HAMSTRING TENDON INJURY

ANNE VAN DER MADE

Hamstring tendon injury

Academisch proefschrift

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HAMSTRING TENDON INJURY

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01 GENERAL INTRODUCTION

GENERAL INTRODUCTION

This thesis focuses on hamstring injury, with emphasis on injury that involves the hamstring tendons. In the general introduction relevant aspects of anatomy, epidemiology, impact, and differences between muscle and tendon injury will be discussed. The introduction is concluded with aims and outline of this thesis.

Hamstring anatomy

Macroscopic anatomy

The hamstrings comprise the long head of Biceps femoris (BFlh), Semitendinosus (ST), Semimembranosus (SM), and short head of Biceps femoris (BFsh). The first three posterior thigh muscles span the hip and knee joint and are therefore biarticular, while the monoarticular BFsh spans only the knee joint. As a result, hamstring function includes knee flexion, and the biarticular hamstrings also facilitate hip extension. Additionally, the hamstrings can assist in internal or external rotation of the knee, serve as antagonists to limit knee extension, and reduce anterior tibial translation during walking and running.

The biarticular hamstrings have their origin on the upper region of the posterior aspect of the ischial tuberosity[1–8]. The proximal hamstring tendons are attached here. In this thesis, tendons are subdivided into free and intramuscular parts (Figure 1). The free tendon is defined as the part that is attached to the bony origin or insertion, and continues until the point at which the first muscle fibres attach to it. The intramuscular tendon is defined as the part that extends alongside and into the muscle like the rachis in a **feather**, thereby having muscle fibres attached to it.

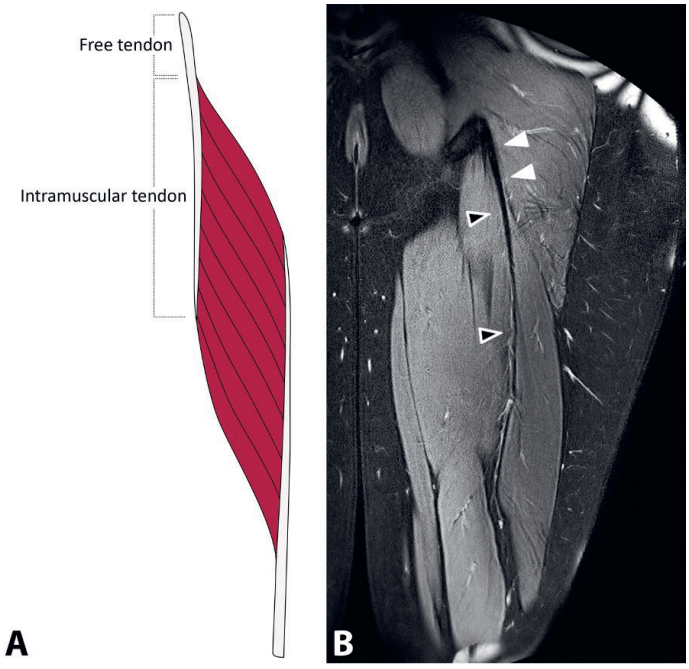

Figure 1. (A) Schematic overview dividing the tendon into a free and intramuscular part (source: van der Made et al. [9], with permission). (B) Coronal MR image demonstrating the free (white arrows) and intramuscular (black arrows) tendon parts of the conjoint tendon.

The hamstring origin on the ischial tuberosity is subdivided into the medial and lateral facets[1–6,8]. The BFlh and ST have a shared (i.e. conjoint) proximal tendon that attaches to the medial facet, while the ST also partly attaches directly onto the ischial tuberosity[2,8,10]. The conjoint tendon continues distally and then divides into two separate (intramuscular) tendons[8,10]. The long proximal SM tendon attaches on the lateral facet with anterolateral

positioned variations. It is of note that both proximal tendons are densely connected at their ischial attachment[7,8], with the sciatic nerve lying in very close proximity. These anatomical interrelationships have implications for injury patterns, symptomatology, and surgical technique.

The insertion of all hamstring muscle is distal to the knee joint. The BFlh courses distally towards the lateral side and is joined by the BFsh, that has its origin on the lateral lip of the linea aspera. Together, the BFlh and BFsh have a rather complex insertion at the fibular head with connections to each other and several adjacent structures[11]. The ST and SM course towards the medial side of the knee and insert on the pes anserinus and on the posteromedial tibia, respectively. The distal SM attachment is variable and, in analogy with the BFlh/BFsh attachment, is rather complex with attachments to structures within the posteromedial corner of the knee[12].

Microscopic anatomy

Skeletal muscle is composed of parallel muscle cells (myofibres) containing myofibrils, contractile elements that facilitate force generation through shortening (i.e. contraction) by interaction between filamentary proteins, actin, and myosin. Myofibres are connected by a vast network of connective tissue that also contains the neurovascular structures (Figure 2)[13]. This network organises the muscle on several levels: the epimysium surrounds the muscle as a whole, the perimysium envelops bundles of myofibres (fascicles), and the endomysium surrounds each myofibre. In addition to providing a structural framework, the network of connective tissue plays an important role in force transmission so that individual contraction of myofibrils results in a joint effort such as locomotion or resisting an external force.

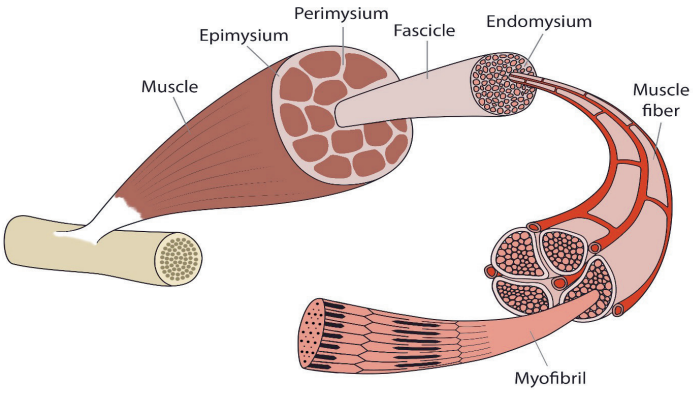

Figure 2. Schematic overview of skeletal muscle structure (source: van der Made et al.[13], with permission)

The tendon is ultimately the structure that transmits forces between muscle and bone. Tendon tissue is organised in a structural hierarchy that is somewhat similar to skeletal muscle. It is composed of tendon cells (tenocytes/tenoblasts) that lie within an extracellular matrix (ECM). Tenocytes synthesise collagen and other ECM components. Collagen fibrils composed of cross-linked tropocollagen form collagen fibres. Fibres are grouped into subfascicles. Multiple subfascicles are bundled into fascicles, which in turn make up the

tendon. Like in muscle, connective tissue organises the tendon unit on several levels: endotenon surrounds fibres, subfascicles, and fascicles. Epitenon surrounds the tendon unit and contains the neurovascular structures. Additionally, there is an outside loose connective tissue layer known as the paratenon surrounding the epitenon.

For this thesis, the specific anatomic sites of interest are located at either end of the tendon: the musculotendinous junction (MTJ) and osteotendinous junction (OTJ).

The MTJ is the area where the muscle attaches to the tendon and where force is transmitted from the intracellular contractile elements in myofibres to ECM proteins in the tendon. As the hamstring tendons extend along and into the muscle for a considerable length after the first myofibres attach, MTJs can be up to approximately 20-25 centimetres long and proximal and distal MTJs may overlap[2,8]. On a microscopic level, the area of contact between muscle and tendon is greatly increased by invaginations of the sarcolemma resulting in furrow-like indentations in muscle tissue making contact with ridge-like protrusions of tendon tissue[14]. The increased area of contact decreases tensile stress on the junction and can be regarded as a protective measure against injury. In spite of this, the MTJ can be considered the **Achilles heel** of the musculotendinous unit. Ex-vivo studies have demonstrated that the MTJ is the site of failure in muscle that is strained to failure[15,16], which corresponds with imaging studies that point toward the MTJ as the most frequent area of injury[17–19].

The OTJ, also known as enthesis, is the region at the other end of the tendon that connects it to bone. It is traditionally divided into four zones: dense tendon, fibrocartilage, mineralized fibrocartilage, and bone[20]. Similar to the MTJ, the OTJ is a specialized area that aims at limiting stress concentration during force transmission between biomechanically different tissues[21]. The OTJ does so by providing a more gradual rather than sharp transition. Consequently, injuries at this junction such as tendon avulsions are relatively infrequent[17–19].

Acute hamstring injury

The "classic" hamstring injury, often referred to as a strain injury, is a common sight on sports fields and athletic tracks. This type of indirect muscle injury results from excessive tensile forces and is typically located at the proximal MTJ injury in the long head of the biceps femoris[17,18,22–24]. The (non-contact) mechanism of injury is often high-speed sprinting or overstretching of the hamstrings in extreme joint positions[25,26].

The impact

It is hard to find an athlete or sports enthusiast that has never had or seen a hamstring injury. This is simply due to the high incidence of hamstring injuries in various sports. For instance, in elite football and athletics, hamstring injury is the single most common injury[23,27]. In these sports, hamstring injuries account for 13% and 17% of all injuries with mean lay-off times of 19±18 and 10±9 (female) to 11±10 (male) days. Because this "classic" hamstring injury may take only several weeks to recover, its impact is easily underestimated when compared to injuries that result in (much) longer absence from sports participation, such as fractures or ligament tears. Yet, underestimation would be a mistake. As set forth by Bahr et al.[28], assessing incidence or severity in isolation provides an incomplete overview. Injury burden, the product of incidence and severity, may be more useful to assess the magnitude of the injury problem. When applying this principle to injury data from the UEFA Elite Club Injury

Study, we can clearly observe that hamstring injury is associated with a major injury burden (Figure 3)[28]. On top of this, there is the issue of re-injury. Hamstring injuries are notorious for their tendency to recur, with rates varying between 14% and 63%[29], resulting in additional and possibly longer absence[30,31]. Considering that both higher incidence and burden have been linked to worse team performance[32,33], it is clear that the hamstring injury problem should not be underestimated.

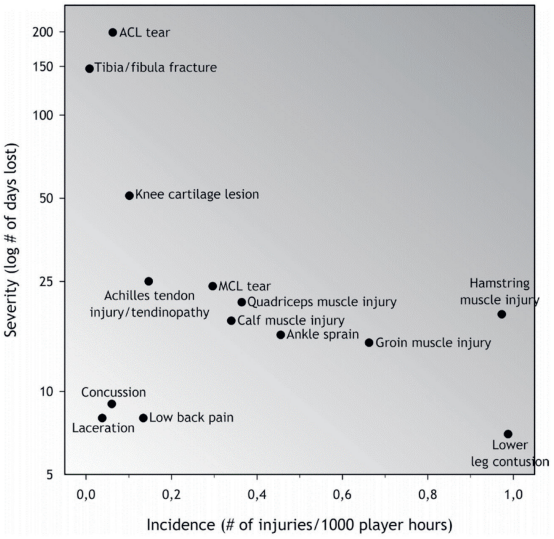

Figure 3. Quantitative risk matrix based on data from the UEFA Elite Club Injury Study illustrating the relationship between incidence and severity of the 14 most commonly reported injury types (source: Bahr et al.[28], with permission).

The need for an adequate prognosis

After injury, clinicians are expected to determine the diagnosis and to provide a prognosis in terms of return to play (RTP) duration. This prognosis is then used to inform treatment decision-making, planning of progression towards short- and long-term athletic goals, as well as inform team management decisions. The second instance where clinicians are expected to guide decision-making is when the RTP decision is nearing. The RTP decision is essentially a form of risk assessment where risk of re-injury is weighed against returning to sports participation and eventually performance as soon as possible.

To be able to provide a prognosis, clinicians require clinical and/or radiological variables that effectively discriminate between injured athletes that RTP early and late, and between those that will and will not re-injure. The search for such factors is reflected by several systematics reviews assessing potential prognostic variables for expected RTP duration[34,35] and re-injury risk[29,36]. Alas, these systematic reviews all conclude that there is no strong evidence to support the use of any clinical and/or radiological variable for a prognosis on RTP or re-injury. Conversely, these reviews do report several variables for which there is limited or moderate evidence. One of these variables has recently stirred up interest and has been anticipated to substantially impact prognosis and treatment strategy: tendon injury[37].

Hamstring tendon injury: a different ballgame?

The bulk of hamstring injuries is located at the MTJ, which is the interface between muscle and tendon tissue (Figure 4A)[18,19,24]. This type of hamstring injury usually resolves in a matter of weeks with non-operative treatment consisting of a rehabilitation program including a combination of range of motion exercises, agility drills, and progressive strengthening exercises[38–41].

A diagnosis of acute hamstring tendon injury, ranging from partial-thickness tears to full-thickness tears with complete discontinuity of the musculotendinous unit, is oftentimes considered **catastrophical** and the option of operative treatment is considered[37].

In this thesis, hamstring tendon injury will be divided anatomically into free and intramuscular hamstring tendon injury.

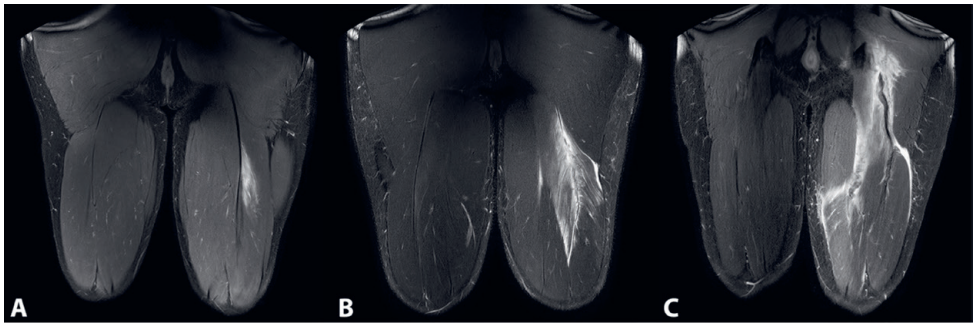

Figure 4. (A) Coronal MR image demonstrating injury at the musculotendinous junction (MTJ), (B) full-thickness intramuscular tendon injury, and (C) free tendon (avulsion) injury.

Free hamstring tendon injury

The free hamstring tendon is the tendon part that attaches to the bone and has no myofibres attaching onto it, as it becomes the intramuscular tendon at that point. Essentially, it is the part of the tendon between the OTJ and start of the MTJ. Full-thickness injury (i.e. tendon avulsion or rupture) results in complete discontinuity of the musculotendinous unit. Free tendon injury mainly affects the proximal OTJ (Figure 4C). Koulouris et al. reported MRI findings in patients that were referred with a clinical diagnosis of a hamstring injury and noted 25 (14%) free tendon injuries[17]. Proximal free tendon injuries (n=21) were more common than distal tendon injuries (n=4), and were for most part tendon avulsions (n=16). A proximal hamstring tendon avulsion is a forceful separation of tendon and bone at the level of the OTJ, typically due to a combination of forced hip (hyper)flexion and knee extension[42–44]. Traditionally portrayed as a waterskiing injury among novice water-skiers[44], these injuries predominantly affect the so-called "weekend warriors"; the athletically active middle-aged patients[45]. **Similar to the story of Icarus**, this group is potentially at risk due a mismatch between athletic ambitions and musculoskeletal "equipment". While less frequent, elite athletes are also affected by this type of injury[46].

As proximal hamstring tendon avulsions result in debilitating outcome when left untreated[44], they should be regarded as a completely distinct type of hamstring injury. This then entails a vastly different decision-making process. While the bulk of hamstring injuries is treated non-operatively, proximal hamstring tendon avulsions are regarded as

injuries that warrant surgical consideration[43,47,48]. However, evidence to guide clinicians in the treatment decision-making process is very limited. Based on systematic reviews[49–51], the current opinion is in favour of operative treatment as it results in better subjective and functional outcomes than non-operative treatment. Yet, these reviews have also highlighted methodological limitations that have introduced risk of bias: included studies are predominantly retrospective case series with a heavy publication bias towards operative treatment. In a recent systematic review[51] there were over 25 operative patients (n=767) for every non-operative patient (n=28). Prospective comparative studies, with or without randomisation, have scarcely been conducted. As a result, evidence-based indications for operative treatment have not been established and it remains a major challenge to advise either treatment option in the individual patient.

Intramuscular hamstring tendon injury

The intramuscular tendon is the tendon part that extends along and into the muscle with myofibres attached along its length. It is essentially the tendinous side of the MTJ. In an intramuscular hamstring tendon injury, the structural damage is not restricted to the MTJ but extends along and into the intramuscular tendon (Figure 4B). Intramuscular tendon injury is different from free tendon injury in the sense that full-thickness tendon injury is not likely to result in complete discontinuity of the musculotendinous unit as surrounding muscle fibres and fascia will act as a scaffold. It is arguable closer to a "regular" hamstring injury than a tendon avulsion injury. Still, these injuries are dreaded by clinicians dealing with injured athletes. The article that is often referenced in the debate on intramuscular hamstring tendon injury is an editorial by Brukner and Connell[37] in which readers are urged to beware the intramuscular tendon due to its presumed important role in serious thigh muscle injury. This editorial cited two studies in which the clinical relevance of intramuscular hamstring tendon injury was explored[52,53]. Comin et al.[52] reported that nine BFlh injuries with intramuscular tendon injury that were treated non-operatively had a three- to four-fold increase in time to RTP compared to injuries without. Another three intramuscular tendon injuries were even treated operatively. Pollock et al.[53] noted that fifteen intramuscular tendon injuries had a significantly longer time to RTP and higher re-injury rate (of up to 63%) compared to myofascial and musculotendinous injuries.

These observations are certainly cause for concern as the seemingly inferior prognosis of hamstring tendon injury would have clear implications for prognosis, treatment, and RTP decision-making. Yet, we should be cautious not to get ahead of ourselves. The notoriety of this type of injury is based on a retrospective analysis of only 24 injuries that were treated by clinicians who were potentially aware of imaging findings. These limitations warrant further investigation before definitive conclusions can be drawn.

Aims and thesis outline

The research in this thesis aimed to evaluate relevant aspects of hamstring tendon injury for daily clinical practice, with the emphasis on anatomy, diagnosis, treatment decision-making, and outcomes.

This thesis is divided into three parts.

Part I – Hamstring anatomy

Chapter 2 describes the anatomy of the hamstring muscle complex with emphasis on the proximal attachment. This chapter is the (anatomical) basis for the further division of this thesis into: **Part II – Free tendon injury** and **Part III – Intramuscular tendon injury**.

Part II – Free tendon injury

Chapter 3 is a call for awareness as we suspect that proximal free tendon injuries, either tendon avulsion or rupture, are frequently missed leading to delay in diagnosis with possible consequences for treatment outcome. It describes pearls and pitfalls for recognition.

Chapter 4 summarises the available literature in a systematic review of outcome following operative treatment of proximal hamstring avulsions. As a result of the encountered limitations of current evidence, we set out to map current clinical practice with emphasis on treatment decision-making in **Chapter 5**. This expert opinion survey study served to provide an overview of clinical practice as well as generate hypotheses for further research on topics where evidence gaps or discrepancies between evidence and eminence were noted. Additionally, the systematic review underlined the need for prospective studies. **Chapter 6** reports intra- and inter-rater reliability of hand-held isometric hamstring strength tests in high-level rugby players. These are used in clinical and research settings and their reliability is subject to debate, especially in very strong athletes. **Chapter 7** describes inter-rater reliability for the main imaging parameters used in treatment decision-making and introduces a novel radiological sign to identify proximal tendons with full-thickness injury. As previous work by our group demonstrated that the reliability of these imaging parameters was lacking in clinical practice, standardisation and testing of inter-rater reliability was a necessity for their use in decision-making. In **Chapter 8**, short- to medium-term outcomes of operative and non-operative treatment are reported in a prospective cohort study on proximal hamstring tendon avulsions using a shared decision-making model.

Part III – Intramuscular tendon injury

The clinical relevance and implications of intramuscular tendon injury is up for a hefty debate. In **Chapter 9**, we evaluate the association between intramuscular tendon injury and time to RTP, followed by association with re-injury rate in **Chapter 10.**

Finally, in **Chapter 11**, the most important findings of the studies in this thesis are discussed, along with implications and recommendations for current clinical practice and future research efforts.

Chapter 12 summarises this thesis followed by a Dutch summary.

PART I

HAMSTRING ANATOMY

02 THE HAMSTRING MUSCLE COMPLEX

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Abstract

Purpose: The anatomical appearance of the hamstring muscle complex was studied to provide hypotheses for the hamstring injury pattern and to provide reference values of origin dimensions, muscle length, tendon length, musculotendinous junction (MTJ) length as well as width and length of a tendinous inscription in the semitendinosus muscle known as the raphe.

Methods: Fifty-six hamstring muscle groups were dissected in prone position from 29 human cadaveric specimens with a median age of 71.5 (range 45–98).

Results: Data pertaining to origin dimensions, muscle length, tendon length, MTJ length and length as well as width of the raphe were collected. Besides these data, we also encountered interesting findings that might lead to a better understanding of the hamstring injury pattern. These include overlapping proximal and distal tendons of both the long head of the biceps femoris muscle and the semimembranosus muscle (SM), a twist in the proximal SM tendon and a tendinous inscription (raphe) in the semitendinosus muscle present in 96% of specimens.

Conclusion: No obvious hypothesis can be provided purely based on either muscle length, tendon length or MTJ length. However, it is possible that overlapping proximal and distal tendons as well as muscle architecture leading to a resultant force not in line with the tendon predispose to muscle injury, whereas the presence of a raphe might play a role in protecting the muscle against gross injury. Apart from these architectural characteristics that may contribute to a better understanding of the hamstring injury pattern, the provided reference values complement current knowledge on surgically relevant hamstring anatomy.

Level of evidence: IV.

Introduction

Injuries of the hamstring muscle complex (HMC) are common in many sports such as soccer, American football, Australian rules football, athletics and water skiing[44,54–57]. Both hamstring muscle strains and avulsions occur proximally rather than distally with the long head of the biceps femoris (BFlh) most frequently injured[58,59]. Even though there is no consensus on the topic, the semimembranosus (SM) is regarded as the second most-injured hamstring muscle[58]. The most vulnerable part of the muscle-tendon-bone unit is the musculotendinous junction (MTJ)[24,58,60]. The MTJ is the region of the muscle that transmits the force generated by the muscle fibres to the tendon that subsequently transmits the force to the bone[61]. Although evidence regarding the exact localization of hamstring injury is not in agreement (in the MTJ[24] vs. adjacent to the MTJ[61,62]), it is clear that this region plays a pivotal role in the hamstring injury pattern.

Although studies concerning the hamstring injury pattern exist, a clear understanding of this injury pattern is still lacking. In this study, we aim to provide an explanation for the abovementioned hamstring injury pattern by studying the anatomical appearance of the hamstring muscle complex.

Several studies[2,58,63–65] mention the presence of a tendinous inscription, known as the raphe, dividing the m. semitendinosus (ST) in two distinct parts, causing the ST to be occasionally regarded as a digastric muscle. In this study, the raphe is also covered because it is a part of hamstring anatomy and might play a role in the hamstring injury pattern.

Most hamstring strains or tears can be treated conservatively, but proximal hamstring avulsions can cause significant disability and may need surgery[66,67]. Surgery is indicated in active patients with an avulsion of the entire HMC or 1- or 2-tendon avulsion with a retraction of >2 cm[68]. Since there seems to be a recent trend towards a surgical approach for this injury, surgical anatomy of this region is important.

This work studies the anatomical appearance of the HMC and also:

1. aims to provide a hypothesis for the hamstring muscle injury pattern in which injury occurs mainly proximal with a particular high injury incidence of the biceps femoris.
2. provides reference values of origin dimensions, lengths of the m. biceps femoris (long head, BFlh), m. semitendinosus (ST) and m. semimembranosus (SM), lengths of their tendons and subsequently the calculated lengths of their MTJ's as well as references values of length and width of the raphe in the ST.

Materials and methods

Fifty-six hamstring muscle groups were dissected from twenty-nine human cadaveric specimens of the whole-body donation programme of the department of Anatomy, Embryology and Physiology of the Academic Medical Center, that were embalmed using an alcohol-based solution consisting of 32% ethanol, 0.33% phenol, 7.08% glycerol and 2.4% formaldehyde. They were subsequently conserved using 8.3% ethanol, 0.21% phenol and 16.7% glycerol.

No sample size calculation was performed prior to the measurements. The number of specimens dissected was the maximum of specimens that was available to us.

After reflecting the skin and subcutaneous tissue of the entire lower limb, leaving the musculature exposed, both the gluteus maximus and medius muscle were subsequently split to both sides using a longitudinal incision to reveal the hamstring origin on the ischial

tuberosity. After gently removing fascia and excess fat, the muscle morphology was studied, measured with standardized tape measures and recorded using a digital camera (Sony Cybershot DSCW200). The standardized tape measure allows measurements to be presented in one decimal. Mean values and standard deviation were subsequently calculated using SPSS©.

The total length of each separate hamstring muscle was measured as follows: the BFlh was measured from the ischial tuberosity and the short head of the biceps femoris (BFsh) from its most proximal origin on the lateral femur to their common insertion on the head of the fibula. The ST was measured from its common origin with the BFlh on the ischial tuberosity to the pes anserinus on the medial surface of the proximal tibia. The SM was measured from the ischial tuberosity to its insertion on the posteromedial aspect of the proximal tibia.

The length of the proximal tendon of each separate muscle was described as following:

- Total tendon length: measured from ischial tuberosity to where the tendon was no longer visible as it continued into the muscle.
- Free tendon length: measured from the ischial tuberosity to where muscle fibres started to insert into the tendon.

This was also done for distal tendons, measured from their insertion instead of from the ischial tuberosity. MTJ's length could be calculated by subtracting the length of the free tendon from the total-tendon length.

Subsequently, the width and height of the BFlh/ST common origin and the SM origin on the ischial tuberosity and of the BFsh on the lateral femur were studied and recorded.

Next, the partitioning of the common origin (conjoint tendon) of the BFlh and ST into their separate muscles was studied by careful blunt separation while removing cohesive fascia, until common muscle fibres could no longer be separated in this way. The distance to the ischial tuberosity at which the common tendon divided into two separate tendons was measured. The same was done in defining the partitioning of the SM muscle from the ST/BFlh muscles near their origin on the ischial tuberosity. Also, the distance between the ischial tuberosity and the point at which the muscles parted was measured.

The length of the raphe of the ST was studied by examining its nearest and furthest distance from the ischial tuberosity, alongside its maximum width.

Results

Seventeen of twenty-nine cadaver specimens were female, the other twelve were male. Median age was 71.5 (range 45–98).

Hamstring muscles

Mean hamstring muscle length including standard deviation can be found in Table 1.

Table 1. Mean lengths of hamstring muscles.

	Mean length (cm)
Biceps femoris (long head)	42.0±3.4
Biceps femoris (short head)	29.8±3.9
Semitendinosus	44.3±3.9
Semimembranosus	38.7±3.5

Origin dimensions

The common origin of the BFlh/ST muscles was found on the posteromedial aspect of the ischial tuberosity and measured 2.6 ± 0.4 cm medial-to-lateral and 1.8 ± 0.2 cm anterior-to-posterior. In addition to the common origin, muscle fibres of the ST were often seen attaching directly onto the ischial tuberosity.

The origin of the SM was located anterior to the common BFlh/ST origin, with anterolateral positioned variations. An SM origin purely located lateral of the common BFlh/ST origin was found in only two hamstrings, belonging to the same specimen. The SM origin measured a mean 1.3 ± 0.3 cm medial-to-lateral and 1.1 ± 0.5 cm anterior-to-posterior. Proceeding distally, the tendon attaching to this origin twists from anterolateral of the common BFlh/ST tendon to posteromedial where it ends as a wide tendon sheet before proceeding in the SM.

The BFsh has a long origin in the proximal-to-distal direction. Mean distances of the start and end of this origin measured as distance to ischial tuberosity were 12.8 ± 3.4 and 28.1 ± 4.1, respectively, so mean length of this BFsh origin was calculated to be 15.3 cm (Fig. 1a, b).

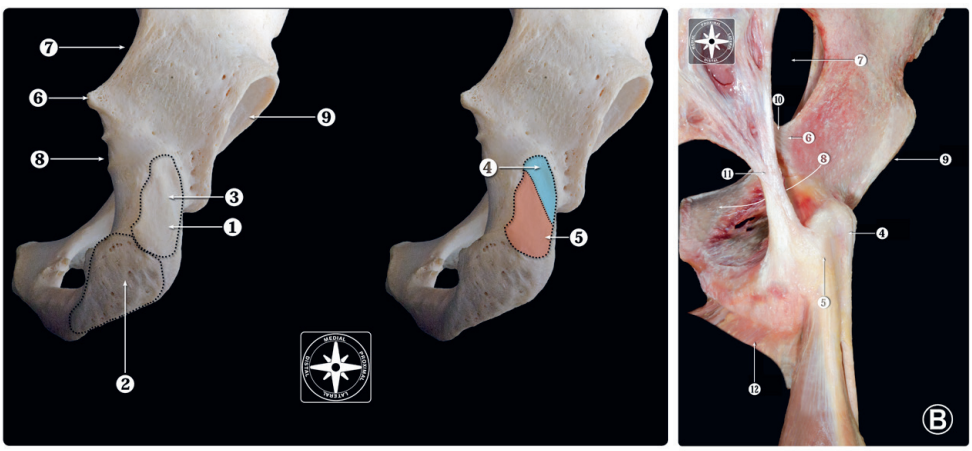

Figure 1a. Posterior view of the right coxal bone showing the ischial tuberosity which can be divided into two regions. 1: Upper region, 2: Lower region, 3: Vertical ridge which divides the upper region in two facets, 4: Lateral facet for insertion of the tendon of the semimembranosus muscle, 5: Medial facet for insertion of the conjoint tendon of the long head of biceps femoris and semitendinosus muscle, 6: Sciatic spine, 7: Greater sciatic notch, 8: Lesser sciatic notch, 9: Acetabulum.

Figure 1b. Osteoarticular dissection showing the insertions in the ischial tuberosity. 10: Sacrospinous ligament, 11: Sacrotuberous ligament, 12: Adductor magnus (ischial origin).

Tendon and MTJ lengths

Mean lengths of free tendon, total tendon and MTJ are given in Table 2. Note that the distal tendon of the biceps femoris is a common tendon of the long and short head.

Table 2. Mean lengths of free tendon, total tendon and MTJ per muscle including length as a proportion of muscle length.

	Muscle	Free tendon length in cm (length as a proportion of muscle length)	Total tendon length in cm (length as a proportion of muscle length)	MTJ length in cm (length as a proportion of muscle length)
Proximal	BFlh	5.0±3.4 (12%)	19.6±4.1 (47%)	14.6 (35%)
	ST	0.2±0.7 (0.4%)	12.4±3.6 (28%)	12.2 (28%)
	SM	9.4±2.6 (24%)	24.3±3.9 (63%)	14.9 (39%)
Distal	BF	9.1±3.0 (22%)	26.2±2.9 (62%)	17.1 (41%)
	ST	13.2±2.9 (30%)	24.9±3.7 (56%)	11.7 (26%)
	SM	5.5±1.9 (14%)	22.0±3.3 (57%)	16.5 (43%)

BF: biceps femoris, BFlh: long head of the biceps femoris, ST: semitendinosus, SM: Semimembranosus

When proximal and distal total-tendon lengths of a muscle are displayed as in Fig. 2, it becomes clear that proximal and distal tendons (and thus also the MTJ) of the biceps femoris (long head) and semimembranosus overlap. This means that the middle sections of these muscles have attachments to both the proximal and distal tendon (Fig. 2). This is not the case for the ST.

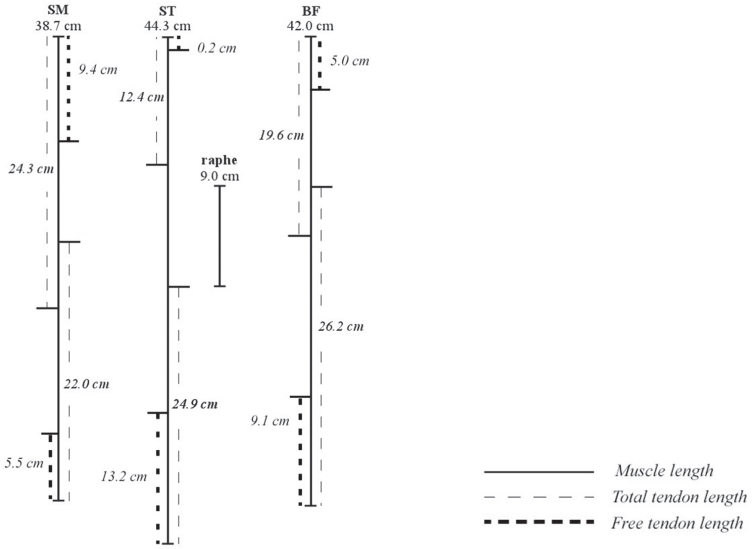

Figure 2. Muscle and tendon lengths of the hamstring muscle complex. Total-tendon length was measured from the muscle origin to where the tendon was no longer visible as it continued into the muscle. Free-tendon length was measured from the muscle origin to where the muscle fibres started to insert into the tendon. BF: biceps femoris, ST: semitendinosus, SM: semimembranosus.

Raphe

A raphe, or tendinous inscription, was present in the ST in all but two ST muscles that belonged to the same specimen (54/56 = 96%). This raphe runs in a proximal-to-distal direction and measured a mean 9.0 cm in length with a maximum width of 3.0 cm medial-to-lateral. The length of this raphe comprises 20.3% of ST muscle length (Figs. 3, 4a).

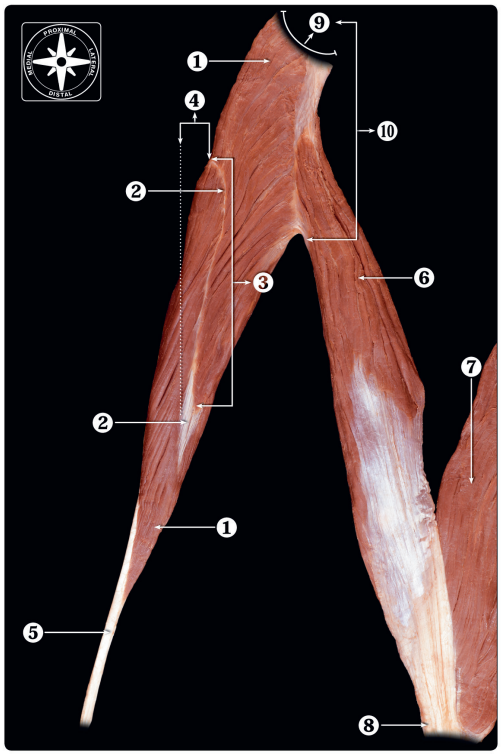

Figure 3. Anatomical dissection showing the muscular characteristics of the semitendinosus muscle. 1: Semitendinosus muscle, 2: Raphe, 3: Length of the raphe (mean 9.0 cm), 4: Width of the raphe (3.0 cm maximum), 5: Semitendinosus tendon, 6: Long head of biceps femoris muscle, 7: Short head of biceps femoris muscle, 8: Biceps femoris tendon, 9: Ischial tuberosity, 10: Conjoint tendon (Long head of biceps femoris and semitendinosus muscles).

Muscle partitioning

The BFlh and the ST have a common origin and a common tendon originating from the ischial tuberosity which ultimately divides into two separate tendons at a mean distance of 9.1 ± 2.3 cm from the ischial tuberosity (Figs. 3, 4a, b).

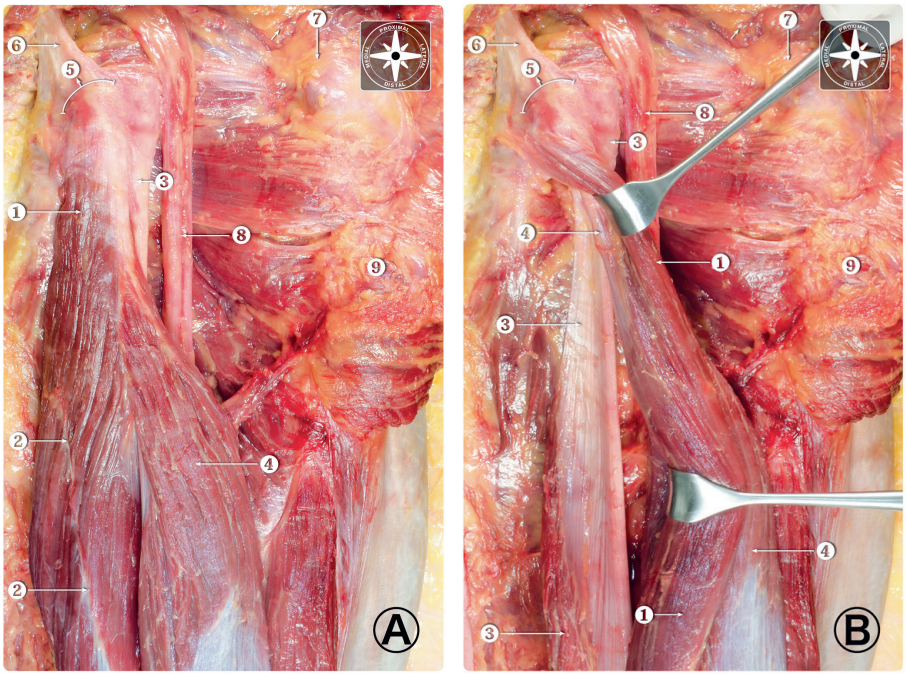

Figure 4. Dissection of the hamstring tendons. Figure 4a: Normal topographic anatomy. Figure 4b: The semitendinosus and long head of biceps femoris muscles have been rejected laterally to observe its relationship with the ischial origin of the semimembranosus muscle. 1: Semitendinosus muscle, 2: Raphe of semitendinosus muscle, 3: Semimembranosus muscle, 4: Long head of biceps femoris muscle, 5: Ischial tuberosity, 6: Sacrotuberous ligament, 7: Greater trochanter, 8: Sciatic nerve, 9: Gluteus maximus (cut and rejected).

