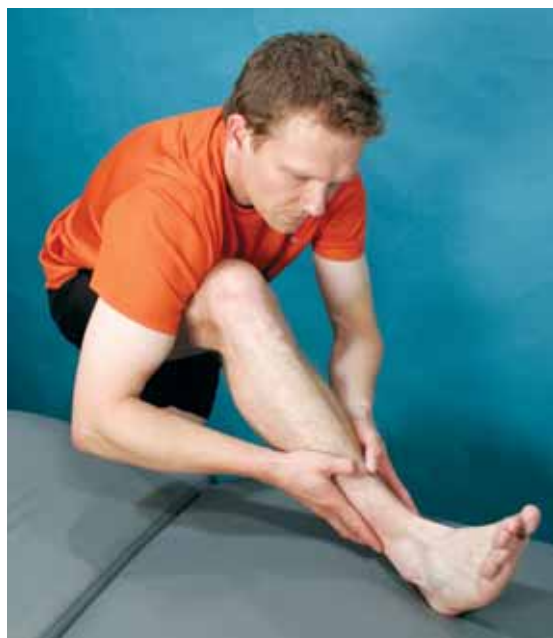
Soft tissue therapy

At an appropriate time depending on the severity of the injury, soft tissue techniques can be used in the treatment of hamstring strains. The distal musculo-



Figure 26.5 Hamstring stretches

(a) Hamstring stretch with contralateral knee flexion. The lower leg can be placed in different degrees of external and internal rotation to maximize the effectiveness of the stretch



(b) Hamstring stretch with bent knee results in maximal stretch to the upper hamstrings

tendinous region is palpated and treated in knee flexion with the foot resting on the therapist's shoulder. Digital ischemic pressure and sustained myofascial tension (Figs 26.6b, c) are used. Abnormalities of the gluteal muscles may be associated with hamstring strains. These regions may be treated in a side-lying position using elbow ischemic pressure with the tissue on stretch and the muscle contracting (Fig. 26.6d).

Manual therapy

The presence of a degree of hypomobility in any segment of the lumbar spine, found on examination, should be treated (Chapter 21). If increased neural tension is found at examination, neural stretches should be included in the treatment regimen (Fig. 26.7).

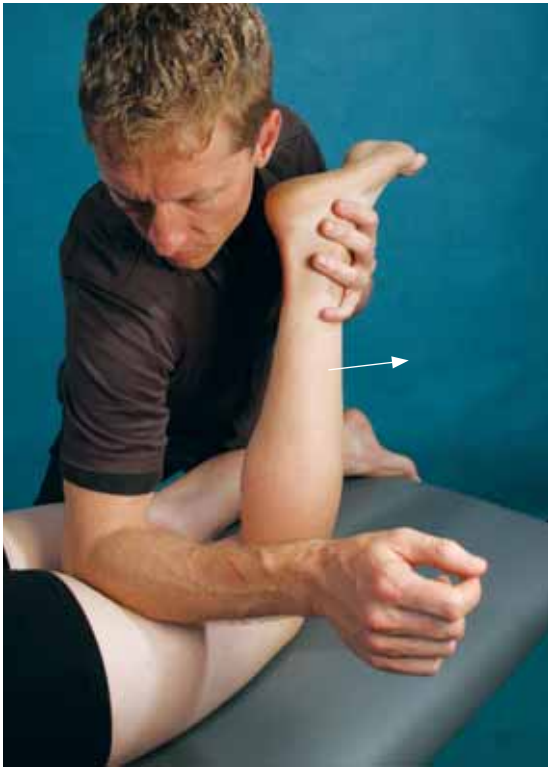
Strengthening

Strengthening is an essential component of prevention and rehabilitation of hamstring injuries. Muscle strengthening should be specific for deficits in motor



Figure 26.6 Soft tissue techniques in the treatment of hamstring injuries

(a) Sustained compression force to hamstring



(b) Sustained myofascial tension combined with passive knee extension. The hand or the elbow (illustrated) is kept stationary and the release is performed by passively extending the knee (arrow)



(d) Treatment of the gluteal region in a side-lying position using elbow ischemic pressure with the muscle contracting



(c) Digital ischemic pressure to the distal biceps femoris tendon



Figure 26.7 Neural stretch. Stretching of neural structures should be performed as part of the treatment of hamstring pain if tightness has been detected on neural tension testing. These neural stretches may be performed with the aid of a therapist or by the patient as shown

unit recruitment, muscle bulk, type of contraction (e.g. eccentric/concentric) and ability to develop tension at speed.

