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SURGICAL TREATMENT OF HAMSTRING INJURIES AND DISORDERS

– the Clinical Spectrum from Chronic Tendinopathy to Complete Rupture

by

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ABSTRACT

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Surgical treatment of hamstring injuries and disorders – the clinical spectrum from chronic tendinopathy to complete rupture

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Hamstring muscle injuries and tendon disorders are common, especially in sports. They can be severe and difficult to treat, often resulting in impaired athletic performance and long rehabilitation times. Previous studies considering treatment of these problems are scarce. The current study was designed to investigate the effect of surgery on different types of hamstring muscle injuries and on proximal hamstring tendinopathy. In addition, we wanted to study the typical histopathological findings relating to proximal hamstring tendinopathy.

In the study of complete (all three muscles torn) proximal hamstring avulsions (41 patients), our results showed that early operative treatment gives significantly better results than late surgery, and is therefore recommended. Despite this, considerable improvement of symptoms could also be achieved in chronic cases.

In the study of partial (one or two muscles torn) proximal hamstring tears (47 patients), we observed that these injuries can cause significant functional deficit and impaired performance in athletes. The main finding was that after surgical repair most of the patients were able to return to their pre-injury level of sports.

In the study of distal hamstring tears (18 patients), the results showed that surgical treatment had a good effect in the majority of these cases.

In proximal hamstring tendinopathy, the main problem is pain which limits sports. In this study (90 patients), we found that after unsuccessful conservative treatment, surgery was a good treatment option resulting in full return to sports in most cases. In tendinopathic hamstring tendons, the morphological changes of tendinosis were largely identical to those previously described in other common (e.g. Achilles and patellar) tendinopathies.

In chronic proximal hamstring avulsions, and also in reoperations, a large defect between distally retracted tendons and the ischial tuberosity may occasionally prevent anatomic reinsertion. We have described a reconstruction method using fascia lata autograft augmentation to be used in these most challenging repairs. This technique was utilized in the treatment of five patients, with encouraging results.

Key words: hamstring, muscle, tendon, injury, rupture, surgical treatment, tendinopathy, histology, tendinosis

TIIVISTELMÄ

Lasse Lempainen

Takareiden lihasvammojen (hamstring-lihakset) leikkaushoito – kliininen kirjo kroonisesta jännesairaudesta täydelliseen lihasrepeämään

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Hamstring-lihaksiin sekä niiden jänteisiin kohdistuvat vammat ovat yleisiä liikuntaa harrastavilla. Ne voivat olla vaikeahoitoisia ja aiheuttavat urheilijoilla usein suorituskyvyn heikkenemistä. Aikaisempia tutkimuksia hamstring-ongelmien hoidosta on vähän. Tämän väitöskirjan tavoitteena oli arvioida leikkaushoidon merkitystä erilaisten hamstring-vammojen sekä hamstring-tendinopatian hoidossa. Lisäksi tarkoituksena oli selvittää proksimaalisen hamstring-tendinopatian histopatologiset löydökset.

Ensimmäisessä osatyössä (41 potilasta) osoitettiin, että varhaisen leikkaushoidon tulokset täydellisen (kaikki kolme lihasta), proksimaalisen hamstring-repeämän hoidossa ovat merkittävästi paremmat kuin myöhäisvaiheessa leikatuilla potilailla. Tästä syystä suosittelemme varhaista leikkaushoitoa täydellisen, proksimaalisen hamstring-repeämän hoidoksi. Tosin oireiden lievittymistä havaittiin myös myöhemmin leikatuilla potilailla.

Toisessa osatyössä tutkittiin leikkaushoitoa urheilijoilla, joilla oli osittainen (yhden tai kahden lihaksen) proksimaalinen hamstring-repeämä (47 potilasta). Tämän kaltainen vamma voi aiheuttaa erityisesti urheilijoilla merkittävää suorituskyvyn heikkenemistä. Tämän osatyön tärkein löydös oli se, että leikkaushoidon jälkeen suurin osa potilaista pystyi jälleen urheilemaan vammaa edeltävällä tasolla.

Kolmannen osatyön (18 potilasta) tulokset osoittivat, että leikkaushoidolla on hyvä vaikutus valtaosaan distaalisista hamstring-repeämistä.

Proksimaalisen hamstring-tendinopatian tyypillinen oire on urheilua, erityisesti juoksemista, rajoittava kipu. Neljännessä osatyössä (90 potilasta) todettiin, että kirurgia on hyvä hoitovaihtoehto epäonnistuneen konservatiivisen hoidon jälkeen ja leikkauksen avulla suurin osa potilaista pystyi jälleen urheilemaan ilman oireita. Osoitimme myös, että morfologiset muutokset hamstring-tendinoosissa ovat samankaltaiset kuin aikaisemmin kuvatuissa muissa yleisissä (esim. akillesjänteen ja polvilumpiojänteen) tendinooseissa.

Kroonisissa ja jo kertaalleen leikatuissa hamstring-repeämisissä anatominen lihasten kiinnittäminen istuinkyhmyyn ei ole aina mahdollista lihasten vetäytymisen vuoksi. Viidennessä osatyössä kuvattiin leikkausmenetelmä, jossa potilaalta otettua fascia lata –siirrännäistä käytettiin hamstring-lihasten uudelleen kiinnittämisessä istuinkyhmyyn. Tätä tekniikka hyödynnettiin viiden potilaan hoidossa lupaavin tuloksin.

Avainsanat: hamstring, lihas, jänne, vamma, repeämä, leikkaushoito, tendinopatia, histologia, tendinoosi

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ABBREVIATIONS

BF	proximally: long head of the biceps femoris (muscle / tendon) distally: common biceps femoris (muscle / tendon)
BFsh	short head of the biceps femoris (muscle)
ENMG	electroneuromyography
H:Q	hamstring-to-quadriceps muscle strength ratio
MRI	magnetic resonance imaging
MTJ	myotendinous junction
NSAID	non-steroidal anti-inflammatory drug
SM	semimembranosus (muscle / tendon)
ST	semitendinosus (muscle / tendon)
US	ultrasound

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following original publications, which will be referred to in the text by their respective Roman numerals:

I Sarimo J, Lempainen L, Mattila K, Orava S. Complete proximal hamstring avulsions: a series of 41 patients with operative treatment. Am J Sports Med 2008;36:1110-1115.

II Lempainen L, Sarimo J, Heikkilä J, Mattila K, Orava S. Surgical treatment of partial tears of the proximal origin of the hamstring muscles. Br J Sports Med 2006;40:688-691.

III Lempainen L, Sarimo J, Mattila K, Heikkilä J, Orava S. Distal tears of the hamstring muscles: review of the literature and our results of surgical treatment. Br J Sports Med 2007;41:80-83.

IV Lempainen L, Sarimo J, Mattila K, Vaittinen S, Orava S. Proximal hamstring tendinopathy: results of surgical management and histopathologic findings. Am J Sports Med 2009. In press.

V Lempainen L, Sarimo J, Orava S. Recurrent and chronic complete ruptures of the proximal origin of the hamstring muscles repaired with fascia lata autograft augmentation. Arthroscopy 2007;23:441.e1-5.

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1. INTRODUCTION

The reasons for participating in sports and physical activity are several, such as pleasure and relaxation, socialisation, competition, maintenance and improvement of fitness and health (Bahr and Holme 2003). Regular physical activity decreases the risk of premature mortality in general, and, for example, of cardiovascular diseases, colon cancer, obesity, and diabetes mellitus in particular (Centers for Disease Control and Prevention 1996, Kujala et al. 1998, Haskell et al. 2007).

However, a physically active lifestyle also entails a risk of injuries, which may prevent the individual from gaining the benefits of sports participation and even, in some cases, may lead to permanent disability (Kujala et al. 2003). Scandinavian studies have reported that injuries occurring in different sports activities constitute 10-19% of all acute injuries seen in the emergency room (de Loës 1990, Lindqvist 1996, Ytterstad 1996). Consequently, sports injuries are a substantial reason for concern – for athletes, sports and society.

Muscle injuries alone are among the most common sports injuries seen in clinical practice, comprising over 30% of all sports-related traumas (Garrett 1996). However, they are not found only in athletes but also in those with physically demanding jobs such as builders and laborers (Middleton and Smith 2007). Tendon injuries and chronic tendon disorders are also commonly seen among athletes (Orava 1980). To prevent injuries, more information is required about the extent of the injury problem, the risk factors contributing to the injury and the effectiveness of strategies designed to reduce the risks. Secondary prevention is also important and is needed to better treat these injuries so that long-term symptoms can be avoided and complications and risks of re-injuries can be reduced.

Hamstring injuries and disorders are especially common in athletes, occurring in various sports (Garrett 1996). However, they have also been reported in the general population as people increase their level of activity. Despite their clinical importance, there are only a few clinical studies concerning their treatment. Although conservative treatment results in good functional outcomes in the majority of cases there are also indications for surgery.

This study focused primarily on the surgical treatment of different types of hamstring muscle injuries. In addition, the effect of surgery on proximal hamstring tendinopathy was investigated, and typical histopathological findings relating to this chronic disorder were also determined.

2. REVIEW OF THE LITERATURE

2.1. HAMSTRING MUSCLES

2.1.1. Etymology

The word 'hamstring' originates from the words *ham* and *string*. The ham refers to meat from the upper part of a pig's leg and the verb string refers to how these hams previously used to be hung up for preservation from their tendons posterior to the knee. (Compact Oxford English Dictionary 2005.)

Furthermore, the verb 'hamstringing' refers to the method used in ancient times when it was common for soldiers to slash their opponents' horses posterior to the knees in order to cut the tendons of their posterior thigh muscles. Unable to stand, the horse and its rider were much easier to fight against. Hamstringing was also thought to have been applied to non-agricultural slaves to hinder their possible escape without destroying their usefulness. (Wikipedia 2008.)

2.1.2. Functional anatomy

The term hamstrings refers to four anatomically separate muscles located in the posterior compartment of the thigh – the long head of the biceps femoris (BF), the short head of the biceps femoris (BFsh), the semimembranosus (SM), and the semitendinosus (ST) (Figure 1A-B). All these muscles have a complete or near-complete intramuscular tendon extending down the entire length of the muscle belly (Garrett et al. 1989, Woodley and Mercer 2005). Proximally, these muscles attach via myotendinous junctions (MTJ) to the ischial tuberosity, except for the BFsh, which originates directly from the linea aspera and the lateral supracondylar line of the femur and the lateral intermuscular septum (Moore and Dalley 1999, Woodley and Mercer 2005). A general observation is that the BF and the ST have a common tendon origin and they split into their respective muscle bellies at an average of 9.9 ± 1.5 cm distally from the ischium (Miller et al. 2007). However, the BF can also arise as a separate and distinct tendon from the ST as an anatomic variant (Koulouris and Connell 2005). The insertion site of the BF and the ST is on the medial portion of the upper half of the ischial tuberosity, whereas the SM passes laterally and more anteriorly compared to the BF and the ST and inserts into the lateral part of the upper half of the ischial tuberosity (Woodley and Mercer 2005). The SM has the longest proximal tendon of the hamstring muscles. From its insertion site the tendon rapidly widens, being thick and rounded at its lateral border and flattening into a thin membrane medially (Woodley and Mercer 2005). Proximally, the sciatic nerve curves obliquely beneath the hamstring muscles from the lateral side of the ischial tuberosity. The distance between the sciatic nerve and the lateral aspect of the ischial tuberosity is an average of 1.2 ± 0.2 cm (Miller et al. 2007).

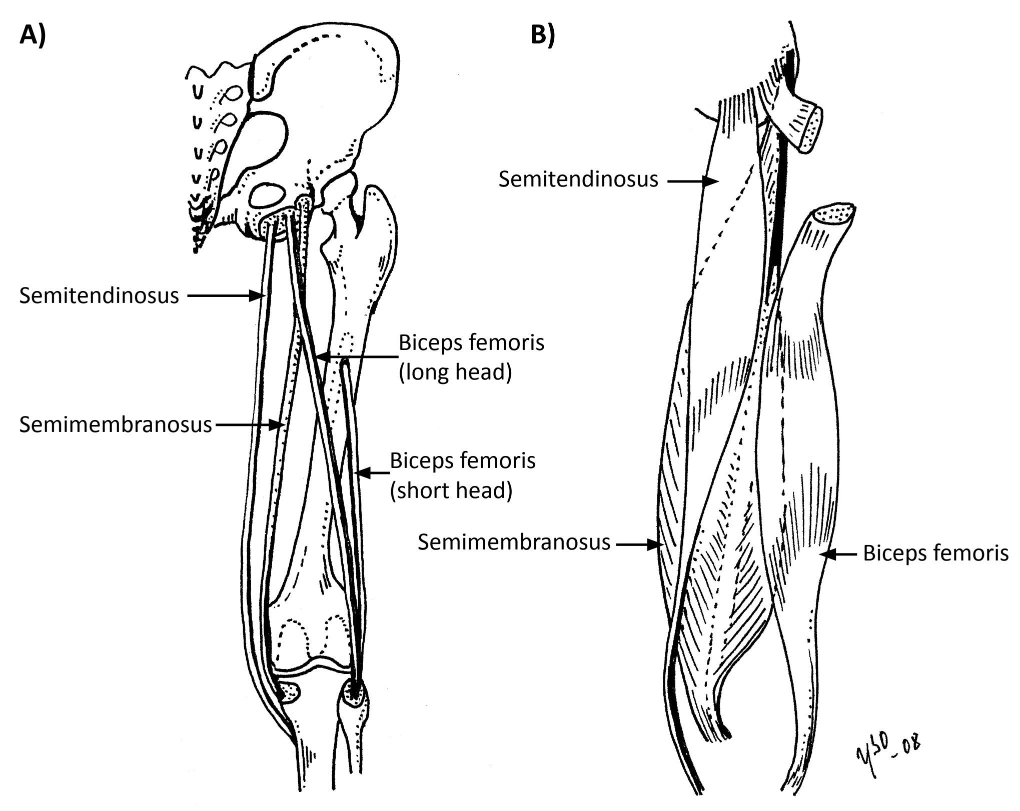

Figure 1A-B. Figure 1A is a schematic drawing of the right hamstring muscle anatomy. In figure 1B the proximal head of the biceps femoris muscle has been cut to expose the origin of the semimembranosus muscle.