The most proximal part of the SM tendon is conjoint with the BFlh/ST common tendon and gets separated at a mean distance of 2.7 ± 1.0 cm from the ischial tuberosity (Figs. 3, 4a, b).

Discussion

The most important findings of the present study were architectural characteristics of the hamstring muscle complex that may very well play a role in the hamstring injury pattern. On top of that, reference values of a relatively large number of specimens were provided.

These architectural characteristics lead to new hypotheses concerning the hamstring injury pattern. Note that these hypotheses are not solid explanations for the injury pattern, but serve to inspire new research.

Injury pattern

According to Askling et al.[25,26], a distinction can be made between two injury mechanisms leading to injury of a different muscle at a different site. Hamstring injuries sustained during high-speed running usually affect the BFlh at a mean distance of 6.7 cm distal to the ischial tuberosity[25]. According to our data, this is located at the MTJ. The most prevalent secondary injury was located in the ST[25]. Hamstring injuries sustained during stretching with a combination of extensive hip flexion and knee extension are usually located in the SM at a mean distance of 2.3 cm distal to the ischial tuberosity[26]. Taking our data in account, this injury occurs at the free tendon of the SM.

For both of these hamstring injury patterns, no obvious hypothesis can be provided purely based on either muscle length, tendon length (both free tendon and total tendon) or MTJ length. Measuring these data as a proportion of total-muscle length also did not contribute to this cause. However, there are some interesting findings to report from this study regarding the hamstring injury pattern.

As discussed above, the most frequently injured muscles are the BFlh during high-speed running and the SM during extensive stretching. Our data show that the proximal and distal tendons of both the BFlh and the SM overlap (Fig. 2). This muscle architecture might very well be a predisposing factor to injury and should be considered in future (biomechanical) studies.

The proximal SM tendon proceeds distally with a twist before ending as a wide tendon sheet. This has been confirmed by Woodley/Mercer[2]. It could very well be that this twist causes a resultant force that is not in line with the direction of the tendon, making the muscle vulnerable to injury at this point. Future studies should aim to study the dynamic interaction of the muscle-tendon-bone complex. It is conceivable that not only individual muscle characteristics, but also dynamic interaction between proximal tendons predisposes to muscle injury (e.g. tendons twisted around each other may create a lever arm during contraction).

The tendinous inscription found in the ST ('raphe') is also a potential factor of influence in the injury pattern. It seems that the raphe could play a role in protecting the ST against gross injury considering the low frequency of injury[25,26,58] in this muscle and the unique appearance of the raphe, but future studies are required to elucidate the role of the raphe in the injury pattern.

Measurements

The anatomy of the hamstring muscle complex has been studied and measured by several other authors[1,2,4,6,63–65,69,70]. Data on total-muscle length corresponds well with data of other studies[2,64,69,70], with some exceptions that are likely attributable to different measuring methods.

Four other studies[2,6,69,70] measured tendon lengths and show great variety of data between studies. Like total-muscle length, this is also probably due to different measuring methods.

The common BFlh/ST tendon divides into two separate tendons at a mean distance of 9.1 ± 2.3 cm from the ischial tuberosity. These findings correspond well with those of Miller et al.[1] and Garrett et al.[63] who found this division at a mean distance of 9.9 ± 1.5 and approximately 10 cm from the ischial tuberosity.

The most proximal part of the SM tendon is conjoint with the BFlh/ST common tendon and gets separated at a mean distance of 2.7 ± 1.0 cm from the ischial tuberosity. Garrett et al.[63] described this division more distally, at approximately 5 cm from the ischial tuberosity.

Possible explanations for these different findings could be the technique of blunt separation of cohesive fascia and the extent to which these were removed.

The anterolateral positioned origin of the SM as reported by Woodley/Mercer[2] and Sato et al.[4] has been confirmed by this study. However, origin dimensions of the common BFlh/ST as described by Miller et al.[1] did not correspond with our findings. Aside from the origin dimensions, we also found the BFlh/ST and SM origins to be positioned differently.

Miller et al. described the SM origin as located purely lateral of the common BFlh/ST origin, which we only found in two of the 56 hamstring complexes, belonging to the same specimen.

Several studies mention the existence of a tendinous inscription in the ST[2,58,63–65]. This inscription, or raphe, architecturally divides the ST into two muscle bellies, making it a digastric muscle. It was found in 96% of our specimens (54/56). Woodley/Mercer[2] described this 'raphe' as a complex 3D structure dividing the ST into two regions. They described it as a V-shaped tendinous inscription with a medial and lateral arm spanning a mean 2.8 and 6.7 cm, respectively. We did not confirm the V-shape, possibly due to the fact that we only approached it posteriorly.

Despite differences in certain findings, we feel confident about the acquired results, due to the fact that we had a considerable number of specimens to study. This study has reported architectural characteristics of the hamstring muscle complex that leads to a series of hypotheses that aim at a better understanding of the hamstring injury pattern. Apart from these characteristics, reference values complement current knowledge on surgically relevant hamstring anatomy. Furthermore, the different outcome in dimensions of the common ST/BF origin and SM origin provides discussion that could result in a revision of the origin of the proximal hamstring tendons, thereby having consequences for surgical reattachment in case of a complete proximal hamstring avulsion.

There were limitations in this study that deserve mentioning. Woodley/Mercer[2] described the raphe as a complex 3D structure. This is the case for the entire anatomy of the hamstring muscle complex. However, our measurements were performed with the specimens in prone position because they were simultaneously used for educational purposes.

Also, median age of the specimens was relatively high (71.5 years). This could play a role since ageing is known to be of influence on muscle architecture (e.g. shortening of muscle fascicles)[71].

In short, these factors may have contributed to differences in certain measurements between our study and the ones discussed.

Conclusion

No definite hypothesis for the hamstring injury pattern can be provided purely based on either muscle length, tendon length (both free tendon and total tendon) or MTJ length. It is possible that overlapping proximal and distal tendons as well as muscle architecture are leading to a resultant force not in line with the tendon predispose to muscle injury, whereas the presence of a raphe might play a role in protecting the muscle against gross injury. Future studies are required to confirm or reject these hypotheses.

Besides studies regarding individual muscle characteristics, future studies should also focus on dynamic interaction between bone-tendon-muscle complexes of the hamstrings.

PART II

FREE TENDON INJURY

03

POTENTIAL HAMSTRING INJURY BLIND SPOT: WE NEED TO RAISE AWARENESS OF PROXIMAL HAMSTRING TENDON AVULSION INJURIES

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Introduction

A recent thought-provoking editorial[72] suggested that the reported annual increase in hamstring injuries could in fact be associated with increased awareness rather than an actual increase in injury incidence. We share the author's optimism on the improving knowledge on (musculotendinous) hamstring injuries, yet we still have concerns regarding awareness of its evil twin; the full-thickness hamstring tendon avulsion.

In this letter, we argue that there is a 'blind spot' when it comes to diagnosing these serious injuries.

Are clinicians more at risk or more vigilant?

Hamstring tendon avulsions mostly affect the proximal tendons, and are typically sustained during sports or slip and fall accidents involving a combination of forceful hip flexion and knee extension[46]. Our ongoing prospective study raised concerns that medical professionals may be disproportionally affected by these injuries. We noticed that 20% (95% CI 9% to 37%) of included patients with a full-thickness proximal hamstring tendon avulsion were medical doctors and physiotherapists. In the Netherlands, medical doctors and physiotherapists make up approximately 0.8% of the adult population[73,74]. This percentage is in sharp contrast with the significantly higher proportion of those medical professionals that we encountered in our cohort of patients with a full-thickness proximal hamstring tendon avulsion.

Interestingly, we observed that substantial diagnostic delay (i.e. time between injury and MRI-confirmed diagnosis) did not occur in medical doctors and physiotherapists (figure 1). Delayed patients were typically diagnosed with a severe hamstring strain injury without further imaging and referred to a physiotherapist. Patients were subsequently referred to our centre when they did not progress as expected despite adequate treatment.

This leaves us with the question: Are medical professionals at specific risk of proximal hamstring tendon avulsion or are they more likely to have their injury adequately assessed within a short interval after injury?

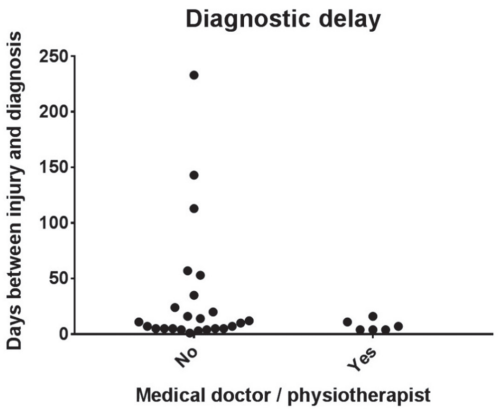

Figure 1. Time (in days) between injury and MRI-confirmed diagnosis.

The blind spot

There is no evidence to support the idea that medical professionals are at increased risk; hence, we argue that our observation can be explained by heedfulness or assertiveness among medical professionals.

Considering that 0.8% of the Dutch adult population are either medical doctors or physiotherapists and assuming that clinicians and non-clinicians have similar risk of sustaining the aforementioned injury, for every eight medical professionals we can expect 992 non-clinicians. This is clearly not the case in our study population, suggesting that many non-clinician patients remain unseen or undiagnosed. Therefore, we hypothesised that there is a hamstring injury blind spot, meaning that this injury may be heavily underdiagnosed due to poor awareness. The overrepresentation of medical professionals is a reflection of this blind spot as it could indicate a selection phenomenon in which an overlooked diagnosis or misdiagnosis is less likely in clinicians. After all, clinicians have been known to demonstrate different illness behaviour due to their knowledge of the human body and medical system, resulting in deviation from regular care pathways[75]. This could improve their chances of an (early) imaging-confirmed diagnosis.

The consequences

Missing a proximal hamstring tendon avulsion could have serious consequences, as poor clinical outcome has been reported if it is left untreated[44]. The current body of evidence, despite its limitations, indicates that surgical intervention yields better subjective and functional outcomes than a non-operative approach and thus surgical consultation should be considered. Moreover, a delayed diagnosis can also affect chances of a good outcome, since delayed intervention (i.e. later than 4[50] or 8[51] weeks after injury) is reported to result in inferior outcome, and is considered to be more difficult for the surgeon[46]. In addition, even if the patient and the doctor were to make a shared decision in favour of conservative treatment, an adequate conservative treatment protocol would be expected to produce favourable results compared with a missed diagnosis[51].

Clinical picture and pitfalls

The potential consequences of a missed or delayed diagnosis underline the need for a high level of suspicion of proximal hamstring tendon avulsion when certain clinical clues are present (box 1). If clinical evaluation is suggestive of a proximal tendon avulsion or leaves room for any doubt, imaging by means of ultrasound or MRI should be performed to confirm or rule out tendon avulsion injury.

Box 1 Key clinical features

Typical clinical findings in proximal hamstring tendon avulsion injury

- Trauma mechanism involves forced hip flexion combined with knee extension.
- Tearing or popping sensation.
- Severe pain, sitting is painful.
- Severe loss of function, walking is difficult.
- Extensive posterior thigh bruising appears within days (figure 2).
- Pain on palpation of ischial tuberosity and over the area of bruising.
- Palpable loss of bone-tendon continuity during resisted knee flexion.

Pitfalls

- Trauma mechanism occasionally involves hip abduction rather than hip flexion.
- Bruising can be subtle (figure 2) or even absent.
- Loss of function (knee flexion) may not be complete, as it can be masked by intact gastrocnemius muscle function.
- Range of motion (straight leg raise and active knee extension test) may be full or even more than the contralateral leg.

Main differences with acute hamstring strain injury

- Trauma mechanism often involves high-speed sprinting.
- Mild loss of function.
- Bruising is limited if present.
- Pain on palpation of muscle belly.
- Range of motion is reduced.

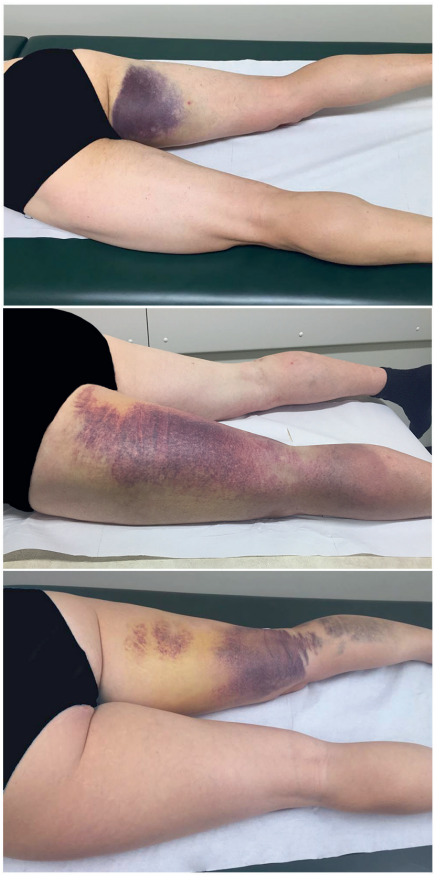

Figure 2. Posterior thigh bruising in three patients presenting at 2 (top), 8 (middle) and 10 (bottom) days after injury. At 2+ weeks after injury, the bruising may be located exclusively around the back of the knee.

Conclusion

Proximal hamstring tendon avulsions are serious hamstring injuries that result in an unfavourable outcome when the diagnosis is missed or delayed. Our anecdotal observation could indicate that this injury is underdiagnosed. The aim of this letter is to improve clinical awareness of proximal hamstring tendon avulsions and to encourage clinicians to maintain a high level of suspicion in combination with a low threshold for the use of imaging when clinical evaluation is suggestive or leaves room for any doubt. We ask the readers of the *British Journal of Sports Medicine* to help enhance awareness by informing peers and referrers about this potential blind spot.

04 OUTCOME AFTER SURGICAL REPAIR OF PROXIMAL HAMSTRING AVULSIONS: A SYSTEMATIC REVIEW

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Abstract

Background: At the present time, no systematic review, including a quality assessment, has been published about the outcome after proximal hamstring avulsion repair.

Purpose: To determine the outcome after surgical repair of proximal hamstring avulsions, to compare the outcome after acute (≤4 weeks) and delayed repairs (>4 weeks), and to compare the outcome after different surgical techniques.

Study Design: Systematic review and best-evidence synthesis.

Methods: PubMed, CINAHL, SPORTdiscus, Cochrane library, EMBASE, and Web of Science were searched (up to December 2013) for eligible studies. Two authors screened the search results separately, while quality assessment was performed by 2 authors independently using the Physiotherapy Evidence Database (PEDro) scale. A best-evidence synthesis was subsequently used.

Results: Thirteen studies (387 participants) were included in this review. There were no studies with control groups of non-operatively treated proximal hamstring avulsions. All studies had a low methodological quality. After surgical repair of proximal hamstring avulsion, 76% to 100% returned to sports, 55% to 100% returned to pre-injury activity level, and 88% to 100% were satisfied with surgery. Mean hamstring strength varied between reporting studies (78%-101%), and hamstring endurance and flexibility were fully restored compared with the unaffected side. Symptoms of residual pain were reported by 8% to 61%, and reported risk of major complications was low (3% rerupture rate). No to minimal difference in outcome was found between acute and delayed repair in terms of return to sports, patient satisfaction, hamstring strength, and pain. Achilles allograft reconstruction and primary repair with suture anchors led to comparable results.

Conclusion: The quality of studies included is low. Surgical repair of proximal hamstring avulsions appears to result in a subjective highly satisfying outcome. However, decreased strength, residual pain, and decreased activity level were reported by a relevant number of patients. Minimal to no differences in outcome of acute and delayed repairs were found. Limited evidence suggests that an Achilles allograft reconstruction yields results comparable with primary repair in delayed cases where primary repair is not possible. High-level studies are required to confirm these findings.

Introduction

Hamstring avulsions account for 3% to 11% of all hamstring injuries in predominantly elite athletic populations[17,22]. Both athletes and middle-aged individuals are affected by proximal hamstring avulsions[47], typically during sports participation or slip and fall accidents with forced hip hyperflexion and ipsilateral knee extension, as well as forced eccentric contraction of the hamstring muscle complex[68,76–84]. Significant functional impairment can result from these injuries, and this can be career threatening for athletes[66,68,77,85–87]. There is a lack of consensus on indication and timing of surgery. Some authors state that surgical treatment should be reserved for displaced bony avulsions, proximal tendinous avulsions involving all 3 tendons, proximal 2-tendon avulsions with retraction of >2 cm, or persisting pain[47,68,88,89]. When it comes to timing of surgery, delayed surgical repair (>4 weeks) is generally considered more challenging[43,84,90,91], while it is suggested that the outcome may be less favourable compared with acute repair (≤4 weeks). Timely assessment (preferably within 2 days after trauma[92]) has been proposed to prevent delay in diagnosis and treatment.

After surgery, range of motion in hip and knee is restricted for about 4 to 6 weeks followed by a phased progressive rehabilitation program that varies considerably between reports. Generally, the rehabilitation programs start with range of motion exercises and gait training, followed by progressive hamstring and core-strengthening exercises. Finally, sport-specific exercises are included before return to (athletic) activities[66,68,76–79,81,82,93].

Non-operative management of proximal hamstring avulsions mainly comprises rest, icing, and exercises with a gradual return to (athletic) activities[47] and appears to lead to conflicting results. Sallay et al.[44] presented 12 cases, of which 58% returned to sports at a lower level, while Malliaropoulos et al.[94] presented 11 high-level athletes with a 100% return to sports rate.

An interesting systematic review in 2011[50] concluded that surgical treatment of proximal hamstring avulsions is preferred over non-operative treatment in terms of subjective clinical outcomes, strength, endurance, and return to sports. The authors reported a return to sports rate at pre-injury level of 79% (236/298), 82% in the surgical repair group (234/284), compared with 14% in the non-operatively treated group (2/14). They concluded that acute surgical repair leads to superior results compared with delayed repair in terms of subjective clinical outcomes, strength, endurance, return to sports at pre-injury level (96% vs 75%), and risk of major complications and rerupture. However, this review did not involve any quality assessment of the studies included, and therefore there is a risk of bias.

The main purpose of this review was (1) to determine the outcome after surgical repair of proximal hamstring avulsions, (2) to compare the outcome of acute (≤4 weeks) and delayed (>4 weeks) repair, and (3) to compare the outcome of different surgical techniques. We hypothesized that (1) surgical repair of proximal hamstring avulsions leads to high patient satisfaction and allows for return to sports at the pre-injury level with good recovery of hamstring function, acute repair does better than delayed repair since the latter is considered more technically challenging, and (3) alternative surgical repair techniques yield less satisfactory results since they are required in more complex cases.

Materials and methods

Search strategy

A systematic literature search was performed up to December 2013 in the databases of Medline via PubMed, CINAHL via EBSCOhost, SPORTdiscus via EBSCOhost, Cochrane Library, EMBASE via OvidSP, and Web of Science. Two keywords (hamstring and avulsion) and related synonyms were used. Within each keyword category, the different synonyms were combined using the Boolean command OR, and categories were linked with the Boolean command AND (online supplementary appendix).

Eligibility criteria

Original articles were included if (1) diagnosis of a proximal avulsion of the biceps femoris, semimembranosus, or semitendinosus muscle or a combination of either was confirmed by magnetic resonance imaging (MRI) or ultrasound; (2) the therapeutic approach was well described; and (3) full texts were available in English or Dutch. Case reports, imaging reviews, anatomic/histologic studies, surgical technique reports, animal studies, studies with less than a mean 12 months of follow-up, studies with fewer than 5 participants, and studies reporting outcomes other than clinical endpoints were excluded.

Study selection

Two reviewers (A.D.M. and G.R.) independently assessed potential eligible studies identified by the search strategy. Titles and abstracts were assessed by applying the eligibility criteria, and full texts of potentially relevant studies were subsequently obtained. If the title and abstract did not provide sufficient information to determine whether eligibility criteria were met, the study was included for full-text selection. The full texts were read independently by the 2 reviewers and assessed for eligibility. If no consensus was reached, a third author (G.M.K.) was available to make the final decision regarding eligibility but was eventually not necessary. We performed additional citation tracking by screening the reference lists of the eligible studies.

Data extraction

Data from the original articles were extracted using a standardized extraction form, including study design, number of participants, mean age, mean duration of follow-up, timing of surgery, surgical method of reattachment, postoperative program, surgical outcome, and complications. Whenever outcome was reported for more than one point in time during follow-up, values of the last recorded follow-up were used.

Quality assessment

Quality assessment of the included studies was performed by 2 authors independently (V.G. and J.L.T.) using the Physiotherapy Evidence Database (PEDro) scale (Table 1)[95,96]. If no consensus was reached, the independent opinion of a third reviewer (A.D.M.) was decisive. The PEDro scale scores 11 items (eligibility criteria, random allocation, concealed allocation, similarity at baseline, participant blinding, therapist blinding, assessor blinding, >85% follow-up for at least 1 key outcome, intention-to-treat analysis, between-group statistical comparison for at least 1 key outcome, and point and variability measures for at least 1 key outcome) as either present or absent. The final score is the number of positive answers on

questions 2 to 11. The first statement relates to the external validity of the study and is not considered in the final quality score. The PEDro scale has been validated[95], and its reliability is rated fair to good[96]. We considered a PEDro score of ≥6 to represent a high-quality study and a score of ≤5 a low-quality study[97].

Table 1. Physiotherapy Evidence Database (PEDro) scale.

	Item PEDro scale
1	Eligibility criteria were specified
2	Subjects were randomly allocated to groups
3	Allocation was concealed
4	The groups were similar at baseline regarding the most important prognostic indicators
5	There was blinding of all subjects
6	There was blinding off all therapists who administered the therapy
7	There was blinding of all assessors who measured at least one key outcome
8	Measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups
9	All subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analysed by "intention-to-treat"
10	The results of between-group statistical comparisons are reported for at least one key outcome
11	The study provides both point measures and measures of variability for at least one key outcome

Best-evidence synthesis

Because of the heterogeneity of outcome measures, a best-evidence synthesis[98] was used instead of a meta-analysis. The results of the quality assessments of the individual studies were used to classify the level of evidence[99]. This qualitative analysis was performed with 5 levels of evidence based on the quality and results of the included studies:

Strong evidence: provided by 2 or more high-quality studies and by generally consistent findings in all studies (≥75% of the studies reported consistent findings)

Moderate evidence: provided by 1 high-quality study and/or 2 or more low-quality studies and by generally consistent findings in all studies (≥75% of the studies reported consistent findings)

Limited evidence: provided by only 1 low-quality study

Conflicting evidence: inconsistent findings in multiple studies (≥75% of the studies reported consistent findings)

No evidence: when no studies could be found

Results

References

The literature search in the selected databases yielded 2192 records. After deleting duplicates and applying the eligibility criteria to the titles and abstracts, 25 potentially relevant studies were included for the full-text review. Full-text articles were subsequently

obtained and eligibility criteria were applied, leading to the inclusion of 13 original studies (Figure 1)[66,68,76–84,93,100]. Citation tracking did not add any studies.

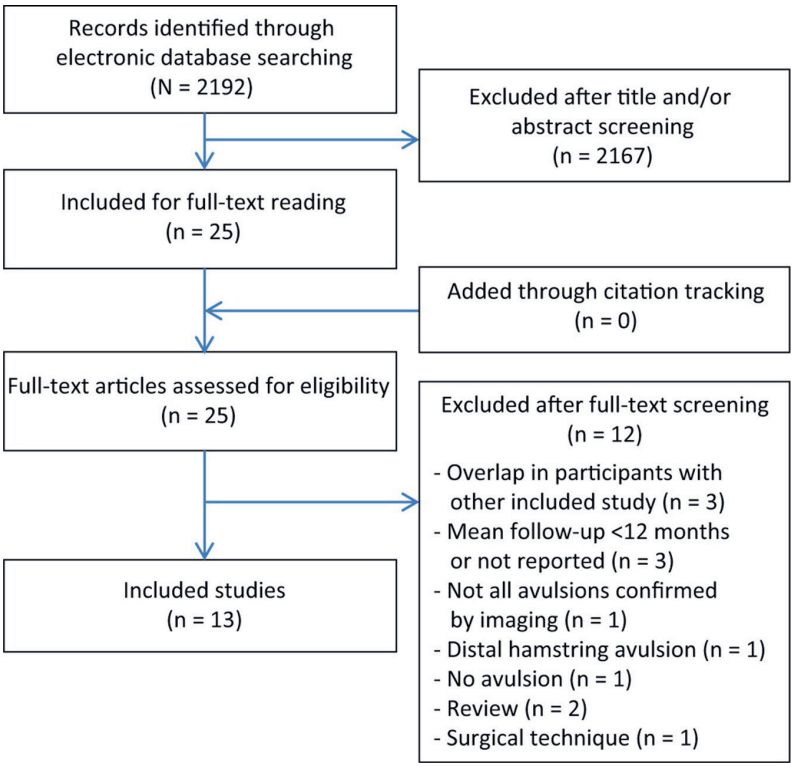

Figure 1. Flowchart of study selection.

Quality assessment

The quality assessment scores of the studies included are shown in Table 2. All included studies were scored as low-quality, which was mainly attributable to the lack of randomization and controls.

Table 2. Quality assessment (PEDro Scale) of the included studies.

Study	Item PEDro scale											Total score
	1	2	3	4	5	6	7	8	9	10	11	
Birmingham (2011)[93]	+	-	-	-	-	-	-	-	+	+	+	3/10
Brucker (2005)[66]	-	-	-	-	-	-	-	+	+	+	+	4/10
Chahal (2012)[76]	+	-	-	-	-	-	-	+	+	+	+	4/10
Cohen (2012)[68]	-	-	-	-	-	-	-	-	+	-	+	2/10
Folsom (2008)[77]	-	-	-	-	-	-	-	+	+	-	+	3/10
Konan (2010)[78]	-	-	-	-	-	-	-	+	+	-	+	3/10
Lefevre (2012)[79]	+	-	-	-	-	-	-	+	+	-	+	3/10
Lempainen (2006)[80]	+	-	-	-	-	-	-	+	+	-	+	3/10
Mica (2009)[81]	-	-	-	-	-	-	-	+	+	-	-	2/10
Sallay (2008)[82]	+	-	-	-	-	-	-	+	+	-	+	3/10
Sarimo (2008)[83]	-	-	-	-	-	-	-	+	+	-	-	2/10
Skaara (2013)[100]	+	-	-	-	-	-	-	+	+	+	+	4/10
Wood (2008)[84]	+	-	-	-	-	-	-	+	+	-	+	3/10
Mean												3/10±0.7

PEDro, Physiotherapy Evidence Database.

Outcome after surgical repair

The 13 original studies retrieved from our systematic search with a total of 387 participants (235 male, 152 female) involved 11 case series (8 retrospective[68,76,80–83,93,100], 1 prospective[78], 2 not further specified[66,84]), 1 cohort study[77], and 1 case-control study[79] that were conducted among different study populations and included different outcome measures (questionnaire, patient satisfaction, pain, functional outcome scales, imaging, return to sports, return to pre-injury activity level, hamstring flexibility, strength and endurance). There were no studies with control groups of non-operatively treated proximal hamstring avulsions. The outcome measures and characteristics of the included studies are shown in Table 3. Table 4 shows the best-evidence synthesis.

Table 3. Study characteristics.

Study	Study design (mean duration of follow-up)	Participants, n (acute/delayed repair), mean age, sex, and type of athlete	Surgical technique
Birmingham et al. (2011)[93]	Retrospective case series (43 mo)	N = 23 (9/14); age = 46 y; sex = 15 M/8 F; type = NR	Reattachment with suture anchors
Brucker and Imhoff (2005)[66]	Case series (33 mo)	N = 8 (6/2); age = 40 y; sex = 6 M/2 F; type = 1 elite athlete, 7 recreational athletes	Reattachment with suture anchors
Chahal et al. (2012)[76]	Retrospective case series (37 mo)	N = 13 (NR); age = 45 y; sex = 8 M/5 F; type = 1 elite athlete, 10 recreational athletes	Reattachment with suture anchors
Cohen et al. (2012)[68]	Retrospective case series (33 mo)	N = 52 (40/12); age = 48 y; sex = 26 M/26 F; type = 1 elite athlete, recreational athletes	Reattachment with suture anchors
Folsom and Larson (2008)[77]	Cohort study (20 mo)	N = 26 (21/5) (1 lost to follow-up); age = 44 y; sex = 12 M/14 F; type = 2 elite athletes, 6 high-level recreational athletes, 17 recreational athletes	Reattachment with suture anchors (21 acute, 1 delayed); Achilles tendon allograft reconstruction (4 delayed)
Konan and Haddad (2010)[78]	Prospective case series (12 mo)	N = 10 (9/1); age = 29 y; sex = 8 M/2 F; type = 10 (semi)professional athletes	Reattachment with suture anchors
Lefevre et al. (2013)[79]	Case-control study (27 mo)	N = 34 (34/0); age = 39 y; sex = 25 M/9 F; type = 3 elite athletes, 12 competitive athletes, 17 recreational athletes	Reattachment with suture anchors
Lempainen et al. (2006)[80]	Retrospective case series (36 mo)	N = 47 (5/42); age = 33 y; sex = 32 M/15 F; type = 13 elite athletes, 15 competitive athletes, 19 recreational athletes	Reattachment with suture anchors (43); reattachment directly to periosteal bone/ proximal tendon stump (5)
Mica et al. (2009)[81]	Retrospective case series (32 mo)	N = 6 (6/0); age = 59 y; sex = 3 M/3 F; type = middle-aged and elderly patients	Reattachment with suture anchors
Sallay et al. (2008)[82]	Retrospective case series (53 mo)	N = 25 (18/7); age = 44 y; sex = 13 M/12 F; type = NR	Reattachment with suture anchors
Sarimo et al. (2008)[83]	Retrospective case series (37 mo)	N = 41 (14/27); age = 46 y; sex = 21 M/20 F; type = 2 competitive athletes, 27 recreational athletes	Reattachment with suture anchors (14 acute, 26 delayed); iliotibial tract autograft reconstruction (1 delayed)
Skaara et al. (2013)[100]	Retrospective case series (30 mo)	N = 31 (28/3); age = 51 y; sex = 16 M/15 F; type = 5 competitive athletes, 26 recreational athletes	Reattachment with suture anchors
Wood et al. (2008)[84]	Case series (24 mo)	N = 71 (NR); age = 40 y; sex = 50 M/21 F; type = 7 elite athletes	Reattachment with suture anchors

F: female, HHS: Harris hip score, H/Q: hamstring-to-quadriceps ratio, LEFS: Lower Extremity Functional Scale, M: male, MAS: Marx activity scale, MRI: magnetic resonance imaging, NR: not reported, ROM: range of motion, RTPA: return to pre-injury activity level, RTS: return to sports, SANE: Single Assessment Numeric Evaluation, TAS: Tegner activity scale, UCLA score: University of California at Los Angeles 10-point scale, VAS: visual analogue scale. A = D indicates no statistically significant difference between acute and delayed repair, R = L indicates no statistically significant difference vs. contralateral leg.

Outcome measure and outcome
Subjective questionnaire: Results excellent in 18 cases, good in 4, and fair in 1 RTS: 21/23 Pain: 14/23 pain with prolonged sitting, 4/23 pain during activity Hamstring strength: Manual: 5/5 hamstring and quadriceps strength bilaterally; isokinetic: R = L, A = D; H/Q: R = L, A = D Endurance: R = L
Patient satisfaction: 8/8 satisfied RTPA: Acute: 5/6; delayed: 2/2 Hamstring flexibility: R = L Hamstring strength: Isokinetic: R = L, A = D
Patient satisfaction: 13/13 extremely satisfied (SANE) RTS: 11/11 RTPA: 6/11 Pain: Mean VAS, 1.3 ± 1.9 (range, 0-5) LEFS: Mean, 75 ± 7.8 (range, 59-80) HHS: Mean, 91 ± 14 (range, 67-100) Hamstring strength: Isokinetic: 78% ± 6.1% (range, 74%-88%) of contralateral limb Hamstring flexibility: R = L MRI examination (12/13): 12/12 successful reattachment; 5/12 grade 0 atrophy, 5/12 grade 1 atrophy, 2/12 grade 2 atrophy of hamstring muscles of the affected leg TAS: No significant difference between preoperative and postoperative situation
Patient satisfaction: 51/52 satisfied RTS: 23/23 (7/23 return to other sports) Pain: 48% pain with prolonged sitting LEFS: Mean, 75 (range, 50-80; A = D) MAS: Mean, 10 (range, 1-16; A = D)
Patient satisfaction: Acute: 19/20 satisfied; delayed: 5/5 satisfied RTS: Acute: 15/20; delayed: 4/5 Pain: No daily pain in 80%, A = D Hamstring strength: Isokinetic: A = D; H/Q: A = D Hamstring flexibility: Symmetric ROM of hips and knees, A = D
Patient satisfaction: 10/10 satisfied RTS: 9/10 Hamstring strength: Peak torque 83% vs contralateral side (range, 47%-118%)
Patient satisfaction: 26/34 very satisfied, 4 satisfied, and 4 moderately satisfied RTS: 32/32 RTPA: 27/32 Pain: 3/34 mild pain with prolonged sitting UCLA score: 9.1 ± 1.3 before injury and 8.7 ± 1.7 at final follow-up (significant difference) TAS: 6/10 (range, 4-10) before injury and 6/10 (range, 3-10) at final follow-up Hamstring strength: Isokinetic: mean 93% ± 18% (90 deg/s), 94% ± 16% (180 deg/s), and 101% ± 13% (240 deg/s) vs contralateral limb MRI examination: Tendon healed in 34/34
Functional result (based on residual symptoms and level of activity): Results excellent in 33/48 cases, good in 9/48, fair in 4/48, and poor in 2/48 RTPA: 41/47
RTPA: 6/6 HHS: Mean, 97 (range, 86-100, R = L, no difference vs status before injury) MRI examination: Tendon healed in 6/6
Patient satisfaction: 25/25 satisfied Pain: 92% of patients had no to minimal daily pain Hamstring strength: Isokinetic: 98% strength return at >12 mo (range, 72%-176%)
Functional result (based on residual symptoms and level of activity): Results excellent in 19/41, good in 10/41, moderate in 5/41, and poor in 7/41. Good to excellent results had a mean delay of 2.4 mo. Poor to moderate results had a mean delay of 12 mo. Significant difference in results between a 0- to 3-mo delay and 3- to 6-mo and >6-mo delay. No significant difference between a 3- to 6-mo and >6-mo delay RTPA: 22/29
Patient satisfaction: 29/31 satisfied RTPA: 18/31 Pain: 39% pain/limitations during activity LEFS: 71 6 10 (range, 47-80) Hamstring strength: Significant difference in peak torque vs contralateral limb
RTPA: 57/71 RTPA Hamstring strength: 84% isotonic strength vs contralateral side (range, 43%-122%). Significant difference in strength between acute (<3 mo) and chronic in case of retraction Endurance: 89% isotonic endurance vs contralateral side (range, 26%-161%). Significant difference in endurance between acute (<3 mo) and chronic in case of retraction

Table 4. Best-evidence synthesis for timing and technique of surgery.

	Outcome measure	high quality (study)	low quality (Study)	Best-evidence synthesis
Timing of surgery	Patient satisfaction		=[66,77]*	Moderate
A: Acute repair (≤4 weeks)	Pain		=[77]	Limited
D: Delayed repair (>4 weeks)	Return to sports		d[66,77]*	Moderate
	Hamstring flexibility		=[77]	Limited
	Hamstring strength		=[66,77,93]	Moderate
	Hamstring-to-quadriceps-ratio		=[77,93]	Moderate
	LEFS		=[68]	Limited
	Marx activity scale		=[68]	Limited
Surgical technique	Patient satisfaction		=[77]*	Limited
R: Achilles tendon allograft reconstruction	Return to sports		=[77]*	Limited
P: Primary repair with suture anchors	Pain		=[77]	Limited
	Hamstring flexibility		=[77]	Limited
	Hamstring strength		=[77]	Limited
	Hamstring-to-quadriceps ratio		=[77]	Limited

LEFS: Lower Extremity Functional Scale.

Effect of the intervention: '=': outcome does not differ between A and D or between R and P, 'd': outcome favours delayed repair, *not statistically tested.

Moderate evidence: provided by 1 high-quality study and/or 2 or more low-quality studies and by generally consistent findings in all studies (≥75% of the studies reported consistent findings), Limited evidence: provided by only 1 low-quality study.

- Return to sports

Six studies (124 participants) reported the return to sports rate as an outcome measure[68,76–79,93]. Surgical repair resulted in a return to sports rate of 76% to 100% (Figure 2). This group includes elite athletes[68,76,77,79], 10 (semi)professional athletes[78], 12 athletes who participated in competitive sports, and 6 high-level recreational athletes (sports participation 3times/wk). The remaining athletes were recreational. In this group, 3 of 4 (75%) elite athletes[68,76,77] were able to return to pre-injury level. Lefevre et al.[79] pooled the elite and competitive athletes and reported that 12 of 15 (80%) returned to sports at the same level. Konan and Haddad[78] pooled the semi-professional and professional athletes, of whom 9 of 10 (90%) returned to sports. The athlete who did not return to sports did so as a personal choice.