In view of the probable mechanism of hamstring injury (see above), it is likely that eccentric strength is particularly important in recovery and prevention of recurrence of hamstring strains. Muscle strengthening is mode-specific, in other words concentric muscle exercises lead to increases in concentric strength, eccentric muscle exercises lead to increases in eccentric strength, with little or no crossover.^{59,60} Therefore, to increase eccentric hamstring muscle strength it is necessary to perform eccentric muscle training. The use of the Nordic eccentric exercise (Fig. 26.8b) has



Figure 26.8 Strengthening exercises

(a) Concentric and eccentric exercises—prone. From a position of hip flexion, the knee is flexed (concentric) and/or extended and stopped just prior to full extension ('drop-and-catch') (eccentric). Weights can be added gradually and speed can be increased progressively



(b) Nordic eccentric hamstring exercise—patients allow themselves to fall forward and then resist the fall for as long as possible using their hamstrings

been shown to be more effective than traditional concentric strengthening in developing eccentric hamstring strength.⁶⁰

Taking into consideration the phase of the sprinting action where hamstring injuries occur, the ideal exercise would be eccentric to decelerate the very high angular knee velocity with maximum force production around 30° of knee flexion. No exercise exactly mimics that situation but, after some weeks of the Nordic hamstring training program, many athletes are able to stop the downward motion completely before touching the ground (i.e. at about 30° of knee flexion) using their hamstrings alone, even after being pushed by a partner at considerable speed. When an athlete can reach this stage, the characteristics of the Nordic hamstring exercise appear to resemble the typical injury situation: eccentric muscle action, high forces, near full knee extension.

Eccentric training has been shown to shift the point of peak torque development (see above) towards a more lengthened position,⁶¹ which may make the muscle less vulnerable to repeated injury.

Eccentric muscle training results in muscle damage and delayed onset muscle soreness in those unaccustomed to it. Therefore, any eccentric strengthening program should allow adequate time for recovery, especially in the first few weeks. The protocol used for the Nordic strengthening program in Mjolsnes study is shown in Table 26.4.⁶⁰

Strengthening exercises for the hamstring group should therefore consist of a mixture of concentric and eccentric exercises, as shown in Figure 26.8. Table 26.5 provides regimen guidelines for hamstring strengthening.

Muscles that assist the hamstrings

Not only should the hamstring itself be considered but also the muscles that assist the activity of the hamstring. Waters and colleagues found that at least 50% of the total hip moment is provided by the gluteal muscles in an isometric contraction of hip extension.⁶² It seems reasonable to hypothesize that if gluteal strength is inadequate in a sprinting athlete, the hamstrings will be overloaded. The adductor magnus should also be considered as an important hip extensor. Therefore, strengthening of the hamstring group should always include specific work to ensure adequate gluteal and adductor magnus conditioning (Fig. 26.9).

Core stability

Neuromuscular control of the lumbopelvic region, including anterior and posterior pelvic tilt, may

Table 26.4 Training protocol for Nordic hamstring exercises

Week	Sessions per week	Sets and repetitions	Load
1	1	2 × 5	Load is increased as subject can withstand the forward fall longer. When managing to withstand the whole ROM for 12 repetitions, increase load by adding speed to the starting phase of the motion. The partner can also increase loading further by pushing at the back of the shoulders.
2	2	2 × 6	
3	3	3 × 6–8	
4	3	3 × 8–10	
5–10	3	3 sets, 12, 10, 8 repetitions	

ROM = range of motion.

Table 26.5 Recommended regimen for hamstring strengthening

Weight	Load	Reps	Sets	Rest time	Speed	Regularity
Motor unit recruitment	60 RM	15	6	30 s	Concentric 2 s Eccentric 2 s	3 per day
Strength	6–8 RM	6–8	3–5	2 min	Concentric 1 s Eccentric 3 s	Once per 1–2 days
Hypertrophy	8–12 RM	8–12	6	2 min	Concentric 1 s Eccentric 3 s	Once per 1–2 days
Power	40 RM	15	3–4	3–4 min	Quick with control	Once per 2–3 days

RM = repetition maximum.

**Figure 26.9** Hip strengthening exercises

(a) One-legged bridging



(b) Squat



(c) Split squat

be needed to create optimal function of the hamstrings in sprinting and high-speed skilled movement. Changes in pelvic position could lead to changes in length–tension relationships or force–velocity relationships.³⁶

A rehabilitation program consisting of progressive agility and stabilization exercises (Fig. 26.10) has been shown to be more effective in promoting return to sport and in preventing injury recurrence in athletes who have sustained an acute hamstring strain than



(b) Single-leg ball rollout



(c) Single-leg stance with trunk straight



Figure 26.10 Agility and stabilization exercises

(a) Bridge catch



(d) Single-leg stance with trunk rotated



(e) Single leg stance with trunk rotated and with further stretch reaching out with arm

has a more traditional stretching and strengthening exercise program.³⁶

Progressive running program

PRACTISE PEARL Early commencement of a progressive running program is an important part of a rehabilitation following a hamstring muscle injury.

Scientific studies need to be performed to validate this program but physiotherapists with over 20 years experience of this program are convinced of its effectiveness. The basic principles are listed below with further detail in Table 26.6.