The hamstrings descend in the posterior aspect of the thigh and their distal tendons are visible posterior to the knee. After crossing the sciatic nerve from the medial to the lateral side the BF fuses with the BFsh and then forms the most lateral component of the hamstring muscles. Distally, the BF inserts mainly into the head of fibula but also to the lateral condyle of the femur, the lateral tibial condyle, the crural fascia, the popliteus tendon and the arcuate popliteal ligament (Tubbs et al. 2006). The SM has its main insertion sites on the medial surface of the superior tibiae. Cross (1974) has described seven different distal attachment sites of the SM. These are the tubercle on the posterior aspect of the medial tibial condyle, the tendon which runs anteriorly on the medial aspect of the condyle and its expansion to the tibial collateral ligament, the popliteus muscle, the oblique popliteal ligament, the posterior knee capsule and the medial meniscus. In addition to these insertion sites, Kim et al. (1997) noticed that SM also had, in some cases, a tendinous insertion into the lateral meniscus. The ST courses from ischial tuberosity anteromedially to become part of the pes anserinus and inserts to the medial surface of the superior tibiae (Moore and Dalley 1999). The ST has the longest isolated distal tendon of the hamstring muscles, measuring on average 11 cm (Woodley and Mercer 2005).

Hamstring muscles are the major flexors of the knee and aid the gluteus maximus muscle in hip extension (Moore and Dalley 1999). Proximally, the BF also functions in the lateral rotation of the extended hip, and together with the SM and the ST, in the adduction of the abducted hip against resistance (Sutton 1984). The SM and the ST also have a role in the medial rotation of the hip (Sutton 1984). Besides their crucial role in knee flexion, hamstring muscles have also functional significance in rotational movements of the leg and in static and dynamic stability of the knee. The BF increases the stability of the knee laterally, and externally rotates the tibia on the femur during knee flexion (Marshall et al. 1972, Terry and LaPrade 1996, Tubbs et al. 2006). The ST and the SM rotate the tibia internally and protect the knee against valgus stress (Cross 1974, Moore and Dalley 1999). During the knee extension they decelerate the forward translation of tibia together. The SM also protects the medial meniscus from impingement between the tibial and femoral condyles during knee flexion (Prosé et al. 1990).

The hamstring muscles are innervated by the tibial division of the sciatic nerve, with the exception of the short head of the biceps femoris which is innervated by the peroneal division (Burkett 1975, Moore and Dalley 1999). According to the results of Woodley and Mercer (2005), the pattern of innervation of the intramuscular neuronal branching is relatively irregular and variation exists.

2.1.3. Functional characteristics

Garrett et al. (1984) determined the muscle fiber type composition of the hamstrings in cadavers. The results showed that type II fibers were dominant (above 50 %) in all analyzed (10 subjects) hamstring muscles. They also had a higher percent of type II fibers than the quadriceps muscle. Type II, or fast-twitch, fibers are well suited to activities requiring speed and strength owing to their rapid contractility and capability for glycolysis, whereas muscles with a larger population of type I fibers behave in a more static fashion, because these slow-twitch fibers are slow to contract and do not easily fatigue owing to their abundance of aerobic cavity (Burkitt et al. 1993). According to this, Garrett et al. (1984) concluded that the hamstring muscles are best trained by means of high-intensity and rapid activity.

2.1.4. Biomechanics during gait cycle

During normal walking, the gait cycle is divided into stance and swing phases, and one limb is in contact with the ground at all times. The phases of running are similar to walking. The stance phase is further divided into foot strike, midstance and takeoff. The swing phase is divided into follow-through, forward swing and foot descent. As speed increases, the length of the stance phase decreases. During running there is a period of non-support time when neither foot is in contact with the ground. (Slocum and James 1968.)

Electromyographic data show that at the beginning of the foot strike, the BF and the SM contract simultaneously (with vastus lateralis and vastus medialis muscles) providing stability of the knee. During the midstance phase, the ST activates and assists the BF and the SM in knee stability and in hip extension. Prior to takeoff, the activity levels of the BF together with the triceps surae muscle further increase, and also the SM and the ST are highly activated. This high level of activity continues through the flexion of the knee. During the follow-through phase, the activity of the hamstrings is quieter until the forward swing occurs. During the late forward swing phase, the SM increases the level of activity and decelerates eccentrically the flexion of the hip. The BF is inactive during this period. In the last third of the swing phase, the hamstring muscles become active and eccentrically control the knee extension and decelerate forward movement of the tibia. Just before the foot strike, the hamstring muscles work concentrically preparing for weight loading. (Elliott and Blanksby 1979, Sutton 1984.)

2.2. HAMSTRING MUSCLE INJURIES

2.2.1. Epidemiology

Hamstring injuries are common in athletes and in everyday clinical practise, representing a major cause of time lost from sports (Garrett et al. 1989). They are in particular associated with sports which involve running and jumping with rapid acceleration and deceleration (Clanton and Coupe 1998).

Hamstring injuries have been reported in various sports, such as sprinting and running, Australian football, track and field, soccer, and rugby (Lysholm and Wiklander 1987, Seward et al. 1993, Bennell and Crossley 1996, Volpi et al. 2004, Brooks et al. 2005). However, these injuries also occur frequently in the general population as people have increased their level of activity.

In Australian Football, hamstring muscle injuries are the most common and most prevalent injury, constituting 15% of all injuries, with the average professional Australian Football League club having six injuries per club (40 players) and 21 missed matches per club per season (Orchard and Seward 2002). Similarly, in British soccer, hamstring muscle injuries account for 12% of the total injuries with an average of five per club per season, resulting in 15 missed matches and 90 missed training days (Woods et al. 2004). The incidence of hamstring muscle injuries has been estimated to be 3.0–4.1 hamstring strains per 1000 h of match play and 0.4–0.5 per 1000 h of training (Arnason et al. 2008).

The most severe hamstring injury, complete proximal rupture, is a rare injury (Folsom and Larson 2008). Anzel et al. (1959) presented in their series of 1014 musculotendinous disruptions, including 745 complete and 269 partial ruptures, only three cases in which the hamstring muscles were involved (2 indirect complete ruptures, and 1 laceration).

2.2.2. Factors predisposing to injury

Studies on the causes of hamstring strains date back to the 1970s, and since then various factors have been implicated in the etiology (Burkett 1970). However, only a few are evidence-based, while others are mainly based on theoretical assumptions (Petersen and Hölmich 2005). Predisposing risk factors are generally divided into intrinsic (person-related) and extrinsic (environment-related) factors.

2.2.2.1. Previous injury and inadequate rehabilitation

Previous hamstring injury is shown to be the most important risk factor for future injury (Orchard 2001, Hägglund et al. 2006). The reason for this might be that the injury site undergoes remodeling with resultant scar formation. Scar tissue is not as functional as the original muscle tissue and therefore the risk of further injury is increased (Taylor et al. 1993, Garrett 1996). A previous injury can also lead to reduced range of motion and to deficits in strength and flexibility, thereby indirectly affecting injury risk (Garrett 1996, Orchard 2001). Previous calf muscle, knee or groin injuries have also been associated with an increased likelihood of hamstring strains (Orchard 2001, Verrall et al. 2001). The reason for this might be that biomechanical properties of the lower limbs change, thereby increasing susceptibility to hamstring injury (Verrall et al. 2001).

Furthermore, Ekstrand and Gillquist (1983) showed that athletes who returned to sport after injury were not only at risk of recurrent injury but also possibly a more severe injury if they had not fully recovered from the previous injury. In a study by Croisier and Crielaard (2000), the results suggested that recurrent injuries may be the result of inadequate rehabilitation after an initial injury.

2.2.2.2. Properties of the hamstring muscles

The high injury incidence of the hamstring muscle group may be partly due to the fact that the hamstrings are biarthrodial, functioning over two joints, and are therefore subject to increased stretch and extrinsic force. Moreover, the greater proportion of type II, fast-twitch, fibers in the hamstring muscles compared with other thigh and leg muscles means that they are capable of higher and rapid force production. The involvement of the hamstrings in high intensity exercise generates increased intrinsic force production in these muscles. Both of these properties might predispose the hamstring muscles to injuries (Garrett et al. 1984). Furthermore, special features of the BF may help to explain its higher rate of injury and the reason why it is the most commonly strained muscle of the hamstring complex (Garrett et al. 1989, Koulouris and Connell 2003). The BF has a long and short head, both with a separate nerve supply, which may lead to asynchronous stimulation and further mistimed contraction of these two parts of the BF. This may cause a reduction in the capacity to generate effective tension to control the imposed loads of the muscle (Sutton 1984, Woods et al. 2004).

2.2.2.3. Strength and muscle imbalance

Hamstring strength is often expressed relative to quadriceps strength as the hamstring-to-quadriceps ratio (H:Q), which may reflect predisposition to injury (Aagaard et al. 1998). This predisposition may result from decreased capacity of the hamstrings to resist extension loads; this is believed to be critical in onset of injury (Bahr and Holme 2003). Low hamstring strength, decreased H:Q ratio or side-to-side imbalances have been shown to be an important predictor of hamstring muscle injury (Jönhagen et al. 1994, Orchard et al. 1997). However, this finding has been contradicted by Bennell et al. (1998). The role of muscle strength remains somewhat obscure with respect to the risk of primary hamstring injury in athletes. Croisier et al. (2002) concluded that persistence of muscle weakness and imbalance may predispose to recurrent hamstring muscle injuries.

2.2.2.4. Age

Several studies have shown that age is a significant risk factor for hamstring injuries (Orchard 2001, Verrall et al. 2001, Arnason et al. 2004, Gabbe et al. 2005). Gabbe et al. (2005) showed that Australian football players aged 23 years or more were almost four times as likely to sustain a hamstring injury as those under 23.

The reason why increasing age is a risk factor for hamstring muscle injuries is not readily apparent, but this relationship may be related to the reduction in the cross-sectional area of skeletal muscle and type II fibers, leading to decreased muscle strength (Doherty 2001). Furthermore, age-related denervation of muscle fibers may increase the risk of hamstring injury (Kirkendall and Garrett 1998). Orchard (2001) suggested that a mechanism for the increased age-related susceptibility might be low lumbar spinal degeneration, leading to L5 and S1 nerve impingement, thus resulting in hamstring and calf muscle fiber denervation, which in turn leads to decreased muscle strength.

2.2.2.5. Race

Athletes with a black or Aboriginal ethnic origin have a higher risk of sustaining a hamstring injury than white athletes (Verrall et al. 2001, Woods et al. 2004). Verrall et al. (2001) proposed that players of Aboriginal descent are generally considered to be the fastest and most skilful players in Australian football, and they may have a greater proportion of type II fibers, which may predispose them to injury.

2.2.2.6. Flexibility and lumbopelvic stability

Pre-season hamstring muscle tightness has been shown to be a risk factor for subsequent hamstring muscle injury (Witvrouw et al. 2003, Gabbe et al. 2005). However, there are retrospective studies showing mixed results, so drawing a conclusion is difficult because any associated hamstring muscle tightness may be the result, rather than the cause, of the hamstring injury (Hennessey and Watson 1993, Jönhagen et al. 1994).

Hennessey and Watson (1993) showed an increased incidence of lumbar lordosis in a group of players with a history of hamstring injury in the previous 12 months when compared to an uninjured group of players. Sherry and Best (2004) stated that changes in pelvic position could lead to changes in length-tension or force-velocity relationships of the hamstring muscles, and good neuromuscular control of the lumbopelvic region may be needed to create the optimal function of the hamstrings in sprinting and high-speed movement.

2.2.2.7. Warm-up and stretching

Safran et al. (1989) concluded that warm-up combined with stretching, increased the elasticity of the muscle, and thereby, a greater force and degree of muscle lengthening were required to tear the muscle in an animal model. There are clinical studies showing that muscle injuries are more likely to occur without adequate warm-up and stretching (Agre and Baxter 1987, Worrell and Perrin 1992, Dvorak et al. 2000). Dadebo et al. (2004) also concluded that more hamstring muscle injuries have occurred in professional football teams in the United Kingdom that did not stretch regularly.

2.2.2.8. Fatigue and low fitness level

Clinical observations have shown that hamstring injuries are more common at the end of matches or training sessions (Hawkins and Fuller 1999, Woods et al. 2004). Fatigue may induce physiological changes within the muscle, as well as altered coordination, technique and concentration, predisposing the player to injury (Devlin 2000). Croisier (2004) suggested that abnormalities in running style may be the consequence of fatigue, increasing the workload of the stabilizing muscles around the pelvis and exposing the athlete to subsequent injury. In addition, inadequate pre-season preparation and training period resulting in low fitness level may contribute to an increased injury rate of the hamstring muscles (Arnason et al. 1996, Hawkins and Fuller 1999, Heidt et al. 2000).

2.2.2.9. Combination of several risk factors

Because of the confounding and mixed results regarding the risk factors of hamstring muscle injury, Worrell (1994) proposed a theoretical model for hamstring muscle injuries that considered the complex interaction between etiological factors. Worrell concluded that a combination of abnormalities (strength, flexibility, warm-up, fatigue) increased the risk of hamstring muscle injury, and therefore rehabilitation protocols should specifically focus on each of these factors. Devlin (2000) suggested that there may be a threshold at which a multifactorial etiology produces an injury, or some factors may be more predictive of hamstring injury than others.

