Proximal Hamstring Tears

From Endoscopic Repair to Open Reconstruction

Thomas Youm
Editor

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To my wife, Janet, for her uncompromising support of my career in sports medicine and for being the rock of my family. Her tireless efforts at home afford me the opportunity to pursue clinical and academic excellence.

To Tyson and Amelia—everything I do is with the hope that you will be proud of your father.

Preface

I am excited to present the first textbook focused on proximal hamstring injuries and their management. The vast majority of hamstring injuries seen in the office are strains of the hamstring muscle and treatment tends to be straightforward for the general orthopedist. Proximal hamstring injury treatment is much more complex and less well studied.

Presenting you with this textbook was only possible because of the breadth of knowledge and expertise of our contributors. All contributing authors worked hard to provide clinically useful information and pearls for our readers. As a team, we feel that we truly have covered proximal injuries from A to Z and our writing is based on the most cutting-edge techniques and most recent high-quality research. I want to thank my colleagues at NYU Langone Orthopedic Hospital for consistently producing excellent work.

Some of the interesting and unique discussions in this textbook include biologics and PRP injections for proximal hamstring injuries, case studies for acute surgical repair and chronic reconstruction of proximal hamstring tears, rehabilitation and bracing after surgery, open versus endoscopic proximal hamstring surgical treatment, and surgical complications which include injury to the sciatic nerve.

Until now, there has not been a comprehensive resource to understand the pathophysiology, rehabilitation, biologic treatments, and surgical treatments for proximal hamstring injuries. I sincerely hope that students, patients, therapists, clinicians, and surgeons from all different professional backgrounds find this book enriching and useful.

New York, NY, USA Thomas Youm

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Functional Anatomy of the Hamstrings

1

Lawrence J. Lin and Robert J. Meislin

Introduction

The hamstrings are composed of a group of muscles found in the posterior compartment of the thigh primarily responsible for extension of the hip and flexion of the knee. These three muscles of the hamstring are *semimembranosus, semitendinosus*, and *biceps femoris*, which can be further divided into a long head portion and a short head portion. The semitendinosus and long head of the biceps femoris are often described as the "conjoint tendon." With the exception of the short head of biceps femoris, the hamstring muscles all originate from the ischial tuberosity and receive innervation from the tibial division of the sciatic nerve. The short head of biceps femoris originates from the lateral lip of linea aspera on the femur and receives innervation from the common fibular (peroneal) division of the sciatic nerve. The large proportion of type II muscle fibers [1] coupled with the crossing of two joints makes the hamstring muscles particularly susceptible to injury, reflected in the high rates of strains seen in athletes [2]. As with many muscles, the hamstrings are typically injured from excessive strain during eccentric contraction, with both speed of elongation and duration of activation prior to contraction influencing severity [3]. These injuries can occur during sprinting as well as during motions that excessively stretch the hamstrings such as kicking or dancing, often resulting in tears to the musculotendinous junction where the eccentric load is greatest as well as avulsions from the ischial tuberosity [4–9].

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Semitendinosus

Named for its long tendon of insertion, semitendinosus has the longest muscle belly of the hamstring muscles and is characterized by a tendinous inscription that divides the muscle into separate superior and inferior regions. Larger only than the short head of biceps femoris, semitendinosus has the second smallest physiological cross-sectional surface area and volume of the hamstring muscles. This suggests a limited potential for force production and may also account for its lower rates of injury [10]. Semitendinosus functions to extend the hip and stabilize the pelvis as well as flex and internally rotate the knee.

Origin

Semitendinosus and the long head of biceps femoris share a common origin on the ischial tuberosity with conjoined proximal tendons (Figs. 1.1 and 1.2) [11]. While some authors describe a posteromedial attachment site [11–14], others report a directly medial [15, 16] or lateral origin on the ischial tuberosity [17, 18]. The footprint of the conjoint tendon measures roughly 3.9 ± 0.4 cm in length and 1.4 ± 0.5 cm

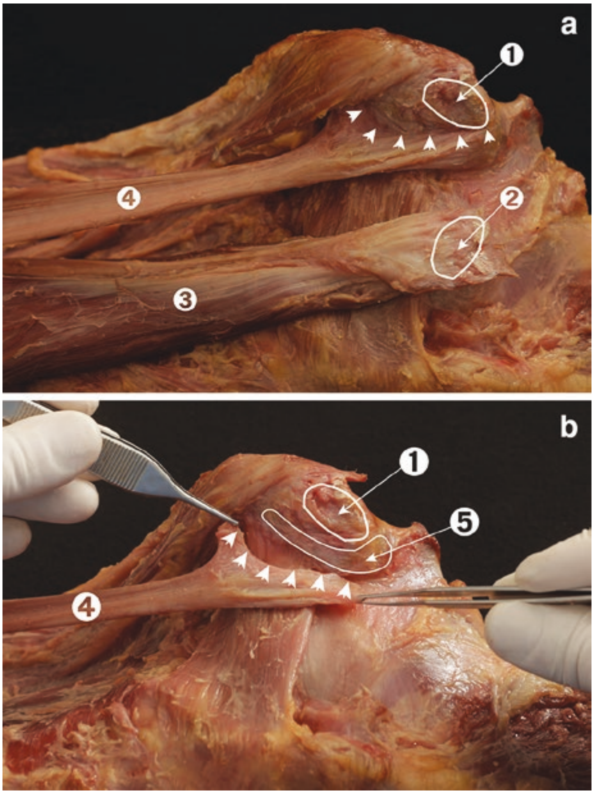

Fig. 1.1 (**a**, **b**) Image showing posterolateral view of the area of the proximal attachment of the hamstring muscles (right lower extremity). (1) Area of the attachment of the conjoined tendon of the semitendinosus and the long head of the biceps femoris; (2) the proximal attachment area of the conjoined tendon; (3) conjoined tendon of the semitendinosus and the long head of the biceps femoris—cut and rotated 180°; (4) proximal tendon of the semimembranosus muscle; (5) area of the attachment of the semimembranosus muscle; arrowheads—shape of the semimembranosus attachment. (With permissions from Stępień et al. [11])

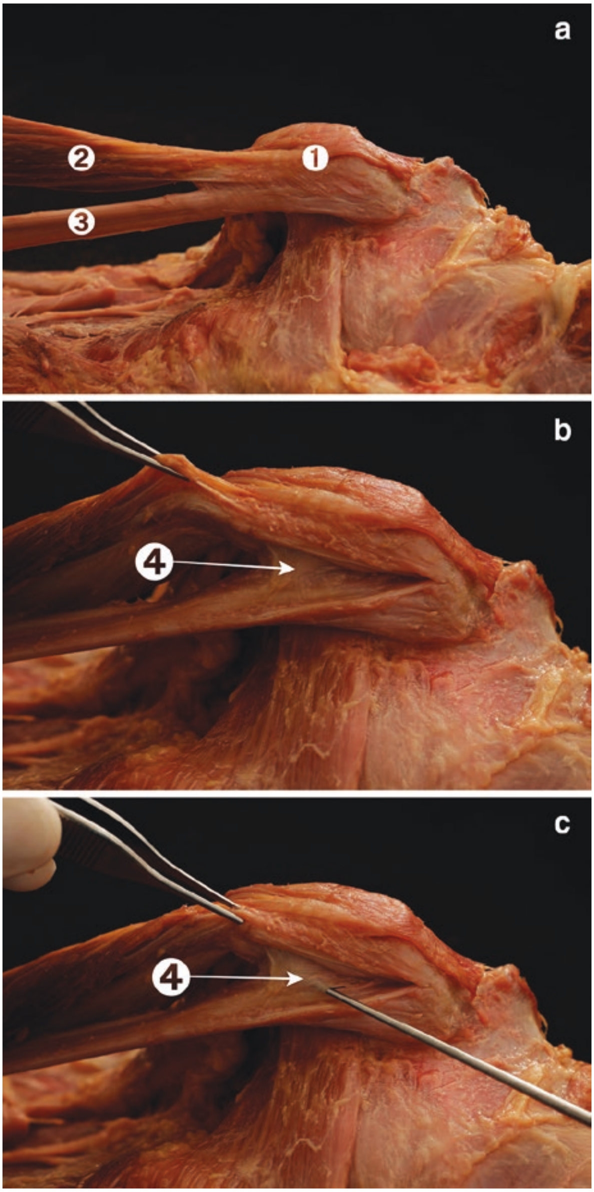

Fig. 1.2 (**a**–**c**) Image showing lateral view of the area of the proximal attachment of the hamstring muscles (right lower extremity). (1) Ischial tuberosity; (2) conjoined tendon of the semitendinosus and the long head of the biceps femoris; (3) proximal tendon of the semimembranosus muscle; (4) bursa of the proximal biceps femoris between split tendons. (With permissions from Stępień et al. [11])