1. Running program starts 48 hours after injury.
2. 20 minute running sessions twice a day.
3. Preceded by 10 minutes of gentle hamstring stretching.
4. Commences with jogging with short stride (shuffle).
5. Patient encouraged to increase stride length and pace gradually over the session as the ache allows.
6. Interval running over 100 m (~110 yd) with acceleration, maintenance and deceleration phases.
7. If there is even the slightest increase in pulling sensation through the hamstring, then the session must immediately cease. The athlete should apply ice and the program can be attempted again as early as the next 12 hours.
8. Finish with 10 minutes of gentle hamstring stretching and then apply ice to the injured area for 10 minutes.

Table 26.6 Progressive hamstring running program

1. 2 km jog
2. 2 km varying pace up to 75% of maximum
3. Run throughs: accelerate 40 m, constant speed 20 m (time 3.5 s), decelerate 40 m (×3)

35 m	20 m	35 m (×3)
30 m	20 m	30 m (×3)
25 m	20 m	25 m (×3)
20 m	20 m	20 m (×3)
15 m	20 m	15 m (×3)
4. Run throughs: accelerate 40 m, constant speed 20 m (time 2.5 s), decelerate 40 m (×3)

35 m	20 m	35 m (×3)
25 m	20 m	25 m (×3)
20 m	20 m	20 m (×3)
15 m	20 m	15 m (×3)
10 m	20 m	10 m (×3)
5. Running out to catch ball—uncontested (×5)
6. Running out to catch ball—contested (×5)
7. Running and picking up ball—contested (×5)

Criteria for return to sport

There is no standard time for return to sport after hamstring injury as every hamstring injury is different. No scientific studies have examined the outcomes of various return to play strategies.⁶³ It does not appear that the MRI appearance is a good indicator of readiness to return to play. Abnormalities on MRI tend to persist well after athletes are back to full sport.⁵

The length of time is proportional to the severity of the injury. Generally, an athlete with a mild hamstring strain may be able to return to sport in 12–18 days if optimally treated (Table 26.3).

Rather than a specific time frame it is preferable to have definite criteria for return to sport:

- Completion of progressive running program
- Full range of movement (equal to uninjured leg)
- Full strength (equal or almost equal to uninjured leg)
 - 90¹⁷–95%^{31, 45} of eccentric strength of uninjured leg
- Pain-free maximal contraction
- Functional tests
 - Sprinting from a standing start
 - Abrupt changes of pace during run
 - Side stepping
 - Bending to catch ball at full speed (if appropriate for the sport)
- Successful completion of a full week of maximal training

It is important to continue the strengthening program for a few weeks after return to sport.

Referred pain to posterior thigh

The possibility of referred pain should always be considered in the athlete presenting with posterior thigh pain. Hamstring pain may be referred from the lumbar spine, the SIJ or from soft tissues, for example, the proximal fibers of the gluteus maximus and especially gluteus medius and the piriformis muscle (Fig. 26.11). Often, there is a history of previous or current low back pain.

The slump test (Fig. 26.2f) should be used to detect neural tightness. The test is positive when the patient's hamstring pain is reproduced and subsequently relieved with reduction of the neural tension by neck extension. Examination may reveal reduced range of movement of the lumbar spine, tenderness and/or stiffness of lumbar intervertebral joint(s) or tenderness over the area of the SIJ.

A positive slump test is strongly suggestive of a referred component to the patient's pain. However, a negative slump test does not exclude the possibility of referred pain and the lumbar spine should be carefully examined to detect any intervertebral segment hypomobility. Systematic soft tissue palpation of the hip extensors, abductors and rotators should also be performed.

Trigger points

Trigger points are common sources of referred pain to both the buttock (Chapter 22) and posterior thigh. The most common trigger points that refer pain to the mid hamstring are in the gluteus minimus, gluteus medius and piriformis muscles. The clinical syndrome associated with posterior thigh pain without evidence of hamstring muscle injury on MRI and reproduction of the patient's pain on palpation of gluteal trigger points is now well recognized and extremely common.⁶⁴

The clinical features are described in Table 26.2. The patient will often complain of a feeling of tightness, cramping, 'twinge' or a feeling that the hamstring is 'about to tear'. On examination there may be some localized tenderness in the hamstring although it is usually not focal and there is restriction in hamstring and gluteal stretch. Firm palpation of the gluteal muscles will detect tight bands that contain active trigger points, which when firmly palpated are extremely tender, refer pain into the hamstring and elicit a 'twitch response'.