2.2.3. Mechanism of injury

Hamstring injuries are usually non-contact injuries and mostly occur during sprinting and running (Woods et al. 2004). Experimental and clinical studies have shown that hamstring strains usually occur at the MTJ (Noonan and Garrett 1992). During sprinting and running, the hamstring muscles become highly active in the later part of the swing phase when they work eccentrically to decelerate the swinging tibia and control extension of the knee: in this phase, the hamstrings develop tension while lengthening (Stanton and Purdam 1989, Thelen et al. 2005). After the swing phase, the hamstrings remain active into the initial stance phase, when they work concentrically as an active extensor of the hip joint (Stanton and Purdam 1989). It has been suggested that it is during this rapid changeover from eccentric to concentring function that the hamstrings are maximally activated and approaching peak length, and that they are most vulnerable to injury (Petersen and Hölmich 2005).

Askling et al. (2002) suggested that hamstring strains can be of at least two different types, one occurring during high speed running as described above, and the other occurring in extreme positions during slow stretching movements in elite dancers. The results of this study showed that acute hamstring strains can also occur even in slow, apparently well controlled, stretching exercises performed to the limit of the range of motion.

A common mechanism for the most severe hamstring injury is a rapid flexion of the hip during an ipsilateral eccentric knee extension sustained injury from a fall while, for example, water skiing, resulting in a complete proximal hamstring rupture (Blasier and Morawa 1990, Sallay et al. 1996, Klingele and Sallay 2002).

2.2.4. Classification

Muscle injuries can be divided into two basic types: in situ necrosis and shearing injury (Kalimo et al. 1997). Clinically shearing types of muscle injuries can be further classified as strains, contusions and lacerations (Lehto and Järvinen 1991).

Hamstring injuries are typically strains, but also contusions occur in contact sports (Kujala et al. 1997a). Furthermore, delayed onset muscle soreness induced by eccentric exercise is also a common hamstring injury in sports (Kalimo et al. 1997, Kujala et al. 1997a, Äärimaa et al. 2004).

Hamstring muscle injuries represent a continuum of injuries ranging from minor damage of a few myofibers without loss of structural integrity to a complete hamstring muscle rupture with fiber disruption (Clanton and Coupe 1998). These injuries are often classified into one of three groups according to their severity: mild (grade I), moderate (grade II), and severe (grade III) (Kalimo et al. 1997, Kujala et al. 1997a).

Grade I injuries represent a small disruption of the structural integrity of the musculotendinous unit with minor swelling and discomfort and with no or only minimal loss of strength and function. However, these injuries may be distressing to the athlete.

Grade II injuries represents partial tears with at least some intact fibers left but also with a clear loss of strength and function. In the literature regarding hamstring injuries, for example, isolated SM or isolated BF rupture is usually considered as a partial tear because the whole hamstring muscle complex (the BF, the ST, and the SM) is not ruptured (Sallay et al 1996, McGrecor et al. 2008).

Grade III injuries are characterized by complete disruption of the musculotendinous unit, resulting in a total lack of muscle function. In hamstring injuries, complete rupture of the hamstring muscle group usually occurs as an avulsion injury from the ischial tuberosity (Drezner 2003). Avulsion fractures of the ischial tuberosity are also included in this group but they are more prevalent among the skeletally immature (Kujala et al. 1997b).

Typically, hamstring injuries occur at the MTJs but, as anatomical studies have shown that the long proximal and distal tendons of the hamstrings extend far into the muscle bellies and thereby form elongated MTJs, almost any area along the course of the muscle can be injured (Garrett 1996, Kujala et al. 1997a, Woodley and Mercer 2005). According to this, hamstring injuries could also be categorized into proximal, central and distal ones (Mann et al. 2007). Proximally, hamstring injuries affect the tendon origin sites of the ischial tuberosity and proximal MTJs, and injuries from partial tears to complete ruptures have been reported (Orava and Kujala 1995, Bencardino and Mellado 2005, Brucker and Imhoff 2005). Centrally, hamstring injuries affect the MTJs and muscle bellies causing intramuscular tears (Kujala et al. 1997a, De Smet and Best 2000, Mann et al. 2007). Distal hamstring injuries affect the distal MTJs, distal tendons or tendon insertion sites (Sebastianelli et al. 1990, Alioto et al. 1997, Schilders et al. 2006).

Formation of hematoma is strongly associated with muscle injuries and also its classification. Because muscle is a well vascularized tissue, a shearing type of muscle injury often results in substantial hematoma formation. Hematomas can be divided into intramuscular or intermuscular hematomas. In the case of the intramuscular hematoma, the extravasated blood within the intact muscle fascia results in increased intramuscular pressure, which subsequently compresses the bleeding vessels and eventually limits the size of the hematoma. In contrast, an intermuscular hematoma develops if the fascia surrounding the muscle is also ruptured and the extravasated blood has free access to interstitial and interfascial spaces without a significant increase in the pressure within the muscle. (Järvinen et al. 2005.)

2.2.5. Clinical presentation

The clinical picture of a skeletal muscle injury depends on the severity of the injury and on the nature of the resulting hematoma (Kalimo et al. 1997). Information about the injury mechanism, combined with a careful examination and clinical findings, is essential to make a correct diagnosis of the hamstring injury. The main goal of the examination is to differentiate those patients with severe injuries requiring possible surgical treatment from patients with mild injuries.

Patients with grade I hamstring injuries will probably seldom seek medical evaluation immediately after injury. Delayed onset muscle soreness is caused by any unaccustomed physical activity with a strong eccentric component, for example, strenuous downhill running (Cheung et al. 2003). This symptom is typically characterized by tenderness, pain, stiffness and a marked reduction in maximal muscle force, usually peaking during the second day after the exercise. Normally, these symptoms alleviate within a few days.

Severe hamstring injuries (grades II-III) are typically characterized by a history of sudden onset of posterior thigh pain associated with localized tenderness and loss of function. An audible pop is occasionally described, and immediate pain limits continuation of activity (Clanton and Coupe 1998). After the injury, there is often swelling and ecchymosis in the posterior thigh. The patient may have difficulty even in walking. A palpable defect is a common finding at the injury site, although, in the early acute phase, this can be masked by a hematoma (Klingele and Sallay 2002). A retracted muscle bulge is often palpated when the patient is asked to flex the knee against resistance. In severe hamstring ruptures, there is typically a marked decrease in strength in knee flexion and in hip extension.

Patients with chronic complete proximal hamstring ruptures often describe feelings of tightness and weakness of the posterior thigh, as well as poor leg control, cramping of the hamstrings, and a sense of giving way of the affected extremity (Cross et al. 1998, Folsom and Larson 2008). Usually they also have difficulty in running or they are unable to run. Sitting may aggravate the pain at the site of the ischial tuberosity. Sciatica-type symptoms may also be present (Orava and Kujala 1995, Sallay et al. 1996, Cross et al. 1998).

2.2.6. Imaging

When there is uncertainty regarding clinical findings of hamstring injuries, imaging modalities such as magnetic resonance imaging (MRI) and ultrasound (US) can be used.

MRI provides anatomical detailed information on the hamstrings and their pathology. It is sensitive in depicting causes of symptoms related to the hamstring tendons and muscles (De Paulis et al. 1998, Bencardino and Mellado 2005). Furthermore, MRI correctly assesses the amount of tendon retraction, which is an important feature for preoperative planning in proximal hamstring avulsions (Bencardino and Mellado 2005). In proximal hamstring injuries, MRI is more accurate than US. With US, only 58% of hamstring avulsions are diagnosed despite the examination being performed by experienced musculoskeletal sonologists, whereas MRI correctly identifies all avulsion cases (Koulouris and Connell 2003). In distal hamstring injuries, US is more suitable for detecting injuries than in proximal ones because of the more superficial anatomy of the distal hamstring tendons (Koulouris and Connell 2005).

The limited availability and costs of MRI may restrict the use of this modality for routine assessment of injuries, for example, among junior or amateur athletes. Schneider-Kolsky et al. (2006) showed that MRI was not required for estimating the duration of rehabilitation for an acute minor hamstring injury in professional football players. However, they concluded that a positive MRI result appeared useful as a predictor of duration of rehabilitation in severe hamstring injuries, and also that MRI was helpful in the planning of surgical interventions.

Plain radiographs are usually unnecessary when evaluating hamstring injuries. They may be useful when the injury appears to be localized near the ischial tuberosity, indicating a possible avulsion fracture (Kujala et al. 1997b, Gidwani and Bircher 2007). In adults, plain radiographs are typically negative, because proximal hamstring rupture usually occurs without bone involvement. In adolescents, the injury is usually bone avulsion. However, a bone fragment may also be x-ray negative, especially in children (Kujala and Orava 1993).

2.2.7. Injury-related complications

Recurrence is the most common complication of hamstring injuries, which makes it one of the most frustrating injuries for athletes, coaches, treating doctors and physiotherapists. Seward et al. (1993) reported that the recurrence rate of hamstring muscle injuries is as high as 34% in the Australian Football League. The reason for this may be as simple as shown by Garrett (1996) in an animal model. After injury the muscle is weaker and at risk of further injury. Furthermore, possible causes of recurrence include alteration to normal biomechanics and reduced functional properties of the scar tissue (Taylor et al. 1993, Garrett 1996). Similarly, after a hamstring injury, too early and enthusiastic mobilization may induce a rerupture of the muscle. The highest risk of recurrence appears to be within the first two weeks of return to sports, but there is a persistent significantly increased risk of recurrence for several weeks after return to play (Orchard and Best 2002). Orchard and Best (2002) showed that in Australian footballers the recurrence rate of hamstring strains was 12.6% during the first week of return to sports and 8.1% during the second week. In this study, the cumulative risk of recurrence for the entire 22-week season was 30.6%.

After a shearing type of injury, the affected area of skeletal muscle undergoes remodeling, with resultant scar formation (Järvinen et al. 2005). Excessive scarring, if present, may lead to impaired regeneration of the injured muscle. Adhesions and impaired biomechanical properties of the hamstring muscles have been reported (Kujala et al. 1997a, Orava et al. 1998).

There are a couple of cases presented in the literature in which a complete proximal hamstring rupture has caused a dysfunction of the sciatic nerve with resulting complete foot drop and numbness of the lateral calf and dorsal foot (Street and Burks 2000, Hernesman et al. 2003). Similar cases have been described, occurring after partial proximal hamstring tears (Carmody and Prietto 1995, Takami et al. 2000). The damage to the intramuscular nerve branches of the hamstring muscles is also a possible complication and could be seen, for example, in chronic proximal avulsion injuries.

A large hematoma following hamstring injuries graded II-III is a typical finding in the early acute phase. In proximal hamstring injuries, bleeding and hematoma may be massive, extending from the proximal thigh to the distal foot (Kujala et al. 1997a). Even acute posterior thigh compartment syndrome has been reported to develop after proximal hamstring avulsion (Oseto et al. 2004, Kwong et al. 2006).

A complication of muscle contusions is the occurrence of myositis ossificans, which, involving the hamstring muscles, can also cause sciatica-like symptoms (Dashefsky 1973, Jones and Ward 1980, King 1998). The major risk factor for development of myositis ossificans may be a reinjury during the early stages of recovery or a too early return to activity after the injury. Ectopic bone often resorbs with time and early surgery should be avoided because it may exacerbate bone formation and prolong disability. Surgical treatment could be indicated when the ectopic bone is mature and no changes are occurring in the radiologic evaluation of the patient. Usually this takes at least 12 months (Järvinen et al. 2005).

Local skeletal muscle injuries seldom cause systemic complications. However, excessive eccentric exercise and repeated stretch injuries without adequate fluid intake or muscle crush syndrome may lead to destruction of myofibers and severe rhabdomyolysis causing accumulation of myoglobin and subsequent renal failure (Milne 1988).

2.2.8. Conservative treatment

There are only few clinical studies concerning conservative treatment of hamstring muscles injuries or of human skeletal muscles injuries at all (Mason et al. 2007). Thus, the scientific evidence is mainly derived from experimental studies.

2.2.8.1. Effects of immobilization and remobilization on muscle healing

A short immobilization period following muscle injury is beneficial but it should be limited to the first few days after injury. This limits the extent of the scar tissue and decreases the risk of early rerupture. By restricting the length of the immobilization to the first few days, the negative effects of immobility per se can be minimized. After this, the mobilization of the injured muscle should be started gradually as soon as possible since it has been shown to enhance the regeneration phase. Early mobilization, for example, returns the tensile strength of the muscle, allows better penetration of myofibers through the scar, limits the size of the permanent scar, facilitates the proper alignment of the regenerating myofibers, and induces capillary ingrowth into the injured area. With active mobilization, atrophy of the healthy myofibers is also better avoided. (Järvinen and Lehto 1993, Järvinen et al. 2007.)

In clinical practice, Järvinen et al. (2007) recommended the following treatment protocol for acute muscle injuries in athletes. The required relative immobility can be achieved by taping the injured muscle. If the injured muscle(s) is located in the lower extremity or in the groin area, the use of crutches is recommended and all kind of active stretching should be avoided for the first 3–7 days. After this period, more active mobilization can be started gradually within the limits of pain.

2.2.8.2. Immediate treatment

The classic 'RICE' (rest, ice, compression, elevation) principle is still the immediate treatment method for muscle injuries (Järvinen et al. 2007). The aim of RICE is simple, as all these four elements minimize the bleeding into the injury site. This treatment should be started as soon as possible after the injury occurs. 'Rest' after the injury prevents further retraction of the ruptured muscle stumps, reduces the size of the hematoma and, subsequently, also the extent of the scar tissue (Järvinen and Lehto 1993, Järvinen et al. 2007). Cryotherapy provides a short-term analgesic effect, shortens the period of disability, and reduces hematoma formation (Deal et al. 2002). 'Ice' (cold) is also associated with less inflammation and tissue necrosis, and it may accelerate the early regeneration (Schaser et al. 2007). The combination of cold and 'compression' should be applied in bouts of 15-20 minutes in duration, and repeated at intervals of 30-60 minutes for at least several (6) hours (Järvinen et al. 2007). The effect of 'elevation' is based on decreased hydrostatic pressure; the elevation of an injured extremity above the level of the heart reduces swelling.