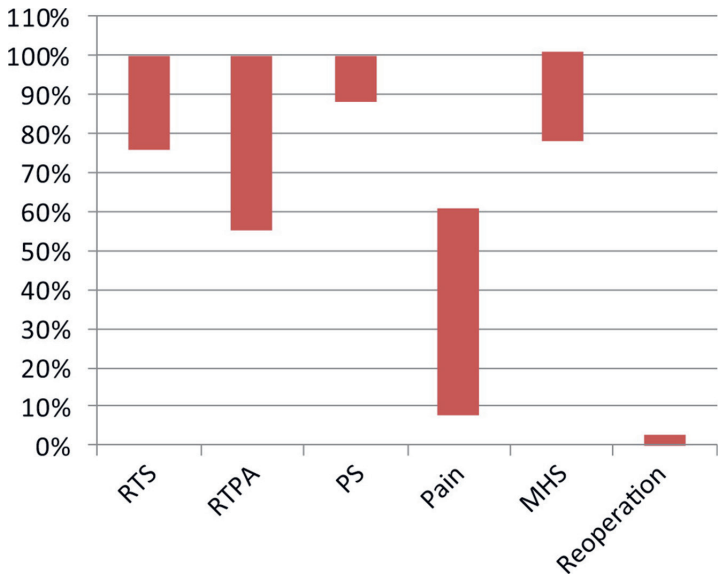

Figure 2. Reported outcome measures (range in %) after surgical repair of proximal hamstring avulsion. MHS: mean hamstring strength, PS: patient satisfaction, RTPA: return to pre-injury activity level, RTS: return to sports.

- Level of activity

Eight studies (235 participants) reported the return to a pre-injury activity level rate as an outcome measure[66,76,79–81,83,84,100]. This was either level of activity in their field of sports or activities of daily life. Surgical repair resulted in a return to a pre-injury activity level rate of 55% to 100% (Figure 2). Eighteen of 22 (82%) elite athletes in this group were able to return at a pre-injury level at a minimal follow-up of 6 months[66,76,80,84].

Tegner activity scale scores (range 0-10, where a higher score indicates a higher activity level) before injury (6; range, 4-10) and after recovery (6; range, 3-10) were equivalent, as reported by Lefevre et al.[79] Similarly, Chahal et al.[76] used this scale to assess level of activity after injury and after recovery and found equivalent scores.

Cohen et al.[68] used the Marx activity scale score (range 0-16, where a higher score indicates a higher activity level) and reported an average of 10 (range, 1-16). Using a custom version of this scale, they reported maximum scores (score of 20) in the acute group and 19

(range, 12-20) in the delayed group. Lefevre et al.[79] reported a University of California at Los Angeles activity scale (range 1-10, where a higher score indicates a higher activity level) score of 9.1 ± 1.3 before injury and 8.7 ± 1.7 at final follow-up (P = .03).

- Patient satisfaction

Eight studies (198 participants) reported patient satisfaction[66,68,76–79,82,100]. Good-to-excellent patient satisfaction ranged from 88% to 100% (Figure 2). Birmingham et al.[93] used a subjective questionnaire to evaluate patient satisfaction and rated the results excellent in 18 cases (78%), good in 4 (17%), and fair in 1 (4%). Using the Single Assessment Numeric Evaluation, Chahal et al.[76] concluded that all patients (13/13) were extremely satisfied with the surgery performed.

- Pain

Seven studies (203 participants) used pain as an outcome measure[68,76,77,79,82,93,100]. Residual symptoms of pain were reported by 8% to 61% of patients (Figure 2). We included reports of daily pain (8%-20%)[77,82], pain during activity (17%-39%)[93,100], or pain with prolonged sitting (9%-61%)[68,79,93]. Chahal et al.[76] reported a mean visual analogue scale score (range 0-10, where a higher score indicates more pain) of 1.3 ± 1.9 (range, 0-5), which was classified as minimal to no pain.

- Functional outcome scales

Sarimo et al.[83] used a grading system based on residual symptoms and level of activity to grade the outcome of surgery. Of 41 cases, results were excellent in 19 (46%), good in 10 (24%), moderate in 5 (12%), and poor in 7 (17%). Similarly, in 48 cases, Lempainen et al.[80] achieved excellent results in 33 cases (69%), good in 9 (19%), fair in 4 (8%), and poor in 2 (4%).

Chahal et al.[76], Cohen et al.[68], and Skaara et al.[100] reported high scores on the Lower Extremity Functional Scale (LEFS; range, 0-80, where a higher score indicates less functional impairment): 75 ± 7.8 (range, 59-80), 75 (range, 50-80), and 71 ± 10 (range, 47-80), respectively. A custom version of this scale was used by Cohen et al.[68], who reported separate scores for their acute and delayed group: 71 (range, 48-80) and 71 (range, 47-80), respectively.

Chahal et al.[76] and Mica et al.[81] reported high scores on the Harris hip score (range 0-100, where a higher score indicates less functional impairment, deformity, and pain): 91 ± 14 (range, 67-100) and 97 (range, 86-100), respectively.

- Strength testing

Nine studies reported hamstring strength measurements[66,76–79,82,84,93,100]. Mean isokinetic strength return ranged from 78% to 101% compared with the unaffected side[66,76–79,82,93,100] (Figure 2). Birmingham et al.[93] reported no significant difference in isokinetic hamstring strength or endurance of the operated leg compared with the contralateral leg. Lefevre et al.[79] and Sallay et al.[82] reported near-equivalent isokinetic hamstring strength, while Brucker et al.[66] and Konan et al.[78] reported a deficit in peak torque, with hamstring strength of 88% (not statistically significant) and 83%, respectively. Chahal et al.[76] found isokinetic hamstring strength of 78%, and Skaara et al.[100] reported significant difference in peak torque (84%) compared with the contralateral leg. Wood et al.[84] reported mean isotonic

hamstring strength of 84% and mean hamstring endurance of 89% compared with the contralateral leg.

Hamstring-to-quadriceps ratio[93] and hamstring flexibility[66,76,77] did not differ significantly when compared with the contralateral leg.

- MRI examination

Three studies[76,79,81] showed healing of the reattached tendons in all 52 participants (at a follow-up of at least 6 months[79], a mean of 36 months[76], and 32 months[81]). There were 5 cases in which grade 1 atrophy of the hamstring muscles of the affected leg was found on MRI, 2 cases with grade 2 atrophy, and 3 cases with mild tendinopathy[76].

- Complications

Several postoperative complications were reported. In a total of 387 participants, reoperation was needed in 10 cases (3%)[66,77,80,83,84] (Figure 2). There were 3 cases with a deep vein thrombosis (1%)[68,82,83]. Eleven patients had a wound infection (3%; 1 deep infection[77] and 10 superficial infections[77,80,83,84,100]). There was mention of evacuation/drainage of 1 postoperative hematoma[79], 1 seroma[83], and 1 patient with hypertrophic scarring[80]. Stiffness of the operated leg was reported in 12 patients (3%)[76,82]. Symptoms of numbness/tingling in the incisional area were reported in 34 patients (9%)[68,93], in the posterior thigh and below the knee in 30 patients (8%)[68,76,78,83,93,100], and in the affected leg (area not specified) in 2 patients (1%)[82]. Symptoms of sciatica were reported in 5 patients (1%)[84,93]. One patient developed complex regional pain syndrome, with severe pains and muscle spasms[77].

Outcome after acute and delayed repair

Six studies made a distinction between acute and delayed repair[66,68,77,83,84,93] (Table 4). Acute repair was defined as surgical treatment ≤4 weeks after injury. Delayed repair was defined as surgical treatment >4 weeks after injury.

- Return to sports

Only 2 studies mentioned the return to sports (RTS) rate separately for acute and delayed repairs[66,77]. In the acute repair group, 75% to 83% of patients returned to sports versus 80% to 100% in the delayed repair group. Of the 3 elite athletes[66,77], 2 (67%; 1 acute and 1 chronic repair) were able to return to sports at their previous level after a full recovery[77].

- Patient satisfaction

The only study that made a distinction between patient satisfaction of the acute and delayed repair group was that of Folsom and Larson[77]. In this study, 19 of 20 (95%) patients in the acute repair group were satisfied with the performed surgery versus 5 of 5 (100%) patients in the delayed repair group. However, although Brucker and Imhoff[66] did not distinguish between patient satisfaction of the acute and delayed group, all patients were satisfied, implying no difference between acute and delayed surgery groups.

- Pain

Residual symptoms of pain were identical for patients in both the acute (20%) and delayed repair (20%) groups[77].

- Functional outcome scales

The LEFS and Marx activity scale scores were compared between acute and delayed repair groups[68]. Comparing the acute repair group with the delayed repair group, the LEFS scores averaged 76 (range, 62-80) and 72 (range, 50-80) (P = .2), respectively, and Marx activity scale scores averaged 10 (range, 1-16) and 10 (range, 2-16) (P = .6). Thus, no significant difference was found between acute and delayed repair. On the other hand, results on the custom Marx scale designed by the authors to be more hamstring specific were significantly higher in the acute repair group (20 for all participants) than in the delayed repair group (19; range, 12-20) (P =.001). Their mean custom LEFS score was not significantly different between the acute repair group (71; range, 48-80) and the delayed repair group (71; range, 47-80) (P = .7). In the study by Sarimo et al.[83], a 4-category system based on residual symptoms and postinjury level of activity was used to evaluate the results of surgical treatment. Unfortunately, this study did not use the same definition of acute and delayed surgery as we did but divided patients into 3 groups: 0- to 3-month delay from injury to surgery, 3- to 6-month delay, and >6-month delay. They found that patients with good to excellent results had shorter delays to surgery (mean, 2.4 months) than did patients with moderate to poor results (mean, 12 months) (P < .001). They reported a significant difference in results between the 0- to 3-month delay group and the 3- to 6-month (P = .004) and >6-month (P = .009) delay groups. No significant differences were found between the 3- to 6-month delay group and the >6-month delay group.

- Strength testing

Hamstring muscle strength was compared between the acute and delayed repair group in 4 studies[66,77,84,93]. No significant difference was found in isokinetic hamstring strength between acute and delayed repair[66,77,93]. Folsom and Larson[77] reported mean hamstring strength deficits of 17% (concentric 60 deg/s) and 12% (concentric 180 deg/s) in the acute repair group and deficits of 21% (concentric 60 deg/s) and 2% (concentric 180 deg/s) in the delayed repair group (P = .3). Birmingham et al.[93] and Brucker et al.[66] did not report separate data for acute and delayed repair groups. The difference in isotonic hamstring strength (91% 6 4.8% vs 77% 6 5.7%, P = .009) and endurance (100% 6 8.5% vs 80% 6 13, P = .04) between acute and delayed repair (<3 or ≥3 months in this study) was significant only in cases of complete avulsion with retraction[84].

- Complications

Three studies reported (some of the) complications separately for acute and delayed repairs[68,77,93]. Cohen et al.[68] reported ''neuralgia'' symptoms in 45% in the acute group and 58% in the delayed group. Birmingham et al.[93] reported that all patients with symptoms of sciatica underwent delayed repair. Conversely, all complications reported by Folsom and Larson[77] occurred in the acute repair group (1 reoperation, 1 complex regional pain syndrome, 1 deep infection, and 5 superficial infections).

Outcome after repair with alternative surgical techniques

All studies treated most if not all avulsions with the use of suture anchors. Only 3 studies used an alternative technique[77,80,83] (Table 4). These included direct reattachment of the tendon stump to the proximal tendon stump[80], an iliotibial tract autograft reconstruction[83], and an

Achilles tendon allograft reconstruction[77] to either augment the reconstruction or span a defect that made primary repair impossible. In the studies by Sarimo et al.[83] and Lempainen et al.[80], no distinction was made between results of primary repair with suture anchors and the alternative technique. In the study by Folsom and Larson[77], 4 of 5 delayed repairs were performed with an Achilles tendon allograft reconstruction. In the delayed group, they reported 100% patient satisfaction and return to sports rate of 80%, comparable with acute repairs with suture anchors (95% patient satisfaction and 75% return to sports rate). There was no significant difference in hamstring flexibility, hamstring-to-quadriceps ratio, isokinetic strength, and reported pain of the acute repair group compared with the delayed repair group. Note that in this particular study, no clear distinction was made in the delayed repair group between results of the allograft reconstruction (4/5) and the delayed repair with suture anchors (1/5).

Discussion

This systematic review shows that all studies included are of low methodological quality. Acute and delayed surgical repair of proximal hamstring avulsions appears to result in a comparably subjective highly satisfying outcome. However, decreases in level of activity and strength, as well as symptoms of residual pain, are frequently reported. Limited evidence suggests that an Achilles allograft reconstruction yields comparable results to delayed primary repair in cases where primary repair is not possible.

Overview of surgical repair

A previous systematic review done by Harris et al.[50] reported a return to sports rate at a pre-injury level of 82% following surgical repair but did not report data concerning hamstring strength, patient satisfaction rates, and functional outcome scales, which prevents further comparison. For comparison, Sallay et al.[82] and Malliaropoulos et al.[94] reported return to sports rates after non-operative management of 58% and 100%, respectively. Studies included in our systematic review reported that surgical management of proximal hamstring avulsions leads to varying rates of return to sport (76%-100%) and return to pre-injury activity level (55%-100%), high scores on functional outcome scales, and high patient satisfaction (88%-100%). Reported mean hamstring muscle strength ranged from 78% to 101% compared with the unaffected side. Residual symptoms of pain during daily life, activity, or (prolonged) sitting were reported by 8% to 61%. Surgical complications such as rerupture and other major complications (deep vein thrombosis, wound infection, postoperative hematoma, and symptoms of stiffness or numbness/tingling) were uncommon.

This systematic review shows that high-quality studies are lacking. All studies scored ''no'' on points 2 to 7 of the PEDro scale.

We found no to minimal differences in outcome between acute and delayed repairs, with equal percentages of reported pain and even higher rates of return to sports and patient satisfaction in the delayed than in the acute repair group. Hamstring muscle strength was not significantly different between acute and delayed repairs[66,77,84,93], unless there was a significant degree of retraction[84]. Functional outcome scales were not significantly different for acute and delayed repairs except for the (non-validated) custom Marx Activity Scale[68], which was significantly higher for acute repairs. Sarimo et al.[83] used a non-validated

4-category system based on residual symptoms and postinjury level of activity and reported a significant difference in results between the 0- to 3-month delay and >3-month delay. There were relatively more cases of postoperative neuralgia and ''sciatica'' in the delayed repair groups[68,93], which, in the case of ''sciatica'' symptoms, is thought to be related to the increased difficulty of neurolysis in delayed repairs[93]. Conversely, all complications reported by Folsom and Larson[77] occurred after acute repairs. In contrast, in their systematic review, Harris et al.[50] reported that acute surgical repair leads to better results than delayed repair in terms of subjective clinical outcomes, strength, endurance, and return to sports at the pre-injury level. This difference may be attributable to differences in included studies, easily leading to different results due to the scarcity of comparative studies regarding the timing of surgery and small sample sizes. While only small outcome differences between acute and delayed repair are reported, there seems to be consensus that delayed repair is technically more challenging. This is probably caused by extensive scar tissue formation near the sciatic nerve[77,78,80,82–84,93], often requiring larger incisions, more dissection, and even fractional lengthening or reconstruction[77].

Overview of surgical technique

There is considerable variety in surgical techniques reported. The studies identified were used to create an overview of these variations. Patients undergoing surgery for a proximal hamstring avulsion are typically placed in a prone position. Most authors use a longitudinal incision starting at the gluteal crease, which is extended distally[77,79,80,83,85,86,93,101–106].

Some authors advocate a transverse incision in the gluteal crease for improved cosmetic results[68,76,90]. Yet others choose the type of incision based on the extent of the injury and the timing of surgery. Typically, a transverse incision is chosen, unless there is significant retraction or surgery is considered technically more challenging due to development of adhesions if surgery is delayed, in which case a longitudinal incision or a combination of a transverse and longitudinal incision is made for better exposure[43,66,67,78,82,87,91,100,101,107–109].

Since the sciatic nerve can become trapped in the adhesions that can develop in cases with delayed repair leading to sciatic symptoms, neurolysis may be required for symptom relief and to prevent iatrogenic injury during surgery[66,68,77–80,82,83,85–88,90,91,93,101–107,109–112].

Reattachment of the avulsed tendon should be performed at the correct anatomic site[8] and is mainly achieved by placement of suture anchors into a debrided ischial tuberosity to which the tendons are secured. Debridement of the ischial tuberosity (removing devitalized tissue) is performed to create a bleeding cancellous bed to augment healing. The number of anchors used as well as the configuration of the suture anchors in the bone varies. A few articles have described reattachment without suture anchors[80,85,86]. In some of these cases, the avulsed tendon was sutured directly to the proximal tendon stump.

Allografts (Achilles tendon) or autografts (such as fascia lata) can be used to augment a primary repair or to span a defect caused by chronic retraction of a tendon that prevents proper reattachment[77,90,103–105,107,111]. Alternatively, distal fractional lengthening is also reported to facilitate repair in these cases[82,87].

Endoscopic repair of hamstring avulsions also has been reported[113,114]. Two working portals are initially created in or near the gluteal crease. Additional portals can be added for anchor placement. The subgluteal space is cleared of scar tissue. Identification and mobilization of the sciatic nerve follow to protect it during the procedure. Neurolysis

is performed if necessary. Similar to open repair, the ischial tuberosity is debrided in preparation of reattachment with suture anchors.

Both the longitudinal and transverse incision mentioned above are also used in surgical treatment of bony avulsions[115–117]. However, some authors use a ''Kocher-Langenbeck-type'' approach[88,112,118] to provide visualization of the posterior acetabular column. The avulsed apophysis is cleared of fibrous tissue and consequently reduced and fixed with plates[112], (cancellous) screws[115–117], or both[88,118]. Bone graft may be used to augment the repair[88].

Three studies used alternative techniques (instead of primary repair with suture anchors) to achieve reattachment[77,80,83]. According to Folsom and Larson[77], 4 of 5 delayed repairs were performed with an Achilles allograft reconstruction, leading to good rates of patient satisfaction and return to sports, comparable with those in the acute repair group (all primary repairs with suture anchors). It is conceivable that an Achilles allograft reconstruction is a suitable alternative technique in (delayed) cases where a significant degree of retraction prevents anatomic reinsertion. However, further studies are required to be able to draw solid conclusions.

Limitations and strengths

The low quality of included studies is a major limitation. The quality assessment indicates substantial risk of selection bias due to lack of randomization and blinding in all included studies. Another major limitation is the use of non-validated questionnaires and grading systems. Although validated, it has been suggested that the Lower Extremity Functional Scale score[119] and the Harris hip score scale might not be effective as outcome measures for this type of injury due to unacceptably high ceiling effects.

Rather than a quantitative analysis (meta-analysis), we chose to perform a qualitative analysis because of the heterogeneity of outcome measures used, which can be considered a limitation. Also, there is great heterogeneity in study population (age, sex, level and type of sports), type of injury (partial or complete), outcome measures, rehabilitation programs, duration of follow-up, and variability in surgical technique. This may also be attributable to our search since we performed a sensitive search rather than further specify a study population and outcome measures. If results were reported for more than one point in time during follow-up, values of the last recorded follow-up were used, leading to considerable range in length of follow-up at which results were reported by the included studies. Unfortunately, studies comparing acute and delayed repair are scarce, which is even more so the case for alternative surgical techniques. With this paucity of available literature in mind, one must therefore be critical when drawing conclusions regarding timing of surgery or surgical techniques.

The strengths of this review are the thorough selection, in-depth analysis, and quality assessment of the included studies. Although the PEDro scale is a tool to assess the quality of randomized controlled trials, it particularly shows where the risk of bias lies. Rather than supporting the conclusion that acute surgical repair is undoubtedly indicated in case of a proximal hamstring avulsion, it stresses the need for further high-level comparative studies to give better insight in the indications for surgical repair and prognostic factors.

Future perspective

Outcome after non-operative management of proximal hamstring avulsions has not been well established. Although it has been associated with poor outcomes, especially in complete proximal avulsions[44], there are no comparative prospective (randomized) trials to confirm this.

Furthermore, non-operative management of partial and complete proximal avulsions has recently been reported to lead to acceptable results in high-level athletes[94]. Future high-level prospective studies are needed to accurately assess the outcome after both non-operative and surgical treatment of proximal hamstring avulsions. The PEDro scale revealed where the risk of bias lies in the included studies, and so future studies should at least include proper controls and randomization with blinding if feasible. Very few studies compare acute and delayed repairs, and even fewer studies compare surgical techniques. Therefore, the need for further high-level comparative studies also applies to timing of surgery and different surgical techniques.

Conclusion

The included studies report that surgical repair of proximal hamstring avulsions leads to a subjective highly satisfying outcome. However, it appears that both function (mean hamstring strength of 78%-101% compared with the contralateral leg) and level of activity are not fully restored in all cases (return to sports rate of 76%-100% and return to pre-injury activity level rate of 55%-100%). In addition, a relevant number of participants report symptoms of residual pain (8%-61%). We found minimal to no differences in outcome of acute and delayed repairs with equivalent satisfaction, pain, functional scale scores, and strength/flexibility. It appears that an Achilles allograft reconstruction is a suitable alternative to primary repair in delayed cases where primary repair is not possible. Evidence is limited to low-quality studies, and further high-level studies are needed to accurately assess outcome after surgical repair of proximal hamstring avulsions.

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PROXIMAL HAMSTRING TENDON AVULSION TREATMENT CHOICE DEPENDS ON A COMBINATION OF CLINICAL AND IMAGING-RELATED FACTORS: A WORLDWIDE SURVEY ON CURRENT CLINICAL PRACTICE AND DECISION-MAKING

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Abstract

Objectives: To evaluate current practice in the treatment of proximal hamstring tendon avulsions and identify decision-making preferences.

Methods: An invitation to an anonymous e-survey containing 32 questions was sent to 3475 members of the International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine (ISAKOS) and the European College of Sports and Exercise Physicians (ECOSEP).

Results: We received 403 (12%) unique responses with a completion rate of 79%. Participants were orthopaedic/ trauma surgeons (90%), sports medicine physicians (7%) or physical therapists (2%). For 83% of the participants, the preferred treatment (i.e. surgical or non-operative) depends on the individual case. Participants base their decision-making process on patient- and injury-related factors (decision modifiers). The five most frequently selected decision modifiers that support the choice for surgical treatment were diminished function (84%), neurological symptoms (74%), involved tendons (82%), tendon retraction on MRI (84%) and patient preference for surgery (78%). The majority prefer early surgical repair (<2 weeks after injury) to achieve highest functional outcome (63%) and ensure a low complication risk (61%). Suture anchors are used by 93% of the participants for tendon reattachment. Estimated recovery duration (i.e. time to return to sports) was a median 12 weeks (IQR: 12–20) for non-operative treatment and 17 weeks (IQR: 12–24) for surgical treatment. Estimated re-injury risk was a median 25% (IQR: 10–31.5) and 10% (IQR: 5–20), respectively.

Conclusion: This survey among experienced medical professionals has summarised current practice and identified treatment decision-making preferences. The typical surgical patient has a retracted (>2 cm) two-tendon avulsion (i.e. common tendon and semimembranosus tendon), is unable to engage in sports or activities of daily life, reports sciatic symptoms and prefers surgical treatment. Surgery is thought to prolong recovery and decrease re-injury risk compared with non-operative treatment and is preferably performed early.

Level of evidence: Level V.

Introduction

Proximal hamstring tendon avulsions are estimated to constitute around 3% to 9% of hamstring injuries[17,22]. Until the late 20th century, reports of full-thickness proximal hamstring injury due to tendon avulsion or rupture were limited to a handful of case reports[120–122]. In the last two decades, the number of clinical studies on proximal hamstring avulsions has increased rapidly[44,66,68,76–79,81–87,93,100,123–127].

Despite the recent advances in knowledge on these injuries, treatment decision-making has not become easier for several reasons. First, present systematic reviews on outcome after surgical and non-operative treatment have highlighted methodological limitations (and the ensuing risk of bias) of current studies making it difficult to provide clear recommendations[46,49–51]. Second, the comparison between surgical and non-operative treatments suffers from a paucity of data on outcome of non-operative treatment, let alone the lack of comparative studies. Currently, outcome of only approximately 60 non-operatively treated patients has been described, including two small retrospective comparative studies[44,125,126,128–131].

As a result of this lack of evidence, the comparison between outcomes following surgical and non-operative treatment is very limited. Therefore, it remains difficult to advise a surgical or non-operative approach for the individual patient and provide an accurate prognosis. We aim to evaluate current practice and decision-making for proximal hamstring tendon avulsions through an international survey among medical professionals in the field of orthopaedic traumatology and sports medicine.

Materials and methods

An invitation to an online survey was sent by email to all members of the International Society of Arthroscopy, Knee surgery and Orthopaedic Sports Medicine (ISAKOS) and the European College of Sports and Exercise Physicians (ECOSEP). The email contained information about the study purpose and procedures, as well as the link to the online survey. The first invitation was sent on 1 November 2016 with a reminder 4 weeks later. The survey closed on 1 January 2017.

Procedures and survey content

The survey was anonymous and did not collect sensitive data and was therefore exempted from ethics review by the local Institutional Review Board (Anti-Doping Lab Qatar, ADLQ). Participants were informed about the nature of the survey, the responsible research group and data collection. This included a statement that the survey was voluntary and that continuing to the survey signified agreement to participate. There was no incentive for the participants.

The survey was conducted using an online survey tool (Survey-Monkey, San Mateo, California, USA). For the development of the survey content and reporting of the survey results, the Checklist for Reporting Results of Internet E-Surveys (CHERRIES)[132] was used. The survey consisted of a total of 32 items and made use of adaptive questioning. All questions required an answer to continue. Participants were able to review and change their answers through a 'back' button. A 'review' step displaying a summary of the responses was not included. Each response was assigned a unique identification number. No data on IP addresses was recorded to ensure anonymity of the participants.

The survey was conceptualised by one author (ADM) to reflect topical issues regarding hamstring avulsion treatment in the current literature. All authors including three peers per author provided feedback on content which was incorporated in the definitive survey.

Survey questions were related to the participants' experience level with proximal hamstring tendon avulsions, treatment and prognosis. Using adaptive questioning, only participants that were involved in the treatment of proximal hamstring tendon avulsions were able to complete the survey. Based on participants' preferred treatment, further questions only enquired about details/decision modifiers for the preferred treatment. Participants that only considered non-operative treatment were asked about how non-operative treatment was organised, while participants that only considered surgical treatment were asked about how surgical treatment was organised. In addition, participants that considered surgical treatment were asked how various factors influenced the choice for surgical treatment. These included age, gender, level of sports participation, activity frequency, tendons involved, extent of retraction, complaints of pain, complaints of neurological symptoms, complaints of diminished function and patient wish to undergo surgery. Participants that considered either treatment depending on the individual patient answered all survey questions.

An overview of the questions and distribution of responses can be found in the online supplementary appendix.

Statistical analysis

Descriptive data analysis was carried out using SPSS (Released 2015, IBM SPSS Statistics for Windows V.23.0, Armonk, New York, USA: IBM Corp). Frequencies and portions were reported as N (%). Continuous variables were presented as mean ± standard deviation for parametric data and as median (interquartile range) for non-parametric data.

Results

The invitation to participate in the survey was sent to 3475 members, and we received 403 (12%) unique responses with a completion rate of 79%. Participants were orthopaedic/trauma surgeons (90%), sports medicine physicians (7%), physical therapists (2%) or other (1%). Thirty-one participants (8%) were not involved in the treatment of proximal hamstring tendon avulsions, and their survey ended here. Thirteen per cent treated more than 50 proximal hamstring tendon avulsions. Data for this group is presented separately in the online supplementary appendix.

Treatment choice and decision modifiers

Preferred treatment and frequency of surgical treatment in practice are shown in table 1. Rationales for surgical treatment selected by the majority (i.e. >50%) of participants were return to sports at pre-injury level (69%) and improved recovery of hamstring strength (lower strength deficit) (59%).

Participants were subsequently asked to select which decision modifiers (i.e. patient- or injury-related characteristics) support the choice for surgical treatment and how selected modifiers impact their decision-making (table 2).

Table 1. Distribution of responses on preferred treatment for proximal hamstring tendon avulsions, frequency of surgery in practice and preferred timing of surgery.

Questions on preferred treatment	Options	Proportion of participants that selected the option
Preferred treatment	Always non-operative	11%
	Always surgical	6%
	Dependent of individual patient	83%
% of patients managed surgically in practice	0%	8%
	1-25%	35%
	26-50%	17%
	51-75%	19%
	76-99%	19%
	100%	3%
Optimal timing of surgery to achieve highest functional outcome	<2 weeks after injury	63%
	2-3 weeks after injury	24%
	4-6 weeks after injury	5%
	7-12 weeks after injury	2%
	Does not influence outcome	3%
	I do not know	4%
Optimal timing of surgery to ensure a low risk of complications	<2 weeks after injury	61%
	2-3 weeks after injury	25%
	4-6 weeks after injury	5%
	7-12 weeks after injury	2%
	Does not influence outcome	3%
	I do not know	4%
Surgery is beneficial until	3 months after injury	43%
	6 months after injury	11%
	9 months after injury	2%
	1 year after injury	4%
	2 years after injury	1%
	No restriction	13%
	I do not know	15%
	Other	11%

Table 2. Overview of decision-making modifiers for treatment of proximal hamstring tendon avulsions.

Potential decision modifiers	Selected by majority (>50%) as decision modifier	Supports choice for surgical treatment if	Proportion of participants that selected the option
Question domain: Patient characteristics			
Age	Yes (54%)	Age below 40 years Age below 50 years Age below 60 years (mean: 44.7±13.4 years)	12% 10% 7%
Gender	No (7%)		
Level of sports participation*	Yes (71%)	No sports participation Recreational athlete Competitive athlete Professional athlete	7% 36% 60% 60%
Activity frequency	No (48%)		
Patient preference for surgery	Yes (78%)	Affects decision by shared decision-making Is an overruling factor	74% 4%
Question domain: Symptoms and function			
Pain*	Yes (68%)	Pain during activity (occupational) Pain during activity (athletic) Pain during prolonged sitting Any other pain	53% 51% 39% 13%
Diminished function*	Yes (84%)	Inability to participate in sports at pre-injury level Inability to participate in sports at any level Inability to perform heavy work-specific activities Inability to perform any work-specific activities Inability to perform activities of daily life	53% 63% 53% 55% 63%
Neurological symptoms*	Yes (74%)	Numbness/paraesthesia Sciatic pain Muscle weakness Any other neurological symptoms	45% 53% 42% 23%
Question domain: Imaging characteristics			
Tendons involved*	Yes (82%)	Common tendon (Biceps femoris & Semitendinosus) Semimembranosus tendon Both tendons	32% 7% 76%
Extent of retraction	Yes (84%)	Any retraction Retraction more than ___ cm (median: 2 cm, IQR: 2-3 cm)	27% 57%

*Multiple answers were allowed.

Surgical treatment

When surgical treatment was chosen, 93% use suture anchors to reattach the hamstrings to the ischial tuberosity. Allograft (9%) or autograft (8%) reconstruction is also performed. Preferred timing of surgery is summarised in table 1. Following surgery, 43% always immobilise the operated leg using a cast (5%) or brace (39%). Two per cent sometimes use a cast, 24% sometimes use a brace and the remaining 31% never use a cast/ brace. For postoperative rehabilitation, 79% refer to a physiotherapist. The remaining participants provide a standard exercise protocol/home exercises (15%) or focus on symptom relief (2%).

Non-operative treatment

If a non-operative approach was chosen, 77% refer to a physiotherapist, 9% provide a standard exercise protocol/home exercises and 9% focus on symptom relief.

Prognosis

Estimated recovery duration (i.e. time to return to sports) was a median 12 weeks (IQR: 12–20) for non-operative treatment and 17 weeks (IQR: 12–24) for surgical treatment. The estimated risk of re-injury was a median 25% (IQR: 10–31.5) for non-operative treatment and 10% (IQR: 5–20) for surgical treatment.

Discussion

This survey among experienced medical professionals to evaluate current practice in treatment of proximal hamstring tendon avulsions has identified several treatment decision-making preferences.

First, the decision for non-operative and surgical treatment should depend on the individual patient. For the decision-making process, the five most used decision modifiers are diminished function, neurological symptoms, involved tendons, extent of tendon retraction on MRI and patient preference for surgery. Second, when a surgical treatment is chosen, early surgery (within 2 weeks after injury) is preferred. Suture anchors are typically used for reattachment. When a non-operative treatment is chosen, patients are predominantly referred to a physiotherapist. Third, median recovery duration (i.e. return to sports) is estimated to be 5 weeks longer for surgical treatment than for non-operative treatment. However, re-injury risk is estimated to be higher in patients that are treated non-operatively.

Treatment choice: practice versus evidence

We observed a sharp contrast between the relatively high frequency of non-operatively treated patients in practice reported by participants in our study and the low number of non-operatively treated patients in the literature. The vast majority (83%) of participants stated that the treatment choice should be based on the individual patient. About 60% reported that less than half of their patients with a proximal hamstring tendon avulsion were treated surgically. Yet, in current literature there are over 10 surgically treated patients for every non-operatively treated patient[44,51,125,126,128–131], potentially indicating publication bias.

The uneven distribution of published data on outcome following surgical and non-operative treatment, a scarcity of controlled studies and the high risk of (e.g. selection) bias as highlighted by recent systematic reviews together make it difficult to properly

compare surgical and non-operative treatment. The paucity of non-operatively treated patients in the literature is problematic for another reason. Without these data, evidence-based indications for surgical treatment cannot be determined. For identifying patients that will maximally benefit from surgical treatment, it is crucial to understand which patients would do poorly without surgery.

Decision modifiers

Participants selected several decision modifiers that are relevant for their decision-making process. Among the five most used decision modifiers, diminished function and patient preference are non-specific factors for this injury and should be considered in the decision-making process for any intervention. More hamstring-specific decision modifiers that complete this top five are neurological symptoms, tendons involved and extent of tendon retraction on MRI.

For three quarters of the participants, presence of sciatic pain supports a decision for surgical treatment. The sciatic nerve lies in close proximity to the proximal hamstring tendons[1,2,8,133], resulting in potential sciatic nerve-related symptoms in case of a proximal hamstring tendon avulsion. In an early phase, symptoms may result from stretch injury or nerve compression by an accompanying haematoma. In later stages, sciatic symptoms can arise from entrapment by adhesions. In a study by Wilson et al.[134], distal (i.e. below the knee) sciatic symptoms occurred in 45 of 162 (28%) of patients with a proximal hamstring tendon avulsion. Sciatic symptoms were divided into motor deficits (5%), sensory deficits (7%) and pain (22%). In surgically treated patients, within 1 year after surgery, motor deficits improved in 100%, sensory deficits in 75% and pain in 89% of patients. Median time to noted initial improvement for motor deficits, sensory deficits, and pain was 87, 23 and 44 days, respectively. However, since the rate of improvement of these symptoms in non-operatively treated patients is unknown, it remains speculation whether these symptoms resolved spontaneously or because of the intervention.

Two decision modifiers were related to imaging: the involved tendons and the amount of tendon retraction on MRI. For over 80% of participants, avulsion of both the common tendon (biceps femoris and semitendinosus) and semimembranosus tendon supports the decision for surgery. In other words, such two-tendon avulsions (i.e. common tendon and semimembranosus tendon) are thought to do poorly with non-operative treatment and are therefore thought to require surgery. In the first case series of non-operatively treated proximal hamstring avulsions, all patients that were unable to run or return to sports requiring agility indeed had a two-tendon avulsion[44]. Conversely, a recent non-operative series demonstrated that 71% of patients with a two-tendon avulsion returned to their previous sporting level activity[125]. For comparison, surgical repair of two-tendon avulsions resulted in return to sports at pre-injury level rates of 55-96%[66,76,78,83,123,135].

More than 80% of the participants use the presence and extent of retraction as a decision modifier. To our knowledge, there are no studies indicating that the degree of retraction is of prognostic value in non-operatively treated patients. Nevertheless, retraction is reported to increase over time and results in a more technically challenging repair[68,78,84,87,127,135].

In summary, the decision modifiers to support the choice for surgical repair used in practice are not well supported by evidence. Further research is necessary to determine the

prognostic value of these variables in non-operatively treated patients and, by extension, whether these variables are to be used in the treatment decision-making process as indications for surgery.

Prognosis and timing of surgery

The estimated recovery duration was longer for surgical (median 17 weeks) than for non-operative treatment (median 12 weeks). This difference is not surprising considering that there is often some degree of delay between injury and surgery[51], as well as an initial postoperative phase that focuses on protection of the reattached hamstrings[43]. The recovery durations estimated by the survey participants were notably shorter than expected. There are no controlled trials comparing time to return to sports following both treatments. However, Hofmann et al.[125] recommended at least 4 months of physiotherapy as non-operative treatment, while surgically treated patients are generally allowed to return to sport from about 6 months after surgery[66,68,76–79,82,87,123,127].

Estimated re-injury risk following surgical (10%) and non-operative (25%) treatment is notably higher than reported in aggregated literature: the risk of a re-injury following surgical treatment is estimated at around 3%[46,50], re-injury risk for non-operatively treated patients has not been reported.