Treatment involves deactivating the trigger point either with ischemic pressure using the elbow (Fig. 26.12a) or dry needling (Fig. 26.12b). Following the

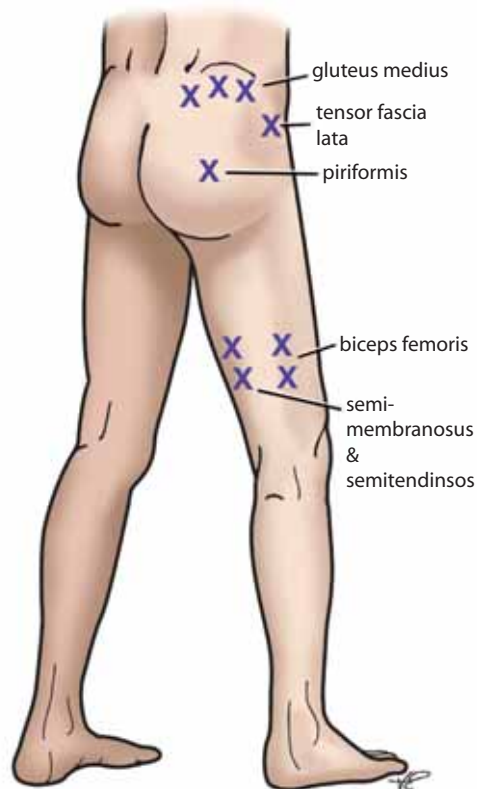


Figure 26.11 Pattern of referred pain to the hamstrings from trigger points

local treatment the tight muscle groups, the gluteals and hamstrings, should be stretched.

Lumbar spine

The lumbar spine is a source of pain referral to the posterior thigh. Unfortunately, it is difficult to distinguish between sources based on the behavior and distribution of the pain. Pain may be referred from the disk, zygoapophyseal joints, muscles, ligaments or any structure that can produce pain locally in the lumbar spine.⁶⁵

Nerve root compression may also be a cause of hamstring pain. Diagnostic blocks and provocation injections have been advocated to isolate sources of pain in the lumbar spine. However, in the clinical setting, this is often not possible. It is important to examine the lumbar spine carefully (Chapter 21). This will assist in the identification of the lumbar spine as a source of hamstring pain. It is also important to remember that the lumbar spine may be a cause of lumbar pain indirectly. For example, the lumbar



Figure 26.12 Treatment of gluteal trigger points

(a) Elbow pressure



(b) Dry needling

spine may cause a biomechanical block to extension of the lower limb, resulting in overload of the SIJ and referred pain to the hamstring group.

The slump technique (Fig. 26.2f) has been advocated as a method of treatment of hamstring pain in AFL footballers.³⁴ This is a quick test and it can be carried out rapidly to assess the relevance of neural structures as a cause of hamstring strain.

True nerve root compression is usually more definitive in its presentation. The patient may have associated neurological symptoms, such as numbness and loss of foot eversion. The management of these injuries usually involves an extended period of rest and, in certain cases, an epidural injection. In extreme cases, surgical decompression of the nerve root may be warranted.

Spondylolisthesis and spondylolysis have both been implicated as a source of hamstring pain and tightness.⁶⁶ Examination findings of positive lumbar quadrant tests or single leg standing lumbar extension are suggestive of either condition and can be confirmed with isotopic bone scan and CT. Stabilization programs are the treatment of choice as it has been shown that the deep abdominal muscles are deficient in people with back pain as a result of spondylolisthesis and spondylolysis.⁶⁷ In severe cases, corticosteroid injection under X-ray control into the deficient pars interarticularis may be effective in reducing pain from spondylolysis.

Hamstring pain occurring in the sporting environment can often be due to loading of the lumbar spine outside of the training and competition environment. Pain in the hamstring may be the result of referred pain from the lumbar spine as a result of prolonged sitting or bending forward. Athletes in sedentary occupations should be aware that sitting posture is a cause of injury to the hamstring. Travel involving prolonged sitting prior to training and competition may cause injury. This includes car, bus or airplane travel, and care should be undertaken to limit prolonged sitting and to provide adequate lumbar support.

Lumbar referred hamstring pain may also be the result of repeated forward bending or squatting. This occurs in many manual occupations or in those with young children. Again, correct posture and lifting should be taught, along with strategies for limiting the frequency and load of bending.

Sacroiliac complex

The SIJ can refer pain into the hamstring or cause indirect pain in the hamstring similar to the lumbar spine. The SIJ is discussed in Chapter 22.

Less common causes

Nerve entrapments

The hamstring group is supplied by the tibial branch of the sciatic nerve except for the short head of the biceps femoris, which is supplied by the peroneal branch of the sciatic nerve. These nerves arise from the lumbosacral plexus, specifically from the roots of L5, S1 and S2.

Nerve damage can occur at a variety of sites resulting in pain in the posterior thigh. Compression of the nerve roots of the sacral plexus will often result in pain into the hamstring group. Usually this is distinguished from other conditions by the identification of associated neurological symptoms such as alteration in sensation, loss of the Achilles reflex or weakness in muscles not in the hamstring group, such as the ankle evertors.