2.2.8.3. Treatment after 3 to 7 days

The severity of the muscle injury naturally has an effect on the rehabilitation program. The main goal is to start the rehabilitation as soon as possible, to avoid the adverse effects of a long immobilization period and to minimize the risk of recurrence. In this phase, more active treatment of the injured muscle and injured extremity should be started gradually with regular strength exercises; first with isometric, then with isotonic, and later with isokinetic muscle training. Also other activities maintaining cardiovascular fitness such as swimming and stationary bike riding can be initiated. (Petersen and Hölmich 2005, Järvinen et al. 2007.)

Eccentric muscle exercises are begun after concentric exercises, because eccentric contraction causes greater force than concentric contraction (Mjølsnes et al. 2004). It is important that all these muscle exercises are performed only within the limits of pain to avoid a possible rehabilitation-induced recurrence. Adequate warm-up of injured muscle before rehabilitation activities and muscle stretching exercises are also recommended (Petersen and Hölmich 2005, Järvinen et al. 2007).

Not only should the hamstring muscles themselves be considered for rehabilitation but also the muscles that assist the activity of hamstrings and maintains the posture. A study by Sherry and Best (2004) compared the efficacy of two rehabilitation programs for acute (grade I-II) hamstring strains. In this study, 11 athletes were assigned to a protocol consisting of static stretching, isolated progressive hamstring resistance exercise, and icing (STST group). Thirteen athletes were assigned to a program of progressive agility and trunk stabilization exercises and icing (PATS group). The results showed that athletes in the PATS group had a significantly reduced re-injury rate compared to the athletes in the STST group. They also made a more rapid return to sport activity after injury, but this difference was not statistically significant. The authors showed that exercises focusing on improving common pelvic neuromuscular control, muscle strength and coordination were more effective for rehabilitating hamstring muscle injuries than isolated hamstring stretching and strengthening exercises.

Malliaropoulos et al. (2004) assessed the role of stretching in the rehabilitation of acute (grade II) hamstring muscle injuries. In this study, 80 athletes were divided into two groups. In both groups the rehabilitation program was the same, but the number of daily static hamstring stretching sessions differed. The results showed that a more intensive stretching program (four times a day compared with once) significantly accelerated the rehabilitation process (earlier return to sport and normal range of motion) and had a positive effect over the short term.

2.2.8.4. Return to sports

The final phase of the rehabilitation is return to sports-specific training. Järvinen et al. (2007) summarized that when the athlete is able to stretch the injured muscle as much as the healthy contralateral muscle, and when painless use of the injured muscle shows success in basic movements, then permission to gradually start sports-specific training is granted.

There are no consensus guidelines or common criteria for a safe return to sports after hamstring muscle injuries that completely eliminate the risk of recurrence (Orchard et al. 2005). Worrell (1994) suggested that pain-free participation in sports-specific activities is the best indicator for a safe return to sports.

Orchard et al. (2005) found that a professional Australian footballer returns to sport, on average, three weeks after hamstring muscle injury with a 30% recurrence rate. In soccer, a professional player normally returns to sports 18 days after the hamstring injury, with a recurrence rate of 12% (Woods et al. 2004). In a study by Askling et al. (2006), sprinters were able to return to their preinjury level of sports, on average, 16 weeks (range, 6-50) after the injury, and dancers after 50 weeks (range, 30-76). In this study, three (9%) hamstring reinjuries were noted, all in sprinters.

2.2.8.5. Medication

Non-steroidal anti-inflammatory drugs (NSAIDs) are frequently used following muscle injuries to provide analgesia and to limit the inflammatory response even though their role in the muscle healing process is controversial (Rahusen et al. 2004). In a study by Reynolds et al. (1995), NSAIDs had no additive effect on the healing of acute hamstring muscle injuries compared to physiotherapy alone. In contrast, in a study by O'Grady et al. (2000), a short-term use of NSAIDs resulted in a transient improvement in the recovery from exercise-induced muscle injury.

In experimental studies, a short-term use of NSAIDs in the early healing phase has been shown to reduce inflammatory reaction with no adverse effects on the healing process (Järvinen et al. 1992). At the same time, there has, however, been concern that the use of NSAIDs may result in delayed healing and improper myoregeneration (Almekinders and Gilbert 1986, Mishra et al. 1995).

The effect of NSAIDs on satellite cell and myofiber regeneration after injury has also shown conflicting results in an animal model (Thorsson et al. 1998, Mendias et al. 2004). In a recent clinical study by Mackey et al. (2007), the results suggested that NSAIDs attenuate the exercise-induced increase in satellite cell number, supporting the role of the cyclooxygenase pathway in satellite cell activity.

It seems that if NSAIDs are used, their use should be restricted to the early phases of muscle repair (Drezner 2003, Järvinen et al. 2007). However, it also seems that the routine use of NSAIDs in muscle injuries needs to be critically evaluated, and perhaps the use of simple analgesics (acetaminophen = paracetamol) should be preferred (Rahusen et al. 2004, Brukner and Khan 2007).

In experimental studies, corticosteroids have been shown to be detrimental for the healing process following muscle injury (Järvinen et al. 1992, Beiner et al. 1999). In these studies, delayed resolution of hematoma and the necrotic tissue, retarded muscle regeneration and decreased tensile properties have been associated with the corticosteroid treatment.

Levine et al. (2000) reported a clinical series using intramuscular corticosteroid injections in the treatment of severe acute hamstring strains in professional football players. They concluded that intramuscular corticosteroid injection after hamstring muscle injury hastened players' return to play, and limited the time lost from practice and competition. However, in the literature, the common consensus is that further studies are needed before use of corticosteroid injections can be recommended (Drezner 2003, Brukner and Khan 2007).

2.2.8.6. Therapeutic alternatives

Hyperbaric oxygen therapy has been reported to accelerate recovery after acute muscle injury in experimental studies (Best et al. 1998). However, further studies are required before this therapy could be utilized in clinical practice (Bennett et al. 2005, Best et al. 1998, Research Committee of the AOSSM 1998).

Even though therapeutic ultrasound and massage are widely recommended and also commonly used after muscle injuries, neither of them seems to have a significantly positive effect on muscle healing (Rantanen et al. 1999, Jönhagen et al. 2004, Wilkin et al. 2004).

2.2.9. Surgical treatment

2.2.9.1. General indications

Operative treatment is seldom considered in the treatment of muscle injuries, including hamstring strains, and the phrase 'muscle injuries do heal conservatively' could be used as a guiding principle in the treatment of muscle traumas (Petersen and Hölmich 2005, Järvinen et al. 2007). However, there are certain highly specific indications in which surgical intervention might actually be beneficial even though no evidence-based treatment protocol is available for operative treatment of severe skeletal muscle ruptures (Äärimaa 2006, Järvinen et al. 2007). These indications include the athlete with a complete (grade III) rupture of a muscle with few or no agonist muscles, a tear (grade II) if more than half of the muscle is torn, or a large intramuscular hematoma(s) (Almekinders 1991, Kujala et al. 1997a, Järvinen et al. 2007). Furthermore, surgical treatment should be considered if a patient complains of permanent extension pain (duration, >4-6 months) in a previously injured muscle, especially if the pain is accompanied by a clear extension deficit (Järvinen et al. 2005). In such a case, formation of scar adhesions restricting the movement of the injured muscle has to be suspected and surgical deliberation of adhesions should be considered (Järvinen et al. 2005).

2.2.9.2. Proximal injuries

A common guideline regarding proximal hamstring injuries is that only in the presence of a complete rupture of the proximal attachment of the musculotendinous complex should surgical repair be considered (Clanton and Coupe 1998, Drezner 2003, Petersen and Hölmich 2005, Mann et al. 2007). However, also more active recommendations have recently been shown. Folsom and Larson (2008) suggested that a pure isolated conjoint tendon (the BF and the ST) avulsion should be operated in active patients. At the same time, Cohen and Bradley (2007) suggested that surgical treatment should already be advocated if two out of three hamstring tendons are ruptured from the ischial tuberosity. Regauer et al. (2005) recommended early operative treatment also for an isolated proximal SM rupture. Because of the low incidence of proximal hamstring avulsion injury, most published reports are retrospective case series with limited numbers of patients (Folsom and Larson 2008).

2.2.9.3. Distal injuries

Distal hamstring injuries are usually associated with severe traumas to the knee joint or with other traumatic musculotendinous injuries around the knee (LaPrade and Terry 1997, Clanton and Coupe 1998, Bencardino et al. 2000). However, isolated distal hamstring tendon avulsions have also been described, and then operative treatment is generally recommended (Sebastianelli et al. 1990, David et al. 1994, Alioto et al. 1997, Clanton and Coupe 1998, Werlich 2001, Mann et al. 2007).

2.2.9.4. Proximal avulsion fracture

In adolescents, apophyseal avulsions at sites of proximal hamstring muscle insertions are occasionally seen (Rossi and Dragoni 2001). Operative treatment has been recommended if the displacement of the avulsed fragment is 2 cm or more (Kujala and Orava 1993, Servant and Jones 1998). Gidwani and Bircher (2007) suggested even more active operative treatment and recommended early surgical fixation if the fracture displacement is more than 1 cm.

2.2.9.5. Historical aspect

Overton and England (1954) were the first to report operative treatment of a complete proximal hamstring avulsion. In this case report, a 55-year-old man fell down after slipping while playing tennis. Because of the patient's age, the injury was first treated conservatively with regular daily exercises. After 2.5 months no improvements were noted either in strength or in coordination. Since the patient wanted to become more active and return to playing tennis, surgery was performed. In the operation the completely retracted hamstring tendons were reinserted to the ischial tuberosity by suturing. Postoperatively, for four weeks, a long leg cast was applied with the knee in 90° flexion. Six months after surgery he returned to playing tennis with no residual symptoms.

No other cases were reported until 1988 when Ishikawa et al. published a report of two proximal avulsion cases treated surgically. In the first case (sustained in judo), a complete avulsion of all the three hamstring tendons was observed. Reattachment of the ruptured tendons was performed to the ischial tuberosity by suturing through the drill holes. In the second case (motorcycle accident), a complete avulsion of the SM and the ST from the ischial tuberosity was identified, while the BF remained intact. In both of these cases surgical repair produced satisfactory results. In conclusion, Ishikawa et al. (1988) referred to the results of Schlonsky and Olix (1972) and proposed that because functional disability follows after avulsion fracture of the ischial tuberosity, surgical treatment should also be recommended in patients with a complete avulsion of the hamstring muscles.

2.2.9.6. Previous results

Since those first cases, promising results have been reported after surgical treatment of both acute and chronic complete proximal hamstring ruptures (Cross et al. 1998, Klingele and Sallay 2002, Brucker and Imhoff 2005, Chakravarthy et al. 2005, Cohen and Bradley 2007). Furthermore, it has been shown that an athlete is unlikely to return to the previous level of sporting activity after complete proximal hamstring rupture unless treated surgically (Kurosawa et al. 1996, Sallay et al. 1996, Gidwani and Bircher 2007). On the other hand, no differences between early and late repairs have been identified in regard to functional outcome or return to sport (Klingele and Sallay 2002). However, mainly based on the authors' own experiences and assumptions, early surgical refixation of complete proximal hamstring ruptures is usually to be recommended (Orava and Kujala 1995, Brucker and Imhoff 2005, Chakravarthy et al. 2005, Cohen and Bradley 2007, McGrecor et al. 2008, Stradley et al. 2008).

2.2.10. Prevention

Hamstring injuries have long been recognised as a priority for preventive efforts because these injuries often result in considerable costs such as missed training time, unavailability for competition, and treatment.

2.2.10.1. Stretching and flexibility

Hartig and Henderson (1999) showed that increased hamstring flexibility significantly decreased the number of lower extremity overuse injuries, including hamstring muscle strains, in a military population.

2.2.10.2. Strengthening program

A study by Askling et al. (2003) examined the effect of preseason strength training with eccentric hamstring muscle exercises in Swedish elite soccer players. They concluded that the eccentric strength training significantly decreased the risk of mild hamstring muscle injuries. Furthermore, players' performance level (maximum running speed and muscle strength) was also increased.

In the study by Arnason et al. (2008), the main finding was that eccentric strength training with so-called 'Nordic hamstring lowers' combined with warm-up stretching seemed to be effective in preventing hamstring muscle injuries in soccer. In this study, stretching during warm-up and flexibility training of the hamstring muscles had no effect on the incidence of hamstring injuries. In studies by Brooks et al. (2006) and by Gabbe et al. (2006), the Nordic hamstring strengthening programs seemed to reduce the incidence and severity of hamstring muscle injuries more than conventional concentric strengthening programs.

2.2.10.3. Thermal pants

A study by Upton et al. (1996) suggested that the wearing of thermal pants might have a role in preventing recurrent hamstring injuries. However, they concluded that other risk factors such as pre-season physical fitness, correct warm-up and stretching procedures before activity were probably more important.

2.2.10.4. Combined programs

Junge et al. (2002) reported that a combined program focusing on general interventions such as warm-up, regular cool down, flexibility and strength training, as well as on coordination, reaction time and endurance was effective in reducing injuries, including hamstring muscle injuries, in soccer players. The study concluded that also the education of trainers and players concerning training protocols, as well as injury prevention strategies, was an important factor in injury prevention.

A multifactorial program by Verrall et al. (2005) demonstrated that the incidence and consequence of hamstring injuries could be reduced in Australian football players by undertaking a training program that more accurately reflects match-playing conditions where the majority of injuries occur. The program consisted of stretching while the muscle was fatigued, sport-specific training drills, and increased anaerobic interval training.