in height [17]. The proximal tendon and musculotendinous junction of semitendinosus are the shortest of all the hamstring muscles [10].

Insertion

Semitendinosus travels medially across the knee joint to insert on the medial surface of the tibia where the distal tendon contributes to the formation of pes anserinus alongside the distal tendons of sartorius and gracilis. The distal tendon of semitendinosus is the longest of the hamstring muscles [10] and can be found superficial to semimembranosus.

Innervation

Semitendinosus is supplied by two motor branches derived from the tibial nerve [11]. One nerve branch enters the muscle above the tendinous inscription while another enters the muscle below the inscription [10]. Due to its proximity to the ischial tuberosity, the sciatic nerve can be injured during surgical repair of proximal hamstring avulsions [19]. Moreover, delayed repair can cause scarring around the sciatic nerve leading to increased risk for injury [9, 19–21].

Anatomical Variants

There can be partial fusion of the semitendinosus and semimembranosus muscles. Additionally, accessory slips of semitendinosus have been known to originate from the coccyx, sacrotuberous ligament, and iliotibial band [22]. Semitendinosus can have an extra tendinous slip that attaches to the gracilis tendon at its point of insertion [23], and the distal tendon can insert into the crural fascia of the leg instead of the tibia [24].

Biceps Femoris Muscle Long Head

Biceps femoris derives its name from its two heads of origin: one long and one short. The long head of biceps femoris originates from the ischial tuberosity and is adjoined with the proximal tendon of semitendinosus, potentially contributing to instances of concurrent injuries to both muscles [13]. The long head of biceps femoris can be split into a superficial and a deep region based on differences in attachment site and fascicle direction [10]. The long head of biceps femoris has the second largest physiological cross-sectional surface area and muscle belly volume [10] and is the most commonly injured muscle of the hamstring [25]. Much like semimembranosus, the distal and proximal tendons and musculotendinous junctions of the long head of biceps femoris overlap within the muscle belly [14]. In addition to hip extension and knee flexion, the long head of biceps femoris functions to externally rotate the knee.

Origin

The long head of biceps femoris originates from the posteromedial aspect of the ischial tuberosity from a proximal tendon continuous with semitendinosus (Figs. 1.1 and 1.2). As previously described, the location of the tendon on the ischial tuberosity has been reported as posteromedial [11–14], directly medial [15, 16] or lateral [17, 18]. After separating from the conjoint tendon of semitendinosus, the proximal tendon of the long head of biceps femoris continues laterally.

Insertion

The long head of biceps femoris travels inferiorly to join the short head of biceps femoris in the posterolateral region of the femur. Together, the long and short heads insert on the fibular head as well as the lateral tibial condyle and fascia of the leg [26].

Innervation

The tibial division of the sciatic nerve gives off a motor branch to the long head of biceps femoris in the proximal region of the posterior thigh [11].

Anatomical Variants

Although the long head of biceps femoris typically shares a common proximal tendon with semitendinosus, there have been reports of biceps femoris originating independently from the ischial tuberosity [26]. Additionally, the long and short heads of biceps femoris do not always join before inserting on the fibular head, and a third head of biceps femoris has also been previously reported [27]. Other variations include hypertrophy of the distal tendon to the tibia, late bifurcation of the tendon, or absence of the fibular attachment site. These variations in the distal tendon have been associated with snapping biceps femoris tendon syndrome [28]. Like semitendinosus, the long head of biceps femoris may exhibit a tendinous inscription with separate innervation within the divided muscle [29].

Biceps Femoris Short Head

As the only muscle of the hamstring that receives innervation from the common fibular (peroneal) nerve, the short head of biceps femoris contains two anatomic partitions with one superficial region and one deep region. Biceps femoris short head has the longest fascicles but smallest surface area of all the hamstring muscles, suggesting a limited role in force production [10]. The short head of biceps femoris flexes and externally rotates the knee.

Origin

Biceps femoris short head originates from the linea aspera of the femur, lateral supracondylar ridge, and lateral intermuscular septum [10].

Insertion

After joining with the long head of biceps femoris, the short head inserts predominantly on the fibular head as well as the lateral tibial condyle and fascia of the leg [26].

Innervation

Biceps femoris short head is the only muscle of the hamstring that does not receive innervation from the tibial division of the sciatic nerve, instead supplied by the common fibular (peroneal) division. Its separate innervation from biceps femoris long head may interfere with coordination and increase risk of injury [30].

Anatomical Variants

The short head of biceps femoris may be absent entirely [22], and the long and short heads do not always join before inserting on the fibular head. A third head of biceps femoris has been previously reported [27], and there can be several variations in the distal tendon as described above.

Semimembranosus

The semimembranosus muscle is the largest of all the hamstring muscles by physiological cross-sectional surface area as well as volume [10] and is so named for its broad tendon of origin. Three partitions can be grossly appreciated in semimembranosus [10]. The proximal and distal tendons overlap within the muscle belly, which may be relevant to both muscle function and potential injuries at the musculotendinous junction [10]. Similar to semitendinosus, the semimembranosus muscle participates in hip extension and pelvis stabilization as well as flexion and internal rotation of the knee.

Origin

With the longest proximal tendon and musculotendinous junction of all the hamstring muscles [10], semimembranosus originates from the ischial tuberosity and travels deep to the proximal tendons of semitendinosus and the long head of biceps femoris (Figs. 1.1 and 1.2) [13]. The site of origin has been described as the anterolateral aspect of the ischial tuberosity by some [11–14, 31], and the anterior [17] or lateral aspect by others [16]. The footprint of the proximal tendon measures roughly 4.5 ± 0.5 cm in length and 1.2 ± 0.3 cm in height [17].

Insertion

The distal tendon of semimembranosus has been known to insert on several sites at or near the knee. These sites include a groove at the posteromedial aspect of the tibia (direct arm), (2) the tibia deep to the medial collateral ligament (anterior arm), (3) the oblique popliteal ligament, (4) the posterior oblique ligament (capsular arm), (5) the coronary ligament of the posterior horn of the medial meniscus (meniscal arm), and (6) an extension over the popliteus muscle (distal arm) [32–34]. There have also been reports of attachments to the posterior capsule and the lateral meniscus [33, 34]. Given the complex anatomy of the distal tendon, there is agreement on several attachment sites (direct arm, anterior arm, oblique popliteal ligament) but lingering uncertainty regarding others [32]. Although the distal tendon of semimembranosus is similar in length to those of semitendinosus and the long head of biceps femoris, the distal musculotendinous junction is the longest of all the hamstring muscles [10].