The sciatic nerve may be damaged at any point along its pathway as a result of direct impact or pelvic trauma. Compression of the nerve at the level of the piriformis has been described as an alternative cause of sciatica.⁶⁸ However, work by McCrory and Bell suggests that it is not only the piriformis but also the other hip external rotators that may cause compression of the sciatic nerve.⁶⁹

The peripheral nerves of the body may also be a source of posterior thigh pain. The posterior cutaneous nerve of the thigh (PCNT) and the inferior cluneal nerve supply the skin over the posterior thigh. The PCNT has been described as the source of pain in piriformis syndrome as an alternative to the sciatic nerve.⁶⁹ If symptoms do not extend below the knee and there is no associated loss of neurological function in the structures supplied by the sciatic nerve, then the PCNT should be considered.

Upper hamstring tendinopathy

Tendinopathy of the hamstring may occur at the origin or the insertion of the hamstring muscle group. Both present with the typical inflammatory pattern of warming up with activity and an increase in pain post activity. Tenderness is easily elicited over the tendon with associated thickening.

Proximal hamstring tendinopathy is often associated with repetitive sprinting and instability of pelvic mechanics. There may be some difficulty differentiating it from ischial bursitis, which tends to be more a result of friction with sitting on hard surfaces or 'hamstring syndrome', which has more neurological symptoms. Upper hamstring tendinopathy may respond to transverse frictions in the short term and

this will often allow an athlete to continue performing. However, the prognosis is usually protracted. A hamstring strengthening program should be commenced.

This condition is often resistant to treatment. We have had some success with extracorporeal shock wave treatment.

Ischial bursitis

It is often difficult to distinguish between hamstring tendinopathy and ischial bursitis. Both conditions have an inflammatory pain pattern at the origin of the hamstring muscle. An inflamed bursa is not readily palpated, however, athletes tend to complain of pain when sitting on hard surfaces where the ischium is under pressure. Ultrasound or MRI can confirm the presence of a fluid-filled bursa.

Anti-inflammatory medications combined with ice and rest are of limited benefit. Cortisone injections can be performed under X-ray control but the results are not always satisfactory.

Lower hamstring tendinopathy

Lower hamstring tendinopathy is often the result of large volumes of resisted flexion knee exercises. It also occurs in sprinters. The pain pattern is inflammatory and the pain is localized to the tendons of the hamstring group. Posterior capsular pain should be differentiated from tendinopathy. Pain associated with knee hyperextension, such as in kicking, is usually capsular. Management consists of anti-inflammatory agents, taping to reduce load and appropriate rehabilitation focusing on biomechanical defects.

Adductor magnus strains

Adductor magnus strains are rare but, when they do occur, behave similarly to a hamstring strain. The mechanism tends to be more of a rotatory action of eccentric internal rotation on one hip. Prognosis tends to be far better than hamstring strains; therefore, it is important to differentiate it from strains in the hamstring. The key to differentiating this condition is careful palpation to elicit the precise location of the tissue damage. Side-lying on the affected leg allows that hamstring group to fall laterally so that ready access can be made to the adductor magnus.

Compartment syndrome of the posterior thigh

While not as common as lower leg compartment syndromes, a compartment syndrome of the posterior

thigh is occasionally seen. Patients present with dull pain, stiffness, cramps and weakness of the posterior thigh during and after training.⁷⁰ Two groups of patients with this syndrome are seen: endurance athletes without a history of trauma, and those with a history of hamstring injury.

Conservative management has not been successful and posterior fasciotomy of the thigh appears to be an effective treatment.⁷⁰

Avulsion of the hamstring from the ischial tuberosity

Avulsion of the hamstring from the ischial tuberosity is seen in two groups of patients: adolescents who instead of sustaining a hamstring muscle tear, tear their hamstring from its bony attachment at the ischium, and older people, often with a history of chronic tendinopathy.

Young sportspeople in the 14–18 year age range are prone to avulsions of the ischial apophysis. Any young adult presenting with an incident of acute severe hamstring pain should be treated as if with an avulsion until proven otherwise. Plain X-ray or bone scan may be used to identify the avulsion. According to the literature, a separation of greater than 2 cm (1 in.) requires open reduction and internal fixation.⁷¹ Separations of less than 2 cm (1 in.) are often managed conservatively, requiring eight to 12 weeks' rest. However, some caution should be exercised with conservative management as these athletes can be left with decreased power in their hamstrings, which limits future sporting performance. Occasionally, there is neurological involvement associated with this injury.⁷²

In adults, complete rupture of the ischial origin of the hamstring muscles is relatively rare.^{73,74} The injury results from a sudden forceful flexion of the hip joint when the knee is fully extended and the hamstring muscles powerfully contracted. The most common activities associated with the rupture are waterskiing and power lifting. If treated with prompt surgery, the final functional results are good.

Vascular

Endofibrosis of the external iliac artery usually produces pain in the lateral and anterior thigh. However, in some cases, pain may be experienced in the posterior thigh. This condition is associated with cycling⁷⁵ and has been observed in triathletes. The pain is claudicant in nature. Pain may arise after 15–20 minutes of exercise but usually ceases immediately with the cessation of exercise.