For achieving the highest functional outcome and low complication risk, participants prefer early surgical repair (<2 weeks after injury). The preferred timeframe may indicate that early surgery is considered easier, leads to better results and lower risk of complications or both. Two systematic reviews using 4 weeks as cut-off drew conflicting conclusions regarding differences in outcome between acute and delayed surgical treatment[46,50]. A third systematic review using 8 weeks as cut-off noted significant differences in terms of satisfaction, hamstring strength, single-legged hop test and Lower Extremity Functional Scale score[51]. With regard to surgical complications, no significant differences were found between acute and delayed surgery[51].

Limitations

There are limitations to this study. First and foremost, questions often made use of a 'black-and-white' scenario with fixed answers. Although such a hypothetical scenario may not reflect the diversity of clinical practice and leaves no room for nuances, this approach was taken to allow for descriptive statistics. It forces all participants to provide an answer for an identical situation rather than an answer that may only apply within a certain context.

Second, the response rate was low (12%). However, given the large number of participants stating that they have clinical experience with this injury (92%), it is likely that the invitation to participate functioned as a first selection process filtering out those that are unfamiliar with this injury.

Implications and future directions

Our survey has provided insight into current practice and preferences in regard to treatment of proximal hamstring tendon avulsions. It has exposed gaps in the literature in regard to support for some of the aspects of current practice and can therefore serve to direct future research efforts. These studies should ideally employ randomised controlled study designs. Given our findings, such studies should randomise treatment and stratify based on the

involved tendons, retraction and timing of surgery. Alternatively, as some argue that the principle of equipoise is not met based on current evidence, an international multicentre collaboration in the form of a prospective registry should be developed.

Additionally, this survey might be used to guide the clinical decision-making process as evidence-based indications for surgery have not yet been established.

Conclusion

Clinicians dealing with proximal hamstring tendon avulsions choose a surgical or non-operative treatment depending on the individual patient. Decision modifiers include diminished function, neurological symptoms, involved tendons, extent of tendon retraction on MRI and patient preference. The typical surgical patient has a retracted (>2 cm) two-tendon avulsion, is unable to engage in any sports or activities of daily life, reports sciatic symptoms and has a preference for surgical treatment. Surgical reattachment is preferably carried out within 2 weeks after injury. Recovery duration is estimated to be longer for surgical compared with non-operative treatment. Re-injury risk is estimated to be higher in patients that are treated non-operatively.

06

ASSESSMENT OF ISOMETRIC KNEE FLEXOR STRENGTH USING HAND-HELD DYNAMOMETRY IN HIGH-LEVEL RUGBY PLAYERS IS INTERTESTER RELIABLE

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Abstract

Objective: To assess intertester reliability of isometric knee flexor strength testing in high-level rugby players with testers of different physical capacity and different methods of dynamometer fixation.

Design: Reliability study. Patients: Thirty non-injured high-level (Tegner Activity Score ≥9) rugby players, free from hamstring injury in the previous 2 months.

Assessment: Isometric knee flexor strength (in N) in prone 0/15 degrees (hip/knee flexion) and supine 90/90 degrees position. Tests were performed by 1 female and 2 male testers whose upper-body strength was measured with a 6-repetition maximum bench press test. The prone 0/ 15 degrees measurement was performed with manual and external belt fixation of the dynamometer.

Main Outcome Measures: Absolute and relative intertester reliability were calculated using intraclass correlation coefficient (ICC) and minimal detectable change. Paired t-tests were used to identify systematic measurement error between testers and to test for a difference in recorded knee flexor strength between methods of dynamometer fixation.

Methods: Isometric knee flexor strength was measured in prone 0/15 degrees (hip/knee flexion) and supine 90/90 degrees position.

Results: Good intertester reliability was found for all pairwise comparisons (ICC 0.80-0.87). MDCs (as percentage of mean strength) ranged from 15.2% to 25.4%. For tester couples where systematic error was identified, Bland–Altman plots and Pearson correlation coefficients demonstrated no statistically significant correlation between mean knee flexor strength and between-tester difference. There was no significant difference in isometric knee flexor strength between manual and belt fixation of the dynamometer.

Conclusions: In strong high-level rugby players, hand-held dynamometry for isometric knee flexor strength assessment in prone 0/15 degrees and supine 90/90 degrees position is intertester reliable.

Introduction

Hamstring strength assessment is widely used for screening, injury prognosis, and monitoring of recovery[136–142]. Hand-held dynamometry (HHD) is a portable, relatively cheap, and quick method to assess isometric strength[143], making it an appealing clinical alternative to isokinetic strength assessment. These measurements can be performed with manual and external belt fixation of the dynamometer.

Intertester reliability of HHD has been questioned when testing strong athletes or when using testers of different physical capacity[144–148]. Hand-held dynamometry requires that the tester is able to oppose the strength of the tested individual.

A mismatch in physical capacity between tester and tested individual, which is more likely to occur with strong athletes (e.g. high-level rugby players), may produce less valid test results. This mismatch could have implications for intertester reliability, especially with testers of different physical capacity. Thorborg et al.[148] found that using testers of different sex and upper extremity strength introduced systematic intertester bias for hip strength assessment using HHD. Mulroy et al.[149] raised the same issue in regards to knee extensor strength assessment. However, it is unknown whether these findings can be extrapolated to isometric knee flexor (hamstring) strength assessment, a different muscle group that is tested in different positions.

A mismatch could be overcome by eliminating the influence of the testers' strength, for example with external fixation of the testing device[150–152]. Thorborg et al.[151] reported good intertester reliability for isometric hip and knee strength assessments using belt fixation despite using testers of different sex. However, it is unknown whether belt fixation is required for a reliable isometric strength assessment of the knee flexors. Considering the additional equipment and steps needed for belt fixation and the limited amount of time per patient in clinical practice, it is relevant to determine whether belt fixation is necessary for a reliable and valid assessment.

The aim of this study was to evaluate relative and absolute intertester reliability of isometric knee flexor strength assessment in high-level rugby players using testers of different physical capacity and different methods of dynamometer fixation. Secondary aims were to evaluate whether there was systematic error in recorded knee flexor strength between testers of different physical capacity and whether testing with external belt fixation resulted in significantly higher knee flexor strength compared with manual fixation of the testing device. Our hypotheses were that (1) differences in physical capacity of testers result in systematic measurement error and (2) testing with external belt fixation of the dynamometer yields systematically higher values than HHD.

Methods

Participants were recruited from Dutch rugby clubs participating in the top domestic league. Participants were eligible if they were male rugby players aged between 16 and 35 years, playing at least on a competitive level (≥9 on the Tegner Activity Scale), and were free from hamstring injury in the past 2 months. This study was exempted from ethical review by the Medical Ethics Committee (METC, Amsterdam UMC, Amsterdam, the Netherlands, project W18_246). All participants provided written informed consent, and their rights were protected.

Testers

Isometric knee flexor strength was assessed by 2 male testers (M1: 185 cm, 92 kg and M2: 195 cm, 117 kg), and 1 female tester (F: 167 cm, 60 kg). All testers were right dominant. Upper-body strength was measured by a 6-repetition maximum bench press (6RMBP) test according to the testing protocol of Wong et al.[153]. Weight increments were 2.5 kg per set instead of 2 kg in the original 6RMBP testing protocol.

Isometric knee flexor strength assessment

Isometric knee flexor strength (in N) was measured using a Hoggan MicroFET2 (Hoggan Scientific, LLC, Salt Lake City, UT). Testers received identical instructions and were trained until they were familiar with the protocol and able to perform the assessment independently.

Knee flexor strength assessment consisted of 2 testing positions that have been shown to be clinically relevant with regard to hamstring injury prognosis and monitoring of recovery progression[140,142]; prone 0/15 degrees (0 degrees hip flexion and 15 degrees knee flexion) and supine 90/90 degrees (90 degrees hip flexion and 90 degrees knee flexion). Prone 0/15 degrees was performed twice, once with manual fixation of the dynamometer and once using external belt fixation. No belt fixation was used for the supine 90/90 degrees position due to lack of a feasible method without compromising the practicality of HHD (i.e. using a frame or additional equipment).

For the prone 0/15 degrees position, the participant was lying in a prone position, with the feet just hanging over the edge of the bench—which was adjustable in height. With the ankle in neutral position, the tester passively flexed the knee to 15 degrees and placed the dynamometer at the heel of the participant. When a belt was used for fixation (Figure 1A), another tester ensured that the belt and dynamometer transducer were in line with the direction of force applied by the participant. For manual fixation, the tester held the dynamometer with both hands to oppose the participant's effort (Figure 1B). To minimize the number of repetitions that participants had to perform potentially leading to a fatigue effect, only 2 testers performed measurements with belt fixation.

For the supine 90/90 degrees position (Figure 1C), the participant was lying in a supine position. A belt was used to prevent the pelvis from being lifted off the bench, and the participant was instructed to hold the bench with both hands. The tester passively flexed the hip and knee to 90 degrees flexion and placed the dynamometer at the heel of the participant with the dominant hand. The tester's nondominant hand supported their dominant hand, and the elbow of the dominant arm was placed on the ipsilateral iliac crest to counter the participant's effort.

There were no significant rest periods between the 3 efforts during testing in a single position. To minimize influence of muscle fatigue, the left leg was used for the prone 0/15 degrees measurement and the right leg for the supine 90/90 degrees measurement, alternating between both legs during testing. Tester and fixation method order were randomized by drawing lots.

Participants were instructed to gradually build up force in the first second of a 3-second maximum effort and were verbally encouraged during each effort. The highest recorded value of 3 repetitions was recorded by a fourth person that was not one of the testers.

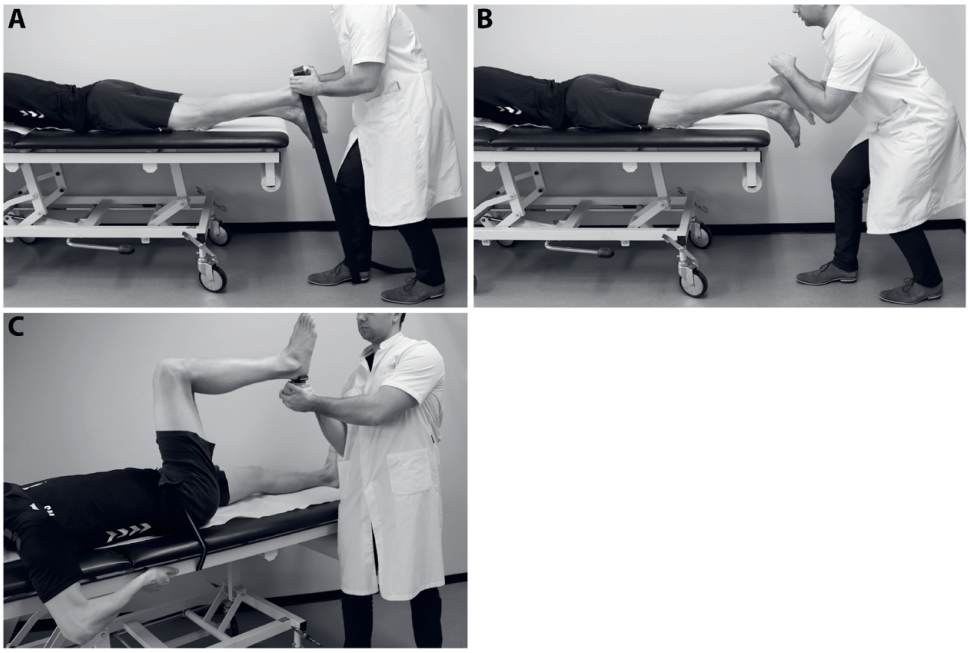

Figure 1. Prone 0/15 degrees with external belt fixation (A) versus manual fixation (B). Supine 90/90 degrees with manual fixation (C).

Statistical analysis

With an expected ICC of 0.85[140,142] and a 95% confidence interval of ±0.1, the calculated sample size was determined at 30 participants[154].

Statistical analysis was performed with SPSS (version 23.0; SPSS, Chicago, IL). Normality of data, either for descriptive statistics or for use in subsequent analyses, was evaluated by graphical assessment of histograms and normal Q–Q plots. ICCs were calculated using a two-way random-effects model with the agreement definition ($ICC_{2,1}$). ICCs were used to determine whether there was poor (<0.50), moderate (0.50-0.75), or good (>0.75) relative reliability[155]. The standard error of measurement (SEM) and minimal detectable change (MDC) were calculated to determine absolute reliability. SEM was calculated as $SD \times \sqrt{1-ICC}$, and MDC was calculated as $1.96 \times \sqrt{(2)} \times SEM$. SEM and MDC were also given as a percentage of the average test value. Bland–Altman plots were constructed and paired t-tests were performed to visualize and test for systematic error between testers of different physical capacity and different methods of dynamometer fixation. When paired t-tests identified systematic error for a tester couple, Pearson correlation coefficients were calculated to test for a correlation between knee flexor strength and between-tester differences. The level of significance was set at $\alpha = 0.05$.

Results

Thirty male rugby players with a mean age of 24 ± 4 years and median weight of 94 (interquartile range: 85-100) kg were included. The bench press test revealed a 6RMBP of 77.5, 97.5, and 37.5 kg for testers M1, M2, and F. Mean isometric knee flexor strength of the rugby players is shown in Table 1.

Table 1. Mean (±SD) isometric knee flexor strength for all testers per testing position and method of dynamometer fixation.

Position	Dynamometer fixation	Mean (±SD) isometric knee flexor strength (N)			
		Overall	M1	M2	F
Prone 0/15 degrees	Manual	341.7±65.8	357.0±60.9	333.9±70.0	334.1±65.7
Prone 0/15 degrees	Belt	341.3±72.6	355.5±75.4	327.1±68.0	
Supine 90/90 degrees	Manual	437.4±67.2	448.9±67.2	441.0±68.9	422.2±64.9

F: female tester, M1: male tester 1, M2: male tester 2.

Relative and absolute reliability

Relative and absolute reliability are presented in Table 2. Good relative intertester reliability was found for the prone 0/15 degrees and supine 90/90 degrees measurements. Good relative intertester reliability was found for all pairwise comparisons. SEM and MDC as a percentage of mean recorded strength values ranged from 5.5% to 9.2% and 15.2% to 25.4%, respectively.

Table 2. Intertester reliability and systematic error for isometric knee flexor strength assessments (hip flexion/knee flexion).

Position	Testers	Dynamometer fixation	$ICC_{2,1}$ (95% CI)	SEM (N)	MDC (N)	SEM, %*	MDC, %*	Paired t test
Prone 0/15 degrees	Overall	Manual	0.83 (0.68-0.91)	27.5	76.1	8.0	22.3	
Supine 90/90 degrees	Overall	Manual	0.84 (0.70-0.92)	26.8	74.3	6.1	17.0	
Prone 0/15 degrees	M1 & M2	Manual	0.84 (0.51-0.94)	26.4	73.3	7.7	21.2	P<0.001
Prone 0/15 degrees	M1 & F	Manual	0.80 (0.49-0.91)	28.6	79.2	8.3	22.9	P=0.001
Prone 0/15 degrees	M2 & F	Manual	0.83 (0.68-0.92)	27.4	76.0	8.2	22.8	P=0.982
Prone 0/15 degrees	M1 & M2	Belt	0.82 (0.42-0.93)	31.2	86.5	9.2	25.4	P<0.001
Supine 90/90 degrees	M1 & M2	Manual	0.87 (0.75-0.94)	24.5	67.8	5.5	15.2	P=0.221
Supine 90/90 degrees	M1 & F	Manual	0.85 (0.31-0.95)	25.6	70.8	5.9	16.3	P<0.001
Supine 90/90 degrees	M2 & F	Manual	0.80 (0.58-0.90)	30.1	83.3	7.0	19.3	P=0.014

CI: confidence interval, F: female tester, ICC: intraclass correlation coefficient, M1: male tester 1, M2: male tester 2. *Percentage of mean.

Systematic error between different testers

There were statistically significant between-tester differences (i.e. systematic error) in knee flexor strength in both testing positions. Systematic error was found for tester couples with the exception of prone 0/15 degrees (M2 & F, hand-held) and supine 90/90 degrees (M1 & M2, hand-held) (Table 2). For tester couples where systematic error was identified, Bland–Altman plots and Pearson correlation tests demonstrated no statistically significant correlation between mean knee flexor strength and between-tester difference (Figure 2).

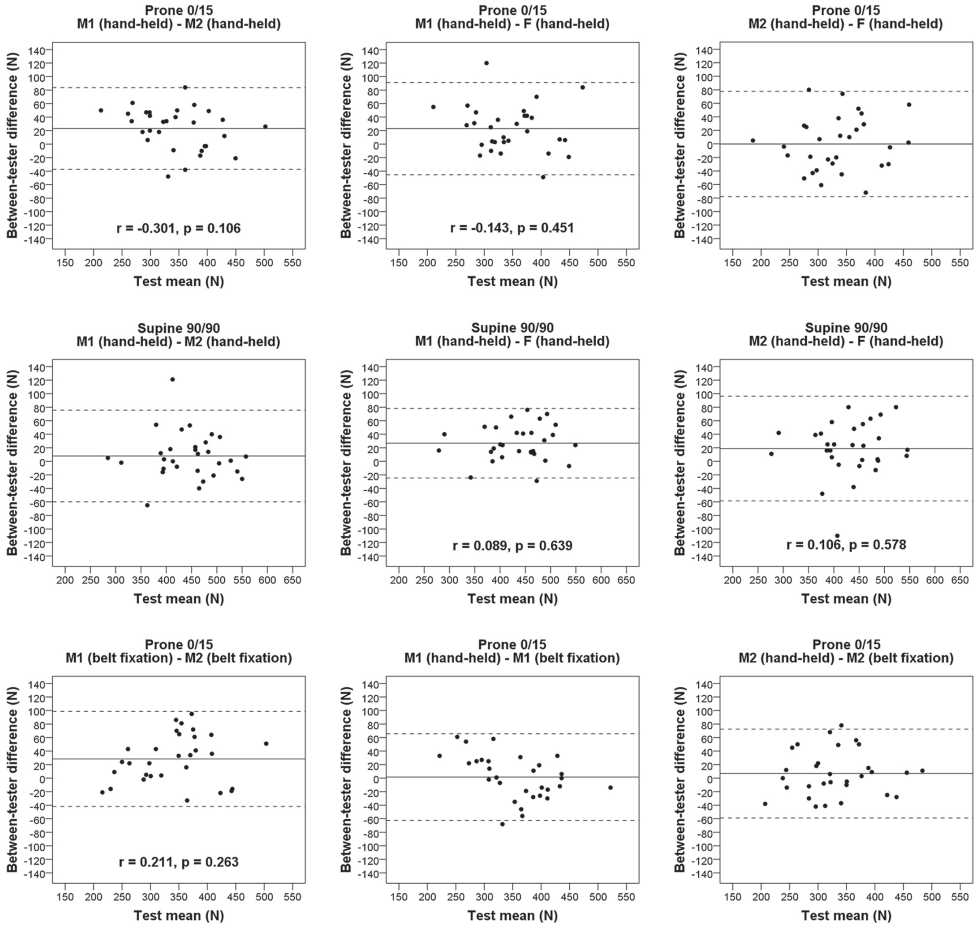

Figure 2. Bland–Altman plots demonstrating between-tester differences and their relationship with knee flexor strength for both testing positions (hip flexion/ knee flexion). For pairwise comparisons with systematic error according to paired t-tests, Pearson correlation tests demonstrated no statistically significant correlation between knee flexor strength and between-tester difference.

Systematic error between methods of dynamometer fixation

There was no statistically significant difference in isometric knee flexor strength in prone 0/15 degrees between manual and external belt fixation of the dynamometer (M1: P = 0.799, M2: P = 0.275).

Discussion

The most important finding was that isometric knee flexor strength measurements (prone 0/15 degrees and supine 90/90 degrees) are intertester reliable in strong high-level rugby players despite differences in physical capacity of testers. There is no added value of external belt fixation of the dynamometer for reliable isometric knee flexor strength measurements.

Participants in our study averaged notably higher isometric knee flexor strength than in most studies that included non-injured participants and/or sides[140,142,146,151,152,156–158]. The comparison with previous studies is limited by the differences in testing positions and study populations. Absolute and relative intertester reliability of hand-held isometric knee flexor strength assessment correspond reasonably well with other studies using similar testing positions[140,142]. Using HHD, Reurink et al.[140] reported an ICC of 0.73 and an MDC of 26% (prone 0/15 degrees), and Whiteley et al.[142] reported ICCs of 0.89 to 0.90 with MDC%s of 19% to 20% (mid range and outer range). Thorborg et al.[151] used external belt fixation of the dynamometer and reported an ICC of 0.84 and an MDC% of 25% (prone 0/0 degrees). Hickey et al.[156] used a construction involving a metal frame for external belt fixation of the dynamometer and reported ICCs of 0.90 to 0.91 and an MDC of 61 to 63 N (supine 90/90 degrees, dominant and nondominant leg). Our results fall in between those studies with ICCs of 0.83 to 0.84 and MDC%s of 17% to 22%.

Minimal detectable change

The MDC (as a percentage of the mean recorded strength value) in the current study is relatively high, ranging from approximately 17% to 22%. Minimal detectable change is the minimal intertester difference that falls outside measurement error. A difference between testers that is larger than the MDC is considered a real difference in isometric knee flexor strength. In clinical practice, this does not pose a problem in a setting where larger changes in strength can be expected over time, for example, during the course of a postoperative rehabilitation. When smaller differences are anticipated, however, this translates into a difficulty in distinguishing between measurement error and actual change between measurements. The MDC values in the current study correspond well with those reported in studies with weaker participants[140,142,151]. Relatively high MDCs are therefore not directly attributable to a mismatch between physical capacity of the tester and tested individual.

Mechanical advantage instead of external belt fixation

Our testing positions offer sufficient mechanical advantage for testers to reliably test strong individuals with testers of different physical capacity and without external belt fixation of the dynamometer. There are several arguments to support this claim. First, good reliability was found for all pairwise comparisons with testers of different physical capacity. Second, any systematic error that was identified between different testers was not significantly correlated with magnitude of knee flexor strength, arguing against tester's physical capacity

(i.e. upper-body strength) as a causative factor. Differences in upper-body strength between testers as potential explanation for systematic error would result in increasing between-tester differences with increasing knee flexor strength. This was not the case in this study. Although systematic error between testers in our study should not be ignored, it should not be attributed to differences in physical capacity between testers. Potential other causes could be minor differences in technique or (leg) positioning, verbal encouragement, and even tester's physical appearance. Third, hand-held testing did not result in significantly lower isometric knee flexor strength than with external belt fixation of the dynamometer. Belt fixation of the dynamometer has been reported to result in high intertester reliability[16,21] and could theoretically improve intertester reliability by taking the tester's strength out of the equation. Based on our data, this is not the case for the prone 0/15 degrees measurement. While this may seem counterintuitive, belt fixation may be associated with its own limitations. It can be challenging to line up the dynamometer exactly in the direction of the force applied by the participant, thereby potentially influencing measurement results.

Strengths and limitations

Strengths of this study include quantification of testers' physical capacity, high knee flexor strength within our study population, close resemblance to clinical practice, and randomization of tester order and testing position. As in clinical practice, no rest periods between efforts were included, testers were of different physical capacity, and all measurements used in this study are easily applicable in clinical practice.

This study has one main limitation. Ideally, this study would have included belt fixation of the HHD in the supine 90/90 degrees position. Then, a conclusion regarding validity of the manually fixated measurement in strong individuals could be drawn, as with the prone 0/15 degrees position. This comparison was not included for 2 reasons. First, this study aimed to evaluate reliability of measurements used in our daily clinical practice in strong individuals. Belt fixation for this position would require a construction hanging above the tested leg[156], thereby compromising the advantages of HHD and limiting clinical applicability. Second, as the number of maximum contractions would significantly increase with an additional testing position, the number of repetitions was kept to a necessary minimum to minimize a potential fatigue effect. Adding significant rest periods between efforts would mean deviating from our clinical practice and thereby limit the external validity of any conclusions drawn. Participants and testers were not blinded, which could have introduced bias.

Implications for clinical practice

Intertester reliability of hand-held isometric knee flexor strength dynamometry in strong athletes is good, independent of testers' physical capacity. In a setting where larger changes in strength can be expected over time, different testers with different upper-body strength may perform the measurements. For the prone 0/15 degrees position, belt fixation of the dynamometer is not required.

Conclusions

In strong high-level rugby players, isometric knee flexor strength measurements in prone 0/15 degrees and supine 90/ 90 degrees position are intertester reliable, regardless of testers' physical capacity and regardless of method of dynamometer fixation.

07

GOOD INTERRATER RELIABILITY FOR STANDARDIZED MRI ASSESSMENT OF TENDON DISCONTINUITY AND TENDON RETRACTION IN ACUTE PROXIMAL FULL-THICKNESS HAMSTRING TENDON INJURY

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Abstract

Background: Proximal full-thickness free hamstring tendon injury (i.e. tendon avulsion or rupture) is a severe injury. Treatment decision making relies on clinical factors and magnetic resonance imaging (MRI) variables; it specifically relies on which tendons are injured as well as the extent of tendon retraction. According to a worldwide evaluation of current practice, discontinuity of both proximal tendons and retraction of >2 cm are used as surgical indications. However, both the diagnosis and the use of MRI variables in decision making may be fraught with uncertainty in clinical practice. A reliable standardized MRI assessment is required.

Purpose: To propose an MRI assessment for acute proximal full-thickness free hamstring tendon injury and to evaluate its interrater reliability.

Study Design: Cohort study (diagnosis); Level of evidence, 2.

Methods: We included 40 MRI scans of patients with acute (≤4 weeks of injury) proximal full-thickness free hamstring tendon injury. Three musculoskeletal radiologists assessed proximal full-thickness free hamstring tendon discontinuity using the novel ''dropped ice cream sign'' and tendon retraction (in mm). Quantification of tendon retraction (in mm) was performed using 2 different methods: (1) a direct (i.e. shortest distance between the centre of the hamstring origin and the tendon stump) method and (2) a combined craniocaudal/mediolateral measurement method. Absolute and relative interrater reliability were calculated.

Results: We found an almost perfect interrater agreement (kappa = 0.87) for assessment of full-thickness tendon discontinuity using the dropped ice cream sign. Interrater agreement for the direct and craniocaudal retraction measurements was good for both the conjoint (intraclass correlation coefficient [ICC], 0.88 and 0.83) and the semimembranosus tendons (ICC, 0.81 and 0.79). The mediolateral retraction measurement yielded only moderate to poor reliability for the conjoint (ICC, 0.53) and semimembranosus tendons (ICC, 0.41).

Conclusion: The standardized MRI assessment to identify proximal hamstring tendon discontinuity and quantify tendon retraction is reliable. We recommend using the novel dropped ice cream sign and the direct retraction measurement in clinical practice and research.

Introduction

Acute proximal full-thickness free hamstring tendon injury (i.e. tendon avulsion or rupture) is a severe injury that can result in persisting symptoms and dysfunction[46,51,159]. Treatment delay may negatively affect the outcome[50,51]; thus, a timely diagnosis and adequate treatment decision making are essential. Magnetic resonance imaging (MRI) plays a pivotal role in both diagnosis and treatment decision making[43,48,160,161]. MRI is considered the gold standard for diagnosis[43,48,160] because of its superior sensitivity.

After a diagnosis, MRI is additionally used for treatment decision making, as identification of involved tendons and assessment of tendon retraction on MRI are widely used as decision modifiers[160,161]. Specifically, injuries involving both the conjoint and semimembranosus tendons and retraction of >2 cm are used to support the choice for operative treatment[161]. Additionally, MRI is valuable for preoperative planning. However, both the diagnosis and the use of MRI variables in decision making may be fraught with uncertainty in clinical practice.

Alaia et al.[162] conducted a survey among radiologists to identify the preferred ischial tuberosity landmark and perceived difficulties in quantifying tendon retraction. They concluded that substantial variability in tendon retraction measurements can be expected because of the differences in choosing a proximal landmark from which to measure and the perceived difficulties in precisely locating the proximal tendon stump.

An MRI assessment of the proximal hamstring complex after injury that is to be used for decision making in clinical practice should be reliable. However, based on the aforementioned work of Alaia et al.[162], we currently cannot assume that such assessment is done reliably without evaluation of measurement reliability. In a previous study, Six et al.[163] evaluated the reliability of the proximal hamstring tendon assessment on MRI without a standardized approach or a previous calibration session to evaluate the routine, unmodified reliability in our current clinical practice. They found a substantial interrater agreement for tendon discontinuity, but only a moderate agreement for tendon retraction. We hypothesized that, in accordance with the work of Alaia et al., this resulted from the lack of a standardized approach. Studies reporting hamstring tendon retraction have not included measurement methods.

In this study, we present a standardized assessment for (1) proximal free tendon discontinuity using the novel ''dropped ice cream sign,'' and (2) tendon retraction for acute (≤4 weeks from onset of injury) proximal full-thickness free hamstring tendon injury on MRI. We subsequently evaluated interrater reliability. Our hypothesis was that this standardized assessment can be used to reliably evaluate tendon discontinuity and the extent of tendon retraction on MRI.

Methods

Participants

A total of 40 eligible participants were included between January 2013 and February 2019 as part of an ongoing prospective study on the outcome of operative and non-operative treatment of proximal full-thickness hamstring tendon injury. This study was exempted from ethics review by the institutional review board (Medisch Ethische Toetsingscommissie, Amsterdam UMC, Amsterdam, the Netherlands, No. W17_231). All patients gave informed consent.

Patients included in the current study had an acute proximal full-thickness hamstring tendon injury that was confirmed by MRI acquired ≤28 days after injury. Eligibility criteria are shown in Table 1.

Table 1. Eligibility criteria of participants

Inclusion criteria

- Age ≥18 years
- MRI-confirmed full-thickness injury of ≥1 proximal free hamstring tendon(s)
- MRI performed ≤28 days of injury
- MRI includes coronal fluid-sensitive sequence

Exclusion criteria

- Previous full-thickness injury of ≥1 proximal free hamstring tendon(s) in the same leg
- Bony avulsion
- Unwilling to participate or unable to give written informed consent
- Concurrent or subsequent disease/injury that renders the patient unable to follow the rehabilitation program

MRI: magnetic resonance imaging.

MRI protocol

The initial MRI was made at the referring centre or in the study centre. In the latter, images were acquired with a 3.0T magnet system (Ingenia System, Philips) and a body matrix coil. Coronal Dixon T2-weighted images (TR/TE 2000-6000/60 ms; FOV 450x450; slice thickness 4 mm; matrix 820x651) were obtained. Subsequently, axial T2-weighted TSE images (TR/TE 2500-6000/70 ms; FOV 450x250; slice thickness 2.5 mm; matrix 900x360) and axial Dixon proton density (PD)-weighted images (TR/TE 2000-3500/shortest possible time; FOV 400x450; slice thickness 3.5 mm; matrix 800x699) were obtained.

Standardized MRI assessment

The MRI assessment was performed using a standardized scoring form by 3 raters, who were musculoskeletal radiologists (F.F.S., C.F.B., M.M.) with between 5 and 29 years of experience. All raters were blinded to patient data and clinical findings. The order in which MRI scans were assessed was randomized. Before the assessment, a calibration session was held to make sure all raters understood the measurements and were able to perform them independently. All raters were instructed using an identical slideshow (online supplementary appendix) with illustrated measurement methods, along with 3 exemplary cases.

All raters assessed tendon discontinuity (i.e. free tendon avulsion or rupture of the conjoint tendon, the semimembranosus tendon, or both) using the novel dropped ice cream sign and they quantified tendon retraction (in mm) using the craniocaudal, mediolateral, and direct methods.

Proximal full-thickness free tendon discontinuity

To assess proximal full-thickness free tendon discontinuity, we introduced the dropped ice cream sign (Figure 1). On axial sequences, the ischial tuberosity resembled a tilted ice cream cone. The 2 hamstring tendon attachments then represented 2 scoops of ice cream: the conjoint tendon attached on the medial facet and the semimembranosus tendon attached on the lateral facet [8]. In case of a proximal hamstring tendon avulsion, it appeared as if 1 or both of the ''scoops'' had fallen off the ice cream cone. A ''single dropped ice cream sign'' could be noted in case of proximal tendon avulsion of a single tendon. A ''double dropped ice cream sign'' was seen in case of avulsion of both the conjoint and the semimembranosus tendons. The remainder of the proximal free tendon distal to the ischial tuberosity was subsequently assessed for full-thickness rupture.

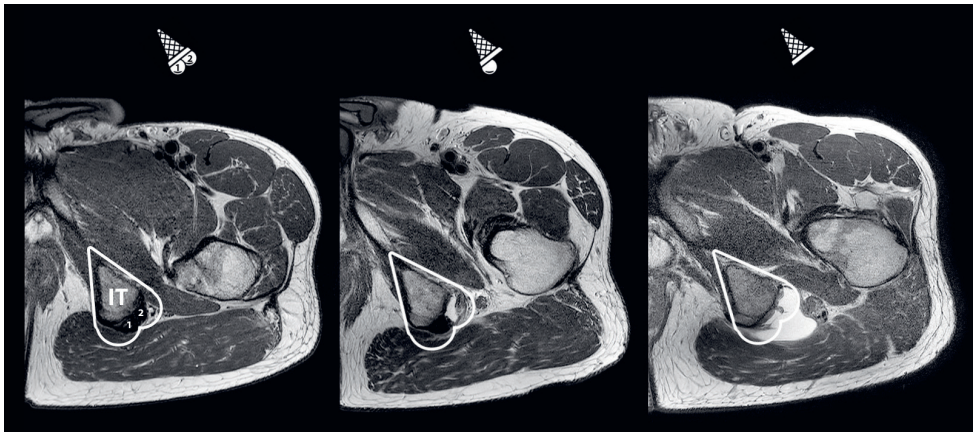

Figure 1. The dropped ice cream sign to assess if and which proximal tendons are avulsed. On an axial magnetic resonance sequence depicting a left pelvic area, the ischial tuberosity (IT) resembles an ice cream cone. The 2 scoops represent the proximal tendons: (1) the conjoint tendon medially and (2) the semimembranosus tendon laterally. Depending on whether 1 or both proximal hamstring tendons are avulsed, there is a single (middle) or double dropped ice cream sign (right). The ice cream flavours **c**ara**mel** (**c**onjoint **me**dial) and **s**tracciatel**la** (**s**emimembranosus **la**teral) can serve as a mnemonic for which tendon is affected by using the first and last syllable.

Tendon retraction

The extent of tendon retraction (in mm) was measured on coronal fluid-sensitive sequences using 2 separate methods. Multiple plane reconstruction was not allowed as this is not typically employed in assessing anisotropic MRI sequences. The first method was the direct (i.e. shortest) distance between the anatomic footprint and the most proximal part of the tendon stump (Figure 2). For the proximal landmark, the footprint of the proximal hamstring complex, the centre of the upper region of the ischial tuberosity [8] can was taken.

In the coronal plane, the lateral outline of the ischial tuberosity was divided into 2 slopes with differing angles. The upper region was the superior/steeper slope (Figure 2; dotted line). The most proximal part of the tendon stump was defined as the most proximal point of low signal intensity that could be confidently identified as part of the hamstring tendon.

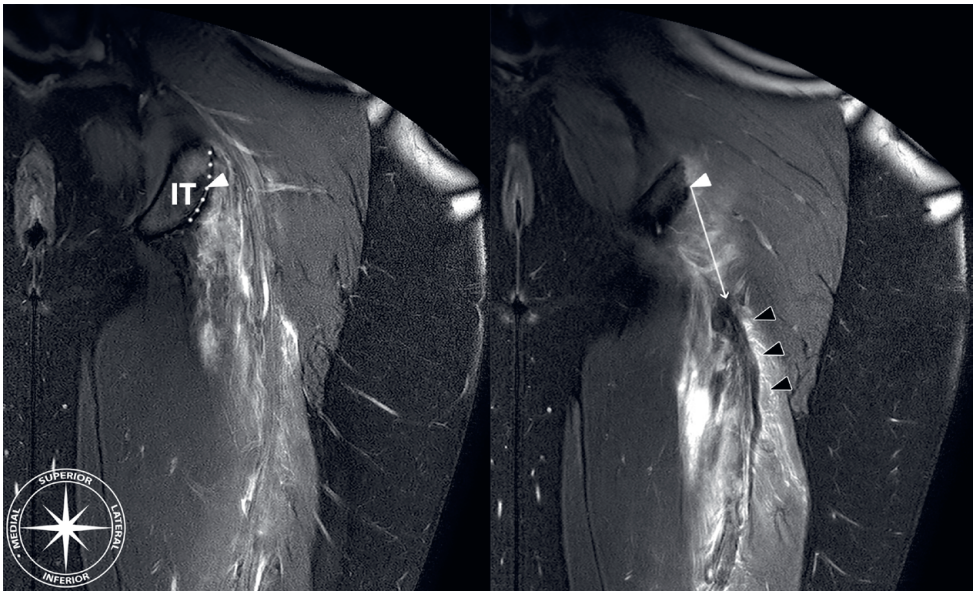

Figure 2. Direct retraction measurement. First, the point representing the centre (white triangle) of the proximal hamstring complex origin on the upper region (dotted line) of the ischial tuberosity (IT) is determined. From this point, the direct (i.e. shortest) distance (white arrow) to the most proximal part of the hypointense tendon stump (black triangles) was measured (in mm). Note that determining the anatomic landmarks is done on different images within 1 magnetic resonance imaging sequence.