Innervation

Semimembranosus is innervated by the tibial division of the sciatic nerve, with the superior and inferior regions receiving a primary nerve branch. The middle region receives a secondary nerve branch coming from a primary branch to either the superior or inferior regions [10].

Anatomical Variants

There is reported variation in the size of semimembranosus, which can be completely absent or duplicated. Semimembranosus can also originate from the sacrotuberous ligament and give off slips to adductor magnus [22]. Additionally, there is a documented case of semimembranosus sharing a common proximal tendon with both semitendinosus and the long head of biceps femoris [17].

Collective Function of the Hamstrings

Since the hamstring muscles span the hip and the knee joints, they function as extensors of the hip, flexors of the knee, and abductors of the lower limb [11]. As a group, the hamstrings primarily undergo eccentric contraction and perform several roles when sprinting [11]. The hamstrings shorten prior to foot strike and throughout the stance phase of the gait cycle. During the swing phase, the muscles contract to coordinate hip extension and prevent excessive extension of the knee. During the terminal swing phase, the hamstrings perform negative work and reach peak musculotendinous strain [35, 36]. This can be considered a period of increased risk as the majority of hamstring injuries occur at or near the musculotendinous junction

[37–39]. Additionally, many hamstring injuries can be attributed to sudden contraction of the muscles against resistance, producing an excessive eccentric load often seen in sports such as sprinting, gymnastics, and waterskiing, as well as in slips and falls [9].

Additionally, the hamstrings contribute to balance in the lower limb by serving as the primary antagonist to quadriceps femoris [40] and assist the anterior cruciate ligament (ACL) in decreasing anterior tibial translation during knee extension [41]. By attaching to the ischial tuberosity, the hamstrings can also affect pelvis position and body posture [11, 42]. As a result, the hamstrings wield considerable influence on lower limb movement and stability.

Individual Function of the Hamstrings

Although the combined effect of hamstrings activation is flexion of the knee and extension of the hip, important differences exist between individual muscles [11]. By inserting laterally on the proximal fibula and tibia, biceps femoris rotates the lower leg externally during contraction and contributes to stability in the posterolateral corner of the knee [43]. Biceps femoris also decreases anterior tibial translation to reduce ACL loading by quadriceps femoris [41]. On the other hand, semitendinosus and semimembranosus insert medially on the proximal tibia and cause internal rotation of the tibia during contraction [44]. In doing so, they serve as antagonists to biceps femoris [43].

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2 Epidemiology, Biomechanics, and Classification of Proximal Hamstring Injuries

Michael Pickell and Brendan Swift

Epidemiology

Hamstring injuries are an exceedingly common injury in both athletes and the general population. Estimates of injury prevalence range from 8% to 25% of recorded injuries in athletes [1, 2]. Despite the common nature of these injuries, there is a paucity of epidemiological data to reflect hamstring injuries in the general public. Much of the published epidemiological data arises from professional sporting leagues [3–6]. Their large-scale preexisting datasets and close monitoring of players allows for the collection and analysis of many musculoskeletal injuries in a population at higher risk than the general public. This well-documented sample of professional athletes provides a very specific insight on this demographic but may not be completely transferrable to the general public.

Sports requiring bursts of explosive sprinting patterns are frequently noted to have high incidences of injury. Much of the epidemiological data stems from professional rugby, football, and soccer leagues [4, 5, 7–9]. Other activities with a high incidence of hamstring injuries include waterskiing and dancing, likely due to the compromising positions involved [10, 11].

As much of the data surrounding hamstring injury arises from elite athletes, generalizability to recreational athletes or the general public may be limited. The data does, however, provide some insight into risk factors for injury and pathomechanics involved in injury.

There is significant heterogeneity in the established data in terms of sport and competition level. Similarly, the risks of injury are varied and depend on the nature of a given sport. Injury audits of English professional football players demonstrated that hamstring injuries represented 12% of all reported injuries [6, 12]. The majority

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of these injuries (62%) occurred during match play, and specifically tended toward the end of the half [6]. Injuries tended to occur while running (57%) and were non-contact in nature 91% of the time. Reinjury in the setting of hamstring strain is also common, ranging from 12% to 17% [6, 7, 12]. Of the hamstring strains recorded, only 5% were radiographically investigated with even fewer (1.9%) being treated surgically [12], demonstrating that although hamstring injuries are common, the majority do not require any advanced work-up or surgical intervention. Similarly, a study of National Football League player injuries identified hamstring injuries as the second most frequent injury suffered by players, with a rate of 4.07 per 1000 athlete exposures in game situations [3]. Of the most common injuries they recorded, hamstring strain was one of the leading causes of time spent away from play with an average of 8.3 days lost for hamstring injuries experienced in practices and 9.5 days for those suffered in games [3].

Numerous modifiable and non-modifiable risk factors have been identified for hamstrings injuries. Age has been identified as an independent risk factor for hamstring injury, with some reports suggesting the odds of sustaining hamstring injury increase by 1.78 times with each increasing year in age [9]. Sex differences among athletes also contribute to differences in risk profile. A study of American collegiate soccer players demonstrated that men were 64% more likely to suffer a hamstring strain than women and were nearly twice as likely to experience a recurrence [5]. Modifiable risk factors that have been implicated in hamstrings injury include hip flexibility as well as lower extremity power and muscle imbalance [2]. Commonly, the muscle imbalance is the hamstring to quadriceps strength ratio. It is thought that an imbalanced strength ratio increases the extension moment through the knee. This places the hamstring in eccentric stress beyond its elastic capabilities [13]. Specifically, the risk of injury is increased in athletes with hamstring:quadriceps strength ratio less than 0.6 [2]. With regard to hip flexibility, Henderson et al. [9] demonstrated in Premier League soccer players that for each 1° lack of hip flexion range of motion, injury propensity increased by 1.29 times. Similarly, injury propensity increased by 1.47 times for each centimeter increase in non-countermovement jump performance [9].

Injury recurrence and time away from play is a concern for athletes at any level, and many factors have been identified as contributing to the time to return to play [14]. Anatomic location, type of injury, distance from ischial tuberosity [7] have all been identified as factors effecting time to return to play. For example, Askling et al. [7] evaluated the injury characteristics and time to return to sport in athletes suffering hamstring injuries during ballistic movements (sprinting) as compared to extreme length stretching injuries (dancing). They noted that the athletes who suffered running injuries observed a more rapid decline in performance followed by a faster return to pre-injury function when compared to the stretch type injuries experienced by the dancing group.

Biomechanics

The hamstrings represent a group of muscles in the posterior thigh, whose unique anatomy plays a crucial role in the posterior chain by stabilizing both the hip and knee. Their biarticular insertion and high force generation expose the hamstrings to unique stresses and a high rate of injury [15]. The hamstring complex is made up of three muscles: the semimembranosus, semitendinosus, and the short and long heads of the biceps femoris (Fig. 2.1). All three muscles are innervated by the tibial branch of the sciatic nerve, with the exception of the short head of biceps femoris, which receives its innervation from the common peroneal nerve. The semitendinosus and long head of biceps femoris share a common origin from the lateral ischial tuberosity in the form of the conjoint tendon. The long head of biceps femoris travels laterally to unite with the short head of biceps along the posterior femur and inserts on the posterolateral tibia. Semitendinosus travels medially to insert with the gracilis and sartorius at the pes anserinus.