On examination, a bruit is heard during the exercise that causes the pain. Diagnosis may be confirmed with echography or arteriography. If the condition is affecting performance, then treatment is either surgical or balloon dilation of the area where the artery is narrowed.

Recommended Reading

- Croisier J-L. Factors associated with recurrent hamstring injuries. *Sports Med* 2004; 34(10): 681–95.
- Drezner JA. Practical management: hamstring muscle injuries. *Clin J Sport Med* 2003; 13(1): 48–52.
- Garrett WE Jr. Muscle strain injuries. *Am J Sports Med* 1996; 24(6): S2–S8.
- Petersen J, Holmich P. Evidence based prevention of hamstring injuries in sport. *Br J Sports Med* 2005; 39(6): 319–23.

References

- Orchard J, Seward H. Epidemiology of injuries in the Australian Football League, seasons 1997–2000. *Br J Sports Med* 2002; 36: 39–45.
- Hawkins RD, Fuller CW. A prospective epidemiological study of injuries in four English professional football clubs. *Br J Sports Med* 1999; 33: 196–203.
- Hawkins RD, Hulse MA, Wilkinson C, et al. The Association Football medical research programme: an audit of injuries in professional football. *Br J Sports Med* 2001; 35: 43–7.
- Woods C, Hawkins RD, Maltby S, et al. The football association medical research programme: an audit of injuries in professional football—analysis of hamstring injuries. *Br J Sports Med* 2004; 38: 36–41.
- Connell DA, Schneider-Kolsky ME, Hoving JL, et al. Longitudinal study comparing sonographic and MRI assessments of acute and healing hamstring injuries. *AJR Am J Roentgenol* 2004; 183: 975–84.
- Koulouris G, Connell DA. Evaluation of the hamstring muscle complex following acute injury. *Skeletal Radiol* 2003; 32(10): 582–9.
- Stanton P, Purdam C. Hamstring injuries in sprinting—the role of eccentric exercise. *J Orthop Sports Phys Ther* 1989; March: 343–9.
- Verrall GM, Slavotinek JP, Barnes PG, et al. Clinical risk factors for hamstring muscle strain injury: a prospective study with correlation of injury by magnetic resonance imaging. *Br J Sports Med* 2001; 35: 435–40.