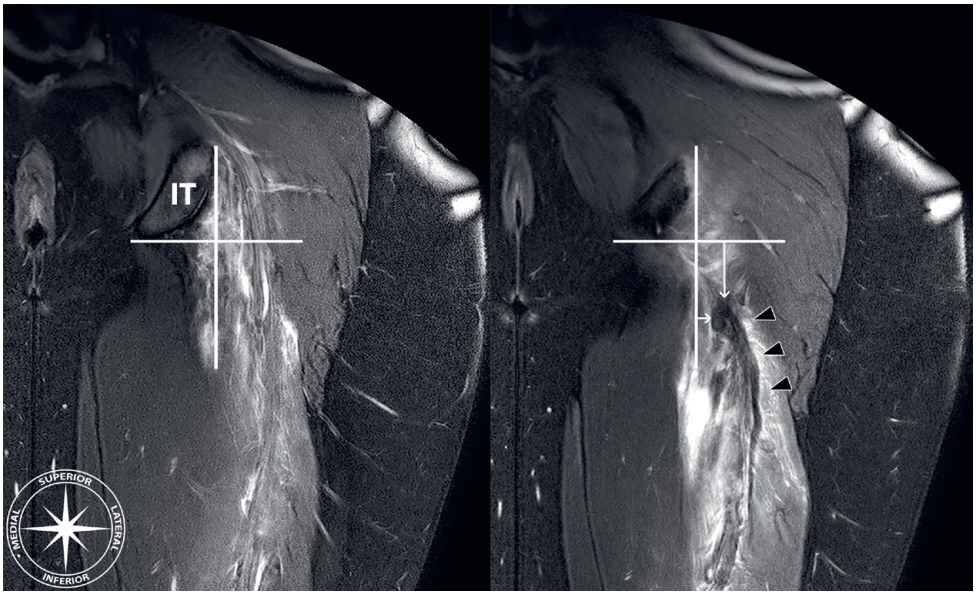

Figure 3. Craniocaudal and mediolateral retraction were quantified by drawing reference lines at the level of the most inferior (horizontal line) and the lateral border (vertical line) of the ischial tuberosity (IT). The craniocaudal (vertical white arrow) and the mediolateral (horizontal white arrow) distances between the reference lines and the most superior and medial margins of the hypointense tendon stump (black triangles) were measured (in mm).

The second method comprised purely craniocaudal and mediolateral distances between the ischial tuberosity and proximal tendon stump (Figure 3). The craniocaudal distance between the most distal margin of the ischial tuberosity and the most proximal part of the hypointense tendon stump and the mediolateral distance between the most lateral margin of the ischial tuberosity and the most medial part of the proximal tendon stump were measured separately. As a result of these landmarks, a tendon stump that is located proximal to the most distal margin of the ischial tuberosity would result in a ''negative'' retraction. The same applied to a tendon stump that was positioned medial to the most lateral margin of the ischial tuberosity. Although this method did not respect the anatomic tendon footprint and could be considered more abstract because of the possibility of negative retraction, it was included because these anatomic landmarks hypothetically left little room for interpretation and could therefore yield higher reliability than the direct measurement.

Statistical analysis

Statistical analysis was performed using SPSS (Version 25.0; SPSS Inc). With an expected intraclass correlation coefficient (ICC) of 0.8 and a 95% CI of ±0.1, the calculated sample size was determined to be 40 participants[154]. A descriptive analysis was used to present demographic data of the study participants and to present outcome of the MRI assessment. The approximate normal distribution of data was evaluated using a qualitative graphical assessment, and descriptive data were presented as mean ± SD or median (interquartile range [IQR]) as appropriate.

Interrater reliability was evaluated using the ICC for continuous variables and the Fleiss kappa (κ) for categorical variables as >2 raters carried out the measurements. ICC values, calculated using a 2-way random effects model with the agreement definition ($ICC_{2,1}$), were used to determine whether there was poor (<0.50), moderate (0.50-0.75), good (0.76-0.90), or excellent (>0.90) reliability[164]. Additionally, we calculated the SEM and the minimal detectable change (MDC). The SEM was calculated as $\sqrt{(MSw)}$ and MDC was calculated as $1.96 \times \sqrt{(2)} \times SEM$. Kappa values were used to determine whether there was poor (<0.00), slight (0.00-0.20), fair (0.21-0.40), moderate (0.41-0.60), substantial (0.61-0.80), or almost perfect (0.81-1.00) agreement[165].

Results

The 40 participants (Figure 4) included 17 women and 23 men with a mean age of 49 ± 9.9 years. A total of 24 (60%) MRI scans were performed at the study centre and 16 (40%) at the referral centre. The injury involved the right leg in 15 (37.5%) and the left leg in 25 (62.5%) participants. The median time between injury and MRI was 7.5 (IQR, 4.5-16.5) days.

The outcomes of the standardized MRI assessment and interrater reliability are provided in Tables 2 and 3. There was an almost perfect interrater agreement for the assessment of tendon discontinuity using the dropped ice cream sign. The raters unanimously reported tendon avulsion of both the conjoint and semimembranosus tendons in the 19 patients who were treated operatively. This was confirmed during operative repair.

For tendon retraction, using the direct and craniocaudal measurements, we noted a good interrater agreement for both the conjoint and the semimembranosus tendons. The mediolateral measurement was not reliable, with only moderate and poor agreement for the conjoint and the semimembranosus tendons, respectively.

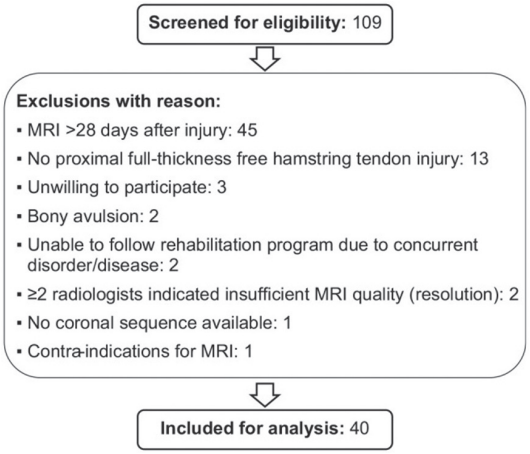

Figure 4. Flowchart of the inclusion process. MRI: magnetic resonance imaging.

Table 2. MRI assessment of tendon discontinuity and retraction per rater in acute proximal full-thickness free hamstring tendon injury.

Variable	Rater 1 (N = 40)	Rater 2 (N = 40)	Rater 3 (N = 40)
Proximal free tendon discontinuity			
Conjoint tendon	2 (5)	3 (7.5)	3 (7.5)
Semimembranosus tendon	3 (7.5)	3 (7.5)	3 (7.5)
Both	35 (87.5)	34 (85)	34 (85)
Retraction of conjoint tendon			
Direct, mm	34 (IQR: 19-56)	41 (IQR: 25-65)	28 (IQR: 20-61)
Craniocaudal, mm*	12±28	15±29	15±25
Mediolateral, mm*	5±9	-3±12	-2±11
Retraction of semimembranosus tendon			
Direct, mm	35 (IQR: 23-66.5)	36.5 (IQR: 25.5-27.5)	46.5 (IQR: 25-60)
Craniocaudal, mm*	16±34	15±31	13±25
Mediolateral, mm*	6±10	2±8	-3±12

Data are given as n (%) for categorical data and mean± SD or median (IQR) for continuous data. IQR: interquartile range, MRI: magnetic resonance imaging. *Includes negative values.

Table 3. Interrater reliability of free tendon discontinuity and quantification of tendon retraction on MRI in acute proximal full-thickness hamstring tendon injury.

Variable	κ / ICC (95% CI)	SEM	MDC	Agreement
Overall				
Proximal free tendon discontinuity (dropped ice cream sign)	0.87 (0.73-1.00)			Almost perfect
Retraction of conjoint tendon, mm				
Direct	0.88 (0.80-0.94)	9	24	Good
Craniocaudal	0.83 (0.73-0.90)	11	31	Good
Mediolateral	0.53 (0.27-0.72)	8	22	Moderate
Retraction of semimembranosus tendon, mm				
Direct	0.81 (0.69-0.89)	13	35	Good
Craniocaudal	0.79 (0.67-0.96)	14	38	Good
Mediolateral	0.41 (0.19-0.62)	9	24	Poor
Rater 1 vs. Rater 2				
Proximal free tendon discontinuity	0.90 (0.70-1.00)			Almost perfect
Retraction of conjoint tendon, mm				
Direct	0.87 (0.74-0.94)	8	23	Good
Craniocaudal	0.89 (0.80-0.94)	9	26	Good
Mediolateral	0.42 (0.00-0.69)	9	25	Poor
Retraction of semimembranosus tendon, mm				
Direct	0.82 (0.68-0.90)	14	38	Good
Craniocaudal	0.85 (0.72-0.92)	13	37	Good
Mediolateral	0.39 (0.08-0.63)	8	23	Poor
Rater 1 vs. Rater 3				
Proximal free tendon discontinuity	0.90 (0.70-1.00)			Almost perfect
Retraction of conjoint tendon, mm				
Direct	0.92 (0.85-0.96)	7	19	Good
Craniocaudal	0.77 (0.59-0.87)	13	36	Good
Mediolateral	0.49 (0.06-0.74)	8	22	Poor
Retraction of semimembranosus tendon, mm				
Direct	0.75 (0.56-0.86)	15	41	Moderate
Craniocaudal	0.72 (0.52-0.84)	16	45	Moderate
Mediolateral	0.29 (0.00-0.56)	11	30	Poor
Rater 2 vs. Rater 3				
Proximal free tendon discontinuity	0.81 (0.56-1.00)			Almost perfect
Retraction of conjoint tendon, mm				
Direct	0.86 (0.69-0.93)	10	27	Good
Craniocaudal	0.83 (0.69-0.91)	11	31	Good
Mediolateral	0.69 (0.48-0.83)	6	18	Moderate
Retraction of semimembranosus tendon, mm				
Direct	0.88 (0.77-0.94)	9	26	Good
Craniocaudal	0.84 (0.68-0.92)	11	31	Good
Mediolateral	0.48 (0.18-0.69)	8	21	Poor

ICC: intraclass correlation coefficient, κ: kappa, MDC: minimal detectable change, MRI: magnetic resonance imaging.

Discussion

The most important finding from this study is that the standardized MRI assessment of acute proximal full- thickness free hamstring tendon injury is interrater reliable. We found an almost perfect agreement for assessing proximal free tendon discontinuity using the novel dropped ice cream sign. We noted good agreement for quantifying tendon retraction using the direct and craniocaudal measurements. The direct measurement had superior absolute reliability (i.e. SEM/MDC) compared with the craniocaudal measurement and is thus the preferred method.

Little research has been done on the reliability of tendon retraction measurements on MRI after hamstring avulsion or rupture. This is surprising considering that such data are essential to determine clinical utility of a variable or a measurement. Alaia et al.[162] conducted a survey among musculoskeletal radiologists and predicted that substantial variability in tendon retraction can be expected due to differences in choosing proximal and distal landmarks for the measurements. The proximal landmark used was either the origin of the conjoint tendon (47%), the origin of the semimembranosus tendon (39%), or the posterior-inferior edge of the ischial tuberosity (14%). Almost half (44%) of the radiologists expressed difficulty in determining the location of the retracted tendon stump. Six et al.[163] evaluated the reliability of proximal hamstring tendon assessment on MRI without a standardized scoring method to evaluate routine, unmodified reliability in current clinical practice. A standardized MRI assessment was recommended, mainly because of lower interrater agreement for tendon retraction measurements than was acceptable for use in clinical practice. Six et al. found substantial agreement for identifying tendons with a full-thickness injury ($\kappa = 0.77$) and moderate/moderate agreement for quantifying retraction of the conjoint/semimembranosus tendons (ICC, 0.73/0.57; MDC, 38/57 mm). Such issues have also been found in other muscle groups. Several studies noted substantial interrater variability of MRI measurements after rotator cuff injury. Interrater reliability for assessing the number of involved rotator cuff tendons and determining the amount of retraction in qualitative manner demonstrated only a moderate agreement (κ, 0.40-0.55 and κ, 0.44-0.58)[166–168].

Using the proposed standardized assessment in the current study, we found an almost perfect and good/good interrater agreement. Using standardized assessments, absolute and relative reliability are substantially more favourable compared with the study by Six et al.[163]. Corresponding SEM/MDC values for the quantification of tendon retraction were non-negligible but arguably acceptable. Yet, the MDC values should be taken into account when using retraction beyond a certain cut-off value as an indication for operative repair. We found that the direct method to quantify tendon retraction is the most reliable. The alternative method comprising craniocaudal and mediolateral distances was less reliable and is therefore not preferred. However, the craniocaudal distance may be used to correlate physical examination findings with imaging findings, as the inferior margin of the ischial tuberosity is an easily palpable landmark. Interrater reliability for the craniocaudal distance was rated as good, but mediolateral distances cannot be reliably measured. The mediolateral distance was part of the combined cranio-caudal/mediolateral measurement method to ensure a more complete description of tendon retraction rather than craniocaudal distance alone, but we argue that it likely has no clinical relevance in isolation. We hypothesize that the mediolateral displacement, often due to hematoma formation resulting from tendon avulsion or rupture, is reversible upon hematoma resorption.

Limitations

The main limitation of this study was that not all MRI scans were performed in the study centre. Identical MRI protocols would have potentially further increased reliability. Heterogeneity in imaging protocols and quality reflects clinical practice and increases its external validity. Also, no gold standard (e.g. intraoperative findings and measurements) was available to draw conclusions regarding the measurement validity of quantifying tendon retraction.

Recommendations for clinical practice and research

This study presents a reliable MRI assessment for proximal free tendon discontinuity and quantifying tendon retraction in acute proximal full-thickness free hamstring tendon injury. We recommend that the MRI assessment of acute proximal hamstring injury includes the dropped ice cream sign and the direct retraction measurement. The measured extent of retraction depends on the measurement method used and on the precise landmarks employed in the measurement (Table 2). Therefore, we recommend that MRI reports and studies using this variable should be explicit in how the measurement was performed. Ideally, the anatomic landmarks used to measure retraction should be reported. We propose the centre of the upper region of the ischial tuberosity [8] and the most cranial extent of clearly identifiable (PD/T2) hypointense tendon stump as standardized landmarks.

Tendon discontinuity and tendon retraction are important factors for treatment decision making[160,161]. Although the development of a reliable MRI assessment is a vital step in the right direction, additional data are needed to assess clinical utility. For one, further validity testing is necessary to investigate whether tendon retraction on MRI correlates with intraoperative findings to ensure accurate preoperative planning. With regard to using retraction as an indication for operative repair, the association between tendon retraction and outcome after non-operative treatment needs to be examined. After all, retraction is only useful for decision making if there is a retraction threshold beyond which non-operative treatment results in poorer outcomes. Such research efforts should also include analyses to determine whether 2 cm is an appropriate cut-off value, ideally employing the standardized and reproducible measurements outlined in this study.

Conclusion

The standardized MRI assessment to identify full-thickness free tendon injury and to quantify tendon retraction in acute (≤4 weeks of injury) proximal hamstring tendon injury was reliable. We recommend using the novel dropped ice cream sign and direct retraction measurement (i.e. the shortest distance between the centre of the proximal hamstring complex origin and the proximal tendon stump) in clinical practice and research.

08

PROXIMAL HAMSTRING TENDON AVULSIONS: COMPARABLE CLINICAL OUTCOMES OF OPERATIVE AND NON-OPERATIVE TREATMENT AT 1-YEAR FOLLOW-UP USING A SHARED DECISION-MAKING MODEL

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Abstract

Objective: To prospectively evaluate 1-year clinical and radiological outcomes after operative and non-operative treatment of proximal hamstring tendon avulsions.

Methods: Patients with an MRI-confirmed proximal hamstring tendon avulsion were included. Operative or non-operative treatment was selected by a shared decision-making process. The primary outcome was the Perth Hamstring Assessment Tool (PHAT) score. Secondary outcome scores were Proximal Hamstring Injury Questionnaire, EQ-5D-3L, Tegner Activity Scale, return to sports, hamstring flexibility, isometric hamstring strength and MRI findings including proximal continuity.

Results: Twenty-six operative and 33 non-operative patients with a median age of 51 (IQR: 37–57) and 49 (IQR: 45–56) years were included. Median time between injury and initial visit was 12 (IQR 6–19) days for operative and 21 (IQR 12–48) days for non-operative patients (p=0.004). Baseline PHAT scores were significantly lower in the operative group (32±16 vs 45±17, p=0.003). There was no difference in mean PHAT score between groups at 1-year follow-up (80±19 vs 80±17, p=0.97). Mean PHAT score improved by 47 (95% CI 39 to 55, p<0.001) after operative and 34 (95% CI 27 to 41, p<0.001) after non-operative treatment. There were no relevant differences in secondary clinical outcome measures. Proximal continuity on MRI was present in 20 (95%, 1 recurrence) operative and 14 (52%, no recurrences) non-operative patients (p=0.008).

Conclusion: In a shared decision-making model of care, both operative and non-operative treatment of proximal hamstring tendon avulsions resulted in comparable clinical outcome at 1-year follow-up. Operative patients had lower pre-treatment PHAT scores but improved substantially to reach comparable PHAT scores as non-operative patients. We recommend using this shared decision model of care until evidence-based indications in favour of either treatment option are available from high-level clinical trials.

Introduction

Proximal hamstring tendon avulsion injuries have a substantial burden, compromising sports participation and the more physical aspects of daily life[44,46,49,51,159]. Systematic reviews report superior outcome after operative treatment in terms of satisfaction, patient-reported outcome measures, return to sports (RTS) and strength[46,49,51]. Yet, they highlight the risk of bias as most studies are retrospective, and there is a lack of data on non-operative outcome. In a recent systematic review[51], less than 30 non-operative patients were included compared with more than 750 operative patients. As the comparison between treatments is limited, prospective data are needed, especially on outcomes following non-operative treatment.

In the absence of strong evidence, treatment decision-making for these severe injuries remains challenging. As little is known about non-operative outcomes, and operative treatment carries risks of complications, it is paramount to include patients' preferences in the decision-making. Shared decision-making is a collaborative process in which patients and clinicians jointly establish treatment plans that integrate clinical evidence and patient preferences[169]. It improves patient satisfaction and adherence through increased knowledge, lower decisional conflict and greater likelihood of receiving care aligned with patient values[170,171]. In this pragmatic study, we employed a shared decision-making model.

Our objective was to prospectively evaluate 1-year clinical and radiological outcomes after operative and non-operative treatment of proximal hamstring tendon avulsions. Our hypothesis was that, in a shared decision-making model, operative treatment results in superior clinical and radiological outcomes.

Methods

Participants

Patients with a suspected proximal hamstring tendon injury between October 2016 and August 2019 were screened. Eligibility criteria are shown in box 1.

Box 1. Eligibility criteria.

Inclusion criteria

- Age ≥18 years.
- MRI-confirmed full-thickness injury of ≥1 proximal free hamstring tendon(s).

Exclusion criteria

- Contraindication to MRI.
- Previous full-thickness injury of ≥1 proximal free hamstring tendon(s) in the same leg.
- Bony avulsion.
- Unwilling to participate or unable to give written informed consent.
- Concurrent disease/injury that renders the patient unable to follow the rehabilitation programme.

Shared decision making

Through a shared decision-making process with a surgeon (GMMJK/RWP) or sports medicine physician (JLT) and physiotherapist (CV), operative or non-operative treatment was chosen. All clinicians involved have more than 10 years of experience in muscle injury treatment. Key steps included choice talk, option talk and decision talk[169]. Patients were informed

about the diagnosis and the choice between operative or non-operative treatment. Using visual aids, patients were informed about anatomy, injury characteristics, advantages and disadvantages of operative and non-operative treatment and expected outcomes. For operative treatment, this included restoration of proximal continuity, improved functional/strength recovery, higher chance of resolution of radiating pain and pain during sitting, postoperative protection and risk of operative complications. For non-operative treatment, the ability to start physiotherapy immediately without risk of operative complications or need for postoperative protection were discussed, at the cost of uncertainty of proximal continuity restoration, and a possible greater chance of residual functional limitations/strength deficits.

To facilitate up-to-date shared decision-making, the information provided during the option talk was continuously updated based on annual quantitative interim analyses and emerging evidence. The latter included systematic reviews[49,51] and world-wide surveys that evaluated current practice and preferences regarding the decision-making process[160,161]. During the study period, decision-making was initially generally operative-minded and non-operative treatment was reserved for middle-aged patients with lower functional demand. Due to satisfactory outcome in this group, the provided information was updated and gradually more patients opted for non-operative treatment, but operative treatment was typically advised in 2-tendon avulsions with substantial retraction and persistent functional limitations/sciatic symptoms. Ultimately, patients without a strong preference for either treatment started physiotherapy and chose operative or non-operative treatment after evaluating progression of symptom resolution and functional recovery after approximately 2 weeks. Elite athletes always opted for operative treatment.

We refer to online supplementary appendix A for a modifiable shared decision-making aid for use in clinical practice.

Operative treatment

Operative reattachment of the proximal hamstring tendons was performed per the current standard[172] (online supplementary appendix B). By varying the degree of knee flexion during surgery following reattachment, tension on the repair was assessed. Based on this assessment, a cast was applied in the operating room. Cast immobilisation was continued for 2 weeks followed by a hinged knee brace that limited full knee extension but allowed knee flexion for 4 weeks. The brace was set at 30° knee flexion and gradually (10° per week) progressed towards full knee extension. A criteria-based rehabilitation programme (online supplementary appendix B) was initiated as soon as the knee brace was applied.

Non-operative treatment

Non-operative patients were referred to a physiotherapist with extensive experience with these injuries (CV) and immediately started the rehabilitation programme (online supplementary appendix B) in phase II. Phase I served as a protective phase for operative patients only. Phase II focused on normalising gait and regaining control with functional movement without pain. Non-impact balance and proprioceptive exercises, gait training using an antigravity treadmill, and strengthening exercises of the hamstrings with addition of electrical stimulation as well as strengthening of hip rotators and trunk were initiated. Phase III was started when gait was normal and functional movements were carried out

without pain or having to unload the injured leg. This phase focused on restoring pain-free control of work-specific and sport-specific movements. Hamstring strengthening was progressed to lengthened positions. Impact control and running exercises were started. Phase IV focused on preparing patients for return to work-specific and sport-specific activities. It was started when patients demonstrated dynamic neuromuscular control with multiplane activities at low-to-medium velocity without pain or swelling. During this phase, running, strengthening, and impact control exercises were progressed further. Drills were initiated to replicate work-specific or sport-specific demands. The goal of this final phase was to achieve dynamic neuromuscular control with multiplane activities at high velocity and asymptomatic unrestricted participation in work-specific or sport-specific activities.

Data collection

Data collection was performed at the initial visit and at 2 months (questionnaires), 6 months (questionnaires and clinical tests) and 1 year (questionnaires, clinical tests and MRI) after start of treatment (date of surgery or physiotherapy referral). We chose not to use date of injury as baseline considering the potential delay between injury and diagnosis[46,51,173] associated with this injury as well as potential treatment delay.

Questionnaires

Questionnaires included the Perth Hamstring Assessment Tool (PHAT)[174], Proximal Hamstring Injury Questionnaire (PHIQ)[82], EQ-5D-3L and Tegner Activity Scale (TAS)[175]. The PHAT (0–100, higher scores correspond with better outcome) consists of four questions on symptoms of pain/discomfort and level of activity specific for proximal hamstring tendon injury. It has high reproducibility (ICC: 0.84) and a minimal detectable change of 16.4 points[174]. The PHIQ is a hamstring avulsion-specific questionnaire consisting of 11 questions on proximal hamstring tendon-specific symptoms, functional restrictions, subjective rate of recovery, and sports participation. No data on its psychometric properties are available. The PHAT and PHIQ were chosen as they specifically explore symptoms and functional limitations resulting from proximal hamstring tendon injury. The EQ-5D-3L and TAS were chosen to explore recovery more broadly in terms of quality of life, activities of daily living function and activity level. Details on the questionnaires are available in online supplementary appendix B.

Clinical tests

Tests to assess hamstring flexibility and strength were performed by one of five male physicians. Hamstring flexibility was measured in two positions: the passive straight leg raise (PSLR)[142] and active knee extension test (AKET)[176]. Isometric knee flexor strength was assessed with a Hoggan MicroFET2 handheld dynamometer (Hoggan Scientific, Salt Lake City, Utah, USA) in three positions: prone 0°/90° (°hip flexion/°knee flexion), prone 0°/15° and supine 90°/90°[176,177]. Patients were verbally encouraged to perform a maximal voluntary contraction for 3 s while the tester held the dynamometer in place. We recorded the best of three efforts per position per leg in Newtons. If a patient reported onset of pain (pain score ≥3/10), that specific measurement was terminated. Previously reported inter-rater reliability for these testing positions was good (ICC 0.76–0.84)[140,177]. Detailed measurement methods are included in online supplementary appendix B.

MRI

The MRI protocol is included in online supplementary appendix B. MRIs were scored by an experienced musculoskeletal radiologist (FS). Assessment included proximal continuity, direct tendon retraction, fatty infiltration and assessment of the sciatic nerve.

Continuity of the hamstring tendons with the ischial tuberosity was scored as either absent, continuity by means of separate tendons, or by a shared tendon (tendons are scarred together and attached to the ischial tuberosity with an organised, tendon-like structure) (figure 1). Direct retraction was defined as the shortest distance between mid-origin and most proximal margin of the tendon stump[178]. Fatty infiltration per individual hamstring muscle was scored using a modified MRI version of the Goutallier classification[179] (normal-to-mild: normal muscle or fatty streaks, moderate: fat ≤muscle and severe: fat >muscle). The sciatic nerve was evaluated for increased signal intensity, enlargement and contact with perinervous scar tissue.

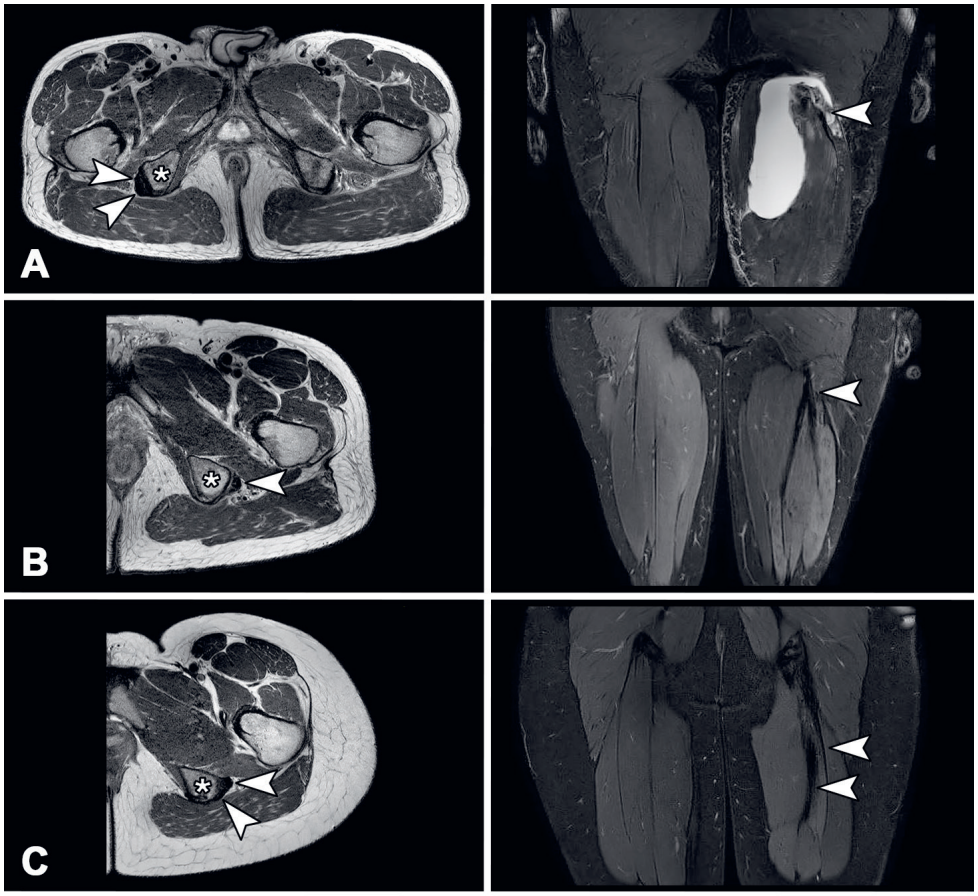

Figure 1. MRI assessment of proximal continuity following left-sided injuries. (A) No continuity. The axial image demonstrates both the conjoint (CT) and semimembranosus (SM) tendon (arrows) attached to the ischial tuberosity (asterisk) on the right but no tendons attaching on the left. The coronal image demonstrates discontinuity with the (hypointense) CT stump (arrow) in a haematoma indicating acute injury. (B) Continuity by a shared tendon at follow-up. The axial image shows a single attached neotendon (arrow) on the ischial tuberosity (asterisk). The coronal image demonstrates merging of both the CT and SM tendons (arrow) into a joint neotendon that courses proximally. (C) Continuity by separate tendons (arrows) on the ischial tuberosity (asterisk) at follow-up.

Primary outcome

The primary outcome was the PHAT score at 1 year after start of treatment.

Secondary outcomes

Secondary outcome measures included questionnaires (PHAT score and PHAT score change, PHIQ, EQ-5D-3L and TAS), rate of and time to RTS, and recurrence rate at 2 months, 6 months and 1 year after start of treatment. We additionally report clinical tests (hamstring flexibility and isometric strength) at 6 months and 1 year, and MRI findings at 1 year. RTS was recorded as: (1) return to the same sport at pre-injury level, (2) at a lower level, (3) in different sports or (4) no RTS. We also recorded time to RTS (in any sport at any level, in weeks from injury). Recurrence was defined as an MRI-confirmed full-thickness injury of ≥1 proximal free hamstring tendon(s) in the same leg within 1-year follow-up. Patients were instructed to contact the coordinating researcher in case of suspected adverse events.

Statistical analysis

Analysis was performed using SPSS (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, V.26.0. IBM). Descriptive data are presented as appropriate. Normality of data was assessed visually using histograms and normal Q-Q plots. Patients were analysed by intention to treat.

To test for the between-group differences in PHAT score at 1 year and PHAT score change in 1 year, a repeated measures general linear model was used. To test for between-group differences in secondary outcome measures at 1 year, we used χ^2 tests and independent t-tests/Mann-Whitney U tests.

Post-hoc analysis

In a post hoc analysis for the primary outcome, adjustments were made for baseline variables (online supplementary appendix B) that influenced the primary outcome with $p<0.1$. As between-group differences at baseline could potentially be attributed to timing of the initial visit, we repeated this sensitivity analysis with 'time between injury and initial visit' as covariate instead of 'time between injury and start of treatment', as well as the combination of both, to explore whether our choice of included time variable impacted outcome.

In case of missing data, data from the last observation were carried forward. Additional best-case/worst-case scenario analyses were performed in which highest and lowest values were entered for missing PHAT values.

Results

We included 59 patients (figure 2); 26 (44%) women and 33 (56%) men with a median age of 51 (IQR: 45–56). Twenty-six (44%) patients received operative and 33 (56%) patients received non-operative treatment. There were no crossovers. Baseline data are presented in table 1. Operative patients presented significantly earlier after injury (median 12 vs 21 days, $p=0.004$) with significantly larger hamstring flexibility deficits (–34° and –28° compared with –12° and –11° for PSLR and AKET respectively, $p<0.01$), lower isometric strength (39%, 0% and 32% of contralateral strength compared with 64%, 32% and 50% in the prone 0/90, prone 0/15 and supine 90/90 positions $p<0.01$), and lower PHAT scores (32±16 vs 45±17, $p=0.003$).

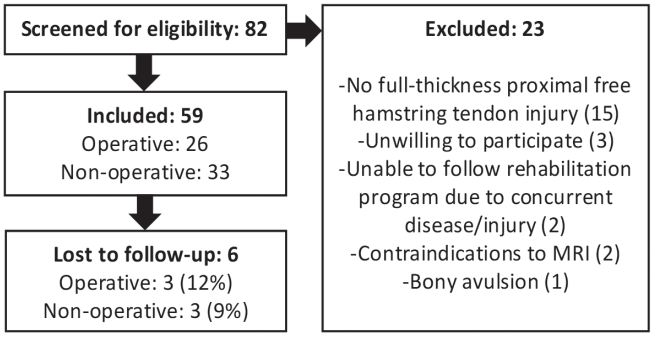

Figure 2. Flow chart of inclusion process.

MRI demonstrated avulsion of both proximal tendons in 53 (90%) patients, isolated conjoint tendon avulsion in 2 (3%) and isolated semimembranosus tendon avulsion in 4 (7%). In the operative group, all injuries involved both tendons. In the non-operative group both tendons were affected in 27 (82%) patients, the conjoint tendon in 2 (6%) and the semimembranosus tendon in 4 (12%).

Median time between injury and start of treatment was 30 (IQR: 21–45) days in the operative group and 21 days (IQR: 12–48) in the non-operative group.

Clinical outcome

- Primary outcome

PHAT scores in the operative and non-operative group at 1-year follow-up were 80±19 vs 80±17 (figure 3). There was no between-group difference in mean PHAT score at 1-year follow-up (p=0.97). There was no between-group difference in mean adjusted PHAT score at 1-year follow-up (p=0.23). The post hoc analyses with different time covariates did not change outcome. Best-case/worst-case scenario analyses also revealed similar outcomes (online supplementary appendix B).

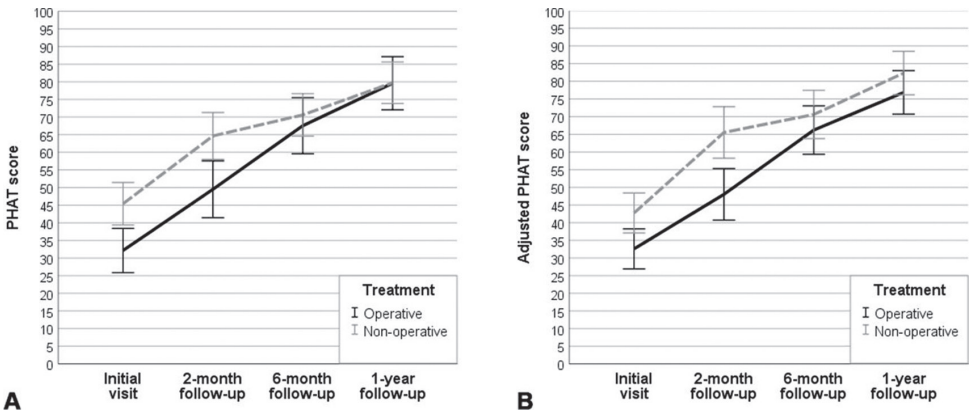

Figure 3. Mean (95% CI) unadjusted Perth Hamstring Assessment Tool (PHAT) score (0–100) (A) and adjusted score (B) for operative (solid line) and non-operative group (dashed line) at initial visit and at 2-month, 6-month and 12-month follow-up.

Table 1. Demographic data, clinical tests and MRI characteristics at initial visit.

		Operative N=26	Non-operative N=33	Total N=59	P
Demographic data					
Gender	Female	11 (42%)	15 (45%)	26 (44%)	0.81
	Male	15 (58%)	18 (55%)	33 (56%)	
Age		51 (IQR: 37-57)	49 (IQR: 45-56)	51 (IQR: 45-56)	0.85
Level of participation	No sports	1 (4%)	2 (6%)	3 (5%)	0.26
	Recreational	13 (50%)	19 (58%)	32 (54%)	
	Competitive	10 (38%)	12 (36%)	22 (37%)	
	Professional	2 (8%)	0 (%)	2 (3%)	
Days from injury to initial visit		12 (IQR: 6-19)	21 (IQR: 12-48)	15 (IQR: 9.5-39)	0.004
Days from injury to start of treatment		30 (IQR: 21-45)	21 (IQR: 12-48)	29 (IQR: 16-47)	0.35
Acute or delayed treatment	Acute (≤8 weeks)	22 (85%)	26 (79%)	48 (81%)	0.57
	Delayed (>8weeks)	4 (15%)	7 (21%)	11 (19%)	
Clinical tests					
Hamstring flexibility (° difference with contralateral leg)	PSLR	-34±18	-12±17	-21±20	<0.001
	AKET	-28±19	-11±17	-18±20	0.001
Isometric hamstring strength (% of contralateral leg)	Prone 0°/90°*	39 (IQR: 24.5-45.5)	64 (IQR: 50-86.5)	50 (IQR: 39-65.5)	<0.001
	Prone 0°/15°*	0 (IQR: 0-26)	32 (IQR: 20.5-50)	26.5 (IQR: 0-43)	0.001
	Supine 90°/90°*	32±17	50±22	43±22	0.003
MRI					
Side of injury	Right	14 (54%)	12 (36%)	26 (44%)	0.18
	Left	12 (46%)	21 (64%)	33 (56%)	
Tendon(s) with proximal full-thickness free tendon discontinuity	Conjoint tendon	0 (0%)	2 (6%)	2 (3%)	0.07
	Semimembranosus tendon	0 (0%)	4 (12%)	4 (7%)	
	Both tendons	26 (100%)	27 (82%)	53 (90%)	
Tendon retraction	Conjoint tendon (mm)	33 (IQR: 25-60)	63 (IQR: 28-83)	47 (IQR: 26-71)	0.12
	>20 mm	21/26 (81%)	23/29 (79%)	44/55 (80%)	0.89
	Semimembranosus (mm)	40 (IQR: 27-71)	74.5 (IQR: 31-91)	57 (IQR: 28-84)	0.08
	>20 mm	25/26 (96%)	25/31 (81%)	50/57 (88%)	0.08
Sciatic nerve†	Increased signal intensity	16 (62%)	18 (55%)	34 (58%)	0.59
	Enlargement	21 (81%)	24 (73%)	45 (76%)	0.47
	Contact with peri-nervous scarring	4 (15%)	11 (33%)	15 (25%)	0.12
Questionnaires					
TAS (before injury)		5.5 (IQR: 4-7.5)	6 (IQR: 4-7)	6 (IQR: 4-7)	0.71
PHAT score		32±16	45±17	40±18	0.003

*Degrees hip/knee flexion. †More than one answer possible. AKET: active knee extension test, PHAT: Perth Hamstring Assessment Tool, PSLR: passive straight leg raise, TAS: Tegner Activity Scale.