Many biomechanical and kinematic studies have examined the role of the hamstrings in walking and running gait. The biarticular organization, dual innervation of biceps, muscle fiber type, and pelvic tilt have all been implicated in injury

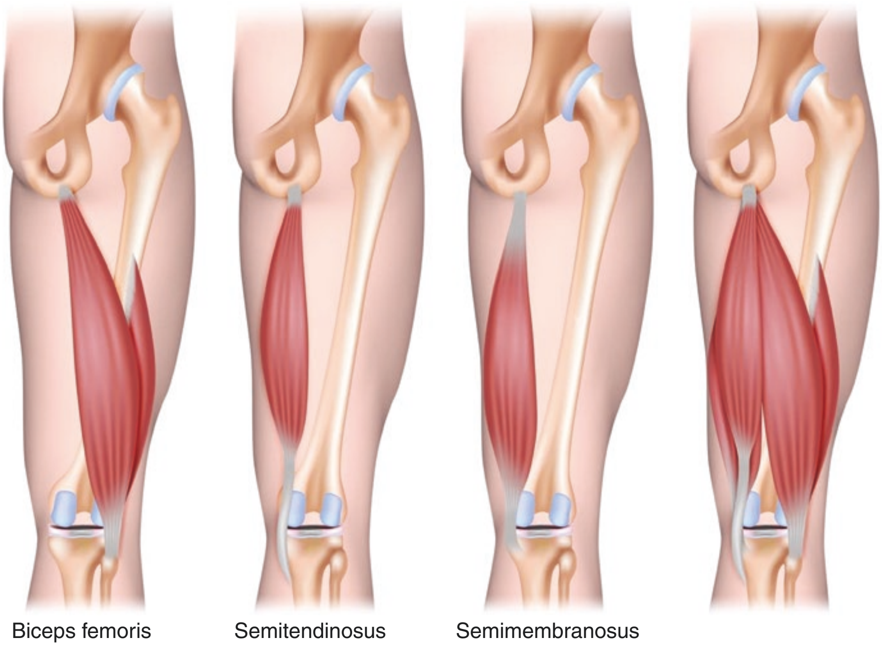

Fig. 2.1 Anatomy of theposterior thigh. Biceps femoris, semitendinosus, and semimembranosus and their relationship as labeled. (From Alila Medical Media. Reproduced with permission)

predisposition [16] Given their biarticular anatomy, the hamstrings act to both extend the hip and flex the knee. During walking gait, the hamstrings assist in flexing the knee as the hip flexes to assist ground clearance of the foot through swing phase [17]. In contrast, kinematic studies of running have demonstrated that the hamstrings remain active throughout nearly the entire cycle of running gait [18–20]. Specifically, eccentric contraction of the hamstring complex is noted in both late swing phase and late stance phase; however, the peak eccentric contraction speeds are far greater in late swing phase [18]. Further it is thought that the application of peak eccentric force, at the moment of maximal fiber length observed in late swing phase create the conditions required for hamstring injury [13, 18, 21]. A schematic representation of the running gait cycle is demonstrated in Fig. 2.2.

A few case reports have been published around studies which coincidentally captured hamstring injuries during kinematic analysis [22, 23]. These injuries were unfortunate for the participants; however, the active data capture during injury has provided excellent insight on the conditions surrounding injury. The first of which captured a hamstring injury in a 31-year-old professional skier who was running at 5.36 m/s on a 15% incline. Kinematic analysis did demonstrate that the moment of injury occurred in late swing phase, resulting in an injury to the long head of biceps while it was in a position 12.2% longer than standing resting length [22]. A similar injury was captured in a sprint trial with an elite Australian Football player [23]. Kinematic data again identified the moment of injury as occurring in late swing phase. Interestingly, both individuals in the case reports had suffered previous hamstring injuries, further supporting the high rate of hamstring injury recurrence.

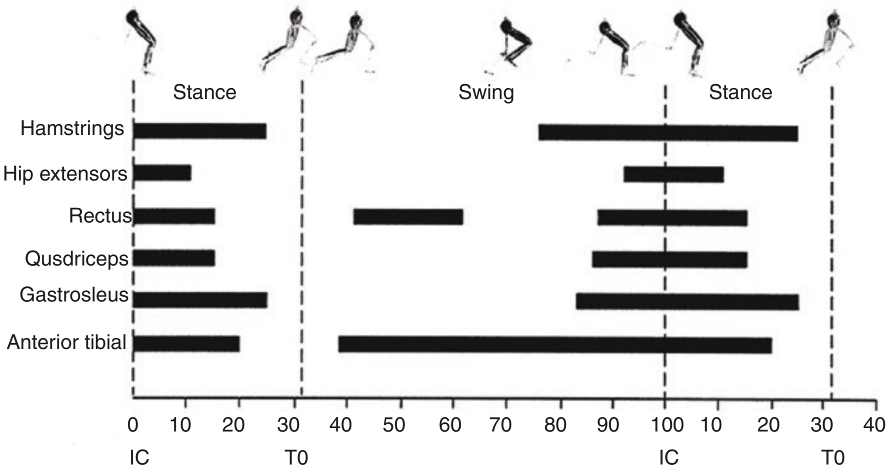

Fig. 2.2 Running gait cycle. Approximately 1.3 gait cycles are depicted in an effort to better visualize the continuous nature of running gait. Muscle activity is represented by the solid bars in relation to the gait cycle. (Reproduced with permission from Novacheck [20])

Classification

Characterization of injury severity represents an important part in the work up of suspected hamstring tear. Ideally classification systems assist in guiding therapeutic interventions and aid in prognostication of injuries. However, classification of hamstring injuries remains a challenge. Many classification systems exist but most only examine certain injury characteristics. Currently no overarching system has been identified to include all facets of injury, and many of the existing classification systems have not yet been validated [24].

Classic descriptions of magnetic resonance findings in muscle strain injuries have been previously described and can be generalized and applied specifically to hamstring injuries [25]. These descriptions are outlined in Table 2.1. First degree strains are described as microscopic injury with adjacent hyperintense T2 signal without identifiable muscle fiber disruption. Second degree strains encompass moderate strains with macroscopic tears at the myotendinous junction, this is represented by high signal intensity on T2 imaging and focal hematoma. Third degree strains present as severe strains with complete disruption of the myotendinous junction, with or without retraction. In this case, imaging demonstrates disruption of fibers and fluid-filled collection in the negative space, should the muscle demonstrated retraction [26].

One hamstring-specific radiographic classification system was proposed by Peetrons [27] which can be applied to ultrasound or magnetic resonance imaging and outlines four grades of muscle injury severity. Grade 0 injuries are described as a lack of ultrasound (or MRI) lesion, contrasted by Grade I injuries which describe minimal elongations with less than 5% of muscle involved. Grades 2 and 3 encompass injuries with muscle fiber tearing. Grade 2 injuries are comprised of partial tears involving 5–50% volume or cross-sectional diameter, whereas Grade III lesions demonstrate complete muscle tears, subcategorized by a lack (3A) or presence (3B) of muscle retraction. An example of a grade 3B tear is demonstrated in Fig. 2.3. Excellent inter and intraobserver reliability was demonstrated with the use of this classification system in MR imaging in acute hamstring injuries in athletes [8]. This classification system was further explored to assess its role in prognostic prediction. A study of 516 hamstring injuries in Union of European Football Association (UEFA) players evaluated the use of Peetrons grading on MRI as a prognostic factor for time out of play following injury. Of those athletes who underwent MRI, 13% were Peetrons grade 0, 57% grade 1, 27% grade 2, 3% grade 3 [4].