2.3. PROXIMAL HAMSTRING TENDINOPATHY

Tendon injuries and chronic tendon disorders are common especially among athletes (Kannus 1997a). They are known to be difficult to treat and often result in considerable morbidity and impaired athletic performance (Sharma and Maffulli 2005).

Tendinopathy is the preferred term used to describe different tendon pathologies, including paratendinitis, tendinitis and tendinosis in the absence of biopsy-proven histopathologic evidence (Maffulli et al. 1998). Furthermore, tendinopathy is a clinical condition characterized by activity-related pain and impaired performance, focal tendon tenderness and swelling and intratendinous imaging changes (Maffulli et al. 1998, Warden 2007). It represents a common and remarkable problem, with a prevalence of 14% in elite athletes, and requiring a recovery time of three to six months with first-line conservative treatment (Lian et al. 2005, Warden 2007).

Tendinopathies typically involve the Achilles and patellar tendons and the common wrist extensor origin of the lateral elbow (Gabel 1999, Paavola et al. 2002b, Peers and Lysens 2005). Other common sites of tendinopathy include the rotator cuff tendons, the wrist flexor tendon insertion at the medial elbow, and the proximal hamstring insertion (Maffulli et al. 2003). The chronic and often frustrating problems involved in these above-mentioned tendinopathies are under active research but only limited information exists on proximal hamstring tendon disorders (Puranen and Orava 1988, Migliorini et al. 2000, Fredericson et al. 2005).

In the literature, proximal hamstring tendinopathy has also been reported under the name of ‘hamstring syndrome’, ‘ischiatic intersection syndrome’, ‘hamstring enthesopathy’, ‘high hamstring tendinopathy’ and ‘hamstring origin tendinopathy’ (Puranen and Orava 1988, De Paulis et al. 1998, Migliorini et al. 2000, Koulouris and Connell 2005, Fredericson et al. 2005, Brukner and Khan 2007).

2.3.1. Epidemiology

Proximal hamstring tendinopathy has been reported in various sports, but especially in middle- and long-distance runners and sprinters (Orava 1997, Migliorini et al. 2000, Fredericson et al. 2005). During the years 1980-1988 proximal hamstring tendinopathy was the fourth most common chronic disorder requiring surgical treatment in athletes, just after various long-lasting knee symptoms and Achilles and patellar tendinopathies in the Oulu–Kokkola region in Finland (Orava et al. 1991).

2.3.2. Etiology and pathophysiology of common tendinopathies

The etiology and pathophysiology of tendinopathy in humans have not been scientifically proven (Alfredson and Cook 2007). Typical intrinsic factors contributing to the different tendinopathies include, for example, such features as malalignments, leg length discrepancy, muscle weakness and imbalance, decreased flexibility, joint laxity, female gender, young or old age, and overweight (Kannus 1997b). The most common extrinsic factors related to chronic tendon disorders include excessive, repetitive load on the body, training errors, environmental malconditions, and poor equipment (Kannus 1997b). Furthermore, hypoxia, ischemic damage, oxidative stress, hyperthermia, impaired apoptosis, inflammatory mediators, fluoroquinolones, and matrix metalloproteinase imbalance have all been associated with tendon degeneration (Sharma and Maffulli 2005).

It is most frequently theorized that excessive, 'overuse' loading of tendons during vigorous physical training may lead to cumulative microdamage and further failed tendon healing response without any remarkable acute trauma. Under normal conditions, this damage is of little consequence because a tendon is capable of intrinsic repair. However, under certain conditions, imbalance can develop between damage generation and tendon repair capabilities. The subsequent accumulation of damage and failed healing attempts then finally results in formation of tendinosis. (Kannus 1997b, Sharma and Maffulli 2005, Warden 2007.)

This theory explains why tendinopathy has a much higher prevalence in individuals involved in active endeavours. For instance, the age-adjusted odds ratio for developing Achilles tendinopathy in male orienteering runners is 10.0, when compared to less active controls (Kujala et al. 2005). However, overloading does not alone explain why tendinopathy develops in some individuals but not in others with equivalent loading, or why tendinopathies have also been reported in inactive patients (Maffulli et al. 2006, Warden 2007). It seems obvious that development of tendinopathy is likely to be caused by a range of factors with the relative contribution of each varying among individuals (Kannus 1997b, Sharma and Maffulli 2005, Warden 2007).

2.3.3. Histopathology of common tendinopathies

Histopathological studies of different chronic tendinopathies have consistently shown that tendinopathy in humans is typically due to tendinosis (Puddu et al. 1976, Khan et al. 1999). The specific histopathological picture of hamstring tendinopathy is lacking in the literature.

Collagen degeneration with fiber disorientation, increased mucoid ground substance, neovascularization, hypercellularity and an absence of inflammatory cells are the basic characteristic histopathological features of tendinosis (Khan et al. 1999, Brukner and Khan 2007, Warden 2007). It appears that tendinosis is the major clinically relevant chronic tendon lesion, even though minor histopathological variations may exist at different anatomical sites (Khan et al. 1999, Maffulli et al. 2004). Macroscopically, the affected tendon site loses its normal glistening white appearance and becomes grey and amorphous (Khan et al. 1999).

Recent histopathological studies of Achilles tendinopathy have shown signs of neurogenic inflammation by finding neurotransmitters such as substance P, glutamate and calcitonin gene-related peptide. However, no signs of prostaglandin-mediated inflammation have been seen in those studies either. These neurotransmitters, combined with neovascularization and neural ingrowth, might provide an explanation for the pain associated with tendinosis. (Alfredson and Cook 2007.)

In this context, it should be noted that the pathways and cellular mechanisms that lead to the development of tendinosis are not well understood (Kannus and Józsa 1991). The absence of inflammatory cell infiltration in the chronic state of tendinopathy does not exclude a prior inflammatory condition of the affected tendon (Paavola et al. 2002b). It is obvious that further studies are needed to investigate the cellular basis of the development of tendinosis (Scott et al. 2008).

2.3.4. Clinical presentation

A through history and examination play a key role in the diagnosis of proximal hamstring tendinopathy (Fredericson et al. 2005). The onset of pain, duration, and aggravating factors should be clearly documented.

The main symptom of proximal hamstring tendinopathy is pain in the lower gluteal region, sometimes radiating along the hamstring muscles to the posterior thigh, during sports activities and especially during running at a faster pace (Orava 1997, Fredericson et al. 2005). Most of the patients also suffer from pain while sitting for a prolonged period (Puranen and Orava 1988, Migliorini et al. 2000, Fredericson et al. 2005). Typically, the pain appears without any acute trauma and gradually gets worse (Puranen and Orava 1988). In general, continued exercises and stretching of the posterior thigh make the situation gradually worse (Migliorini et al. 2000).

On clinical examination, there is often tenderness over the ischial tuberosity. Active stretch tests of the posterior thigh recreate the pain at the site of the ischial tuberosity. Typically, peripheral neurological tests and ENMG studies are normal and no strength deficiencies are noted in knee flexion or in hip extension. (Puranen and Orava 1988, Migliorini et al. 2000, Fredericson et al. 2005.)

2.3.5. Imaging and differential diagnostics

US has been used to examine common tendinopathies since it is readily available, quick, safe and inexpensive. However, it is operator-dependent, provides limited soft-tissue contrast, and is less sensitive than MRI (Paavola et al. 2002b). Tendon thickening and intratendinous lesions are characteristic findings of US in chronic hamstring tendinopathy (Koulouris and Connell 2005). Further, colour Doppler US can be used to assess neovascularization (Koulouris and Connell 2005).

Because chronic pain in the gluteal region and in the posterior thigh is often a diagnostic challenge, MRI is typically used to confirm the diagnosis of hamstring tendinopathy and to exclude other sources of pain (Fredericson et al. 2005). MRI provides extensive information on the internal morphology of the tendon and the surrounding structures, and is useful in evaluating chronic tendon degeneration (Bencardino and Mellado 2005). Typical MRI findings of proximal hamstring tendinopathy include increased tendon girth, altered signal appearance within the tendon tissue, and asymmetric involvement of hamstring tendons in unilateral cases (De Paulis et al. 1998, Bencardino and Mellado 2005). Also the close position of the sciatic nerve to ischial tuberosity is clearly seen on MRIs.

Concerning the main differential diagnoses of proximal hamstring tendinopathy, lumbar radicular pain, piriformis syndrome, stress fractures, apophysitis, avulsion fractures, bursitis and partial proximal hamstring tears should be borne in mind. MRI also has an invaluable role in this issue.

2.3.6. Treatment

Various modalities have been recommended as appropriate treatment options for common tendinopathies but the scientific evidence for most of the conservative and surgical treatments remains sparse (Alfredson and Cook 2007). In the initial phase, treatment should be directed towards relieving symptoms using relative rest, ice and physical modalities and reducing possible risk factors (Brukner and Khan 2007). In conservative treatment, especially eccentric training, glyceryl trinitrate patches and sclerosing injections have shown promising results in the treatment of different tendinopathies (Alfredson and Cook 2007, Alfredson and Lorentzon 2007, Murrell 2007, Visnes and Bahr 2007, Woodley et al. 2007). The role of NSAIDs, corticosteroid injections, extracorporeal shock wave therapy and bipolar radiofrequency microtenotomy as treatment modalities in these chronic tendon disorders has also been investigated (Green et al. 2002, Paavola et al. 2002a, Smidt et al. 2002, Furia 2008, Takahashi et al. 2007). As a general guideline, the treatment of common tendinopathies is primarily conservative but if this is not successful, then surgery is often a viable option in the majority of cases (Paavola et al. 2000, Peers and Lysens 2005, Alfredson and Cook 2007, Brukner and Khan 2007).

In the case of proximal hamstring tendinopathy, to our knowledge, no results of conservative treatment have been published except for one case report presented in a review study by Fredericson et al. (2005). In this study, mainly on the basis of their 12-year experience of treating hamstring tendinopathy patients, Fredericson and colleagues recommended an aggressive rehabilitation program, including soft-tissue mobilization, frequent stretching, and progressive eccentric hamstring and core-stabilization strengthening exercises. They also concluded that in some cases corticosteroid injections can be helpful and also occasionally surgery may be necessary.

Previous studies have shown that proximal hamstring tendinopathy may be resistant to conservative treatment. In such cases, surgery seems to be a good option, and satisfactory results can often be expected (Puranen and Orava 1988, Migliorini et al. 2000).

3. AIMS OF THE STUDY

The primary purpose of the present study was to evaluate the role of surgical treatment in the management of hamstring muscle injuries and tendon disorders. The specific aims were as follows:

1. To evaluate the results of surgical treatment of complete proximal hamstring avulsions, and to compare the outcome of surgery in cases operated in the acute or in the chronic phase (I).
2. To study the effect of surgical treatment on partial tears of the proximal origin of the hamstring muscles (II).
3. To provide more information on surgical treatment concerning distal tears of hamstring muscles (III).
4. To analyze the results of surgical management of proximal hamstring tendinopathy, and to determine typical histopathological findings related to this chronic tendon disorder (IV).
5. To introduce a new reconstruction technique using fascia lata autograft augmentation that can be used in the most challenging complete proximal hamstring muscle ruptures (V).

4. PATIENTS AND METHODS

4.1. STUDY DESIGN AND PATIENTS

The patients in this study were treated surgically because of hamstring muscle injury (I, II, III, and V) or because of proximal hamstring tendinopathy (IV). Studies I-IV are retrospective case series studies. Study V is a technical note describing a surgical reconstruction technique, but information on five patients treated with this method has also been given. The study protocol was approved by the local hospital ethics committee of Satakunta Central Hospital, Pori, Finland.

The study consisted of the following groups of patients in studies I-V (Table 1.).

Table 1. Summary of the number and the mean age of the patients and the years of the operations in studies I-V.

STUDY	NUMBER OF PATIENTS (men / women)	MEAN AGE AT OPERATION OF THE PATIENTS (years)	TIMING OF OPERATIONS (years)
I	41 (21 / 20)	46 (range, 18-71)	1995-2004
II	47 (32 / 15)	33 (range, 16-61)	1994-2005
III	18 (16 / 2)	28 (range, 18-40)	1992-2005
IV	90 (58 / 32)	34 (range, 16-63)	1991-2005
V	5 (2 / 3)	42 (range, 19-59)	1995-2004

4.1.1. Complete proximal hamstring avulsions (I)

Forty-one patients with a complete (all three muscles torn) proximal hamstring avulsion were included in this study. Two patients were excluded: one because of a concomitant posterior cruciate ligament injury in the ipsilateral knee, and one because of insufficient follow-up time (6 months). Apophyseal avulsion fractures were also excluded. All the patients were treated operatively during the years 1995-2004. There were 21 men and 20 women with a mean age of 46 years (range, 18-71).

Twenty-nine of the patients were actively involved in sports, and two of them were competitive athletes. In 22 cases, the injury was sports-related. The three most common sports in which the injuries occurred were cross-country skiing (9 cases), waterskiing (3 cases) and downhill skiing (3 cases). In all the sports-related injuries and in most of the non-sports related injuries, the injury mechanism was falling or slipping, resulting in a forceful flexion of the hip with the ipsilateral knee in extension, thereby violently overstretching the hamstrings.

All patients had weakness of the hamstring muscles and they were unable to run. They typically reported pain and discomfort in the posterior thigh and symptoms of instability, a feeling of poor leg control, and a sense of giving way of the affected extremity. In the acute phase, physical examinations typically revealed massive hematoma and swelling of the posterior thigh. A palpable defect of the proximal hamstring musculature just distal to the ischial tuberosity was noted, and a distal bulge was seen, caused by retracted muscles, especially when the knee was flexed against resistance. Marked weakness in knee flexion was noted in all patients. Sciatica-type symptoms were often reported in the chronic phase.