Table 2. Clinical outcome at 2-month follow-up, 6-month follow-up and 1-year follow-up.

		2-month follow-up		
		Operative N=26	Non-operative N=33	Total N=59
Return to sports (RTS)	RTS at pre-injury level	0 (0%)	3 (9%)	3 (5%)
	RTS at different level	2 (8%)	2 (6%)	4 (7%)
	RTS in different sport	1 (4%)	8 (24%)	9 (15%)
	No RTS	21 (84%)	18 (55%)	40 (68%)
	No sports prior to injury	1 (4%)	2 (6%)	3 (5%)
Time to RTS (weeks)				
Recurrence		0 (0%)	0 (0%)	0 (0%)
Clinical tests				
Hamstring flexibility (difference with contralateral leg in °)	PSLR			
	AKET			
Isometric hamstring strength (% of contralateral leg)	Prone 0°/90°*			
	Prone 0°/15°*			
	Supine 90°/90°*			
Questionnaires				
EQ-5D-3L	Mobility†	13 (50%)	22 (67%)	35 (59%)
	Self-care†	17 (65%)	32 (97%)	49 (83%)
	Usual activities†	8 (31%)	22 (67%)	30 (51%)
	Pain/discomfort†	11 (42%)	15 (46%)	26 (44%)
	Anxiety/depression†	22 (85%)	30 (91%)	52 (88%)
	Quality of life (VAS)	70±17	75±16	73±16
		N=20	N=25	N=45
TAS		2 (IQR: 2-4)	4 (IQR: 3-4)	4 (IQR: 2-4)
PHIQ	Pain (past week, VAS)	2 (IQR: 1-4)	0 (IQR: 0-2.5)	1 (IQR: 0-3)
	Use of pain medication	6 (30%)	4 (17%)	10 (22%)
	Stiffness in injured leg	11 (55%)	10 (40%)	21 (47%)
	Numbness/tingling in injured leg	7 (35%)	11 (44%)	18 (40%)
	Self-estimated recovery‡	0 (0%)	1 (4%)	1 (2%)
	Self-estimated strength‡	0 (0%)	1 (4%)	1 (2%)
	Satisfied with outcome	11 (55%)	12 (48%)	23 (51%)
	Sports participation (hours/week)	0 (IQR: 0-2.5)	4 (IQR: 0-6.5)	1 (IQR: 0-4.5)

6-month follow-up			1-year follow-up			
Operative N=26	Non-operative N=33	Total N=59	Operative N=26	Non-operative N=33	Total N=59	P
2 (8%)	7 (21%)	9 (15%)	7 (27%)	11 (33%)	18 (31%)	0.80
8 (31%)	5 (15%)	13 (22%)	10 (39%)	12 (36%)	22 (37%)	
5 (19%)	9 (27%)	14 (24%)	2 (8%)	4 (12%)	6 (10%)	
10 (39%)	10 (30%)	20 (34%)	6 (23%)	4 (12%)	10 (17%)	
1 (4%)	2 (6%)	3 (5%)	1 (4%)	2 (6%)	3 (5%)	
			25 (IQR: 20-33.5)	24 (IQR: 16-36)	24 (IQR: 16-36)	0.71
0 (0%)	0 (0%)	0 (0%)	1 (4%)	0 (0%)	1 (2%)	0.26
-6±10	2±11	-2±11	0±9	2±10	1±9	0.63
-2±10	3±11	1±10	0±9	4±10	3±9	0.12
67.5 (IQR: 64-80)	84.5 (IQR: 74.5-93)	76 (IQR: 66.5-92.5)	73 (IQR: 64-81.5)	91 (IQR: 80-96)	82.5 (IQR: 73-94)	<0.001
62 (IQR: 51.5-70)	54.5 (IQR: 45.5-73.5)	61.5 (IQR: 47.5-72.5)	66.5 (IQR: 54-80)	60 (IQR: 46-74.5)	63.5 (IQR: 50.5-77.5)	0.12
77.5 (IQR: 68-95.5)	72.5 (IQR: 61.5-85)	76 (IQR: 65.5-86.5)	78 (IQR: 64-93.5)	76.5 (IQR: 68-89)	77 (IQR: 66.5-91)	0.87
17 (65%)	24 (73%)	41 (70%)	22 (85%)	23 (70%)	45 (76%)	0.18
22 (85%)	33 (100%)	55 (93%)	25 (96%)	33 (100%)	58 (98%)	0.26
15 (58%)	23 (70%)	38 (64%)	19 (73%)	26 (79%)	45 (76%)	0.61
10 (39%)	18 (55%)	28 (48%)	14 (54%)	19 (58%)	33 (56%)	0.78
21 (81%)	31 (94%)	52 (88%)	25 (96%)	32 (97%)	57 (97%)	0.86
80±16	75±15	78±15	83±12	83±15	83±13	0.86
N=20	N=25	N=45	N=20	N=25	N=45	
4 (IQR: 3.5-5)	4 (IQR: 4-6)	4 (IQR: 4-5)	4.5 (IQR: 4-6)	5 (IQR: 5-6)	5 (IQR: 4-6)	0.13
1 (IQR: 1-2.5)	1 (IQR: 0-2)	1 (IQR: 0-2)	1 (IQR: 0-2)	1 (IQR: 0-2)	1 (IQR: 0-2)	0.38
6 (30%)	5 (20%)	11 (24%)	2 (10%)	1 (4%)	3 (7%)	0.43
16 (80%)	12 (48%)	28 (62%)	12 (60%)	7 (28%)	19 (42%)	0.03
3 (15%)	10 (40%)	13 (29%)	2 (10%)	10 (40%)	12 (27%)	0.03
1 (5%)	4 (16%)	5 (11%)	4 (20%)	6 (24%)	10 (22%)	0.75
0 (0%)	1 (4%)	1 (2%)	2 (10%)	3 (12%)	5 (11%)	0.83
15 (75%)	10 (40%)	25 (56%)	17 (85%)	19 (76%)	36 (80%)	0.46
2.5 (IQR: 0-6)	3.5 (IQR: 2-5.5)	3 (IQR: 2-6)	4.5 (IQR: 0-6.5)	4 (IQR: 2.5-7)	4 (IQR: 2-7)	0.37

*Degrees hip/knee flexion. †% of patients reporting no symptoms/problems. ‡% of patients estimating recovery at 100%. AKET: active knee extension test, PHIQ: proximal hamstring injury questionnaire, PSLR: passive straight leg raise, TAS: Tegner Activity Scale, VAS: Visual Analogue Scale.

- Secondary outcome

An overview of secondary clinical outcome measures is provided in table 2.

The increase in mean PHAT score after 1 year in the operative group was 47 points (95% CI 39 to 55, p<0.001) and 34 points (95% CI 27 to 41, p<0.001) in the non-operative group (figure 3). The adjusted increase in mean PHAT score after 1 year in the operative group was 44 (95% CI 37 to 51, p<0.001) and 40 (95% CI 32 to 47, p<0.001) in the non-operative group. We adjusted for injured side, tendon retraction, perinervous scarring and days from injury to start of treatment.

In the operative group 6 (23%) patients did not return to sports at 1 year and 7 (27%) had returned to sports at pre-injury level. In the non-operative group, 4 (12%) did not return to sports and 11 (33%) had returned to sports at pre-injury level. Time to RTS for the operative and non-operative group was median 25 (IQR: 20–33.5) and 24 (IQR:16–36) weeks. There were no statistically significant between-group differences in rate of and time to RTS. There was 1 (4%) recurrence in the operative group due to a waterskiing accident after 10 months.

Hamstring flexibility was near-symmetrical, without significant between-group differences. Isometric strength deficits were present in both groups. Operative patients had isometric hamstring strength (% of contralateral leg) of 73% (IQR 64–81.5), 66.5% (IQR 54–80) and 78% (IQR 64–93.5) in the prone 0/90, prone 0/15 and supine 90/90 positions. Non-operative patients had 91% (IQR 80–96), 60% (IQR 46–74.5) and 76.5% (IQR 68–89). Isometric strength in the prone 0/90 position was significantly higher in the non-operative group (p<0.001).

There were no significant between-group differences in TAS and EQ-5D-3L responses. The PHIQ revealed a significantly higher rate of stiffness (60% vs 28%, p=0.03) and lower rate of numbness and/or tingling in the injured leg (10% vs 40%, p=0.03) in the operative group compared with the non-operative group. There were no infections, deep vein thromboses, nor iatrogenic sciatic nerve injuries. At final follow-up, 96% of operative patients and 91% of non-operative patients stated that they would make the same treatment choice again (p=0.45).

Radiological outcome

Radiological outcomes are presented in table 3. MRI was available at 1 year for 21 (81%) operative and 27 (82%) non-operative patients. Proximal continuity was present in 20 (95%) operative and 14 (52%) non-operative patients (p<0.008). The only operative patient without proximal continuity at follow-up had sustained a re-injury due to a second water-skiing accident before the 1-year follow-up MRI. After excluding this re-injury, proximal continuity at follow-up was present in 100% of operative patients. In the non-operative group, restoration of continuity was significantly associated with tendon retraction in mm (OR 0.96, 95% CI 0.92 to 0.99, p=0.02).

Discussion

Our prospective study of patients with proximal hamstring tendon avulsions showed that when a shared decision-making model of care was used, at 1-year follow-up: (1) clinical outcomes were comparable for operative and non-operative patients, (2) non-operative patients have better clinical outcome than previously assumed when treated using a phased rehabilitation programme and (3) proximal continuity of the hamstring complex was restored in approximately half of non-operative patients and nearly all operative patients.

Table 3. Radiological outcome at 1-year follow-up.

			Operative N=21	Non-operative N=27	Total N=48	P
Proximal free hamstring tendon continuity	No continuity		1 (5%)*	13 (48%)	14 (29%)	0.008
	Continuity (shared tendon)		15 (71%)	11 (41%)	26 (54%)	
	Continuity (separate tendons)		5 (24%)	3 (11%)	8 (17%)	
Fatty infiltration	Biceps femoris	Normal-to-mild	10 (48%)	6 (22%)	16 (33%)	0.16
		Moderate	8 (38%)	19 (70%)	27 (56%)	
		Severe	3 (14%)	2 (7%)	5 (10%)	
	Semitendinosus	Normal-to-mild	5 (24%)	9 (33%)	14 (29%)	0.50
		Moderate	15 (71%)	14 (52%)	29 (60%)	
		Severe	1 (5%)	4 (15%)	5 (10%)	
	Semimembranosus	Normal-to-mild	11 (52%)	6 (22%)	17 (35%)	0.19
		Moderate	9 (43%)	19 (70%)	28 (58%)	
		Severe	1 (5%)	2 (7%)	3 (6%)	
Sciatic nerve†	Increased signal intensity		0 (0%)	3 (11%)	3 (6%)	0.12
	Enlargement		7 (33%)	15 (56%)	22 (46%)	0.13
	Contact with peri-nervous scarring		14 (67%)	18 (67%)	32 (67%)	1.00

*Follow-up MRI made after re-injury. †More than one answer possible.

Outcomes for operative and non-operative treatment groups

There is a lack of published data on non-operative outcomes. In this study, more than half of patients chose non-operative treatment after shared decision-making. This study contributes the largest group of non-operative patients to gain insight into non-operative outcomes, guide decision-making and help set patients' expectations. While operative and non-operative treatment resulted in similar clinical outcome at 1-year follow-up, it should be noted that operative patients had lower baseline PHAT scores. It is conceivable that baseline PHAT scores in the operative group were lower because this group presented significantly earlier after injury, but could alternatively indicate worse injury and/or 'collateral' damage to adjacent tissues. It is unclear whether between-group differences in PHAT increase can be attributed to a treatment effect. Based on the adjusted analysis, differences in outcomes between operative and non-operative treatment may be more subtle than assumed to date[44,49–51]. While this cannot be strongly stated because treatment was not randomly allocated, our findings indicate that further comparative studies are necessary and justified.

Aside from treatment effects, there are several potential confounders for outcome to consider as prognostic factors based on the adjusted analysis: we adjusted for injured side,

tendon retraction, perinervous scarring, and days from injury to start of treatment. Tendon retraction and timing of surgery have previously been proposed as prognostic factors for clinical outcome[51,68,160,161]. Accordingly, we noted that increased retraction and time from injury to start of treatment negatively impacted PHAT score improvement. Injuring the dominant leg potentially leads to more functional restrictions considering that a right-sided injury resulted in less improvement in PHAT score. Perinervous scarring on MRI also resulted in less PHAT improvement, potentially indicating that neurolysis may be required for symptom relief.

Return to sport and hamstring strength

Comparing the RTS of this study's cohort with the existing literature reveals similar outcomes, despite our shorter follow-up. RTS is difficult to compare as it is defined variably across studies. In a recent systematic review with approximately 3 to 4 years follow-up, RTS and return to pre-injury level were combined. The reported rates of RTS for operative and non-operative patients were 80% and 71%, which is in line with our findings. However, in our study a substantial proportion did so in other sports (8% in operative and 12% in non-operative patients) or at a lower level (39% and 36%). These findings indicate that return to pre-injury sports at pre-injury level is unrealistic within 1 year for a subset of patients. Persistent hamstring strength deficits, noted in both groups, have also been highlighted in previous smaller retrospective studies with longer follow-up[46,51,131,159]. In these studies, however, operative treatment resulted in superior hamstring strength and RTS rates compared with non-operative treatment[51,131]. It is possible that operative intervention is an 'investment' for superior long-term results, but this should be corroborated in larger prospective long-term analyses.

Continuity restoration and fatty infiltration on MRI

Radiological outcome after proximal hamstring tendon avulsion injury is sparsely reported and limited to postoperative patients. Available studies noted tendon healing after operative treatment in all cases with no-to-mild fatty infiltration of the hamstrings[76,79,81]. We found tendon continuity in 52% of non-operative patients, mostly by a shared neotendon. While the distal semitendinosus tendon is known to 'regenerate' after being harvested for anterior cruciate ligament reconstruction in 60%–72%[180], this is a novel finding for the proximal hamstrings. We hypothesised that a 'neotendon' develops from longitudinal scar tissue in the lateral haematoma wall on resorption. Contrary to previous studies, we noted varying degrees of fatty infiltration in a substantial proportion of patients. Its clinical significance is unknown. Fatty infiltration in rotator cuff injury has been linked to decreased muscle function[181] and appears irreversible after a certain stage[182], with potential implications for prognosis. It is conceivable that fatty infiltration is associated with hamstring strength deficits.

Strengths and limitations

Strengths include a prospective study design and a uniform rehabilitation protocol for both groups. Obvious limitations include the lack of random treatment allocation, lack of assessor blinding for clinical outcome, and the relatively small sample size. These limitations introduce risk of selection bias and assessor bias. The radiologist assessing

radiological outcomes was blinded to clinical data, however, the presence of suture anchors on the follow-up MRI revealed which treatment the patient had undergone. As the shared decision-making process evolved over time, despite being beneficial for patient care, reproducibility is affected. Due to shared decision-making, psychosocial differences in addition to baseline differences in demographics and injury characteristics can be expected. Due to the duration of follow-up in this study, conclusions regarding long-term outcomes cannot be drawn.

Implications for clinical practice and future research

This study can serve to set patient expectations and underlines the clinical value of a shared decision-making model. Outcomes at 1-year follow-up were equally good in both groups with high patient satisfaction. More than 90% of patients stated that they would opt for the same treatment again. This indicates that the shared decision-making model succeeds in selecting the appropriate treatment for the individual patient in a predominantly middle-aged population. Our findings and conclusions cannot be generalised to elite athletes.

We recommend this approach until evidence-based indications for operative intervention are available. Regardless of treatment choice, patients should be informed that return to pre-injury level of sports is unrealistic for the majority within the first year. Residual isometric strength deficits and fatty infiltration on MRI are expected. Proximal continuity of the hamstring complex was restored in approximately half of non-operative patients and nearly all operative patients.

As operative repair serves to restore continuity, it is worth investigating whether specific factors (e.g. retraction, mechanical stimulus) can predict or influence spontaneous continuity restoration. By determining prognostic factors, indications for operative repair may be established. In particular, an in-depth analysis of the effect of tendon retraction on continuity restoration, collateral (nerve) damage and consequently functional outcome in a larger sample of non-operative patients would be beneficial to determine its role in decision-making and identify an evidence-based cut-off value. Large prospective analyses should determine whether there are long-term differences in outcomes between operative and non-operative treatment. Our findings indicate that clinical equipoise exists in the described study population, paving the way for randomised controlled trials.

Additionally, the decision-making process would benefit from future studies exploring which patient-specific and injury-specific factors predict the choice for operative or non-operative treatment.

Conclusion

In a shared decision-making model of care, both operative and non-operative patients with a proximal hamstring tendon avulsion have comparable clinical outcomes at 1year follow-up. Operative patients started with lower pre-treatment PHAT scores, but improved substantially to reach equally high PHAT scores as non-operative patients. There were no clinically relevant between-group differences in secondary clinical outcome measures. Operative repair resulted in a significantly higher rate of proximal continuity. Proximal continuity of the hamstring complex was restored in approximately half of non-operative patients and nearly all operative patients. We recommend using this shared decision model of care until evidence-based indications in favour of either treatment option based on high-level clinical trials are available.

PART III

INTRA-MUSCULAR TENDON INJURY

09

INTRAMUSCULAR TENDON INVOLVEMENT ON MRI HAS LIMITED VALUE FOR PREDICTING TIME TO RETURN TO PLAY FOLLOWING ACUTE HAMSTRING INJURY

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Abstract

Background: Hamstring injury with intramuscular tendon involvement is regarded as a serious injury with a delay in return to play (RTP) of more than 50 days and re-injury rates up to 63%. However, this reputation is based on retrospective case series with high risk of bias.

Objective: Determine whether intramuscular tendon involvement is associated with delayed RTP and elevated rates of re-injury.

Methods: MRI of male athletes with an acute hamstring injury was obtained within 5 days of injury. Evaluation included standardised MRI scoring and scoring of intramuscular tendon involvement. Time to RTP and re-injury rate were prospectively recorded.

Results: Out of 70 included participants, intramuscular tendon disruption was present in 29 (41.4%) injuries. Injuries without intramuscular tendon disruption had a mean time to RTP of 22.2±7.4 days. Injuries with <50%, 50%–99% and 100% disruption of tendon cross-sectional area had a mean time to RTP of 24.0±9.7, 25.3±8.6 and 31.6±10.9 days, respectively. Injuries with full-thickness disruption took longer to RTP compared with injuries without disruption (p=0.025). Longitudinal intramuscular tendon disruption was not significantly associated with time to RTP. Waviness was present in 17 (24.3%) injuries. Mean time to RTP for injuries without and with waviness was 22.6±7.5 and 30.2±10.8 days (p=0.014). There were 11 (15.7%) re-injuries within 12 months, five (17.2%) in the group with intramuscular tendon disruption and six (14.6%) in the group without intramuscular tendon disruption.

Conclusion: Time to RTP for injuries with full-thickness disruption of the intramuscular tendon and waviness is significantly longer (by slightly more than 1 week) compared with injuries without intramuscular tendon involvement. However, due to the considerable overlap in time to RTP between groups with and without intramuscular tendon involvement, its clinical significance for the individual athlete is limited.

Introduction

Hamstring injury with involvement of the 'intramuscular'[18,19,24,37] or 'central'[52] tendon is regarded as a serious injury with prolonged recovery time and high re-injury rate. 'Intramuscular' and 'central' tendon refers to the part of the tendon to which muscle fibres attach. In the British Athletics Muscle Injury Classification[53,183], a lesion extending into the tendon is referred to as an 'intratendinous' or 'c' injury and therefore includes injuries of the free and intramuscular tendon.

Comin et al.[52] initially proposed central tendon disruption as a prognostic factor for delayed return to play (RTP). In a retrospective cohort of 62 injuries among Australian rules football and rugby players, 9 biceps femoris injuries with central tendon disruption took a median 72 days to recover. Compared with a median 21 days for biceps femoris injuries with an intact central tendon, this is a threefold to fourfold increase in recovery time. Moreover, 25% of the central tendon injuries were surgically repaired. Pollock et al.[53] retrospectively analysed outcome for track and field athletes with injuries graded according to the British Athletics Muscle Injury Classification[183]. Compared with myofascial or musculotendinous injury, the 15 intratendinous injuries took significantly longer to return to full training and had a re-injury rate of up to 63%. Injuries classified as 3c (longitudinal tendon disruption >5 cm and >50% of tendon cross-sectional area (CSA) with no evident discontinuity) had a mean time to return to full training (TRFT) of 84 days.

Understanding the role of intramuscular tendon involvement is limited by the retrospective study designs and relatively small sample sizes; with a total of 27 published cases and the substantial risk of bias in both studies. The clinicians involved in the decision for RTP were not blinded to the MRI findings. Therefore, influence of MRI results (i.e. the presence or absence of intramuscular tendon involvement) on progression through rehabilitation and the RTP decision cannot be ruled out. This phenomenon has been referred to as a potentially 'self-fulfilling prophecy'[184]: the hypothesis that a certain type of injury takes longer to heal could potentially influence (i.e. delay) the physician's RTP decision, thereby prolonging time to RTP for this type of injury. Given these limitations, prospective studies with blinding are required to determine whether intramuscular tendon involvement may result in delayed resolution.

In this prospective study, our aim was to exclude the risk of bias by blinding the RTP decision-makers to MRI findings and determine whether intramuscular tendon involvement is associated with delayed RTP or elevated rates of re-injury. Our hypothesis was that injuries with intramuscular tendon involvement are associated with prolonged time to RTP and a higher re-injury rate.

Methods

Participants

Participants in this study were part of a double-blind randomised controlled trial on the effect of platelet-rich plasma (PRP) in hamstring injuries (ClinicalTrial.gov number NCT01812564)[38]. Eligibility criteria are shown in Box 1. Participants were athletes with an acute hamstring injury (MRI-confirmed, grades I and II) that were randomised into three groups. Groups received a 3 mL injection of platelet-rich plasma, a 3 mL injection of platelet-poor plasma or no injection. All participants underwent a standardised criteria-based rehabilitation programme. There was no benefit of PRP injection over

intensive rehabilitation in terms of RTP. For the current study, we only included participants with a complete dataset on completion of the rehabilitation programme and clearance by the treating physiotherapist.

Informed consent was obtained at inclusion, and approval was obtained from the Ethical Committee of Aspetar, Orthopaedic and Sports Medicine Hospital.

Box 1. Eligibility criteria

Inclusion criteria

- Age 18-50 years
- Acute onset posterior thigh pain
- MRI within 5 days of injury
- Positive MRI for grade I-II hamstring injury
- Male sex
- Able to perform five physiotherapy sessions per week at the clinic

Exclusion criteria

- Contraindications for MRI
- Chronic hamstring injury or re-injury
- Concurrent injury inhibiting rehabilitation
- Unwilling to comply with follow-up
- No available data on completion of rehabilitation programme
- Needle phobia
- Overlying skin infection
- Diabetes, immunocompromised state
- Medication with increasing bleeding risk
- Medical contraindication to injection

MRI

All MRIs were performed within 5 days of the injury.

MRI protocol

Images were acquired with a 1.5T magnet system (Magnetom Espree, Siemens, Germany) and a body matrix coil. Coronal and axial proton density (PD) weighted images (repetition time (TR)/ time to echo (TE) 3000/32 ms; field of view (FOV) 240 mm; slice thickness 5 mm; matrix, 333×512) were obtained. Subsequently, coronal and axial PD-weighted images with fat saturation (PD-FS) were obtained (TR/TE 3000/32 ms; FOV 240 mm; slice thickness 3.5 mm; matrix 326×512 for coronal and TR/ TE 3490/27 ms; FOV 320 mm; slice thickness 3.5 mm; matrix 333×512 for axial).

MRI characteristics

MRIs were scored by an experienced musculoskeletal radiologist using standardised scoring forms including size and location of the injury. If more than one muscle was involved, the muscle with the primary (i.e. largest) injury was determined. The radiologist was blinded to clinical details of the injury.

The intramuscular tendon was defined as the section of the tendon that extends along and into the muscle, thereby having muscle fibres attached to it. The free tendon (either proximal or distal) has no muscle fibres attached[8] (Figure 1).

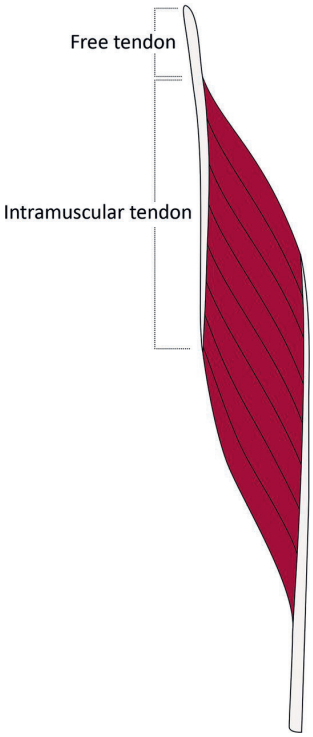

Figure 1. Schematic overview of the free and intramuscular tendon.

We incorporated the components of the central tendon injuries[52] and 'c-injuries' in the British Athletics Muscle Injury Classification[183] into scoring of the intramuscular tendon. We recorded the presence of tendon disruption (Figure 2A), subdivided into <50%, 50%–99% and 100% of tendon cross-sectional area (CSA), (2) longitudinal tendon disruption and (3) the presence of waviness (Figure 2B).

Disruption was defined as the presence of a focal tendon defect (% of CSA), characterised by loss of low signal intensity within the tendon. Longitudinal tendon disruption (in cm) was scored separately for injuries with partial-thickness and full-thickness tendon disruption. For injuries with partial-thickness tendon disruption, we measured the craniocaudal length of tendon disruption. For injuries with full-thickness tendon disruption, the distance between tendon ends, or retraction, was recorded.

Additionally, the injury was graded according to the modified Peetrons classification[185] (grade 0: no abnormalities on MRI; grade I: oedema without architectural distortion; grade II: oedema with architectural distortion; grade 3: complete rupture of the muscle-tendon unit) and the extent of oedema was measured. Extent of oedema, defined as abnormal high signal intensity on fluid-sensitive sequences, was recorded (in cm) in craniocaudal, anteroposterior and mediolateral directions. Subsequently, cross-sectional area (in cm^2) and volume (in cm^3) were calculated. Distance of the cranial pole of the oedema to the caudal margin of the ischial tuberosity was also measured in centimetre. Excellent reliability has been reported for measuring these MRI parameters in acute hamstring injury[186]. The British Athletics Muscle Injury Classification has been tested for intra-rater and inter-rater reliability, revealing at least substantial agreement in all groups[165,187].

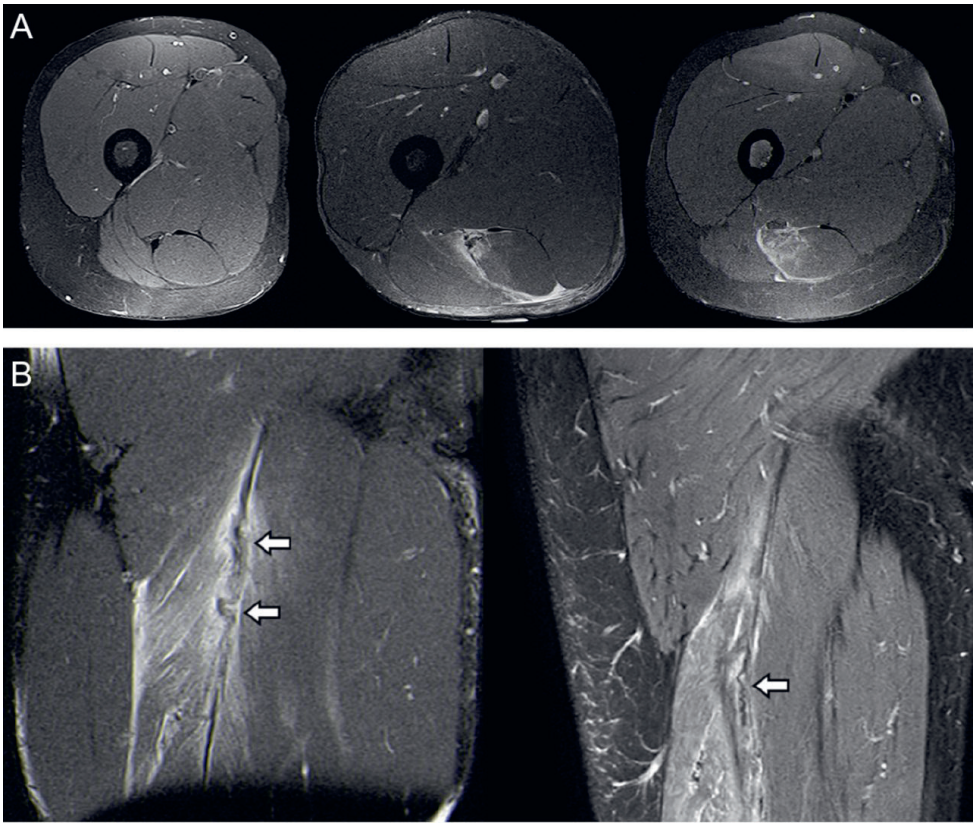

Figure 2. (A) Proton density with fat saturation (PD-FS) weighted axial MR images demonstrating no abnormality of the hamstring tendons (left), partial-thickness disruption of the intramuscular tendon with intrasubstance high signal intensity (middle) and full-thickness intramuscular tendon disruption (right). (B) PD-FS and T2-FS weighted coronal MR images demonstrating evident (left) and more subtle (right) waviness of the intramuscular tendon (arrows).

Outcome measures

- Return to play

Time to RTP was defined as the number of days from injury to completion of a six-stage criteria-based rehabilitation programme, including three sport-specific training phases[141]. Participants progressed from one phase to the next based on predefined clinical progression criteria, while the treating physiotherapist remained blinded to MRI results. The rehabilitation programme was successfully completed when sport-specific activities were performed unrestricted and pain free. Following completion, clearance to RTP was given by the treating physiotherapist.

As recently outlined, there is no uniform RTP definition following hamstring injury[188]. Our chosen definition is an MRI-independent measure of clinical recovery and very closely related to the RTP decision used in clinical practice. For completeness, we also scored the number of days from the injury to clearance by the treating sports medicine physician (SMP), who was not blinded to the MRI results. Guidelines for discharge by the SMP included completion of the rehabilitation programme, results of an isokinetic assessment and clinical evaluation.

- Re-injury rate

Re-injury was defined as acute onset posterior thigh pain occurring during competition or training in the same leg as the index injury within 1 year after RTP. These were subdivided into short-term (≤2 months after RTP), mid-term (≤6 months after RTP) and long-term (≤12 months after RTP) re-injuries. Participants were instructed to consult the hospital or study coordinator in case of any clinical suspicion of a re-injury and were contacted by telephone on a monthly basis.

Statistical analysis

Statistical analysis was carried out with SPSS V.23.0 (SPSS, Chicago, Illinois, USA).

We analysed differences in time to RTP between groups using a multiple regression analysis. In the multiple regression analysis, we controlled for treatment received, MRI grade, extent of oedema and distance of the lesion to the ischial tuberosity, since these have been associated with to time to RTP[18,25,38,41,189–192]. Although a recent systematic review[34] concluded that there is conflicting evidence for these parameters, these variables were included in the analysis to control for any potential effect on time to RTP.

We repeated the analysis to determine whether any effect of intramuscular tendon involvement would also apply to time to RTP if it were defined as the number of days from injury to discharge by the treating SMP.

Pearson correlation tests were carried out to detect a relationship between longitudinal tendon disruption and time to RTP.

Results

Seventy participants with a median age of 24 (IQR 21–30) were included in the analysis (Figure 3). Baseline patient and MRI characteristics are shown in Table 1. Twenty-nine (41.4%) hamstring injuries involved disruption of the intramuscular tendon, including 17 (58.6%) partial-thickness and 12 (41.4%) full-thickness intramuscular tendon injuries. Intramuscular tendon injuries were most often located in the biceps femoris (long head).

Of the 12 full-thickness intramuscular tendon injuries, six were located in the biceps femoris (long head), four were located in the common tendon of the biceps femoris (long head) and the semitendinosus and two were located in the semimembranosus. All 12 athletes were performing at the elite level in Qatar and included nine first division football players, one hockey player, one volleyball player and one decathlete.

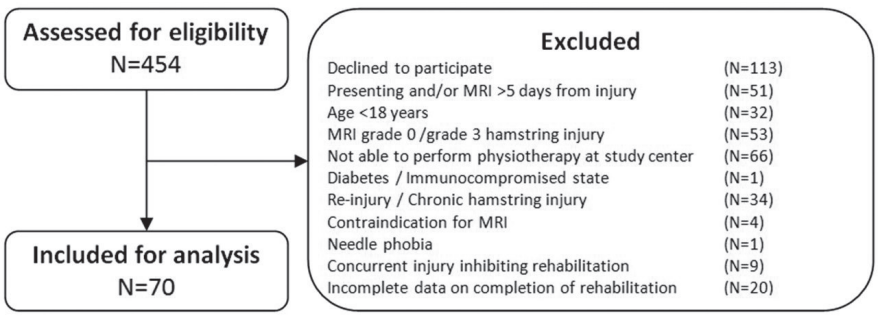

Figure 3. Flowchart of the inclusion process.

Table 1. Baseline demographic and MRI characteristics. Values are presented as mean (±SD) or median (IQR) as appropriate for continuous variables and as frequency (%) for categorical variables.

	N=70
Age (years)	24 (IQR: 21-30)
Sport	
Athletics	3 (4.3%)
Basketball	2 (2.9%)
Decathlon	1 (1.4%)
Football	55 (78.6%)
Futsal	5 (7.1%)
Handball	2 (2.9%)
Hockey	1 (1.4%)
Volleyball	1 (1.4%)
Level of participation	
Professional	69 (98.6%)
Competitive	1 (1.4%)
Side of injury	
Right	36 (51.4%)
Left	34 (48.6%)
Muscle injured	
Biceps femoris (long head)	56 (80.0%)
Biceps femoris (short head)	0 (0.0%)
Semitendinosus	2 (2.9%)
Semimembranosus	12 (17.1%)
MRI grade	
Grade 1	34 (48.6%)
Grade 2	36 (51.4%)
Oedema dimensions	
Cranio-caudal length (cm)	16.4±6.5
Cross-sectional area (cm^2)	17.6 (IQR: 6.3-38.9)
Volume (cm^3)	53.9 (IQR: 14.6-110.1)
Distance to ischial tuberosity (cm)	9.4 (IQR: 3.2-16.3)
Intramuscular tendon involvement	
No intramuscular tendon disruption	41 (58.6%)
Intramuscular tendon disruption	29 (41.4%)
<50% of tendon CSA	5 (17.2%)
50-99% of tendon CSA	12 (41.4%)
100% of tendon CSA	12 (41.4%)
Biceps femoris (long head)	17 (58.6%)
Biceps femoris (long head) & Semitendinosus	7 (24.1%)
Semimembranosus	5 (17.2%)
Longitudinal tendon disruption	
Length of intramuscular tendon disruption (cm)	6.6±2.2 (n=17)
Retraction (cm)	4.4±3.2 (n=12)
Waviness	
Present	17 (24.3%)
Absent	53 (75.7%)

Intramuscular tendon and time to RTP

Mean time to RTP was 24.5±8.9 days. Mean time to RTP in participants without and with intramuscular tendon disruption was 22.2±7.4 and 27.7±10.0 days, respectively. Only injuries with full-thickness intramuscular tendon disruption were correlated with a significantly longer time to RTP compared with injuries without intramuscular tendon disruption ($F(9,58)=2.61$, $p=0.025$, $R^2=0.29$, $R^2_{adjusted}=0.18$) (Figure 4A and Table 2). There was no significant correlation between longitudinal tendon disruption and time to RTP (Pearson correlation coefficient=0.125, p=0.632 for length of tendon disruption in partial-thickness tendon tears and Pearson correlation coefficient=0.114, p=0.724 for retraction in full-thickness tendon tears).

Waviness was present in 17 (24.3%) of all injuries and in 17 (58.6%) of the intramuscular tendon injuries. All injuries with the presence of waviness had either 50%–99% or 100% disruption of intramuscular tendon CSA. Eleven injuries (91.7%) with full-thickness disruption of the intramuscular tendon had the presence of waviness on MRI, compared with six injuries (50.0%) with 50%–99% disruption of tendon CSA. Mean time to RTP for injury without and with waviness was 22.6±7.5 and 30.2±10.8, respectively ($F(7,60)=3.20$, $p=0.014$, $R^2=0.27$, $R^2_{adjusted}=0.19$) (Figure 4B).

In 48.6% of cases, participants were discharged by the SMP the same day the rehabilitation programme was successfully completed. The median number of days between completion of the criteria-based rehabilitation programme and discharge by the SMP was 1 (IQR 0–3) day. For completeness, an additional analysis was performed with time to RTP defined as the number of days from injury to discharge by the treating SMP. This revealed equivalent results.