Table 2.1 Radiologic grade for strain based on MRI

Grade	Description
I	T2 hyperintense signal surrounding a tendon or muscle with no fiber disruption
II	T2 hyperintense signal surrounding and within a tendon or muscle with fiber disruption equal to less than half of the tendon or muscle width
III	Disruption of muscle or tendon fibers greater than half the muscle or tendon width, with hyperintense T2 signal present in the injured tissue

Adapted from Shelley et al. [25]

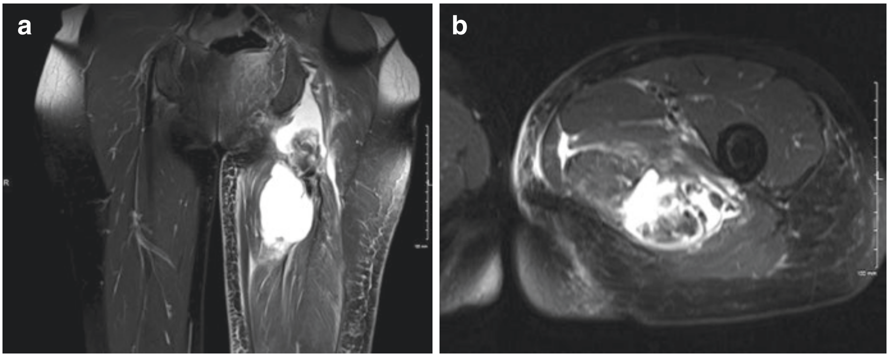

Fig. 2.3 MRI demonstrating complete rupture of the common hamstrings origin with retraction. (**a**) coronal T2-weighted view; (**b**) axial T2-weighted view

Table 2.2 MRI scoring system proposed by Cohen et al. [26]

Points	Age (y)	Muscles involved (n)	Location	Insertion	Muscle injury (%)	Retraction (cm)	Long axis T2 signal length (cm)
0				No	0	None	0
1	≤25	1	Proximal		25	<2	1–5
2	26–31	2	Middle	Yes	50	≥2	6–10
3	≥32	3	Distal		≥ 75		>10

National Football League players with scores >15 were associated with a prolonged recovery, whereas players with scores <10 missed one or fewer games

They further determined that MRI grading of severity did correlate with time off from play, defined as absence from full team practice and match play. Specifically, they demonstrated average time off at 8, 17, 22, 73 days for Grades 0–3, respectively.

An additional predictive scoring system was proposed by Cohen et al. arising from retrospective analysis of hamstring injuries in National Football League players [26]. Their system was developed in efforts to predict time off based on MRI findings. Their scoring system is outlined in Table 2.2. Through their analysis they observed that players with scores less than 10 missed one game or less, whereas scores greater than 15 were associated with prolonged time to return to play (five or more missed games) [26].

Additional classification systems have been developed to provide descriptive categorization. For example, Wood et al. created a surgically focused classification system to describe proximal hamstring avulsion injuries in a case series of 72 successive cases undergoing operative fixation (Table 2.3). Specifically they address proximal hamstring avulsions based on anatomic location, degree of avulsion (complete or incomplete), degree of muscle retraction, and sciatic nerve tethering if present [28]. They divide the injuries into five types: type 1 injuries being osseous avulsions, whereas type 2 avulsions occur at the myotendinous junction. Type 3 injuries are incomplete tendon avulsions from bone. Type 4 represents complete

Table 2.3 Classification of proximal hamstring avulsion injuries as described by Wood et al. [28]

Type	Description
1	Osseous injury in skeletally mature patient
2	Injury at musculotendinous junction
3	Partial tendon avulsion
4	Complete tendon avulsion with no retraction
5A	Complete avulsion with associated retraction but no associated sciatic nerve tethering
5B	Complete avulsion with associated retraction with associated sciatic nerve tethering

avulsions with minimal or no retraction, and type 5 represents complete avulsion with retraction of the junction ends [28]. Interestingly, they identified waterskiing as the most frequent cause of injury (29% of patients) in this operative group.

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3 Nonoperative Treatment of Proximal Hamstring Tendon Tears

Daniel J. Kaplan

Introduction

Hamstring injuries are extremely common, accounting for nearly 30% of all new lower extremity injuries [1]. What's more, they carry a significant risk of residual pain or limitation, with roughly 20% of all hamstring injuries becoming chronic [1]. Of hamstring strains or ruptures that do go on to heal, reported reinjury rates range from 12% to 31% [1]. These four statistics reflect hamstring injuries of all varieties. While an exact definition has not been agreed upon, proximal hamstring injuries can generally be defined as injury from the ischial tuberosity origin of the proximal tendinous attachments to roughly the proximal myotendinous junction [2]. Proximal injuries have been shown to more severely affect activities of daily life and have longer recoveries. The success rate for treatment for proximal hamstring injuries, for both operative and nonoperative treatment have traditionally been particularly poor, though is improving [3]. As more research has been done, a plethora of operative and nonoperative treatment options have been developed, all with varying levels of success [4]. This chapter will focus on nonoperative treatment for proximal hamstring injuries.

Anatomy

A thorough discussion of relevant anatomy can be found in Chap. 1, but a brief description will be given below.

The proximal hamstring complex is made up of three muscles, the semimembranosus, semitendinosus, and long head of the biceps femoris. The posterolateral ischial tuberosity serves as a common origin. The semitendinosus and long head of

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the biceps femoris form a conjoined tendon medially, while the semimembranosus originates ventrally and laterally. The short head of the biceps originates just medial to the linea aspera on the posterior distal femur [4]. Proximally, it is difficult to differentiate the individual tendinous units. Between 5 and 10 cm distal to the ischium, they begin to separate. The semimembranosus is the first muscle to become distinct, followed by the biceps femoris and semitendinosus. The long head of the biceps femoris becomes visible roughly 6 cm distal to the ischial tuberosity, and its proximal myotendinous junction encompasses roughly three-fifths of the total length of the muscle unit [5]. One factor that contributes to the high incidence of hamstring injury is its traversal over two joints (the hip and the knee). The semimembranosus crosses from its relatively lateral insertion on the ischium to insert on the posteromedial tibial condyle. The semitendinosus inserts distally and anteriorly to the semimembranosus as part of the PES anserinus (which includes the sartorius, gracilis, and semitendinosus) on the posterior medial tibia, just proximal and medial to the tibial tubercle [6].

Given that the hamstrings cross two joints, they contribute to two forms of motion: hip extension and knee flexion. Their differing insertions relative to the tibial joint line affect their relative functions. The more distal insertion of the semitendinosus results in preferential knee flexion, while the more proximal insertion of the semimembranosus results in preferential hip extension. The semimembranosus contributes to knee stability (valgus) and medially rotates the calf at the knee, while simultaneously extending, adducting, and medially rotating the thigh at the hip. The semitendinosus also contributes to (valgus) knee stability internal rotation of the calf at the knee [7].

The long and short heads of the biceps femoris insert laterally on the fibular head. Innervation of the hamstrings is provided by the tibial portion of the sciatic nerve, except for the short head, which is provided by the peroneal portion of the sciatic nerve [8]. In addition to hip extension and knee flexion, the biceps femoris complex contributes to varus knee stability and external rotation of the leg at the knee joint [9].

Mechanism of Proximal Hamstring Injury

Hamstring muscle injuries are particularly common, due in large part to its traversal over two joints, as mentioned above. The free tendon end of the semimembranosus is the most commonly injured muscle in proximal hamstring tears [10]. Like other tendon injuries, proximal hamstring injuries are typically due to eccentric loading of the musculotendinous unit. However, two different types of acute hamstring injuries are described, which result from different, albeit related, mechanisms [11–14].

Type I hamstring strains occur during high-speed, deceleration events, typically during the terminal swing phase of running. During the last 25% of the swing phase, the hamstring muscles eccentrically contract while at their maximum length (hip fully flexed, knee fully extended) to decelerate the swinging limb and prepare for foot strike [15]. In type I injuries, the long head of the biceps femoris is most commonly involved, and injury typically occurs at the proximal muscle–tendon junction [16].