The indications for surgical treatment were typical severe symptoms and positive clinical and radiological findings. The time interval from injury to operation averaged 5 months (range, 1 week to 6 years; median 2 months). A total of 14 cases were operated within four weeks from the injury.

4.1.2. Partial proximal hamstring tears (II)

Forty-seven patients (48 cases, 1 bilateral) with a partial (one or two muscles torn) proximal hamstring tear were included in this study. All included patients were actively involved in sports. Two non-athletes with a surgically treated partial proximal hamstring tear were excluded, as well as five athletes because of a short follow-up period (< 6 months). Operations were carried out during the years 1994-2005. There were 32 men and 15 women with a mean age of 33 years (range, 16-61).

Twenty-eight of the patients were actively involved in professional or competitive-level sports, and 19 patients were recreational athletes. The average age of the professional and competitive-level athletes was 25 years and of the recreational athletes 45 years.

Forty-six of the injuries occurred during sporting activities; most often in soccer (16 cases). Patients typically reported the same injury mechanism and similar symptoms as described in study I. Most of the patients had undergone conservative treatment with unsatisfactory results before surgery. The time interval from injury to operation averaged 13 months (range, 2 weeks to 9 years; median 6 months). Five cases were operated within four weeks from the injury.

4.1.3. Distal hamstring tears (III)

Eighteen patients (16 men and 2 women) with a surgically treated distal hamstring tear were included in this study. Operations were carried out during the years 1992-2005. The mean age of the patients was 28 years (range, 18-40). Distal hamstring injuries associated with knee joint traumas were excluded.

There were six professional athletes, ten competitive-level athletes and two recreational athletes. All injuries occurred during sports, and typically while running fast or sprinting. The BF was injured in 11 cases, the SM in five cases and the ST in two cases. Of the 18 cases, 15 were located at the MTJ, two were avulsions, and one was a longitudinal tear in the tendon. In five cases the tear was classified as complete and in 13 cases as partial.

Commonly reported symptoms were weakness in knee flexion, as well as pain and stiffness of the distal part of the posterior thigh. Five patients with a complete tear reported a sense of instability of the knee joint especially during sports. Localised swelling and hematoma were common findings in patients seen in the early phase.

The indications for surgical treatment were disturbing symptoms and typical clinical and radiological findings. The time interval from injury to operation averaged 8.5 months (range, 5 days to 6 years; median 3 months). Four cases were operated within four weeks from the injury.

4.1.4. Proximal hamstring tendinopathy (IV)

Ninety patients (58 men and 32 women) with a proximal hamstring tendinopathy were included in this study. All included patients were actively involved in sports. Eleven patients with insufficient follow-up time (<12 months) and/ or missing information were excluded, as well as four patients not actively involved in sports. Operations were carried out during the years 1991-2005. The mean age of the patients was 34 years (range, 16-63). Thirteen patients had bilateral proximal hamstring tendinopathy. The total number of cases analyzed was thus 103.

There were five professional athletes, 47 competitive-level athletes, and 38 recreational athletes. The average age of the professional and competitive-level athletes was 26 years, and that of the recreational athletes 45 years. The most common sports among professional and competitive-level athletes were long- and middle-distance running and soccer. Recreational athletes were involved in various endurance sports.

Typically, patients reported pain in the lower gluteal region during sports activities especially during running at a faster pace or sprinting, and most of them also suffered from pain while sitting for a prolonged period. On clinical examination, active stretching of the hamstring muscles resulted in pain at the site of the ischial tuberosity. No weakness in knee flexion or in hip extension was noted. Neurological tests such as Lasègue's sign and reflex testing were normal.

The indications for surgical treatment were chronic, disturbing symptoms in spite of conservative treatment and typical clinical and radiological findings of proximal hamstring tendinopathy. The time period from the onset of symptoms to surgery averaged 21 months (range, 4 months to 10 years; median 14 months).

4.1.5. Reconstruction surgery in proximal hamstring injuries (V)

Five patients (3 women, 2 men) were included in this study: four patients with a complete proximal hamstring rerupture after failed surgical treatment, and one with a primary repair of a delayed rupture. These five patients were treated surgically using the fascia lata autograft reconstruction technique during the years 1995-2004. The mean age of the patients was 42 years (range, 19-59). Three of the four rerupture cases were the same patients as described in study I.

Four of the patients were actively involved in recreational sports. Two of the primary injuries occurred during sporting activities; one in waterskiing and one in downhill skiing. The remaining three cases resulted from slipping or falling. In these patients the mechanism of injury and the symptoms were similar to those described previously in study I.

In four rerupture cases, the average delay from injury to primary operation was six months (range, 3-12), and the average time from first operation to reoperation was 14 months (range, 7-24). After the primary repair, no reinjuries had occurred in these four patients before the failure was noted. In the one chronic case the delay from injury to surgery was six years.

4.2. METHODS

4.2.1. Imaging (I-V)

MRI was routinely performed pre-operatively to confirm the diagnosis and to evaluate more precisely the extent of the injury, as well as to exclude other possible pathology. In some cases in study III, ultrasound examination was considered to be sufficient on its own to confirm the correct diagnosis. In study IV, radiographs, ENMG studies and MRIs of the lumbar spine were also occasionally used to rule out other causes of symptoms.

4.2.2. Surgical treatment (I-V)

Information on surgical techniques used in each study:

Studies I and II: The ischial tuberosity was debrided, and ruptured proximal hamstring tendon(s) were reattached to bone by suture anchors (DePuy, Mitek). In chronic injuries the ischial nerve was freed from adhesions.

Study III: If the tear was located at the distal MTJ of the hamstring muscle, it was typically repaired by suturing after excision of scar tissue. The ruptured tendon was reinserted by suture anchor or by sutures.

Study IV: In proximal hamstring tendinopathy, a transverse tenotomy was done to the thickened SM tendon 3-4 cm distal to the origin. The tenotomized SM was then sutured securely to the BF. The sciatic nerve was explored and if there were minor adhesions around the nerve they were freed.

Study V: Retracted hamstring muscles were reattached to the ischial tuberosity by using a tensor fascia lata autograft augmentation. First, a muscle-tendon flap was created from the retracted hamstrings, and fixed to the ischial tuberosity by suture anchors. Secondly, the fascia lata graft was fixed to the ischial tuberosity and to the ruptured hamstring stump. Finally, the fixation was reinforced with sutures passing through the graft, as well as the muscle-tendon bridge and the hamstring stump.

4.2.3. Postoperative rehabilitation (I-V)

The postoperative rehabilitation was planned according to the diagnosis, the surgical procedure and the patient's progress. An elastic bandage was normally used for one to two weeks after the operation. No immobilization, casts, or orthoses were used.

The general guidelines for rehabilitation protocols of each study were as follows:

Studies I and II: Postoperatively, for two to four weeks, light touch weight-bearing was allowed. After that the patients moved gradually to full weight-bearing. After three to four weeks, light pool training including swimming was allowed, and after four to six weeks cycling, was allowed. A range of motion exercises was also started at this phase. All kind of stretching of the hamstrings was avoided for the first four weeks. Running and more active muscle training were allowed two to four months after the operation according to the patient's progress.

Study III: The patients were allowed to begin partial weight-bearing within two weeks. Full weight-bearing was allowed within four weeks, and swimming and water training were allowed two to four weeks after surgery. Bicycling with gradually increasing time and intensity was begun after three to six weeks. Running was allowed from six to eight weeks after the operation.

Study IV: The patients were allowed to begin full weight-bearing gradually during the first two postoperative weeks. Swimming and water training were allowed two to three weeks after surgery. Bicycling with gradually increasing time and intensity was begun after four weeks. Running and heavier weight training were allowed two months after the operation.

Study V: For the first three weeks, no weight-bearing was allowed. Partial weight-bearing was begun after three weeks, and full weight-bearing was allowed and the use of crutches was discontinued five to six weeks after surgery. Sitting and full extension of the hip and knee were avoided for the first three postoperative weeks and, while lying in bed, the hip and knee were kept at approximately 30 degrees of flexion during the first three to four weeks. Light swimming and water training were recommended after six to eight weeks. Bicycling with gradually increasing time and intensity was allowed three months after the surgery.

4.2.4. Follow-up and clinical evaluation (I-V)

The patients were followed-up at the Mehiläinen Hospital and Sports Clinic in Turku, Finland. Follow-ups were routinely arranged with monthly visits up to 3 to 4 months and then at 6 and 12 months postoperatively. Additional follow-ups were scheduled as necessary, as well as for study purposes.

During the follow-up, patients' subjective recovery was evaluated by asking about possible symptoms (pain, stiffness, weakness) of the operated hamstrings associated with athletic activity and/or daily activities. Moreover, the patients' ability to return to sports was evaluated. For functional evaluations, patients underwent routine clinical examinations including assessments of the range of motion of the hip and knee joints and hamstring strength in knee flexion and in hip extension.

In studies I, II, III, and IV a four-category (excellent, good, moderate/fair, or poor) rating system was used to evaluate the overall result of the surgical treatment.

Study I: The result was rated excellent when the patient was free of symptoms and was able to return to the pre-injury level of activity. In the cases rated good, the patient had minor symptoms which, however, did not restrict activity level. The result was graded moderate when the patient's activity level was significantly lowered because of the residual symptoms, but there were only minor symptoms in activities of daily living. Finally, a poor result was assigned to cases in which there were difficulties in activities of daily living due to pain, weakness, and muscle cramps and/or in re-operations without re-injury.

Studies II and III: The result was rated excellent if the patient was asymptomatic and able to return to the pre-injury level of sporting activity. If there were occasional symptoms during strenuous sports activity, but the patient was able to return to the pre-injury level of sports, the result was rated good. The result was graded fair when moderate training was possible but the patient was unable to carry out strenuous exertion and was unable to return to the pre-injury level of sports. Finally, a poor result was assigned to cases when the patient had disturbing symptoms even in activities of daily living.

Study IV: The result was rated excellent if the patient was asymptomatic and able to return to the same level of sporting activity as before the onset of the symptoms. If there were occasional symptoms during strenuous sports activity, but the former level of sports had been achieved, the result was rated good. The result was graded fair if symptoms did not allow a return to the previous level of sport and thus dictated cessation of competitive sports activities or mandated a change in the form of the recreational sport activity. Finally, a poor result was assigned if the patient had given up all sports activities and had occasional disturbing symptoms even in activities of daily living. Also if reoperation was necessary the result was graded as poor.

4.2.5. Histology (IV)

In study IV, biopsy specimens were taken during surgery from 15 consecutive patients. All the biopsies were taken from the tenotomized SM. As a control, one biopsy was taken from a normal SM tendon from an 18-year athlete with operatively treated ischial tuberosity avulsion fracture. Samples were fresh frozen in isopentane, cooled with liquid nitrogen, and stored at –70^{o} C until further processed. The frozen samples were longitudinally cut into 5 μm sections and stained with Herovici's method and Alcian blue for routine structural analysis. CD45 (Ventana Medical Systems, Tucson, Arizona, USA) immunohistochemical staining was also performed to detect possible inflammatory cells.

4.2.6. Statistics (I)

Statistical analyses were used in study I and they were performed with SAS System for Windows, release 9.1/2004. P-values < 0.05 were considered statistically significant. The correlation between the delay from the injury to surgery and the result of the operative treatment was calculated. The normal distribution was tested using Shapiro-Wilk's test. If the data did not pass the test for normality, a non-parametric Mann-Whitney U-test for comparison of two groups and Kruskal-Wallis test for four groups were applied. For further analysis, Student's t-test and Chi-square test were used to investigate the other factors (age, number of used suture anchors) contributing to the result of surgery. Additional logistic regression was used to further evaluate the effect of delay to surgery. Odds ratios were also calculated.

5. RESULTS

5.1. CLINICAL OUTCOME (I-V)

In studies I-IV, altogether 196 patients were included and surgically treated because of different types of hamstring injuries or proximal hamstring tendinopathy. In study II, one patient had a bilateral partial tear and in study IV, 13 patients had bilateral tendinopathy. The total number of cases analyzed in studies I-IV was thus 210 (Table 2.). In study V, five patients with proximal hamstring injury were treated with a fascia lata autograft reconstruction method. Their clinical outcomes were also described in this technical note.

Table 2. Summary of the clinical outcome and time of follow-up in studies I-IV.

STUDY	INJURY / DISORDER	CLINICAL OUTCOME*	FOLLOW-UP TIME (average; months)
I	Complete proximal avulsion	19 excellent 10 good 5 moderate 7 poor	37 (range, 12-72)
II	Partial proximal tear	33 excellent 9 good 4 fair 2 poor	36 (range, 6-72)
III	Distal tear	13 excellent 1 good 3 fair 1 poor	37 (range, 12-78)
IV	Proximal tendinopathy	62 excellent 30 good 5 fair 6 poor	49 (range, 12-156)

*For outcome rating, see clinical evaluation criteria on page 41.

5.1.1. Complete proximal hamstring avulsions (I)

In study I, the main finding was that the delay from injury to surgery in complete proximal hamstring avulsions had a significant effect on the final clinical outcome. In the patients with results rated as excellent or good the mean delay was 2.4 months (range, 1 week to 9 months; median 1.5 months), whereas in patients with results rated as moderate or poor, the mean delay was 11.7 months (range, 2 months to 6 years; median 4.5 months). The difference was statistically significant ($P < 0.001$). Statistical difference was also found in the delay to surgery between the group with an excellent result and the groups with a moderate result (P = 0.0025) or a poor result (P = 0.0014), respectively. In the seven cases with a poor result, the shortest delay from injury to surgery was two months and the longest delay 12 months.

When the patients were divided into three groups (0 to 3 months, 22 patients; 3 to 6 months, 12 patients; and over 6 months, 7 patients) depending on the delay from injury to operative treatment there were statistically significant differences in the result of surgery between groups 0 to 3 months and 3 to 6 months (P= 0.0041), and between groups 0 to 3 months and greater than 6 months (P=0.0091). No statistically significant difference was found between the groups 3 to 6 months and greater than 6 months (P=0.9596).