9. Petersen J, Holmich P. Evidence based prevention of hamstring injuries in sport. *Br J Sports Med* 2005; 39(6): 319–23.
10. Heiderscheit BC, Hoerth DM, Chumanov ES, et al. Identifying the time of occurrence of a hamstring strain injury during treadmill running: a case study. *Clin Biomech* 2005; 20(10): 1072–8.
11. Thelen DG, Chumanov ES, Hoerth DM, et al. Hamstring muscle kinematics during treadmill sprinting. *Med Sci Sports Exerc* 2005; 37(1): 108–14.
12. Wood GA. Biomechanical limitations to sprint running. In: Van Gheluwe B, Atha J, eds. *Current Research in Sports Biomechanics*. Basel: Karger, 1987: 58–71.
13. Arnason A, Tenga A, Engebretsen L, et al. A prospective video-based analysis of injury situations in elite male football: football incident analysis. *Am J Sports Med* 2004; 32(6): 1459–65.
14. Arnason A, Sigurdsson SB, Gudmundson A, et al. Risk factors for injuries in football. *Am J Sports Med* 2004; 32: S5–S16.
15. Gabbe BJ, Finch CF, Bennell KL, et al. Risk factors for hamstring injuries in community level Australian football. *Br J Sports Med* 2005; 39(2): 106–10.
16. Orchard JW. Intrinsic and extrinsic risk factors for muscle strains in Australian football. *Am J Sports Med* 2001; 29(3): 300–3.
17. Drezner JA. Practical management: hamstring muscle injuries. *Clin J Sport Med* 2003; 13(1): 48–52.
18. Garrett WE Jr. Muscle strain injuries. *Am J Sports Med* 1996; 24(6): S2–S8.
19. Witvrouw E, Danneels L, Asselman P, et al. Muscle flexibility as a risk factor for developing muscle injuries in male professional soccer players. a prospective study. *Am J Sports Med* 2003; 31(1): 41–6.
20. Rolls A, George K. The relationship between hamstring muscle injuries and hamstring muscle length in young elite footballers. *Phys Ther Sport* 2004; 5: 179–87.
21. Jonhagen S, Nemeth G, Eriksson E. Hamstring injuries in sprinters. The role of concentric and eccentric hamstring muscle strength and flexibility. *Am J Sports Med* 1994; 22(2): 262–6.
22. Hennessey L, Watson AW. Flexibility and posture assessment in relation to hamstring injury. *Br J Sports Med* 1993; 27: 243–6.
23. Orchard J, Marsden J, Lord S, et al. Preseason hamstring muscle weakness associated with hamstring muscle injury in Australian footballers. *Am J Sports Med* 1997; 25(1): 81–5.
24. Dadebo B, White J, George KP. A survey of flexibility training protocols and hamstring strains in professional football clubs in England. *Br J Sports Med* 2004; 38: 388–94.
25. Burkett LN. Investigation into hamstring strains: the case of the hybrid muscle. *J Sports Med* 1975; 3: 228–31.
26. Christensen C, Wiseman D. Strength, the common variable in hamstring strains. *J Athl Train* 1972; 7: 36–40.
27. Heiser T, Weber J, Sullivan G, et al. Prophylaxis and management of hamstring muscle injuries in intercollegiate football players. *Am J Sports Med* 1984; 12(5): 368–70.
28. Yamamoto T. Relationship between hamstring strains and leg muscle strength. A follow up study of collegiate track and field athletes. *J Sports Med Phys Fitness* 1993; 33: 194–9.
29. Bennell K, Wajswelner H, Lew P, et al. Isokinetic strength testing does not predict hamstring injury in Australian rules footballers. *Br J Sports Med* 1998; 32: 309–14.
30. Dauty M, Potiron-Josse M, Rochcongar P. Consequences and prediction of hamstring muscle injury with concentric and eccentric isokinetic parameters in elite soccer players (Abstract). *Ann Readapt Med Phys* 2003; 46(9): 601–6.
31. Croisier J-L, Forthomme B, Namurois M-H, et al. Hamstring muscle strain recurrence and strength performance disorders. *Am J Sports Med* 2002; 30(2): 199–203.
32. Worrell T, Perrin D, Gansnedder B, et al. Comparison of isokinetic strength and flexibility measures between hamstring injured and noninjured athletes. *J Orthop Sports Phys Ther* 1991; 13: 118–25.
33. Brockett CL, Morgan DL, Proske U. Predicting hamstring strain injury in elite athletes. *Med Sci Sports Exerc* 2004; 36(3): 379–87.
34. Kornberg C, Lew P. The effect of stretching neural structures on grade one hamstring injuries. *J Orthop Sports Phys Ther* 1989; 10(12): 481–7.
35. Turl SE, George KP. Adverse neural tension: a factor in repetitive hamstring strain? *J Orthop Sports Phys Ther* 1998; 27(1): 16–21.
36. Sherry MA, Best TM. A comparison of 2 rehabilitation programs in the treatment of acute hamstring strains. *J Orthop Sports Phys Ther* 2004; 34: 116–25.
37. Cibulka MT, Rose SJ, Delitto A, et al. Hamstring muscle strain treated by mobilizing the sacroiliac joint. *Phys Ther* 1986; 66(8): 1220–3.
38. Safran MR, Seaber AV, Garrett WE Jr. Warm-up and muscular injury prevention: an update. *Sports Med* 1989; 8(4): 239–49.
39. Agre JC, Baxter TL. Musculoskeletal profile of male collegiate soccer players. *Arch Phys Med Rehabil* 1987; 68: 147–50.
40. Ekstrand J, Gillquist J, Moller M, et al. Incidence of soccer injuries and their relation to training and team success. *Am J Sports Med* 1983; 11: 63–7.
41. Dvorak J, Junge A, Chomiak J, et al. Risk factor analysis for injuries in football players: possibilities for a prevention program. *Am J Sports Med* 2000; 28(5): S69–S74.