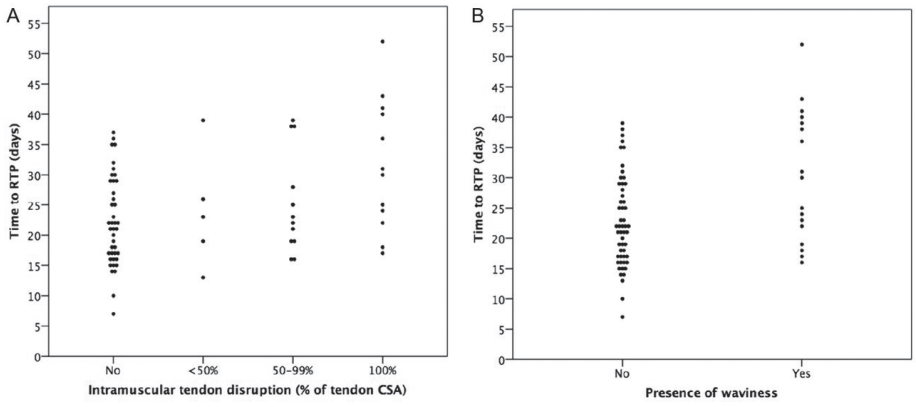

Figure 4. (A) Scatter plot of time to RTP (in days) for injuries without intramuscular tendon disruption and injuries with increasing degrees of intramuscular tendon disruption. (B) Scatter plot of time to RTP (in days) for injuries without and with waviness. CSA: cross-sectional area, RTP: return to play.

Table 2. Time to RTP and re-injuries for injuries without intramuscular tendon disruption and injuries with increasing degrees of intramuscular tendon disruption.

	N	Time to RTP (days)	Re-injury ≤2 months	Re-injury ≤6 months	Re-injury ≤12 months
Overall	70	24.5±8.9	6 (8.6%)	8 (11.4%)	11 (15.7%)
No intramuscular tendon disruption	41	22.2±7.4	3 (7.3%)	4 (9.8%)	6 (14.6%)
Intramuscular tendon disruption	29	27.7±10.0*	3 (10.3%)	4 (13.8%)	5 (17.2%)
<50% of tendon CSA	5	24.0±9.7*	0 (0%)	0 (0%)	0 (0%)
50-99% of tendon CSA	12	25.3±8.6*	1 (8.3%)	2 (16.7%)	3 (25.0%)
100% of tendon CSA	12	31.6±10.9†	2 (16.7%)	2 (16.7%)	2 (16.7%)
No waviness	53	22.6±7.5	3 (5.7%)	5 (9.4%)	8 (15.1%)
Waviness	17	30.2±10.8‡	3 (17.6%)	3 (17.6%)	3 (17.6%)

*No statistically significant difference compared with no intramuscular tendon disruption. †Statistically significant difference compared with no intramuscular tendon disruption ($p<0.05$). ‡Statistically significant difference compared with no waviness. CSA: cross-sectional area, RTP: return to play.

Intramuscular tendon and re-injury rate

All 70 participants were available for the re-injury rate analysis. Re-injury rates are presented in Table 2. In total, there were six (8.6%) recorded re-injuries within 2 months, eight (11.4%) within 6 months and 11 (15.7%) within 12 months. We refrained from further statistical analysis due to the low number of re-injuries.

Discussion

In the largest blinded prospective study on acute hamstring injuries with intramuscular tendon involvement, we found that full-thickness disruption and waviness of the intramuscular tendon are associated with increased time to RTP. Compared with injuries without intramuscular tendon involvement, these injuries take slightly more than a week longer to RTP. However, the considerable overlap between groups with and without intramuscular tendon involvement substantially limits the clinical (i.e. predictive) value of intramuscular tendon involvement. No statistically significant differences were found between injuries without intramuscular tendon disruption and injuries with partial-thickness intramuscular tendon disruption. The low number of re-injuries does not allow for statistical comparisons.

The time to RTP for hamstring injuries with intramuscular tendon involvement is considerably shorter than previously reported. Comin et al.[52] studied hamstring injuries in Australian rules football and rugby players. With a median RTP of 72 days, biceps femoris injuries with intramuscular tendon involvement took 51 days longer than biceps femoris injuries without intramuscular tendon involvement (median 21 days). In these groups, we have found a mean time to RTP of 28 and 22 days. Pollock et al.[53] investigated hamstring

injuries in track and field athletes and presented separate data for different grades with tendon involvement. They reported a mean TRFT of up to 84 days. To be exact, mean TRFT was 27 days for 2c injuries (longitudinal tendon disruption <5 cm and <50% of tendon CSA) and 84 days for 3c injuries (longitudinal tendon disruption >5 cm and >50% of tendon CSA with no evident discontinuity). Pollock et al. reported no 4c injuries (complete discontinuity of the tendon with retraction). In the present study, participants with an acute hamstring injury involving <50% of tendon CSA had a mean time to RTP of 24 days, and those with an injury involving 50%–99% of tendon CSA had a mean time to RTP of 25 days. Moreover, in the present study, injuries involving a full-thickness tear of the intramuscular tendon had a mean time to RTP of 32 days.

Differences in time to RTP between studies may be attributable to several methodological differences. First, an element of the RTP differences may be explained by the different sports of the participants, as different sports have different (functional) requirements. Second, it is highly unlikely that treatment protocols are identical across studies. However, a comparison is not possible due to a limited description of the rehabilitation programmes. Third, in each study, a different definition of time to RTP was used. Clear definitions enhance communication and comparison and are thus recommended. We refer to the consensus statement by Ardern et al.[193]. Comin et al. used 'recovery time'[52], which was not further specified. Pollock et al. used TRFT, which represented unrestricted training sprint efforts at full pace[53]. As both studies involve a retrospective review of medical records, the physicians involved in the RTP decision were not blinded to MRI characteristics such as intramuscular tendon disruption. This is where the possibility of the aforementioned 'self-fulfilling prophecy' is introduced, which may have caused a delay in RTP in cases with tendon disruption. Finally, the intratendinous ('c') injury described by Pollock et al.[53,183] includes injury of the free tendon, which has been associated with longer time to return to pre-injury level[25].

Due to the large spread of time to RTP, it remains difficult to provide an accurate RTP prognosis for the individual athlete. The contribution of intramuscular tendon involvement on MRI to predicting RTP is limited considering the relatively small differences and substantial overlap between groups. This is in accordance with available evidence on the predictive value of MRI parameters for RTP. Despite a growing number of these studies, a systematic review[34] concluded that there is currently no strong evidence to support that any MRI parameter predicts time to RTP. Wangensteen et al. demonstrated that the additional predictive value of MRI was minimal compared with baseline patient history and clinical examination alone[194]. Even with MRI included in the model, only 32% of the variance in time to RTP could be explained by the included parameters, indicating that it remains a major challenge to accurately predict RTP for the individual athlete. Even though intramuscular tendon involvement was not included as a parameter in Wangensteen et al.'s assessment, our data do not suggest that their conclusion needs to be revisited.

We reported lower re-injury rates for injuries with intramuscular tendon involvement compared with those reported by Pollock et al.[53] (up to 25% and 63%, respectively). Any explanation for this difference would be pure speculation at this point. Future research should investigate reasons for these differences.

Strengths and limitations

To our knowledge, this is the largest cohort with hamstring injuries involving the intramuscular tendon. The main strengths are the prospective study design, blinding of MRI results and the controlled rehabilitation parameters. Moreover, the multivariate analysis allowed us to control for potential covariates.

There are limitations to this study. First, the cohort is relatively homogeneous with predominantly professional football players, potentially reducing the external validity of this study. Twenty athletes were excluded due to incomplete data on completion of rehabilitation, which introduces risk of bias. Second, images were acquired by a 1.5T MRI. It is conceivable that greater diagnostic accuracy might be achieved by using a 3.0T MRI. Third, the number of injuries among different degrees of intramuscular tendon involvement is small. Moreover, the low number of rein-juries does not allow for description of this subgroup. For re-injury analysis, to detect moderate-to-strong associations, more than 20 (re-)injuries would be required[195]. We recorded a total of 11 re-injuries.

Clinical relevance

Following standardised criteria-based rehabilitation without specific adjustments for intramuscular tendon involvement, injury with partial-thickness intramuscular tendon disruption is not associated with prolonged RTP. Time to RTP for injuries with full-thickness disruption and waviness is significantly longer (by slightly more than 1 week) compared with injuries without intramuscular tendon involvement. Based on the differences in time to RTP between groups in this study, intramuscular tendon involvement alone does not warrant surgical intervention. Tendon waviness observed on MRI was only seen in those injuries involving intramuscular tendon injuries with more than 50% of tendon CSA.

Conclusion

In acute hamstring injuries among athletes, full-thickness disruption of the intramuscular tendon and waviness are associated with a longer time to RTP. Compared with injuries without intramuscular tendon involvement, these injuries take slightly more than a week longer to RTP. Partial-thickness and longitudinal intramuscular tendon disruption were not significantly associated with time to RTP. Due to the considerable overlap between groups with and without intramuscular tendon disruption, the clinical significance of intramuscular tendon involvement for the individual athlete is limited.

10

INTRAMUSCULAR TENDON INJURY IS NOT ASSOCIATED WITH AN INCREASED HAMSTRING RE-INJURY RATE WITHIN 12 MONTHS AFTER RETURN TO PLAY

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Abstract

Background: Acute hamstring injury that includes intramuscular tendon injury has been suggested to be associated with increased re-injury risk. These observations were based on a relatively small number of retrospectively analysed cases.

Objective: To determine whether intramuscular tendon injury is associated with higher re-injury rates in acute hamstring injury.

Methods: MRIs of 165 athletes with an acute hamstring injury were obtained within 5 days of injury. Treatment consisted of a standardised criteria-based rehabilitation programme. Standardised MRI parameters and intramuscular tendon injury, the latter subdivided into tendon disruption and waviness, were scored. We prospectively recorded re-injuries, defined as acute onset of posterior thigh pain in the same leg within 12 months after return to play.

Results: Participants were predominantly football players (72%). Sixty-four of 165 (39%) participants had an index injury with intramuscular hamstring tendon disruption, and waviness was present in 37 (22%). In total, there were 32 (19%) re-injuries. There was no significant difference (HR: 1.05, 95% CI 0.52 to 2.12, P=0.898) in re-injury rate between index injuries with intramuscular tendon disruption (n=13, 20%) and without tendon disruption (n=19, 20%). There was no significant difference in re-injury rate ($X^2(1)=0.031$, P=0.861) between index injuries with presence of waviness (n=7, 19%) and without presence of waviness (n=25, 20%).

Conclusion: In athletes with an acute hamstring injury, intramuscular tendon injury was not associated with an increased re-injury rate within 12 months after return to play.

Introduction

Hamstring injuries are infamous in sports due to their high incidence[23,196,197] and their tendency to recur early after return to play (RTP)[31], with re-injury rates ranging from 14% to 63%[29,137,198]. As hamstring (re) injury risk is associated with the number of previous hamstring injuries[137], each new injury makes further injury more likely.

Recently, hamstring muscle injury with tendon injury has emerged as a significant risk factor for re-injury[53]. The tendon can be subdivided into a 'free' (i.e. no attaching muscle fibres) and an 'intramuscular' (i.e. to which muscle fibres are attached) component[8,9,18,19,24–26]. Pollock et al.[53] reported that hamstring muscle injuries with tendon injury (including 1 free tendon injury and 14 intramuscular tendon injuries) were associated with delayed time to return to full training and had significantly higher re-injury rates when compared with those hamstring muscle strains that had no associated tendon injury. At 3 months after RTP, re-injury rates in that study were 33% and 4% after index injuries with and without tendon injury, respectively[53]. This observed difference in re-injury rate would be clinically significant if supported by prospective data.

We recently showed that hamstring muscle injury with intramuscular tendon injury was associated with longer time to RTP (by slightly more than a week)[9]. Unfortunately, there was inadequate power to analyse re-injuries. To address the question of the relevance of associated intramuscular tendon injury in hamstring muscle strain, we combined two prospective cohorts of athletes with an acute hamstring injury who underwent imaging prior to treatment. The aim was to examine whether intramuscular tendon injury conferred an increased re-injury rate.

The null hypothesis was that intramuscular hamstring tendon injury is not associated with re-injury rate within 12 months after RTP.

Methods

Participants

The study participants represent pooled data from two randomised (double-blinded) controlled studies on platelet-rich plasma (PRP) for the treatment of acute hamstring injuries (ClinicalTrials.gov NCT01812564 and Dutch Trial Register 2771)[38,40]. All participants provided written informed consent. Neither study found a benefit of PRP on the time to RTP or re-injury rate. Inclusion and exclusion criteria are shown in Table 1.

Rehabilitation programme

All participants were treated using a criteria-based rehabilitation programme. None of the participants were treated surgically.

The Dutch cohort underwent a three-phase, criteria-based rehabilitation programme[40,199]. During the programme and the ensuing RTP decision, both the athlete and the treating physiotherapist were blinded to MRI findings. The RTP decision was made between the athlete and the treating physiotherapist on completion of the rehabilitation programme, including asymptomatic (e.g. pain and stiffness) full range of motion, full speed sprinting and sport-specific movements[40].

Table 1. Eligibility criteria.

Dutch trial[40]	Qatar trial[38]
Inclusion criteria	
• Age 18 – 50 years • Clinical diagnosis acute hamstring injury • Initial MRI within 5 days of injury • MRI-confirmed grade 1 or 2 hamstring lesion • Second MRI within one week of RTP	• Age 18-50 years • Acute onset of posterior thigh pain • Initial MRI within 5 days of injury • MRI-confirmed grade 1 or 2 hamstring lesion • Gender: Male • Available to perform five sessions physiotherapy a week at the clinic • Available for follow-up
Exclusion criteria	
• Contraindication for MRI • Chronic hamstring injury • Chronic low back pain • Cause of injury is an extrinsic trauma • Not capable of performing rehabilitation • No intention to return to full sports activity • Unwilling to receive intramuscular injections • Previous injection therapy for this injury	• Contraindication for MRI • Re-injury or chronic hamstring injury • Concurrent injury inhibiting rehabilitation • Unwilling to comply with follow-up • Needle phobia • Overlying skin infection • Diabetes, immune-compromised state • Medication increasing bleeding risk • Medical contraindication to injection

A criteria-based, six-phase rehabilitation programme[141] was used in the Qatar cohort. The final three phases prior to RTP comprised an on-field supervised sport-specific programme. The treating physiotherapist was blinded to the MRI findings. On completion of the final phase of the sport-specific programme without pain, the athlete was evaluated by a sports medicine physician for RTP clearance. The RTP clearance was guided by completion of the rehabilitation programme, isokinetic assessment and clinical evaluation including consideration of sport risk modifiers and decision modifiers[200].

MRI protocol

Both studies used comparable MRI protocols including sequences that are suitable for detecting muscle injury. With regard to (fat-suppressed) fluid-sensitive sequences, the Dutch study used short tau inversion recovery (STIR) and T2-weighted imaging, and the Qatar study used proton density fat saturation (PDFS)-weighted imaging. Additionally, the Dutch study used T1-weighted imaging, whereas the Qatar study used proton density (PD)-weighted imaging without fat suppression.

MRIs in the Dutch cohort were obtained with a 1.5T magnet system (Magnetom Essenza, Siemens, Erlangen, Germany) with the use of a body matrix coil. The entire injured hamstring was visualised with coronal and sagittal STIR series from the ischial tuberosity to the distal hamstring insertions on fibula and tibia (repetition time/echo time (TR/TE) of 3500/31 ms, field of view (FOV) of 300 mm and a 256×320 matrix). Following this, transverse STIR (TR/TE of 3500/31 ms, FOV of 300 mm and a 205×256 matrix), T1-weighted (TR/TE of 500/12 ms, FOV of 300 mm and a 355×448 matrix) and T2-weighted (TR/TE of 4080/128 ms, FOV of 300 mm and a 355×448 matrix) images were obtained from the injured area.

MRIs in the Qatar cohort were obtained with a 1.5 T magnet system (Magnetom Espree, Siemens) using a body matrix coil. First coronal and transverse PD-weighted images (TR/TE of 3000/30 ms, FOV of 220–240 mm, slice thickness of 5 mm and a 333×512 matrix) were obtained. Then coronal and transverse PDFS images (TR/TE of 3000+/30 ms, FOV of 220–320 mm, slice thickness of 3.5 mm, a 326×512 matrix for the coronal images and a 333×512 matrix for the transverse images) were obtained.

MRI assessment

An experienced musculoskeletal radiologist (EA, MM), blinded to any clinical information, scored all MRIs using a standardised data collection form. This included the size and location of the injury. The original MRIs were used to score intramuscular tendon injury by one radiologist specifically for this study (EA). Scoring of both standard MRI parameters and features of intramuscular tendon injury has been shown to have good interobserver and intra-observer reliability[186,187,201].

Intramuscular tendon injury scoring: disruption and waviness

The proximal and distal free tendons have no muscle fibres attached to them[8]. The intramuscular tendon was defined as the portion of the tendon extending along and into the muscle. The two previous descriptions of intramuscular tendon injuries were both incorporated into the MRI assessment[52,183]. Intramuscular tendon injury was subdivided into intramuscular tendon disruption (Figure 1A) and presence of tendon waviness (Figure 1B)[52]. Intramuscular tendon disruption (i.e. a focal tendon defect, loss of low signal intensity within the tendon) was scored as being present or absent. When present, disruption was divided into <50%, 50%–99% and 100% of the tendon cross-sectional area (CSA). Then, longitudinal tendon disruption was measured in centimetres: in partial disruption the craniocaudal length of the disruption, and in complete disruption the distance between the retracted tendon ends. Waviness was noted as being present or absent.

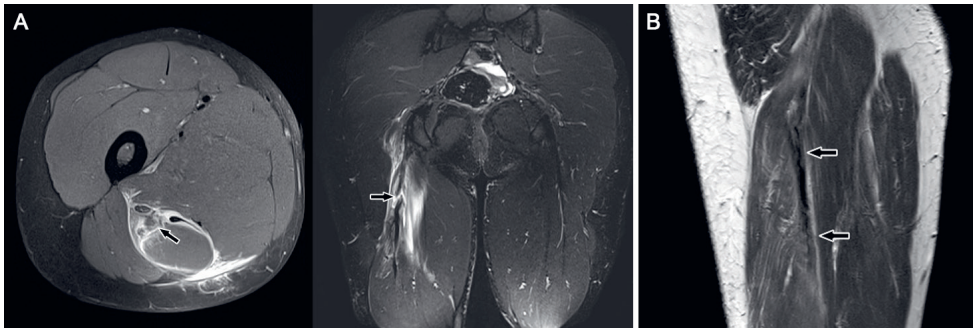

Figure 1. (A) (left) Proton density fat saturation-weighted (axial) and (right) short tau inversion recovery-weighted (coronal) MRIs demonstrating full-thickness intramuscular tendon disruption (arrows). (B) T1-weighted (coronal) MRI demonstrating waviness (arrows) of the intramuscular tendon.

Standardised MRI scoring

The modified Peetrons classification was used to grade the injury: grade 0: no abnormalities; grade 1: oedema without architectural disruption; grade 2: oedema with architectural

disruption; and grade 3: complete rupture of muscle-tendon unit[185]. For the extent of oedema (abnormal high signal intensity on fluid-sensitive sequences), the craniocaudal distance (in centimetres) and CSA (as a percentage of muscle CSA) were scored.

Re-injury

The main outcome measure was the occurrence of a re-injury in the first 12 months after RTP. Re-injury was defined as an acute onset of posterior thigh pain in the same leg. All participants were instructed to contact the principal investigator in any case of a suspected re-injury. The participants in the Dutch trial were also contacted at 1, 4, 8, 16, 26 and 52 weeks after RTP by phone. In the Qatar cohort, participants were phoned monthly.

Statistical analysis

For statistical analysis, SPSS (V.23.0) was used. Cumulative incidence curves were constructed using the one minus survival function. To determine whether an association exists between intramuscular tendon injury and re-injury rate, a Cox proportional hazards model was used. In case graphical assessment of log-minus-log plots revealed that the assumption of proportional hazards was violated, a generalised Wilcoxon (Breslow) test was used. The main variable was the number of days from RTP to occurrence of a re-injury or the end of the follow-up duration. Censoring was applied if participants presented with a severe injury (>28 days of absence from sport participation) that did not involve the hamstrings during the follow-up period, or when participants were lost to follow-up. To achieve the highest power for analysis, intramuscular tendon disruption was treated as a dichotomous variable (i.e. present or absent). A multivariate (i.e. sensitivity) analysis was done to adjust for ipsilateral hamstring injuries in the last 12 months[202], treatment received and study cohort. Level of significance was set at $P<0.05$.

Results

A total of 165 participants with a median age of 26 years who sustained an acute hamstring injury were included (Figure 2). Five participants were excluded from the re-injury analysis because they did not RTP during the study period, four of which as a result of another (non-hamstring) injury and one due to ongoing hamstring complaints[40]. Baseline patient and MRI characteristics are provided in Table 2. The median follow-up was 372 days (IQR: 362.5–385.5). In the survival analysis, 23 (14%) participants were censored due to severe non-hamstring injuries during follow-up or loss to follow-up, of whom 7 (30%) had an index injury with intramuscular tendon injury.

Intramuscular tendon injury

Sixty-four (39%) participants had an acute hamstring injury with intramuscular tendon disruption. Five (3%) had an injury with partial-thickness free tendon disruption. Of the 64 injuries with intramuscular tendon disruption, there were 12 (19%) with <50%, 28 (44%) with 50%–99% and 24 (38%) with 100% disruption of tendon CSA. Waviness was present in 37 (22%) cases, of which 36 (97%) occurred in cases with more than 50% disruption of tendon CSA.

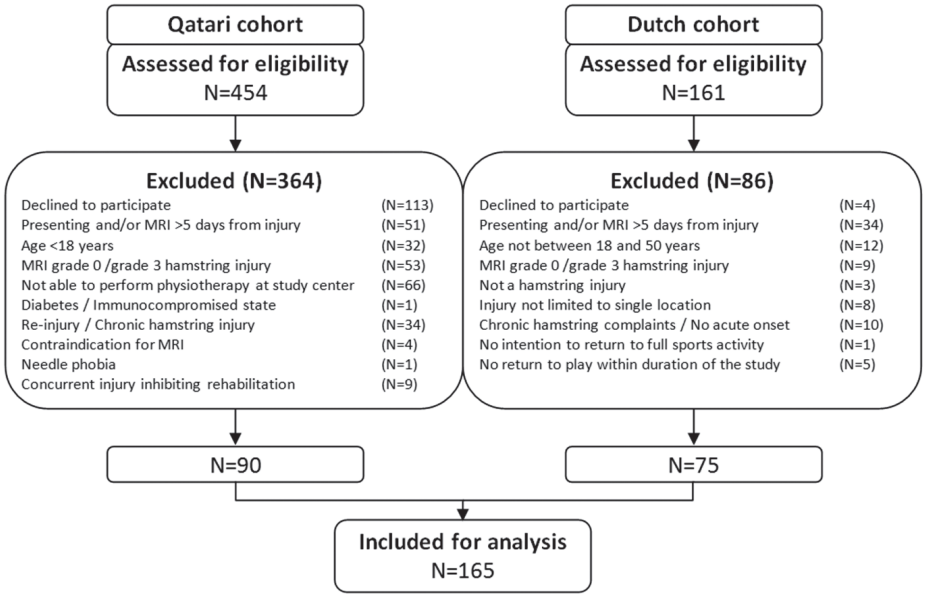

Figure 2. Flow chart of study participants.

Re-injury

There were 32 re-injuries (19%) within 12 months after RTP. Re-injury rates per group are presented in Table 3. The cumulative incidences of re-injuries following index injuries with intramuscular tendon disruption and injuries without tendon disruption are shown in Figure 3A, and following injuries with and without waviness in Figure 3B.

There was no significant association between presence of intramuscular tendon disruption and re-injury rate in the univariate analysis (HR: 1.05, 95% CI 0.52 to 2.12, P=0.898).

Subsequently, the multivariate analysis revealed an adjusted HR of 1.07 (95% CI 0.52 to 2.19, P=0.864). No significant association between re-injury rate and presence of waviness was found ($X^2(1)=0.031$, P=0.861).

Based on post-hoc observation of the cumulative incidence curves (Figure 3A,B) and to facilitate a comparison with relevant literature, a post-hoc analysis was carried out at 2 and 3 months after RTP. This revealed no significant association between intramuscular tendon injury and re-injury rates. At 2 months after RTP, re-injury rates for injuries with intramuscular tendon disruption and waviness were 16% (compared with 7% for no tendon disruption; HR: 2.21 (95% CI 0.84 to 5.81, P=0.107); $HR_{adjusted}$: 2.43 (95% CI 0.91 to 6.51, P=0.077)) and 19% (compared with 8% for injuries without waviness; $X^2(1)=3.352$, P=0.067). At 3 months after RTP, re-injury rates for injuries with intramuscular tendon disruption and waviness were 17% (compared with 8% for no tendon disruption; HR: 2.15 (95% CI 0.86 to 5.33, P=0.101); $HR_{adjusted}$: 2.43 (95% CI 0.96 to 6.12, P=0.061)) and 19% (compared with 9% for absence of waviness; $X^2(1)=2.354$, P=0.125).

Table 2 Baseline patient characteristics and MRI findings.

	All participants (N=165)	Qatar cohort (N=90)	Dutch cohort (N=75)
Age (years)	26 (IQR:22-31)	25 (IQR:21-30)	28 (IQR:23-33)
Sport			
Football	119 (72%)	66 (73%)	53 (71%)
Hockey	14 (9%)	2 (2%)	12 (16%)
Futsal	9 (6%)	8 (9%)	1 (1%)
Athletics	5 (3%)	4 (4%)	1 (1%)
Other	18 (11%)	10 (11%)	8 (11%)
Level of participation			
Professional	87 (53%)	87 (97%)	0 (0%)
Competitive	58 (35%)	3 (3%)	55 (73%)
Recreational	20 (12%)	0 (0%)	20 (27%)
Previous (ipsilateral) hamstring injury in the last 12 months			
Yes	37 (22%)	11 (12%)	26 (35%)
No	128 (78%)	79 (88%)	49 (65%)
MRI grade			
Grade 1	68 (41%)	47 (52%)	21 (28%)
Grade 2	97 (59%)	43 (48%)	54 (72%)
Muscle injured			
Biceps femoris	135 (82%)	69 (77%)	66 (88%)
Semitendinosus	7 (4%)	3 (3%)	4 (5%)
Semimembranosus	23 (14%)	18 (20%)	5 (7%)
Oedema dimensions			
Cranio-caudal length (cm)	13.7±6.8	15.3±6.9	11.7±6.1
CSA (% of muscle CSA)	23.1 (IQR:9.9-48.2)	16.8 (IQR:8.0-46.4)	30.5 (IQR:15.5-49.3)
Intramuscular tendon injury			
No tendon disruption	96 (58%)	53 (59%)	43 (57%)
Free tendon disruption	5 (3%)	5 (6%)	0 (0%)
Intramuscular tendon disruption	64 (39%)	32 (36%)	32 (43%)
<50% of tendon CSA	12 (7%)	5 (6%)	7 (9%)
50-99% of tendon CSA	28 (17%)	14 (16%)	14 (19%)
100% of tendon CSA	24 (15%)	13 (14%)	11 (15%)
Biceps femoris	48 (75%)	19 (59%)	29 (91%)
Biceps femoris & Semitendinosus	8 (13%)	8 (25%)	0 (0%)
Semitendinosus	0 (0%)	0 (0%)	0 (0%)
Semimembranosus	8 (13%)	5 (16%)	3 (9%)
Longitudinal tendon disruption			
Length of intramuscular tendon disruption (cm)	6.2±2.8	6.8±2.2	5.7±3.2
Retraction (cm)	3.7 (IQR:2.0-5.9)	3.3 (IQR:1.5-6.7)	3.7 (IQR:2.1-5.9)
Waviness			
Present	37 (22%)	19 (21%)	18 (24%)
Absent	128 (78%)	71 (79%)	57 (76%)

Normally distributed data are presented as a mean with SD and non-normally distributed data as a median with IQR. CSA: cross-sectional area.

Table 3. Distribution of re-injuries among acute hamstring injuries.

	All participants		Qatar cohort		Dutch cohort	
	N	Re-injuries ≤12 months	N	Re-injuries ≤12 months	N	Re-injuries ≤12 months
Overall	165	32 (19%)	90	11 (12%)	75	21 (28%)
No tendon disruption	96	19 (20%)	53	6 (11%)	43	13 (30%)
Free tendon disruption	5	0 (0%)	5	0 (0%)	0	0 (N/A)
Intramuscular tendon disruption	64	13 (20%)	32	5 (16%)	32	8 (25%)
<50% of tendon CSA	12	2 (17%)	5	0 (0%)	7	2 (29%)
50-99% of tendon CSA	28	8 (29%)	14	3 (21%)	14	5 (36%)
100% of tendon CSA	24	3 (13%)	13	2 (15%)	11	1 (9%)
No waviness	128	25 (20%)	71	8 (11%)	57	17 (30%)
Waviness	37	7 (19%)	19	3 (16%)	18	4 (22%)

CSA: cross-sectional area, NA: not applicable.

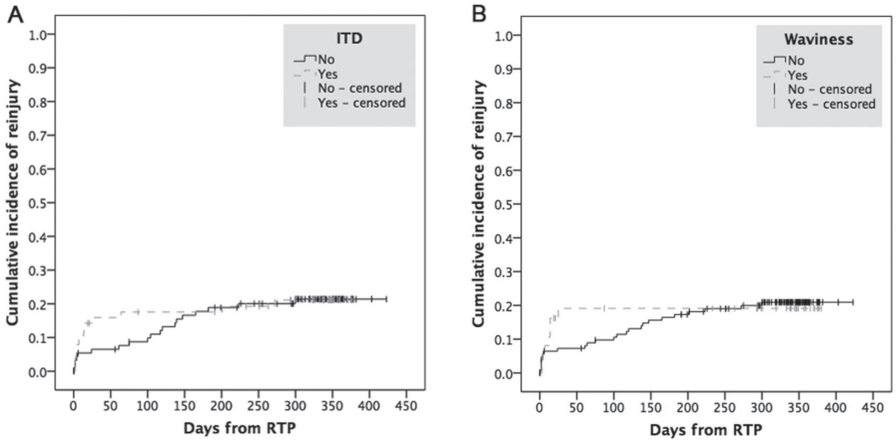

Figure 3. (A) Cumulative incidences of re-injury for acute hamstring injuries with presence of intramuscular tendon disruption (ITD) and injuries without tendon disruption. (B) Cumulative incidences of re-injury for acute hamstring injuries with and without presence of waviness. RTP: return to play.

Discussion

This prospective analysis of 165 athletes with an acute hamstring injury found that on MRI nearly 40% of acute hamstring injuries had intramuscular tendon disruption and around 20% had presence of waviness. The overall 12-month re-injury rate was 19%. There was no significant association between intramuscular tendon injury and re-injury rate. The clinical implication of these data is that there is no difference in risk of hamstring muscle re-injury whether or not there is associated intramuscular tendon injury.

Our finding is in contrast with that of Pollock et al.[53], who reported a re-injury rate after RTP of 33% vs 4% for index injuries with and without tendon injury, respectively. In their study, the 15 injuries with tendon injury comprised 1 free tendon injury and 14 intramuscular tendon injuries[53]. In addition to re-injuries after RTP, Pollock et al. noted six re-injuries during rehabilitation (henceforth referred to as exacerbations): 4 (27%) vs 2 (4%) in the groups with and without tendon injury. In our study, exacerbations were not prospectively recorded and were therefore not included in the analysis.

It should be noted that, in the study by Pollock et al.[53], the follow-up for re-injuries was 3 months after RTP. This brings into question whether intramuscular tendon injury could be associated with 'early' re-injury rate (i.e. within 2–3 months). Despite the relatively large number of participants and intramuscular tendon injuries, our study was not powered to detect differences in re-injury rate at 3 months. Nevertheless, based on post-hoc observation of the cumulative incidence curves (Figure 3A,B) and to allow for comparison of our findings with those of Pollock et al.[53] and potential future studies, we performed a post-hoc analysis. This analysis also revealed no association between intramuscular tendon injury and re-injury rate at 2 and 3 months after RTP, respectively.

There are two important differences between the present study and the work of Pollock et al.[53]. First, differences in study populations could explain the different findings. Pollock et al. reported on acute hamstring injuries in 44 elite track and field athletes, including 31 sprinters (70%) and 8 vertical/horizontal jumpers (18%). Our study population predominantly comprised football players (72%). In team sports, there is the possibility that a player can adjust the style of play such that 'all-out' effort sprinting load can be modified and the players can still compete at their previous level; we know that this is not feasible for competitive sprinters. Second, we used criteria-based rehabilitation programmes including standardised sport-specific training with predefined clinical criteria for progression towards RTP. Pollock et al.[53] reported that no formal criteria for progressing to return to full training (coach-led sessions) were used.

Prognostic value of intramuscular tendon injury on MRI

An important goal was to determine the prognostic value of MRI-diagnosed intramuscular tendon injury at baseline. Our previous work demonstrated that full-thickness intramuscular tendon disruption and presence of waviness were associated with a delay in RTP by 8–9 days[9]. Yet, based on considerable within-group variance and substantial between-group overlap, we concluded that the contribution of intramuscular tendon injury to RTP prediction, and therefore its prognostic value, was limited. The present study extends these findings, considering that intramuscular tendon injury was not associated with an increased re-injury rate.

Strengths and limitations

The main strengths of this study are the sample size, prospective study design, blinding of treating physiotherapists during rehabilitation and the multivariate analysis. A relatively large number of (re)injuries and a multivariate analysis are considered prerequisites for investigating potential risk factors of (re)injury[195]. To date, this is the largest study on acute hamstring injuries with intramuscular tendon injury.

A limitation is that the two cohorts had some differences in inclusion criteria, imaging protocols, rehabilitation protocols and RTP criteria. However, this increases generalisability of our findings, and correcting for potential confounders, including study cohort, did not change the outcome of the analysis. Second, the study cohort has a limited number of athletes from sports other than football. Therefore, we underscore that our results cannot be generalised to, for example, track and field athletes. Lastly, exacerbations were not prospectively recorded, and therefore no statements can be made regarding the association between intramuscular tendon injury and exacerbation rates.

Future directions

Given the potential of prolonged rehabilitation, exacerbation rate should be recorded in future studies. Moreover, future studies with larger sample sizes should aim to determine whether intramuscular tendon injury leads to more 'early' re-injuries. This will require a collaborative multicentre approach[203].

As our conclusion is based on MRI findings at the time of injury, it remains unknown if MRI assessment at RTP might have added value. Future studies might focus on the value of (persistent) presence of intramuscular tendon injury and its association with re-injury rate.

Clinical relevance

When treated with a standardised criteria-based rehabilitation programme, athletes with an acute hamstring injury with and without intramuscular tendon injury have comparable re-injury rates.

Conclusion

In athletes with an acute hamstring injury, intramuscular tendon injury is not associated with an increased re-injury rate within 12 months after RTP.

11 GENERAL DISCUSSION

This thesis aimed to contribute to the growing insight into various aspects of hamstring tendon injury. In this chapter, the implications of our findings for clinical practice and future research will be discussed.

Hamstring tendon injury

In the past twenty to thirty years, there has been an evident upsurge in research interest in hamstring tendon injury. We argue that this is in part due to increased recognition. There is a more widespread availability of suitable imaging modalities that are continuously being improved to allow detection of smaller injuries as well as determine in detail which anatomical structures are involved in the injury. In addition to the recognition of free tendon injuries (i.e. tendon avulsion or rupture), it has become clear that a sizeable proportion of the seemingly 'regular' hamstring injuries that are located at the musculotendinous junction also involve the (intramuscular) hamstring tendon(s). The postulation that tendon involvement might explain why some hamstring injuries are more challenging to manage than others, with potentially different prognosis and treatment requirements, has further catalysed this research interest.

In the following paragraphs relevant aspects of diagnosis, treatment decision-making, and outcome for hamstring tendon injury will be discussed along with recommendations for clinical practice and future research.

Diagnosis

Free tendon injury

A proximal free tendon injury is a serious hamstring injury that warrants surgical consultation. A delay in diagnosis and treatment might lead to inferior outcomes and technically more demanding operative repair if indicated in the chronic setting[46,51]. To that end, considering that we have outlined in **Chapter 3** that this type of injury might be easily missed, timely imaging is indicated to rule out this injury type. The provided clinical pearls and pitfalls are expected to aid clinical recognition. Without question, MRI is required as an adjunct to clinical examination to rule out or diagnose proximal tendon injury.

Previous research findings by our group have indicated that diagnosis on MRI and evaluation of retraction may not be inter-rater reliable in clinical practice without the use of a standardised evaluation method[163]. Both the presence of proximal injury as well as the extent of retraction seem important factors in decision-making[160,161] and pre-operative planning, so accurate evaluation is essential. In **Chapter 7**, we have consequently proposed a standardised MRI evaluation including the novel "dropped ice cream sign" to evaluate presence and extent of proximal free tendon avulsion, along with a method to measure tendon retraction in case of full-thickness injury. This standardised evaluation has been shown to be inter-rater reliable, and we therefore recommend its use in daily clinical practice.