Type II acute preferentially injures the proximal free tendon of the semimembranosus close to the ischial tuberosity [8]. Type II injuries occur due to slow-twitch, excessive lengthening activities, including dancing and water-skiing. Recovery for type II injuries has been shown to be prolonged compared to the more distal type I injury [17].

Proximal hamstring tendons can also be due to a chronic, degenerative condition. This is typically a result of repetitive mechanical overload and stretch and occurs most commonly in long distance runners, dancers, and endurance athletes [8].

Risk Factors for Proximal Hamstring Injuries

Several risk factors exist that may predispose athletes to proximal hamstring injuries, which can be broadly categorized. Inadequate preparation, which includes deconditioning from inactivity, fatigue, and dehydration, have been shown to increase the incidence of hamstring injuries, though not specifically proximally [1]. Inadequate pre-activity stretching has been posited as a potential risk factor, but this remains controversial [18].

Muscular imbalance has also been linked to hamstring injuries, specifically if there is an increased quadriceps-to-hamstring strength ratio [4]. Lastly, anatomic abnormalities, such as leg length inequality or previous injuries can predispose patients to proximal tearing [1]. Prior hamstring injury is associated with the highest risk of hamstring tear [19], and as discussed in Chap. 12, this population needs to be managed cautiously.

Clinical Presentation

Patients with proximal hamstring injuries present based on their mechanism of injury. More commonly, patients will present following an acute injury, with an identifiable event they can trace their pain to, such as a high-kick while dancing [7]. There may be an associated audible pop at the time of injury. Conversely, a patient with chronic proximal tendinopathy will complain of more subtle symptoms, such as posterior thigh pain with sitting or hamstring tightness [3].

A thorough exam is critical, as identifying a proximal hamstring injury can be challenging, as there is a myriad of injuries that may present similarly. The first step in the exam is to observe the patient's gait. Patients with proximal hamstring injuries will try to avoid flexing the hip and extending the knee, which results in a stiff-legged gait [1]. Patients with acute proximal hamstring tears may have significant ecchymosis, which is more common than in mid-substance or distal tendinous insertional injuries. In both acute and chronic injuries, there will likely be tenderness to palpation over the ischial tuberosity. In chronic tears, there may be a thickened area of subcutaneous tissue that can be identified immediately adjacent to the

Fig. 3.1 Puranen–Orava test: The patient flexes the hip to 90°, then fully extends the knee while resting the foot on an elevated platform, which places the hamstring on stretch

injury [4]. Sciatic nerve function should be investigated closely, as scarring from chronic tears has been found to lead to nerve irritation [20].

Some proximal hamstring-specific physical exam maneuvers have been described that may assist in diagnosis. The Puranen–Orava test is performed by the patient flexing the hip to 90°, then fully extending the knee while resting the foot on an elevated platform, which places the hamstring on stretch (Fig. 3.1). To perform the bent-knee stretch, the patient is placed in the supine position, and the hip and knee are maximally flexed. The knee is then passively extended (Fig. 3.2a, b). The modified bent-knee stretch also is performed with the patient in a supine position. The patient is made to lie down with the leg fully extended, and then the examiner maximally flexes the hip and knee, followed by rapid knee extension (Fig. 3.3). Each test is considered positive if the patient reports reproducible pain similar to symptoms [21].

Imaging is helpful for making the diagnosis, particularly in chronic cases, but typically is more useful for grading the severity of the injury. Plain X-rays are usually negative, but should be obtained to rule out an avulsion fracture in an adult or apophyseal fracture in a skeletally immature patient [22]. Ultrasound offers several benefits, including portability, accessibility, and ability to perform a dynamic exam. Findings suggestive of a tear on ultrasound include fluid collections adjacent to the injured tendon representing edema or hemorrhage. The frequency can be adjusted as needed—higher frequencies provide better resolution, while lower frequencies

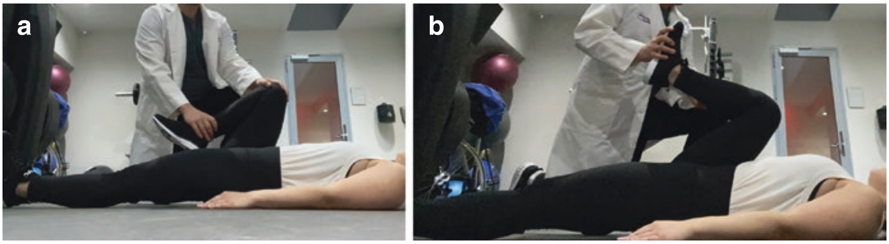

Fig. 3.2 The bent knee stretch: (**a**) the patient is placed in the supine position, and the hip and knee are maximally flexed. (**b**) The knee is then passively extended

Fig. 3.3 Modified bent-knee stretch: With the patient supine, the patient lays with the leg fully extended, then the examiner maximally flexes the hip and knee, followed by rapid knee extension

provide better penetration [4]. Ultrasound is most accurate in the acute phase, when the most edema is present [23].

MRI is the most common modality utilized to detect and assess proximal hamstring tears. Acute ruptures will demonstrate increased fluid signal on T2 sequences between the free tendon edge and ischial tuberosity or intratendinous fluid. Partial tears without retraction may be seen as the, "sickle sign", which represents an area of fluid between the partially torn tendon edge and the bone (Fig. 3.4) [1]. Chronic tears will not have increased signal on T2, as the hemorrhage and edema have largely resolved but will have increased signal on T1 sequences [3].

Indications and Contraindications for Nonoperative Management

Proximal hamstring injuries exist as a continuum. A full discussion on classification can be found in Chap. 2. For acute injuries, the mildest form of injury is a strain or tendinopathy, without discontinuity of the tendon-bone unit. A more severe form of injury would be a partial tear or avulsion. This includes single tendon avulsions, for instance, an isolated long head of the biceps femoris tear. Multiple tendon ruptures are considered complete tears, and the amount of tendon retraction can be quantified on ultrasound or MRI. Based in large part on work done by Wood [24], most clinicians recommend operative fixation for all three-tendon tears, and two-tendon tears with greater than 2 cm of retraction [4]. There is debate over surgical fixation for two tendon tears of less than 2 cm of retraction. All other tears are generally considered nonoperative, with surgery as an option after a failure of conservative treatment [20].