The risk of a moderate/poor result was 29.4-fold (95% CI, 2.92-296.53) in the group with delay from 3 to 6 months compared to the group with delay from 0 to 3 months. In the group with delay over 6 months the risk of a moderate/poor result was 28.0-fold (95% CI, 2.29-342.15) when compared to the group 0 to 3 months.

The average age in patients with an excellent or good result was 45.9 years (range, 24 to 62; median 48), whereas the average age in patients with a moderate or poor result was 46.6 years (range, 18 to 71; median 46). No statistically significant differences were found in age between these groups (P=0.8757). Nor were statistically significant differences reached between the same groups and the number of suture anchors used (P=0.8470). Moreover, there were no statistically significant differences when the response variable was in four classes.

Twenty of the 27 recreational athletes were rated as having an excellent or good result, and they were able to return to their pre-injury levels of sports activities four to ten months after surgery.

During the follow-up, five patients were operated on twice. In one case the patient lost her balance and got a new proximal hamstring avulsion only three weeks after the primary operation. In another case, too strenuous postoperative rehabilitation was thought to have caused the partial rerupture. In these two cases the reoperation was performed using the same technique as in the first operation. The final results of these two patients were graded as good and poor, respectively. In the remaining three cases with reoperation, no specific reinjury was reported by the patients. In these three cases, reattachment of the tendons to the ischial tuberosity was not possible, and therefore a fascia lata reconstruction technique was used as described in study V. Because reoperation was required, the results of all these three cases were rated as poor.

Postoperatively, one patient had a deep venous thrombosis that was treated with anticoagulants. Four patients complained of neuralgia-type pain and decreased sensation in the proximal posterior thigh. These symptoms resolved during the follow-up. Furthermore, there were one superficial wound infection that was treated with per oral antimicrobial drugs, one postoperative seroma that was drained percutaneously, and one partial dehiscence of the wound that was treated without surgical intervention.

5.1.2. Partial proximal hamstring tears (II)

In study II, it was found that with surgical treatment satisfactory results can often be expected in partial proximal hamstring tears. All 47 patients felt that they had benefited from the surgery; their performance, as well as the strength of the operated hamstrings, had improved after the operation. However, the six athletes with result rated as fair or poor were not satisfied with their final outcome.

Twenty-four of the 28 professional and competitive-level athletes were able to return to their pre-injury level of sports activity after an average of six months (range, 2-12) from surgery. However, because of the long follow-up, several top-level athletes had decreased their level of sports activity by the final follow-up for other reasons. Seventeen (18 cases; one bilateral with excellent results in both) of the 19 recreationally active patients were able to return to sports, on average, four months (range, 1-6) after surgery.

Postoperatively, one wound infection was treated with antimicrobial drugs. One patient suffered from hyperesthesia of the incision area, and one from hypertrophic scarring.

5.1.3. Distal hamstring tears (III)

According to study III, excellent or good results can often be expected in distal hamstring tears after surgical methods, especially if used in the early phase. In all, 14 of the 18 athletes were able to return to their pre-injury level of sports, on average, four months (range, 2-6) after surgery. All 18 patients felt that they had benefited subjectively from the operative treatment.

In 11 cases, the tear was located in the distal BF. All these athletes were able to return to their preinjury level of sports, on average, 3.5 months (range, 2-5) after surgery.

However, only one of the five patients with a distal SM tear was able to return to the preinjury level of sports six months after surgery. In this case, the operation was performed six weeks after the injury. In the other four patients, operated 6-72 months after the injury, the results of surgery were evaluated as fair or poor.

Two patients with a complete distal ST tear were operated in the acute phase: two and four weeks after the injury. Both these athletes were able to return to their preinjury level of competitive sports five months after surgery.

Postoperatively, two patients had a seroma formation that was treated with percutaneus aspirations. One patient had hyperesthesia of the incision area during the early follow-up but this symptom later resolved.

5.1.4. Proximal hamstring tendinopathy (IV)

In study IV, it was found that surgery is a good option in proximal hamstring tendinopathy if conservative treatment fails. Of the 90 patients, 80 were able to return to the same level of sporting activity as before the onset of the symptoms, on average, five months (range, 2 to 12) after the first operation. Additionally, four patients were able to return to sports after reoperation carried out because of early (< 12 months) residual symptoms.

Postoperatively, one patient had a deep venous thrombosis in the lower extremity that was treated with oral anticoagulants. Two patients suffered from hyperesthesia of the incision area, but the symptoms resolved during the follow-up. One wound fistula was surgically treated under local anesthesia.

5.1.5. Reconstruction surgery in proximal hamstring injuries (V)

In study V, the mean length of the follow-up was 36 months (range, 9-61). All five patients felt that they had benefited from the surgery. Three of the four recreational athletes were able to return to their sporting activities (golf, running, and downhill skiing) 6 to 18 months (median 10 months) after the reconstruction operation. Before reoperation, none of the patients had been able to participate in their recreational sports.

5.2. HISTOPATHOLOGICAL FINDINGS OF PROXIMAL HAMSTRING TENDINOPATHY (IV)

In all the biopsies taken from the patients with proximal hamstring tendinopathy various degrees of tendinosis were clearly seen. The most significant feature was the absence of inflammatory cells in all samples, as verified by a negative CD45 immunostaining. The typical morphological findings of tendinosis, i.e. rounding of tenocyte nuclei, an increase in the amount of mucoid ground substance, disorganized collagen fibers, and increased vascular proliferation were seen in all biopsies taken from the tenotomized SM. In contrast, the control biopsy showed no signs of tendinosis. No calcification, fibrocartilaginous or bony metaplasia was seen in any of the samples. Signs of tendon rupture were not observed in any of the samples either. However, there were some fat cells in all samples, including the control. In the control tendon, the fat cells were located outside the tendon, but in the tendinosis samples, the isolated fat cells were between the collagen bundles showing fatty degeneration.

6. DISCUSSION

6.1. GENERAL

When dealing with hamstring muscle injuries, conservative treatment is likely to be the first thing to come to mind. The main principles of non-operative treatment of muscle injuries should be used as a common guideline. There are, however, more severe hamstring injuries in which surgical treatment should be considered. Especially in athletes, but also in other physically active people, if misdiagnosed and/or improperly treated, a complete (grade III) or even a partial (grade II) proximal hamstring muscle rupture can cause considerable morbidity and lead to permanently decreased performance. The best possible recovery to minimize the period of disability is not only crucial for professional athletes but also important for the active general population as such an injury may restrict leisure activity and even performance at work.

The indications for surgery in hamstring injuries are not yet validated or even always generally acknowledged. However, the future looks brighter as it seems that the number of published studies dealing with surgical treatment of severe hamstring injuries has been continually increasing. Reasons for this are probably the better availability of MRI to facilitate the diagnosis, as well as the increased experience in treating these injuries. However, according to our experience, underestimation of the severity of the injury and diagnostic difficulties are still the main reasons why optimal treatment is often delayed in cases requiring surgical repair, for example, in complete proximal hamstring ruptures.

In the literature, hamstring tears are commonly categorized as muscle injuries even though they could also be considered as tendinous injuries because the site of the rupture is usually in the MTJ area, often also involving tendinous tissue as well, or the ruptures are pure avulsions, which is typically the case in complete proximal hamstring ruptures (Noonan and Garrett 1992, Slavotinek et al. 2002, Drezner 2003, Connell et al. 2004). This categorization, combined with the fairly common assumption that muscle injuries do not require surgical treatment, can be misleading, and can also be one reason why the severity of hamstring injuries is often underestimated in the acute phase. Early and correct diagnosis, as well as accurate classification of the hamstring injuries, are the basic elements for the proper treatment and recovery from the injury (Koulouris and Connell 2005).

6.2. COMPLETE PROXIMAL HAMSTRING AVULSIONS

The mechanism of the proximal hamstring avulsion injuries is fairly well presented in the previously published studies. Often the injury is the result of a sudden and violent hamstring muscle contraction with the knee in extension and the hip in flexion (Blasier and Morawa 1990, Sallay et al. 1996, Klingele and Sallay 2002). This injury has been most commonly described in waterskiing (Sallay et al. 1996, Cross et al. 1998, Chakravarthy et al. 2005, Folsom and Larson 2008). In our study of complete proximal hamstring avulsions (41 patients), the injury most often occurred in cross-country skiing (9), waterskiing (3), and downhill skiing (3). However, in almost half of the patients, in 19 of the 41, the injury was not sports-related. In those patients, the injury was most often caused by slipping or falling in middle-aged individuals.

Symptoms in complete proximal hamstring avulsions are often severe. In the acute phase, patients typically report pain and weakness in knee flexion and in hip extension, and many of them have trouble even in walking. Patients with chronic injuries seldom do better. They may even have more disturbing symptoms than in the acute phase (Cross et al. 1998). Besides the symptoms mentioned above, they typically report a feeling of poor leg control, muscle spasms and a sense of giving way of the injured extremity. Sciatica-type symptoms may also be present. Considering these severe symptoms in the chronic phase and experiences of delayed surgery it seems that conservative treatment alone has a poor prognosis in complete proximal hamstring ruptures (Orava and Kujala 1995, Kurosawa et al. 1996, Sallay et al. 1996, Cross et al. 1998, Chakravarthy et al. 2005, Colosimo et al. 2005, Cohen and Bradley 2007, Folsom and Larson 2008, McGrecor et al. 2008).

Surgery has gradually established its position in the treatment of severe hamstring injuries. In 1998, Cross el al. reported a series of nine patients with a chronic complete hamstring muscle rupture. Weakness, poor leg control, difficulties in running and sciatica-type symptoms were the main reasons for seeking medical attention. The patients were operated, on average, 36 months (2 to 104) after the injury. After surgery, all nine patients believed that they had benefited from surgery, and seven (78%) were able to return to their preinjury recreational sports. At, on average, 48 months after injury, hamstring strength and endurance averaged 60% and 57%, respectively, compared with the uninjured site in the seven of the nine patients available for testing. In a series by Klingele and Sallay (2002), 10 out of 11 (91%) patients (seven patients treated for acute and four for chronic complete ruptures) were satisfied with their results, and 73% were either pain-free or had minimal pain in all activities. Seven out of nine (78%) athletically active patients were able to return to their sports, on average, six months (range, 3 to 10) after surgery. Isokinetic muscle testing at one year after surgery showed an average hamstring strength return of 85% compared with the uninjured site. The authors concluded that satisfactory results can be achieved in the majority of both acute and chronic cases. However, they also stated that lower risk of injury to the sciatic nerve and better restoration of the anatomy were possible when repairs were performed soon after injury. In a study by Brucker and Imhoff (2005), seven out of eight (88%) patients (six patients treated acutely) were able to return to their pre-injury level of sports. However, in three of the cases, there was not a complete avulsion of the hamstring muscles as the SM was intact. The peak torque of the operated hamstrings in isokinetic muscle testing was 88% as compared to the contralateral side. Chakravarthy et al. (2005) reported results of four surgically treated complete proximal hamstring ruptures. One patient was treated acutely two weeks after injury and three patients in a chronic phase (6 to 13 months from injury) after failed conservative treatment. At 12-month follow-up, all patients had regained near normal function and strength of the injured extremity and were able to return to their pre-injury level of sport. In a conclusion, the authors recommended early surgery because it allowed early functional rehabilitation, and also avoided potential neurological symptoms. In a review by Cohen and Bradley (2007), the results of seven patients with acute hamstring repair were reported. All these patients were satisfied with the procedure, and six out of seven (86%) had returned to their preoperative sport and daily activity levels, on average, 8.5 months after surgery. Folsom and Larson (2008) also reported comparable results for 20 hamstring rupture cases treated in the acute phase. Fifteen out of 20 (75%) patients were satisfied with their results and were able to return to sporting activities.

The results of the study I were comparable to the above-mentioned studies. In our study, 29 out of 41 (71%) patients were rated as having an excellent or good result. They were either free of symptoms or had only minor symptoms which did not restrict their activity level. Twenty-two of the 29 (76%) patients actively involved in sports were able to return to their pre-injury level of sports activities four to ten months after surgery. Some degree of weakness was noted in manual muscle testing also in our cases, even in those who were able to return to their pre-injury level of activity.

The main finding in our study was that early surgical treatment had significantly better results than surgery in the chronic phase. Despite this, it was also noted that considerable improvement of symptoms was often achieved with surgery even in chronic cases. Most of the recently published studies have supported this finding but this study was the first where a statistically significant correlation was found between the delay from injury to surgery and the end result (Brucker and Imhoff 2005, Chakravarthy et al. 2005, Cohen and Bradley 2007, McGrecor et al. 2008, Stradley et al. 2008). This correlation makes sense as fatty degeneration and fibrous remodeling of the ruptured muscle tissue with consecutive atrophy have been shown to occur in chronic hamstring injuries (Sallay et al. 1996, Brucker and Imhoff 2005). Moreover, extensive sciatic nerve neurolysis, which is often necessary in chronic cases, poses a risk of damage to the branches of the sciatic nerve, and therefore may have an effect on the final result.

There were, however, patients in our series who had a moderate/poor result and were operated on in the early phase, and on the other hand, there were patients who had an excellent/good result although the operation was carried out several months after the injury. Therefore, the delay from injury to surgery was not the only parameter affecting the end result. The degree of concomitant nerve damage and, for example, the amount of trauma energy might also have an effect on the end result.

The surgical technique used in all these previously published studies has been quite similar. Ruptured and retracted proximal hamstring tendons have been reattached to the ischial tuberosity using suture anchors. The same method was also used in study I. In our study, the number of suture anchors used had no statistically significant effect on the final outcome. According to our experience, sutures should engage healthy contractile muscle tissue to achieve proper reattachment. In cases in which the proximal part of the torn muscles was denervated and remodelated, the sutures should be continued distally to this pathological part to prevent possible late gradual attenuation or rerupture.