42. Mair SD, Seaber AV, Glisson RR, et al. The role of fatigue in susceptibility to acute muscle strain injury. *Am J Sports Med* 1996; 24(2): 137–43.
43. Devlin L. Recurrent posterior thigh symptoms detrimental to performance in rugby union: predisposing factors. *Sports Med* 2000; 29(4): 273–87.
44. Verrall GM, Slavotinek JP, Barnes PG, et al. Diagnostic and prognostic value of clinical findings in 83 athletes with posterior thigh injury: comparison of clinical findings with magnetic resonance imaging documentation of hamstring muscle strain. *Am J Sports Med* 2003; 31(6): 969–73.
45. Croisier J-L. Factors associated with recurrent hamstring injuries. *Sports Med* 2004; 34(10): 681–95.
46. Pinniger GJ, Steele JR, Groeller H. Does fatigue induced by repeated dynamic efforts affect hamstring muscle function? *Med Sci Sports Exerc* 2000; 32: 647–53.
47. Heidt RS, Sweeterman LM, Carlonas RL, et al. Avoidance of soccer injuries with pre-season conditioning. *Am J Sports Med* 2000; 28(5): 659–62.
48. Verrall GM, Slavotinek JP, Barnes PG. The effect of sports specific training on reducing the incidence of hamstring injuries in professional Australian Rules football players. *Br J Sports Med* 2005; 39(6): 363–8.
49. Almeida SA, Williams KM, Shaffer RA, et al. Epidemiological patterns of musculoskeletal injuries and physical training. *Med Sci Sports Exerc* 1999; 31: 1176–82.
50. Hartig DE, Henderson JM. Increasing hamstring flexibility decreases lower extremity overuse injuries in military basic trainees. *Am J Sports Med* 1999; 27(2): 173–6.
51. Askling C, Karlson J, Thorstensson A. Hamstring injury occurrence in elite soccer players after pre-season strength training with eccentric overload. *Scand J Sci Med Sports* 2003; 13: 244–50.
52. Upton PAH, Noakes TD, Juritz JM. Thermal pants may reduce the risk of recurrent hamstring injuries in rugby players. *Br J Sports Med* 1996; 30: 57–60.
53. Junge A, Rosch D, Lars P, et al. Prevention of soccer injuries: a prospective intervention study in youth amateur players. *Am J Sports Med* 2002; 30(5): 652–9.
54. Obrensky WT, Seaber AV, Ribbeck BM, et al. Biomechanical and histologic assessment of a controlled muscle strain injury treated with piroxicam. *Am J Sports Med* 1994; 22(4): 558–62.
55. Saartok T. Muscle injuries associated with soccer. *Clin Sports Med* 1998; 17: 811–17.
56. Reynolds JF, Noakes TD, Schwellnus MP. Non-steroidal anti-inflammatory drugs fail to enhance healing of acute hamstring injuries treated with physiotherapy. *S Afr Med J* 1995; 85: 517–22.
57. Jarvinen TAH, Jarvinen TLN, Kaariainen M, et al. Muscle injuries: biology and treatment. *Am J Sports Med* 2005; 33(5): 745–64.
58. Levine WE, Bergfeld JA, Tessedorf W, et al. Intramuscular corticosteroid injection for hamstring injuries: a 13-year experience in the National Football League. *Am J Sports Med* 2000; 28(3): 297–300.
59. Kaminski TW, Wabbersen CV, Murphy RN. Concentric versus enhanced eccentric hamstring strength training: clinical implications. *J Athl Train* 1998; 33: 216–21.
60. Mjolsnes R, Arnason A, Osthaugen T, et al. A 10-week randomized trial comparing eccentric vs. concentric hamstring strength training in well-trained soccer players. *Scand J Med Sci Sports* 2004; 14: 311–17.
61. Brockett CL, Morgan DL, Proske U. Human hamstring muscles adapt to eccentric exercise by changing optimum length. *Med Sci Sports Exerc* 2001; 33(5): 783–90.
62. Waters RL, Perry J, McDaniels JM, et al. The relative strength of the hamstrings during hip extension. *J Bone Joint Surg Am* 1973; 56A(8): 1592–7.
63. Orchard J, Best TM, Verrall GM. Return to play following muscle strains. *Clin J Sport Med* 2005; 15(6): 436–41.
64. Huguenin L, Brukner PD, McCrory P, et al. Effect of dry needling of gluteal muscles on straight leg raise: a randomised, placebo controlled, double blind trial. *Br J Sports Med* 2005; 39(2): 84–90.
65. Bogduk N. *Clinical Anatomy of the Lumbar Spine and Sacrum*. 4th edn. Edinburgh: Churchill Livingstone, 2004.
66. Barash HL, Galante JO, Lambert CN, Ray RD. Spondylolisthesis and tight hamstrings. *J Bone Joint Surg Am* 1970; 52A(7): 1319–28.
67. O'Sullivan PB, Twomey L, Allison GT. Dynamic stabilization of the lumbar spine. *Clin Rev Phys Rehab Med* 1997; 9(3 & 4): 315–30.
68. Puranen J, Orava S. The hamstring syndrome. A new diagnosis of gluteal sciatic pain. *Am J Sports Med* 1988; 16(5): 517–21.
69. McCrory P, Bell S, Bradshaw C. Nerve entrapment of the lower leg, ankle and foot in sport. *Sports Med* 2002; 32(6): 371–91.
70. Orava S, Rantanen J, Kujala UM. Fasciotomy of the posterior femoral muscle compartment in athletes. *Int J Sports Med* 1998; 19(1): 71–5.
71. Servant CTJ, Jones CB. Displaced avulsion of the ischial apophysis: a hamstring injury requiring internal fixation. *Br J Sports Med* 1998; 32: 255–7.
72. Street C, Burks R. Chronic complete hamstring avulsion causing foot drop: a case report. *Am J Sports Med* 2000; 28(4): 574–6.
73. Cross MJ, Vandersluis R, Wood D, et al. Surgical repair of chronic complete hamstring tendon rupture in the adult patient. *Am J Sports Med* 1998; 26(6): 785–8.
74. Klingele KE, Sallay PI. Surgical repair of complete proximal hamstring tendon rupture. *Am J Sports Med* 2002; 30(5): 742–7.
75. Abraham P, Saumet JL, Chevalier JM. External iliac artery endofibrosis in athletes. *Sports Med* 1997; 24(4): 221–6.