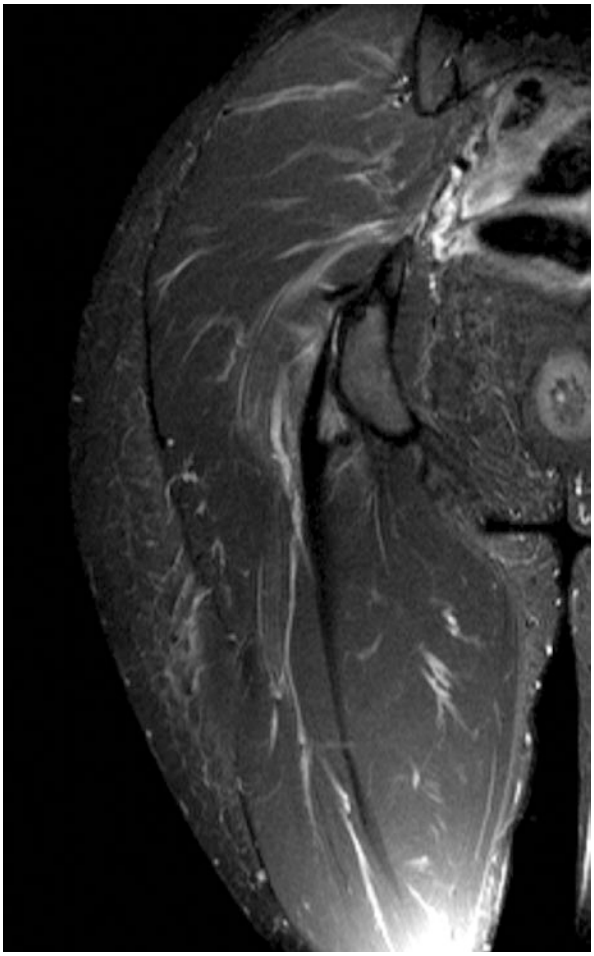

Fig. 3.4 Coronal T2-weighted MRI demonstrating proximal hamstring tear

Nonoperative Management Techniques

Numerous options are available to clinicians for nonoperative treatment of proximal hamstring injuries. The first line of treatment is always RICE therapy (rest, ice, compression, elevation), as well as a comprehensive rehabilitation program. Numerous physical therapy programs and exercises have been investigated with varying degrees of success. Either after failure of physical therapy, or as an adjuvant, various other modalities exist that potentially can further bolster the healing process, including NSAIDS, corticosteroid injections, platelet-rich plasma, shock-wave therapy, and cryotherapy. Each option will be discussed at length here, and further discussions can be found in Chap. 10 (biological treatments) and Chap. 12 (proximal hamstring injury rehabilitation and injury prevention) (Table 3.1—types of nonoperative treatment).

Table 3.1 Types of nonoperative therapy and associated available evidence supporting their use/efficacy

Types of nonoperative treatment	Supporting evidence
Physical therapy	Strong
Nonsteroidal anti-inflammatories	Weak
Corticosteroids	Moderate
Platelet-rich plasma	Weak
Shockwave therapy	Weak

Table 3.2 Types of physical therapy, the theory behind their use, and exercises for each type

Type of physical therapy	Theory behind rehab	Exercise examples
Conventional therapy	Limit inflammation, realign collagen fibers in scar tissue	Static stretching: Thigh flexed, knee extended, on elevated surface
		Pelvic lift: Pelvis raised and lowered while supine
Eccentric rehabilitation	Restore anatomic muscle length and achieve appropriate muscle tension	Nordic hamstring curls: Pt kneels on surface, trunk flexes anteriorly while assistant holds heels
	Counteract neuromuscular inhibition	The extender: Affected hip and knee flexed to 90°, knee slowly extended
		The diver: Stand on affected limb, lean forward to 90° of hip flexion, arms stretched forward
Trunk stabilization	Improve pelvic positioning to facilitate optimal tendon tension	Side bridges (Planks): Support body on elbow and ankle while on side
		Single-leg standing windmill: Stand on injured extremity w/neutral hip, then flex forward
		Lunge twist: Standard lunge position, turn torso toward bent knee

Please see discussion on physical therapy for more in-depth descriptions of each exercise

Physical Therapy

Several types of rehabilitation programs exist, including conventional stretching and strengthening, eccentric lengthening and strengthening, and trunk stabilization. The goal of rehabilitation is to return the athlete to their prior level of function, while minimizing risk of recurrent injury. To this end, rehabilitation of proximal hamstring injuries should emphasize increasing load tolerance while addressing the underlying pathology, including biomechanical deficits, improving posture, neuromuscular training, and core and pelvis strengthening [25]. While each rehabilitation program mentioned has been shown to be successful, randomized control trials have found eccentric lengthening, and trunk stabilization techniques may be more effective than traditional methods in terms of return-to-play and reinjury rates (Table 3.2—types of physical therapy with specific exercises).

Conventional Therapy

Traditional physical therapy is based on a routine organized around the chronologic phases of healing. The initial focus is on limiting inflammation, then utilizing stretching and strengthening to reorganize, remodel, and realign collagen fibers in scar tissue [26]. There is less emphasis on lengthening compared to the newer eccentric techniques.

Stretching, which results in passive viscoelastic change of tendon length, reduces muscle stiffness and decreases actin and myosin bridging due to reflex inhibition [27]. This results in an increased stretch tolerance, which means the same amount of force produces less pain [28]. The combination of decreased pain and improved collagen organization allows for organized, hypertrophic growth, and ultimately healing [29].

Conventional rehab exercises are centered around static stretching, with progression to dynamic stretching at more advanced stages of recovery. As explained by Malliaropoulos et al., due to the viscoelastic properties of tendons, when a tendon is held at a constant length (through static stretching), the tension at that length decreases over time, otherwise known as stress relaxation. Conversely, if a constant force is applied, the length will increase over time, though it will return to its original length once the force is removed [27]. Studies have demonstrated that there is a significant reduction in tension for a given stretching length, as well as an increase in length for a given tensile first between the first four stretches. For this reason, stretching provides maximum benefit during the initial repetitions, with diminishing returns [30]. A 2004 randomized control trial by Malliaropoulos et al. examined a cohort of all types of hamstring injuries (not proximal specific). They found stretching activities multiple times a day led to a shorter time to regain full ROM compared to a once-per-day stretching routine [27].

A simple stretching technique involves the patient placing the heel of their injured leg on an elevated surface to bring their thigh near maximum flexion, while keeping the knee in a relatively extended position (roughly 10° of flexion). The athlete should maintain a retracted shoulder and horizontal head position. The amount of hip flexion is dictated by pain. (Fig. 3.5). For static stretching, as described in the Malliaropoulos's paper, this would be the extent of the exercise [27]. Another facet can be added, as described by Askling, in which the heel is pressed down for 10 seconds, and then after 10 seconds of relaxation, a new position slightly forward for 20 seconds [14].

A second exercise is the pelvic lift, in which the patient is started in a supine position. The patient places their body weight on both heels, and the pelvis is lifted up and down slowly. With progression, the uninjured leg is also lifted off the ground, so that the injured extremity is absorbing all of the load. The load is further increased by increasing knee flexion (after starting at roughly 90°). Eventually, the knee should only be flexed about 10°, with the contralateral extremity elevated (Fig. 3.6) [14].

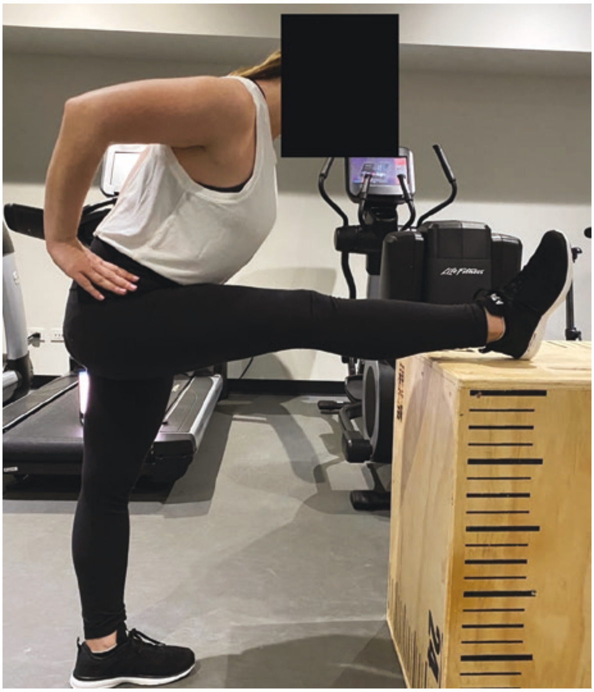

Fig. 3.5 Simple static stretch: The patient placing the heel of their injured leg on an elevated surface to bring their thigh near maximum flexion, while keeping the knee in a relatively extended position (roughly 10° of flexion). The athlete should maintain a retracted shoulder and horizontal head position. The amount of hip flexion is dictated by pain

Fig. 3.6 Pelvic lift: The patient is started in a supine position. The patient places their body weight on both heels, and the pelvis is lifted up and down slowly. With progression, the uninjured leg is also lifted off the ground, so that the injured extremity is absorbing all of the load. The load is further increased by increasing knee flexion (after starting at roughly 90°). Eventually, the knee should only be flexed about 10°, with the contralateral extremity elevated

Eccentric Rehabilitation

After injury, scar tissue develops which creates disorganized crosslinks [31]. This increases the passive stiffness of the muscle-tendon unit and changes the force–length relationship of the hamstring tendon. The remodeling results in hamstring achieving peak force at shorter lengths, which increases the risk of reinjury if an excessive eccentric force is applied. Eccentric exercises have been shown to shift the peak force production to longer muscle lengths. Ultimately, this is meant to help restore optimal tension at a more anatomical (longer) tendon length, thus reducing the risk of injury [18]. Eccentric exercises have also been found to consume less oxygen and use less energy while still generating greater force than concentric exercises [32].