Postoperatively in many prior series, immobilization of the knee at 60 to 90 degrees of flexion with a cast, splint or orthosis for a period ranging from two to eight weeks has been reported (Ishikawa et al. 1988, Sallay et al. 1996, Cross el al. 1998, Klingele and Sallay 2002, Brucker and Imhoff 2005, Chakravarthy et al. 2005, Folsom and Larson 2008). In our series, no immobilization except elastic bandage was used. Whether this is the reason for the three unexplained reruptures in our study is not known.

During postoperative follow-up in our series, five reruptures were noted: one with a new injury, one because of overly aggressive rehabilitation, and three cases with no specific reinjury. Four patients complained of neuralgia-type pain and decreased sensation in the posterior thigh, probably because of intraoperative traction of the posterior cutaneus femoral nerve. Furthermore, four other complications were reported in our series: one deep venous thrombosis, one superficial infection, one seroma formation, and one partial dehiscence of the wound. Folsom and Larson (2008) reported three major adverse events in their series: one rerupture after a fall on a slippery surface, one complex regional pain syndrome, and one deep infection. These three complications represented three of the five patients who were unable to return to their sporting activities in their series. Furthermore five patients had mild superficial wound drainage and/or erythema that were successfully treated with oral antibiotics. In a series by Brucker and Imhoff (2005), one patient with a dislocated suture anchor causing significant discomfort and therefore requiring revision surgery was noted during the follow-up.

6.3. PARTIAL PROXIMAL HAMSTRING TEARS

The number of published studies dealing with surgical treatment of partial proximal hamstring tears is scarce (Ishikawa et al. 1988, Orava and Kujala 1995, Brucker and Imhoff 2005, Regauer et al. 2005, Cohen and Bradley 2007, Folsom and Larson 2008, McGregor et al. 2008). In fact, in almost all of these studies, most patients have had a complete rupture of the proximal hamstrings, and only a few cases with partial tears have been included.

It seems that the prevailing assumption that partial proximal hamstring tears can always be treated non-operatively with good response is mainly derived from the study by Sallay et al. (1996). In this study, Sallay and co-workers clearly showed functional deficit and a low rate of return to sports among the six patients treated primarily non-operatively for complete proximal hamstring avulsions. The other six patients in this study had non-operatively treated partial proximal hamstring tears. It was mentioned that these patients, 'with some remaining hamstring muscle function', returned to their pre-injury sports, albeit at a lower level and described minor limitations. Furthermore, it was also stated that all 10 of these 12 patients suffered from a pulling sensation or cramping of the injured posterior thigh in intense sport activity after the injury. The direct interpretation derived from this study such as 'non-operative treatment of partial hamstring tears usually results in normal or nearly normal functional outcome' as presented in the study by Klingele and Sallay (2002) is in our opinion somewhat too simplistic.

Contrary to the study by Sallay and co-workers (1996), Ishikawa et al. (1988), Orava and Kujala (1995), Brucker and Imhoff (2005), Folsom and Larson (2008) and McGregor et al. (2008) showed that even partial tears can lead to significant functional deficit if left untreated, especially in athletes. They also showed that there are different combinations of partial proximal hamstring muscle tears.

The patients in our study of 47 athletes with surgically treated partial proximal hamstring tear are quite different compared to the study of patients with complete avulsions. In study II, injury most often occurred in soccer (16), and in almost all patients (45) the injury was sports-related. During this study only two patients with surgically treated partial proximal hamstring tear were excluded because they were not actively involved in sports. It could be that non-sports active patients with a partial proximal hamstring tear are coping well with no surgical treatment; they are not seeking medical attention as actively as athletes or they are not treated so actively for one reason or another as patients with a complete rupture. It could also be that if a non-athlete suffers a severe hamstring injury, for example, during a fall, it is most often a complete one.

In study II, 47 athletes were surgically treated because their athletic performance was clearly impaired due to the symptoms. Almost all of the patients had at first undergone conservative treatment with unsatisfactory results. After surgery, all 47 patients felt that they had benefited from the surgery, and their performance, as well as the strength of the operated thigh, had improved.

Other recently published studies have also recommended a more active treatment approach for partial proximal hamstring tears, especially in athletes (Regauer et al. 2005, Cohen and Bradley 2007, Folsom and Larson 2008, McGregor et al. 2008). The main reason for this more aggressive approach may be the increased experience of treating these injuries. It seems that conservatively treated partial hamstring tears can lead to decreased performance in serious recreational and top level athletes, in sports requiring highly coordinated neuromuscular efforts. However, further studies are needed to evaluate who should be operated, and at which point surgery should be considered. Concerning injury classification, the term 'partial tear' comprising collectively all the three hamstring muscles is not necessarily accurate enough. More information might be obtained if these isolated muscle/tendon ruptures were categorized also proximally as complete ones (grade III), for example, complete proximal SM rupture, as Regauer and co-workers did in 2005.

The surgical technique in partial proximal hamstring tears is the same as in complete avulsions. However, according to our experience, even in chronic cases of partial tears, the defect between ischial tuberosity and retracted hamstring tendon(s) is generally smaller, and therefore surgery is often easier than in chronic complete avulsions.

6.4. DISTAL HAMSTRING TEARS

Previously published case reports have already shown that isolated distal hamstring tears may result in pain, weakness, stiffness and instability of the knee joint, especially in athletes (Sebastianelli et al. 1990, David et al. 1994, Alioto et al. 1997, Pan and Ting 2000, Schilders et al. 2006). By surgical means, the results have been mainly promising, and athletes have been able to return to their sports. Our experience in the treatment of distal hamstring tears reinforces these earlier findings.

In study III, only isolated and distally located hamstring tears were included, and overall the data of 18 patients were analyzed. The results showed that the prognosis of surgically treated distal BF (11) and ST (2) injuries are mainly good. In our study, these athletes were able to return to their pre-injury level of sports 2 to 5 months after surgery. Unlike BF and ST injuries, the distal SM injury (5) seems to have a much poorer prognosis after surgical repair at least in late surgery. A muscle biopsy was performed in two of the four distal SM cases with results rated as fair or poor. It seems that if the injury occurs at the distal part of the SM it can cause neuronal damage and denervation of the muscle fibers, even resulting in disabling symptoms.

Injuries at the distal MTJ of the BF are good examples of the kind of effect the formation of scar and adhesions may have on the movement of injured muscle. After surgical deliberation of adhesions, most of the symptoms of these eight partial tears in our study resolved.

Distal ST injuries are an interesting entity. One might question the necessity of surgery in cases of distal ST tears because it is a tendon commonly used as a graft in anterior cruciate ligament reconstructions. However, studies show that harvesting of the ST leads to a loss of knee flexor strength and impaired dynamic stability (Nakamura et al. 2002, Segawa et al. 2002, Tashiro et al. 2003). Furthermore, even though it has been shown that the medial hamstring tendons regenerate in most cases after harvesting, the regenerated neotendon may have impaired biomechanical properties compared with the original ST (Carofino and Fulkerson 2005). In addition, to our knowledge, no one has shown that regeneration of the ST occurs after a traumatic rupture. In our study, the decision on surgical treatment in these two distal ST cases was made because both athletes had severe pain, sense of instability and weakness of the knee after the injury.

6.5. PROXIMAL HAMSTRING TENDINOPATHY

Treatment of proximal hamstring tendinopathy offers an exceptional challenge. It seems that the basic pathology in proximal hamstring tendinopathy is tendinosis of the proximal hamstring tendons, especially of the SM. However, the sciatic nerve's close relation to the proximal hamstring tendons has to be taken into consideration, especially in differential diagnosis but also when making decision between different treatment alternatives (Puranen and Orava 1988, Migliorini et al. 2000, Brukner and Khan 2007, Miller et al. 2007). Surgical and MRI findings have shown that adhesions between the sciatic nerve and proximal hamstring tendons may occasionally be present, and also in rare cases, thickened and swollen proximal hamstring tendons can even cause direct compression on the sciatic nerve (Puranen and Orava 1988, De Paulis et al. 1998, Migliorini et al. 2000). The sciatic nerve may be maximally tautened and impinged during the forward swing phase of running because of swollen tendons and adhesions (Migliorini et al. 2000). This irritation of the sciatic nerve may aggravate the pain caused by hamstring tendinosis alone (Puranen and Orava 1988, Khan et al. 2000).

In our experience, chronic proximal hamstring tendinopathy can be quite resistant to conservative treatment. However, response to surgical treatment in proximal hamstring tendinopathy seems to be mainly good with a low complication rate (Puranen and Orava 1988, Migliorini et al. 2000). In study IV, 80 out of 90 patients were able to return to the same level of sporting activity after surgery as before the onset of the symptoms. This took an average of five months (range, 2-12).

In proximal hamstring tendinopathy, the morphological findings of tendinosis are largely identical to those previously described in other common (e.g. Achilles and patellar) tendinopathies. In all analyzed samples, signs of degenerative processes of various severity were detected without signs of inflammatory cells. This histopathological picture of proximal hamstring tendinosis should be taken into consideration when effective treatment is being planned for athletes.

6.6. RECONSTRUCTION SURGERY IN PROXIMAL HAMSTRING INJURIES

In chronic proximal hamstring ruptures and in reruptures, anatomic apposition of the retracted muscles cannot always be achieved. In study V, a novel technique using fascia lata autograft augmentation has been described in detail. We have used this method in the treatment of five patients (four reoperations and one chronic rupture) with encouraging results. It seems that late reconstruction of complete proximal hamstring rupture with fascia lata autograft augmentation is a useful procedure: it results in enhancement of muscle strength and better function of the hamstrings.

Recently, Folsom and Larson (2008) introduced another reconstruction method for chronic proximal hamstring ruptures. In their study, five patients with chronic injuries underwent a reconstruction procedure with the Achilles allograft technique. They noted that this allograft reconstruction method led to improved muscle strength, better leg control and a predictable functional improvement. We agree with the opinion of Folsom and Larson that restoring the hamstrings in a two-joint muscle with increased tension and proper function improves leg control. It also seems that by both of these reconstruction methods, symptoms derived from retracted hamstrings causing stretching to the sciatic nerve could be alleviated.

6.7. STUDY LIMITATIONS

The current study has several limitations. First of all, it is subject to all the inherent limitations of retrospective studies. The selection bias and possible confounding factors could not be controlled in our study population. Secondly, since no standardized evaluation scales or rating systems have been developed to assess hamstring injuries or proximal hamstring tendinopathy, we set our own criteria for the evaluation of results after surgery. Results were evaluated only by the ability of the patient to return to sports, and by assessing the subjective symptoms of each patient. No objective functional measurements were made during the follow-up. Furthermore, we were unable to include a group of non-surgically treated matched controls. Another major drawback of these studies is the non-blinded outcome assessment. Although studies I-IV are the largest so far, the sample sizes may not be sufficient to draw definitive conclusions. From the point of view of generalization of the results this study represents mainly patients who had been referred to a specialist sports injury unit, and thus there is a potential for referral bias. We are not able to comment on patients who had been treated non-operatively. However, many patients in our studies had been treated operatively only after failed conservative treatment. We also acknowledge that our study group may not be representative of the general population of patients with hamstring injuries or disorders. Despite these limitations, the information from studies I-V may be used as a guide in the treatment of patients with severe hamstring injuries or proximal hamstring tendinopathy, and it can help in planning future prospective studies on this topic.

6.8. FUTURE PERSPECTIVES

The fields of orthopedic surgery and sports medicine are currently in an exciting and rapidly developing era. Advances, for example, in gene therapy, tissue engineering, and molecular biology have already had an effect also on the treatment of muscle and tendon disorders (Ljungqvist et al. 2008). No limits to novel research ideas are yet in sight since sports injuries, led by muscle and tendon disorders, provide excellent options for the development of new treatment methods, which can also be used more widely in other clinical practice.

With increasing athletic activities, the number of hamstring muscle injuries and tendon disorders has and probably will continue to increase. It is important to provide these patients with good possibilities for early and correct diagnosis, optimal treatment, and proper rehabilitation.

There is no doubt that surgery has an important role in the treatment of severe hamstring muscle injuries, and the need for surgery may increase in the future. However, previous studies have mainly consisted of small case reports, with the result that evidence based on larger series is lacking. Thus, more information about surgical treatment of different types of hamstring muscle injuries is needed.

Regarding proximal hamstring tendinopathy, a rating system including possible evaluation of histological degree of tendinosis and MRI findings should be developed, and a randomized controlled trial with standardized outcome measures and long-term follow-up is also needed to assess the optimal treatment. One aim of our ongoing prospective study is to assess the role of eccentric hamstring muscle training in the treatment of proximal hamstring tendinopathy. It would also be interesting to evaluate the effects of sclerosing treatment and bipolar radiofrequency microtenotomy on proximal hamstring tendinopathy.

7. CONCLUSIONS

The data of the present study led to the following conclusions:

1. In complete proximal hamstring avulsions, early operative treatment should be considered as the results are superior to those after late surgery. However, considerable improvement of symptoms is often achieved with surgery even in chronic cases. (I)

2. In partial proximal hamstring tears, surgical treatment should be considered since in most of these cases excellent or good results can be expected after surgical repair. (II)

3. In distal hamstring tears, surgical treatment seems to be beneficial in selected cases and in most of these cases excellent or good results can be expected. (III)

4. In proximal hamstring tendinopathy, surgical treatment is a valuable option when conservative treatment has failed. Histological findings in proximal hamstring tendinopathy correlate well with the typical pathological changes found in other chronic tendinopathies. (IV)

5. A fascia lata autograft augmentation seems to be a useful procedure in chronic complete proximal hamstring muscle ruptures in which a large defect between the retracted muscle belly and the ischial tuberosity prevents direct anatomic repair. (V)

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