Intramuscular tendon injury

The clinical relevance of MRI to detect intramuscular tendon injury is more controversial. For medical teams managing elite injured athletes, MRI is a routine adjunct to establish diagnosis, evaluate extent of the injury, and ideally informs prognosis to guide treatment decision-making. In 2015, Reurink et al.[184] published a thought-provoking editorial titled "*Hamstring injuries and predicting return to play: bye-bye MRI?*". Their takeaway was that MRI findings, based on the current body of evidence at that time, were not useful to predict time to RTP. Their group also cautioned against a potential self-fulfilling prophecy due to

high risk of bias as the studies reporting time to RTP were retrospective and did not blind athletes and clinicians to MRI findings. In the following years, the intramuscular tendon gained notoriety as initial published reports indicated that it might lead to inferior prognosis in terms of time to RTP and re-injury rate, and might even warrant operative treatment[37,53]. As per the only available study on the subject, clinical examination has not been deemed accurate in determining whether intramuscular tendon injury is present[204] and as a such, the indication for MRI had possibly returned.

In **Chapter 9** and **Chapter 10**, we investigated the association of intramuscular tendon injury with time to RTP and re-injury rate. Using a prospective design with blinding of clinicians for MRI findings, we found that time to RTP was extended by nine days in case of full-thickness injury of the intramuscular tendon compared to injury without intramuscular tendon involvement. Although this is a clinically relevant difference, especially at the elite level, we concluded that the prognostic value of intramuscular tendon injury was limited due to substantial between-group overlap and within-group spread in time to RTP, implying that an accurate prognosis for the individual athlete currently cannot be provided[9]. In a follow-up study, we did not find a significantly increased re-injury rate for intramuscular tendon injury within one year after RTP[205].

This contradicted findings by non-blinded retrospective studies published by other groups, especially those investigating track and field athletes[53]. These studies found a three to four-fold increase in time to return to full training, with increased re-injury rates of up to 63%. Differences in findings between studies may in partly be attributed to study population differences (field sports vs. track and field, geographical location), differences in methodology (prospective vs. retrospective, sample size, blinding for MRI findings), unknown factors, or a combination of either.

For intramuscular tendon injury, the use of (baseline) MRI is therefore arguably context- and philosophy-specific, considering that there is no high-quality evidence that supports clinical relevance in terms of prognosis (yet).

Recommendations for clinical practice:

- Use MRI to assess presence of proximal hamstring tendon injury if clinical examination cannot rule it out.
- Use a standardised MRI scoring method. We recommend using the "dropped ice cream sign" to evaluate presence of proximal full-thickness tendon injury and the direct retraction method to measure tendon retraction.

Future research perspective:

- Future prospective research evaluating the association between imaging findings and clinical outcomes is needed, especially in elite athletes. This likely requires large multi-centre and international collaborations. In these future studies, blinding of treating clinicians is absolutely essential.

Treatment decision-making and outcome

Free tendon injury

Once the diagnosis of a proximal tendon avulsion/rupture is made, either operative or non-operative treatment can be chosen. Unfortunately, this decision is hardly evidence-based. Certainly, there are several systematic reviews that have been conducted[49–51], with the current opinion in favour of operative treatment, with reported superior subjective and functional outcomes compared to non-operative treatment. However, these systematic reviews also underline methodological limitations such as retrospective designs, selection bias, and publication bias with a very limited number of published non-operative cases. This renders a cross-comparison between operative and non-operative outcomes quite difficult. To make matters more complicated, two recent studies have indicated that non-operative outcomes may not be inferior to operative outcomes in a middle-aged study population[206,207]. There are currently no published randomised controlled trials to determine which treatment is preferable. In addition, there are no high-quality studies that have determined which patient- or injury-related factors predispose to inferior outcomes following non-operative treatment, and should thus be used as indications for operative treatment.

In absence of a solid evidence basis, one might turn to an eminence-based approach until such high-quality evidence is available to guide decision-making. In **Chapter 5**, we explored current practice patterns and decision-making preferences among experts in the field. These findings were subsequently corroborated by two similar studies[160,208]. In daily clinical practice, a considerable proportion of patients is treated non-operatively. For most respondents, treatment choice depends on a combination of patient- and injury-related factors. Important decision-modifiers that were used as indications for operative treatment were number of involved tendons, tendon retraction, diminished function, neurological symptoms, and patient preference[160,161]. Decision-modifiers that were used as relative contra-indications for operative treatment were severe obesity, drug use, (sedentary) lifestyle, age (over 60 years), and delayed diagnosis (>6 weeks)[208].

In **Chapter 6**, we described reliability of the isometric knee flexor strength tests using hand-held dynamometry. These measurements are parts of the assessment at the initial visit to determine the extent of diminished function, as well as follow-up visits to monitor recovery of hamstring strength. This study demonstrated that hand-held dynamometry, a modality for strength testing which can be easily used in an outpatient clinic setting, was reliable even in very strong athletes. It noted that fixation of the athlete or dynamometer was not required for reliable measurements, also if multiple testers of different gender and upper body strength are performing measurements.

In **Chapter 8**, we employed a shared decision-making model for patients with a proximal hamstring tendon avulsion and reported comparable favourable outcomes at one year after start of treatment in a predominantly middle-aged population. As the operative and non-operative groups differed at baseline, it cannot be concluded that operative and non-operative treatment yielded equal outcome. Rather, this study demonstrated that favourable outcome is possible after both operative and non-operative treatment in subgroups of patients when employing the shared decision-making model. Future research should determine which factors may help predict which treatment is most suited for the individual patient. In other words, evidence-based indications for operative and

non-operative treatment should be identified. We recommend that clinicians use the described shared decision-making model until high-level clinical trials lead to evidence-based treatment indications.

Recommendations for clinical practice:

- Engage in shared decision-making for treatment choice for proximal hamstring tendon avulsion/rupture injury.
- To monitor functional recovery, hand-held dynamometry is inter-tester reliable, even without fixation methods. Isokinetic testing is not strictly necessary to measure knee flexor strength.

Future research perspective:

- For the relatively rare proximal hamstring tendon avulsion/rupture injuries, (international) collaboration is needed to achieve adjusted analyses and/or randomised controlled trials. Such study designs are expected to help determine evidence-based indications for operative and non-operative treatment.
- Tendon retraction on MRI is widely used as an indication for operative treatment, with an arbitrary cut-off value of two centimetres. An evidence-based cut-off value that differentiates between patients that have favourable and inferior outcomes without an operation needs to be established.
- The role of sequential imaging during the early post-injury period should be further investigated. It is currently unknown if and how sequential imaging (MRI) should be used. One might conceive that a delayed treatment decision-making could be employed if sequential imaging could predict which individual patients might regain bone-tendon continuity at favourable (tendon) length.
- Post-operative protection and initial rehabilitation phases have not extensively been studied. Potential areas of interest to explore are modality and duration of post-operative immobilisation/protection, as well as the role of diet and supplements.

Intramuscular tendon injury

In the diagnosis section, the use of MRI to evaluate presence and extent of intramuscular tendon injury to inform prognosis after injury was discussed. While the debate regarding prognostic utility of MRI has not been settled, there is also the matter of whether intramuscular tendon injuries require an adapted rehabilitation programme, or even operative repair, to mitigate risk of re-injury.

In field sports, based on **Chapter 9** as well as studies by other groups[209–211], there seems to be an increase in time to RTP when the intramuscular tendon is injured compared to isolated MTJ injuries. In **Chapter 10**, we demonstrated no significant differences in re-injury rate between injuries with and without intramuscular tendon injury, which was corroborated by a couple of other studies[209,210]. Based on these findings, operative intervention for acute, first-time intramuscular tendon injuries is seemingly not indicated in field sports.

In track and field, there is the possibility that elite athletes may benefit from an adapted rehabilitation programme based on BAMIC grade. Despite the fact that current studies in

track and field lack blinding for MRI findings leading to risk of bias, they currently are the best available evidence. In these studies, higher grade (i.e. grade 3) and intratendinous injuries (or "c-injuries") were associated with an increased time to return to full training. Moreover, the intratendinous injuries were associated with an increase in re-injury rate. Consequently, the BAMIC group created and published a framework for rehabilitation of track and field athletes with muscle injury that included guidelines specifically based on injury grade[212]. A subsequent analysis to evaluate the effect of implementation of this BAMIC framework revealed favourable outcomes. Re-injury rate for intratendinous injuries decreased to 0%. Time to return to full training increased for 2c injuries by about one week compared to non-c injuries, but decreased for 3c injuries by roughly four weeks.

With the current body of literature in track and field, there is an absolute need for studies in which treating clinicians are blinded for MRI finding, which is currently lacking and limiting conclusions that may be drawn. Until these are available, there may be sense in applying the BAMIC framework to (elite) athletes with intramuscular tendon injury.

Recommendations for clinical practice:

- In field sports, there is likely no necessity to tailor current (criteria-based) rehabilitation programmes to presence of intramuscular tendon injury.
- In track and field, the BAMIC framework might lead to reduced re-injury rates for intramuscular tendon injury at the cost of limited increase in time to return to full training.
- Clinical practice may be more nuanced than the above situation; a field sport athlete in a certain position (i.e. wing attacker in football) may demonstrate a profile with relatively high volumes of high-speed sprinting, resembling or approaching that of a track and field athlete. In other words, it remains essential to evaluate the individual athlete and tailor the rehabilitation and secondary prevention accordingly.
- Operative intervention for acute, first-time intramuscular tendon injuries does not seem indicated.

Future research perspective:

- Especially in track and field, additional and larger studies with blinding of treating clinicians to MRI findings are necessary to draw conclusions regarding the association of intramuscular tendon injury with time to RTP and re-injury rate.
- Similar to proximal free tendon injury, the role of tendon retraction and waviness in full-thickness intramuscular tendon injury should be investigated as a potential prognostic factor that might even play a role in treatment decision-making.

Limitations

While research questions have been answered and recommendations can be made, **hubris has led to downfall before**.

Limitations of the respective studies that our research group have conducted have been discussed in detail in the corresponding chapters.

The current body of evidence on the relatively rare yet very impactful injuries has been growing in size and quality. These efforts should be commended.

However, current scientific knowledge on these injuries remains limited mainly due to a lack of high-level (i.e. randomised) studies. A critical attitude towards the current body of evidence remains vital.

12 SUMMARY

Hamstring injury has a major injury burden due to a combination of high incidence, absence from play, and high recurrence. The bulk of hamstring injuries is located at the musculotendinous junction (MTJ), the interface between tendon and muscle tissue. The clinical diagnosis is straightforward and treatment consists of a phased rehabilitation program.

However, when the injury involves the (free or intramuscular) hamstring tendons, prognosis in terms of return to play (RTP) duration and increase re-injury rate is expectedly worse. This injury subtype potentially entails prolonged absence from play, higher re-injury rate, or even persisting functional limitations. Consequently, surgical consultation is warranted.

The research in this thesis aimed to evaluate relevant aspects of hamstring tendon injury for daily clinical practice, with the emphasis on anatomy, diagnosis, treatment decision-making, and outcomes.

Part I – Hamstring anatomy

In **Chapter 2,** the anatomy of the hamstring muscle complex with emphasis on the proximal attachment is evaluated and described. This chapter is the (anatomical) basis for the further division of this thesis into "**Part II – Free tendon injury"**, and "**Part III – Intramuscular tendon injury"**. The free hamstring tendon is the part of the tendon that attaches to the bone and has no myofibres attaching onto it, as it becomes the intramuscular tendon at that point. The intramuscular tendon is the part of the tendon that extends along and into the muscle with myofibres attached along its length. It is essentially the tendinous side of the MTJ.

Part II – Free tendon injury

Chapter 3 is a call for awareness as we suspect that proximal free tendon injuries, either tendon avulsion or rupture, are frequently missed leading to delay in diagnosis with possible consequences for treatment outcome. It describes pearls and pitfalls that may aid clinical recognition. We recommend that an MRI is performed in case of suspicion or doubt to rule out or confirm proximal free tendon injury.

Chapter 4 summarises the available literature in a systematic review of outcome following operative treatment of proximal hamstring avulsions. We found that operative repair yielded a subjective highly satisfying outcome. However, both function and activity level were not completely restored in all patients. A relevant number of patients reported symptoms of residual pain. We found minimal to no differences in outcomes of acute (≤4 weeks) and delayed repairs (>4 weeks). As evidence was limited to low-quality studies investigating operative outcomes only, the following chapters served to improve imaging diagnosis, decision-making, and identify operative and non-operative outcomes.

In **Chapter 5**, a world-wide expert opinion survey, we identified clinical practice patterns and preferences for treatment decision-making in order to establish eminence-based indications for operative repair. For the vast majority of respondents, the preferred treatment (i.e. operative or non-operative) depends on the individual patient. Decision modifiers to guide treatment choice include diminished function, neurological symptoms, involved tendons, extent of tendon retraction on MRI and patient preference. The archetypal surgical candidate has a (>2 cm) retracted two-tendon avulsion, cannot perform in sports or activities of daily life, reports sciatic symptoms, and prefers an operative treatment. When opting for operative repair, respondents preferred early (<2 weeks) repair by means of suture anchors. Interestingly, the survey also demonstrated evident publication bias as the majority of respondents stated that they treated most patients non-operatively.

As part of evaluating our clinical work-up and monitoring of patients with proximal hamstring tendon avulsions, **Chapter 6** describes intra- and inter-rater reliability of hand-held isometric hamstring strength tests in high-level rugby players. This evaluation was needed because the reliability of hand-held dynamometry was questioned based on differences in strength of both different testers and patients. In these very strong individuals, this study demonstrated that hand-held dynamometry for isometric knee flexor strength assessment in prone 0/15 degrees and supine 90/90 degrees position is inter-rater reliable, regardless of testers' physical capacity and regardless of method of dynamometer fixation.

Subsequently, our standardised MRI evaluation was put to the test in **Chapter 7**. As imaging parameters such as involved tendons and tendon retraction are important factors in decision-making in acute injuries, as per our abovementioned expert opinion survey, we sought to identify (the most) inter-rater reliable methods to assess these variables. We demonstrated that MRI assessment was reliably when proximal bone-tendon continuity was evaluated using the novel "dropped ice cream sign", and tendon retraction was measured using the "direct retraction method" (i.e. the shortest distance between the centre of the proximal hamstring complex origin and the proximal tendon stump).

To address research gaps identified in previous chapters, **Chapter 8** reports short- to medium-term outcomes of operative and non-operative treatment in a prospective cohort study using a shared decision-making model. In this study, predominantly active middle-aged patients with proximal tendon avulsions opted for operative or non-operative treatment in a shared decision-making model. Operative patients had lower Perth Hamstring Assessment Tool (PHAT)) scores before treatment, but reported equally high PHAT scores at one-year follow-up as non-operative patients. No clinically relevant differences in secondary clinical outcome measures were found. In terms of radiological outcome measures, we reported a significantly higher rate of proximal continuity in the operative group. A striking finding was that proximal continuity was restored in half of the non-operative patients. We recommend that clinicians use the described shared decision-making model until high-level clinical trials have established evidence-based treatment indications.

Part III – Intramuscular tendon injury

Hamstring injury that involves the intramuscular tendon has been deemed a severe injury type, associated with delay in RTP times of over 50 days and very high re-injury rate of over 60%. This infamous reputation has, however, been based on few retrospective case series with high risk of bias, especially due to lack of blinding for MRI findings.

To be able to draw firmer conclusions on the association between intramuscular tendon injury and outcomes in terms of time to RTP and re-injury rate, we analysed prospective data on professional athletes with an MRI-confirmed hamstring injury, treated by clinicians that were blinded to MRI findings.

In **Chapter 9**, we reported that both full-thickness disruption and waviness of the intramuscular tendon were associated with increased time to RTP. Injuries with full-thickness disruption or waviness of the intramuscular tendon took slightly more than a week to RTP than injuries without intramuscular tendon involvement. The prognostic utility of these variables for the individual patient remains limited, however, due to the considerable overlap in time to RTP between groups. Partial-thickness disruption of the intramuscular tendon did not significantly increase time to RTP.

Chapter 10, as the number of re-injuries in the previous chapter did not allow for statistical comparisons, combined prospective data from two international cohorts to determine whether intramuscular tendon injury increases re-injury rate compared to isolated musculotendinous junction injuries. No significant association between intramuscular tendon injury and re-injury rate was found.

General discussion

In the general discussion section, we discuss the current state of evidence on hamstring tendon injury using chapters from this thesis as well as scientific literature published by experts in the field. This covers diagnosis, treatment decision-making, and outcomes for both free and intramuscular hamstring tendon injury. Additionally, our recommendations for clinical practice and future research perspective are provided.

NEDERLANDSE SAMENVATTING

Hamstringblessures gaan gepaard met een hoge blessurelast vanwege de combinatie van hoge incidentie, herstelduur en een hoge recidiefkans. De overgrote meerderheid van hamstringblessures bevindt zich ter hoogte van de overgang van spiervezels naar pees; de zogeheten 'musculotendinous junction' (MTJ). Een hamstringblessure betreft een klinische diagnose en behandeling bestaat uit een gefaseerd fysiotherapeutisch oefenprogramma.

Wanneer de blessure echter de (proximale of intramusculaire) hamstringpees betreft, is de prognose voor herstelduur en recidiefkans naar verwachting slechter. Dit blessuresubtype leidt mogelijk tot langere herstelduur, toegenomen recidiefkans, of zelfs aanhoudende functionele beperkingen. Om die reden is chirurgische consultatie gerechtvaardigd bij blessures waarbij de pees is aangedaan.

Het wetenschappelijk onderzoek in dit proefschrift is gericht op het evalueren van relevante aspecten van hamstringpeesblessures voor de dagelijkse klinische praktijk, met de nadruk op anatomie, diagnose, besluitvorming en behandeluitkomsten.

Deel I – Hamstring anatomie

In **Hoofdstuk 2** wordt de anatomie van de hamstrings beschreven met nadruk op de proximale aanhechting. Dit hoofdstuk vormt de (anatomische) basis voor de verdere onderverdeling van dit proefschrift in "**Deel II – Proximale (vrije) peesletsels**" en "**Deel III – Intramusculaire peesletsels**". De proximale (vrije) hamstringpees is het deel van de pees waaraan geen spiervezels aanhechten. De intramusculaire pees is het deel van de pees waaraan spiervezels aanhechten, naar distaal langs en in de spierbuik verlopend.

Deel II – Proximale (vrije) peesletsels

Hoofdstuk 3 beoogt bij te dragen aan betere herkenning van proximale (vrije) peesletsels. Dit in verband met het vermoeden dat dergelijk letsels regelmatig worden gemist, wat leidt tot vertraging in de diagnose met mogelijke gevolgen voor de uitkomst van behandeling. Het beschrijft aspecten van anamnese en lichamelijk onderzoek welke klinische herkenning dienen te vergemakkelijken. We raden aan om een MRI te maken in het geval van vermoeden of onzekerheid over de diagnose om zo een letsel van de proximale pees uit te sluiten dan wel aan te tonen.

Hoofdstuk 4 vat de huidige wetenschappelijke literatuur samen middels een systematische review over behandeluitkomsten na operatieve behandeling van proximale hamstringpeesavulsies. Hieruit bleek dat operatief herstel resulteerde in subjectief zeer goede uitkomsten. Echter, zowel functie als het activiteitsniveau herstelden niet volledig bij alle patiënten. Een relevant aantal patiënten rapporteerde restklachten in de vorm van pijn. We vonden minimale tot geen klinisch relevante verschillen in uitkomsten van acute (≤4 weken) en vertraagde (>4 weken) operatieve interventie. Omdat het bewijs beperkt was tot studies van lage methodologische kwaliteit die alleen operatieve uitkomsten onderzochten, dienden de hierop volgende hoofdstukken om naast diagnostiek en besluitvorming ook de kennis over operatieve en niet-operatieve uitkomsten te verbeteren.

In **Hoofdstuk 5**, een wereldwijd vragenlijstonderzoek onder deskundigen, evalueerden we besluitvorming omtrent behandelopties in de dagelijkse klinische praktijk, alsook factoren welke experts gebruiken om behandelindicaties te stellen. Voor de overgrote meerderheid van de

respondenten hangt de voorkeursbehandeling (operatief of niet-operatief) af van de individuele patiënt. Factoren die door experts worden gebruikt voor het ondersteunen van de keuze voor een operatieve behandeling omvatten verminderde functie, neurologische symptomen, het aantal betrokken pezen, mate van peesretractie op MRI en patiëntvoorkeur. De typische patiënt welke baat zou hebben bij een operatie heeft een proximaal (vrije) peesletsel van beide pezen met retractie >2 cm, kan niet deelnemen in sport of dagelijkse activiteiten, meldt neurologische (nervus ischiadicus-gerelateerde) klachten en heeft voorkeur voor operatieve behandeling. Bij het kiezen voor operatieve behandeling gaven respondenten de voorkeur aan vroeg (<2 weken) operatief herstel met gebruik van hechtankers. Het was opvallend dat dit onderzoek ook een duidelijke publicatiebias aantoonde, aangezien de meerderheid van de respondenten rapporteerde dat de meeste patiënten in de praktijk non-operatief werden behandeld, hetgeen conflicteert met de huidige wetenschappelijke literatuur welke voornamelijk gericht is op operatieve behandeling.

Krachtmetingen van de hamstrings zijn een belangrijk onderdeel van de klinische evaluatie gedurende work-up en controles van patiënten met een hamstringletsel. **Hoofdstuk 6** beschrijft de intra- en inter-rater betrouwbaarheid van isometrische krachttesten bij rugbyspelers op professioneel niveau. Deze evaluatie was nodig omdat de betrouwbaarheid van dergelijke krachttesten in twijfel werd getrokken, omdat testresultaten mede afhankelijk zouden zijn van (spier)kracht van de tester (of: rater). Bij deze zeer sterke topsporters toonde deze studie aan dat de gebruikte isometrische krachttesten van de hamstrings betrouwbaar zijn, ongeacht geslacht en spierkracht van de tester en ongeacht de methode van fixatie van de krachtmeter.

Vervolgens werd onze gestandaardiseerde MRI-beoordeling getoetst in **Hoofdstuk 7.** Aangezien letselkarakteristieken zoals het aantal betrokken pezen en peesretractie belangrijke factoren zijn gebleken bij besluitvorming bij acute proximale (vrije) peesletsels, was het van belang om (de meest) betrouwbare methode(n) te identificeren om deze variabelen op een MRI-scan te beoordelen. We toonden aan dat de gebruikte MRI-beoordeling betrouwbaar was wanneer de proximale bot-peescontinuïteit werd beoordeeld met behulp van de "dropped ice cream sign" en peesretractie werd gemeten met behulp van de zogeheten directe retractiemethode (de kortst gemeten afstand tussen het centrum van de peesaanhechting op het bot tot de meest proximale vezels van de peesstomp).

Om in te springen op de in eerdere hoofdstukken geïdentificeerde kennishiaten, worden in **Hoofdstuk 8** zowel de korte- als middellange-termijn behandelresultaten van operatieve en niet-operatieve behandelingen in een prospectief cohortonderzoek gerapporteerd, waarbij gebruik werd gemaakt van een gezamenlijk besluitvormingsmodel. In deze studie kozen voornamelijk actieve patiënten van middelbare leeftijd met een proximale hamstringpeesavulsie voor operatieve of niet-operatieve behandeling. Operatieve patiënten hadden lagere PHAT-scores vóór de behandeling, maar verbeterden aanzienlijk om even hoge PHAT-scores te bereiken als niet-operatieve patiënten na een follow-up termijn van één jaar. Er waren geen klinisch relevante verschillen tussen de groepen in secundaire klinische uitkomstmaten. Operatief herstel resulteerde in een significant hoger percentage proximale continuïteit. Proximale continuïteit van het hamstringcomplex herstelde bij ongeveer de helft van de niet-operatieve patiënten en nagenoeg alle operatieve patiënten. We adviseerden om het gebruikte gezamenlijke besluitvormingsmodel te gebruiken totdat er evidence-based indicaties voor beide behandelingsopties beschikbaar zijn op basis van toekomstige gerandomiseerde onderzoeken.

Deel III – Intramusculaire peesletsels

Hamstringblessures met betrokkenheid van de intramusculaire pees worden beschouwd als ernstige blessures met een langere herstelduur en een verhoogd recidiefrisico (oplopend tot 63%). Deze notoire reputatie was echter gebaseerd op louter retrospectieve series met een hoog risico op bias, niet in het minst vanwege het gebrek aan blindering van behandelaars voor MRI-bevindingen.

Om conclusies te kunnen trekken over het verband tussen aanwezigheid van intramusculaire peesletsels en uitkomsten in de vorm van herstelduur en recidiefkans, hebben we prospectief deze uitkomsten geanalyseerd bij topsporters met een MRI-bevestigde hamstringblessure, waarbij behandelaars geblindeerd bleven voor MRI-bevindingen.

In **Hoofdstuk 9** rapporteerden we dat een volledige ruptuur en een undulerend verloop van de aangedane pees geassocieerd zijn met een langere herstelduur (d.w.z. tijd tot terugkeer naar sport). Vergeleken met hamstringblessures zonder begeleidend letsel van de intramusculaire pees hadden intramusculaire peesletsels een herstelduur die ruim een week langer was. De aanzienlijke overlap in herstelduur tussen groepen met en zonder intramusculaire peesbetrokkenheid beperkt echter aanzienlijk de klinische (d.w.z. voorspellende) waarde van deze variabele. Er werden geen statistisch significante verschillen gevonden in herstelduur tussen hamstringblessures zonder peesbetrokkenheid en partiële intramusculaire peesletsels.

In **Hoofdstuk 10**, aangezien het aantal recidieven in het vorige hoofdstuk onvoldoende was voor nadere formele statistische toetsing, combineerden we prospectieve gegevens van twee internationale studiecohorten om te bepalen of intramusculaire peesbetrokkenheid de recidiefkans van een hamstringblessure daadwerkelijk verhoogt. Er werd geen statistisch significante associatie gevonden tussen aanwezigheid van een intramusculair peesletsel en recidiefkans.

Algemene discussie

In de algemene discussie bespreken we de huidige stand van zaken met betrekking tot wetenschappelijk bewijs over hamstringpeesblessures met behulp van hoofdstukken uit dit proefschrift en wetenschappelijke literatuur die is gepubliceerd door experts binnen dit vakgebied. Dit omvat diagnostiek, besluitvorming en behandeluitkomsten voor zowel vrije als intramusculaire hamstringpeesletsels. Daarnaast worden onze aanbevelingen voor de dagelijkse klinische praktijk en toekomstig wetenschappelijk onderzoek besproken.

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APPENDICES

DANKWOORD

Graag wil ik dit dankwoord beginnen met het bedanken van mijn promotores.
Gino, wat ooit begon als een startgesprek van mijn wetenschappelijke stage is volledig en totaal geëscaleerd tot een (langdurig) promotietraject, een compleet nieuwe onderzoekslijn die inmiddels internationaal is uitgebreid, en mijn inmiddels bijna afgeronde opleiding tot Orthopedisch chirurg. Ik kan me nog goed herinneren dat je in dat kleine hok op G7 destijds aangaf dat je het niet de bedoeling vond dat een student na 16 weken studiepunten in ontvangst nam en er weer vandoor ging. Ik heb het idee dat ik je daarin, meer dan tien jaar later, niet heb teleurgesteld. Ons samenwerken heeft me altijd veel energie gegeven en plezier opgeleverd en dus hoop ik dat de afgelopen periode slechts het begin is geweest van ons samenwerken. Ik wil je bedanken voor alle kansen en avonturen die je me vanaf het begin het geboden, zowel op wetenschappelijk, klinisch, als persoonlijk vlak.

Hans, ook jij bent aanstichter geweest van tal avonturen. Ik moet wellicht direct aangeven dat Jolyn je nog steeds niet vergeven heeft voor het feit dat ik ruim een jaar in Qatar als arts-onderzoeker ben beland. Zelf ben ik vooral dankbaar voor de geboden kans op dat avontuur. Er zijn er weinig die op een prettige manier zo eerlijk, kritisch en direct als jij kunnen zijn. Ik kon er bij jou altijd op vertrouwen dat ik mijn manuscripten voor 75% rood en doorgestreept weer razendsnel terugkreeg, zodat ik weer terug kon naar de tekentafel. Niet altijd even makkelijk om als promovendus te accepteren, maar wel altijd resulterend in een fors verbeterd manuscript welke vervolgens 'gemakkelijk' kon worden gepubliceerd in een vooraanstaand wetenschappelijk tijdschrift. Prrrrrrima!

Ik reken mijzelf rijk dat ik naast mijn promotores nog een aantal sleutelfiguren kan beschouwen als mentoren.

Guus, het moge duidelijk zijn dat ook jij aan de wieg stond van mijn carrière als hamstringonderzoeker. Je was gedurende het schrijven van mijn eerste artikel(en) mijn vaste hulplijn. Ik heb veel van je geleerd over hamstrings, methodologie, kritisch nadenken, omgaan met uitnodigingen van zogeheten 'predator journals' en het stil krijgen van een jong kind tijdens een belangrijke hamstringmeeting. Ook was je één van de eersten in Nederland die keek naar proximale hamstringpeesavulsies, totdat ik dat stokje van je mocht overnemen. Je bent nu de vedette van de 'hamstring boys' (o.a. met Kenny, Joep & Milo), met nog jaarlijks een traditionele BBQ-zomeravond.

Mario, dankzij jou kreeg ik ook buiten de Orthopedie volop kansen om mij verder te ontwikkelen. De altijd uitgestoken hand en fijne discussies aan de monitor in 'de boot' zijn typerend voor de werkcultuur die je hebt neergezet. Als ik aan een dag met Mario denk, denk ik aan discussies over een MRI-scan met een traditionele 'Esma' in de ochtend, een keuzevak opzetten en coördineren in de middag, door met pizza en scoring van MRI-scans voor wetenschappelijk onderzoek rond het avondeten, en een goed persoonlijk gesprek tijdens een avondwedstrijd in de ArenA. Bedankt voor dit alles, ik kijk naar je op.

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De totstandkoming van het onderzoek in dit proefschrift is zonder meer een 'team effort'. Door mijn coauteurs en zeer gewaardeerde collega's in binnen- en buitenland heb ik in de afgelopen jaar met veel plezier en inspiratie kunnen werken. Dit proefschrift zou zonder hen niet in de huidige vorm tot stand zijn gekomen. Deze fantastische groep vrienden en collega's heeft gezamenlijk menig onderzoeksproces, wetenschappelijk congres inclusief galadiners en avonden uit, tegenslagen en klinische avonturen overleefd. Als je dit leest en met mij hebt gewerkt aan artikelen of in de dagelijkse klinische praktijk in Aspetar, Amsterdam UMC, Tergooi MC, of het Amphia ziekenhuis, dan is dit deel van het dankwoord voor jou. Deze groep is te talrijk om hier afzonderlijk iedereen de revue te laten passeren, dus graag tref ik jullie in de nabije toekomst in persoon om te kunnen bedanken.

Dit dankwoord is niet compleet zonder een eervolle vermelding voor de geëngageerde groep patiënten welke mee heeft willen doen aan het wetenschappelijk onderzoek in dit proefschrift. Ik heb me meermaals vol verwondering verbaasd over het enthousiasme, het meedenken en de betrokkenheid. Bedankt voor het mede mogelijk maken van de verkregen inzichten. Ik ben ervan overtuigd dat toekomstige patiënten profijt zullen hebben van jullie inzet en bijdrage.

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Mijn sidekicks a.k.a. paranimfen mogen hier uiteraard niet ontbreken.

Gwen, we go way back. We kennen elkaar vanaf het begin van onze onderzoekscarrière, waarin we regelmatig bij elkaar terecht konden voor goede raad of hulp. Ik heb met heel veel plezier en trots gefungeerd als jouw paranimf en ben je zeer erkentelijk dat je ook voor mij die rol hebt willen vervullen.

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goed in balans houden. Ongetwijfeld vallen we echter meer op door onze grappen en grollen dan onze werkprestaties. Ook buiten werk ben je samen met Kyara een graag geziene gast bij officiële en officieuze gelegenheden. Bedankt voor het leuke contact door de jaren heen, je altijd eerlijke mening en je hulp als paranimf.

Lieve Jolyn, het slotstuk van dit dankwoord is uiteraard voor jou. Bedankt voor je eeuwigdurende geduld en onvoorwaardelijke steun. Of het nou de zoveelste avond- of weekenddienst betreft, of vrije momenten waarop ik weer verscholen zit achter een laptop, je bent er altijd voor me geweest. Sterker nog, ik meen dat ten minste onze laatste drie felle discussies gingen over statistiek in plaats van persoonlijke zaken. Dat betekent niet dat je me niet af en toe even een spiegel voorhoudt en me met beide benen op de grond zet als het gaat om work-life-balance. Ik hoop ook na dit proefschrift nog lang met je te mogen ruziën over methodologie en statistiek!

Bedankt dat ik heb mogen staan op de schouders van reuzen.

PORTFOLIO

PhD training & podium presentations

Courses	Year	Workload
Clinical data management	2017	0.3
Practical biostatistics	2017	1.0
eBROK	2017	1.0
Castor: Data management	2019	0.1

Podium presentations	Year	Workload (ECTS)
Anatomy of the proximal hamstring complex, etiology of proximal hamstring injuries, and surgical treatment of acute proximal hamstring injuries (ESSKA 17th, Barcelona)	2016	0.5
Hamstring injury 2.0 (3M congress, Emmen)	2017	0.5
Hamstrings in the fast lane (SEMS meeting, London)	2018	0.5
Myotendinous injuries in young athletes (German Olympic Congress for Sports Specialists, Hamburg)	2018	0.5
Intramuscular hamstring tendon injury: RTP and re-injury (Sportmedisch wetenschappelijk jaarcongres, Ermelo)	2018	0.5
Proximal hamstring avulsions: anatomy, epidemiology, and surgical treatment (SportsKongres, Copenhagen)	2018	0.5
Proximal tendon avulsion (VFBV jaarcongres, Eindhoven)	2018	0.5
Hamstring anatomy (Fortius International Sports Injury Conference, London)	2019	0.5
Outcome of operative vs. non-operative treatment of proximal full-thickness free hamstring tendon injury (Sportmedisch wetenschappelijk jaarcongres, Ermelo)	2019	0.5
Hamstring injury: anatomy, mechanism, and burden (VeiligheidNL symposium sportblessurepreventie, Amsterdam)	2019	0.5
Proximal hamstring ruptures: what do we know & the new international database (SportsKongres, Copenhagen)	2020	0.5
Hamstring anatomy, injury mechanism & imaging (NIMI thigh conference, Oslo)	2023	0.5
Proximal hamstring tendon avulsion (NIMI thigh conference, Oslo)	2023	0.5
Acute hamstring injury: evidence-based management (Edinburgh Orthopaedics and Sports Medicine Conference, Edinburgh)	2023	0.5
Proximal hamstring avulsion: tendon vs. bone (ESSKA specialty days, Warsaw)	2023	0.5
Incidence of muscle injuries in the winter Olympics & classification (ESSKA 21st, Milan)	2024	0.5
Acute muscle injuries of the lower limb in athletes (Sportmedisch wetenschappelijk jaarcongres, Vianen)	2024	0.5

Other		Workload (ECTS)
Journal club	2016-2019	2.0

Teaching

Supervision	Year	Workload (ECTS)
Brent van der Doelen (Scientific internship/Master thesis; Treatment of proximal hamstring avulsions)	2016	2.0
Miriam den Heijer (Bachelor thesis; Complication rate after surgical treatment of proximal hamstring tendon ruptures)	2017	1.0
Jan-Jaap Mellema (Bachelor thesis; Therapeutic interventions for proximal hamstring tendinopathy)	2018	1.0
Hijleke Nauta (Bachelor thesis; Operatieve vs conservatieve behandeling van proximale hamstring avulsiefracturen)	2018	1.0
Willem Six (Scientific internship/Master thesis; Measuring different clinically relevant variables on MRI after proximal hamstring tendon rupture)	2018	2.0
Rana Badawi (Master thesis; Reliability of proximal hamstrings attachment discontinuity assessment on MRI in orthopedic surgeons in training using the novel dropped ice cream sign)	2019	2.0
Emma Cats (Master thesis; Clinical and radiological outcome one year after acute proximal full-thickness free tendon injuries of the hamstring)	2019	2.0
Bas Michel (Bachelor thesis; Proximal hamstring tendinopathy: A systematic review of clinical outcomes after different treatment modalities)	2023	1.0
Dylan Banigo (Bachelor thesis; A comparison of return-to-sport time between operative and non-operative treatments for proximal rectus femoris tendon avulsions – a systematic review)	2023	1.0
Mitchel Misseyer (Master thesis; Hamstring tendon avulsions)	2024	2.0

Lecturing		
Developer and module coordinator, elective course 'Arts & Topsport' (Medicine bachelor, UvA)	2018	3.0
Module coordinator, elective course 'Arts & Topsport' (Medicine bachelor, UvA)	2019	2.5
Guest lecturer, elective course 'Arts & Topsport' (Medicine bachelor, UvA)	2020	0.3
Guest lecturer (Medicine, SEHSO/UvA)	2024	0.3

Awards, grants, & publications

Awards		Year
Traumaplatform award	Traumaplatform	2016
Star paper ward (SMWJC)	Vereniging voor Sportgeneeskunde	2018

Grants	Provider	Year
AMC PhD Scholarship	Amsterdam UMC (AMC)	2016

Publications (journal articles)	Year
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Publications (book chapters)	Year
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Amsterdam Movement Sciences

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Amsterdam Movement Sciences conducts scientific research to optimize physical performance in health and disease based on a fundamental understanding of human movement in order to contribute to the fulfillment of a meaningful life.

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