Another suggested benefit of eccentric lengthening is its effect on neuromuscular inhibition. It is believed that following an acute proximal hamstring injury, there is an inhibitory effect of voluntary hamstring contracture. This would unnecessarily limit proximal hamstring loading during lengthening exercises, and thus negatively affect hypertrophic recovery [13]. It could also preferentially lead selective hypertrophy of the short head of the biceps distally, resulting in a shift in the torque–angle relationship, further increasing risk of injury [33]. Eccentric training is believed to circumvent this inhibition and more easily facilitate strengthening.

A variety of eccentric exercises exist, which may target different muscle areas. Nordic hamstring curls are performed with the patient kneeling, while their heels are held by an assistant. The athlete then slowly leans forward, which results in eccentric knee extension. A concentric hamstring curl is then performed to reset to the starting position (Fig. 3.7) [34]. Another eccentric technique, "the extender", can be done without assistance from a supine position [14]. The athlete should keep the contralateral leg on the floor, while flexing the affected hip to 90° and the knee to 90°. The athlete uses their hands to hold the hip in place, while slowly extending

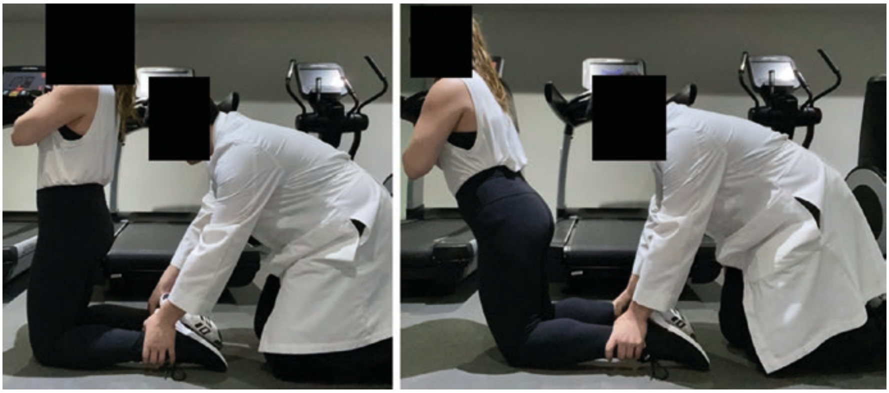

Fig. 3.7 Nordic Hamstring curl: Performed with the patient kneeling, while their heels are held by an assistant. The athlete then slowly leans forward, which results in eccentric knee extension. A concentric hamstring curl is then performed to reset to the starting position

Fig. 3.8 The extender: The athlete should keep the contralateral leg on the floor, while flexing the affected hip to 90° and the knee to 90°. The athlete uses their hands to hold the hip in place, while slowly extending the knee until pain is felt

Fig. 3.9 The diver: The athlete stands on the affected limb, leaning forward to nearly 90° of hip flexion. The arms are stretched forward, with the goal of maximal hip extension of the contralateral, unaffected leg, which is kept off the ground. The planted, injured leg should be kept in about 10–20° of knee extension

the knee until pain is felt (Fig. 3.8). A third technique, known as the diver, is performed as a simulated dive. The athlete stands on the affected limb, leaning forward to nearly 90° of hip flexion. The arms are stretched forward, with the goal of maximal hip extension of the contralateral, unaffected leg, which is kept off the ground. The planted, injured leg should be kept in about 10–20° of knee extension (Fig. 3.9) [25].

Randomized controlled trials have been performed to evaluate the efficacy of eccentric lengthening compared with traditional rehabilitation programs for hamstring injuries. In 2013, Askling et al. prospectively compared the effectiveness of conventional rehabilitation to an eccentric-based protocol in Swedish football (soccer) players with MRI-verified hamstring injuries. Seventy-five football players were randomly assigned to the conventional group or the eccentric lengthening group. Outcomes included days until RTP (return to play) and reinjury rate. They evaluated sprinting-type injuries, which were generally mid-substance tears, as well as stretching-type injuries, which tended to be proximal hamstring tears. RTP was significantly shorter in the lengthening group in both sprinting (28 vs 51 days) and stretching cohorts (43 vs 74 days) ($p < 0.001$). Only one reinjury occurred and that was in the conventional stretching group. They concluded that an eccentric lengthening protocol was more effective in promoting return to play in football players.

A similar 2014 study by the same research group prospectively evaluated the same conventional and lengthening protocols but in randomized sprinters and jumpers with hamstring injuries. Again, the lengthening group had a significantly shorter RTP (49 vs 86 days). This study better defined hamstring injury types and noted proximal hamstring tendon injuries had longer RTP in general, but the lengthening protocol still had a significantly shorter RTP compared to the conventional protocol (73 vs 116 days). They again concluded that lengthening protocols could significantly shorter RTP, in both mid-substance hamstring injuries, as well as proximal tendinous injuries.

As mentioned above, different eccentric exercises target different components of the hamstring complex, and this should be considered when designing a rehabilitation protocol. A 2017 study by Bourne et al. used electromyography and functional MRI studies to determine which exercises selectively activate different components of the hamstring complex [35]. They found hip-extension exercises selectively activate the long head of the biceps, while the Nordic exercise preferentially recruits the semitendinosus. A case report by Cushman et al. similarly evaluated the use of an eccentric hamstring strengthening protocol that could be used with a treadmill. The protocol focused on hip extension and resisted hip flexion and also found positive results, with the long head of the biceps being preferentially targeted [36]. Therefore, specific exercises should be selected based on knowledge regarding which tendons are torn.

Trunk Stabilization

Trunk stabilization can be defined as muscular activity of the trunk and pelvis to maintain the spine and pelvis in a desired neutral posture or alignment [37]. As mentioned above, the origin of the hamstring muscle complex is the posterior aspect of the ischial tuberosity on the pelvis. Concordantly, changes in pelvic position can affect the force–length relationship of the hamstring, and thus optimal tension [37]. Postural dysfunction has thus been proposed as a risk factor for hamstring injury, and something that should be corrected during rehabilitation. It is theorized that anterior pelvic tilt may reduce the flexibility of the hamstring, hip flexors, and quadriceps. Additionally, it may increase the demand of the hamstrings and compress the biceps femoris. Correcting the lumbopelvic position through trunk stabilization by reducing hip flexor and quadriceps tightness may correct anterior pelvic tilt, thereby reducing hamstring tension.

Exercises for trunk stabilization focus on abdominal muscles as well as surrounding pelvic musculature. Side bridges, or planks, utilize abdominal and hip muscles to hold the body while lying in a side, plank position. The elbow and outside of the foot are the only points of contact with the floor (Fig. 3.10). The single-leg standing windmill, similar to the diver, requires the athlete to stand on the injured

Fig. 3.10 Side bridges, or planks, utilize abdominal and hip muscles to hold the body while lying in a side, plank position. The elbow and outside of the foot are the only points of contact with the floor

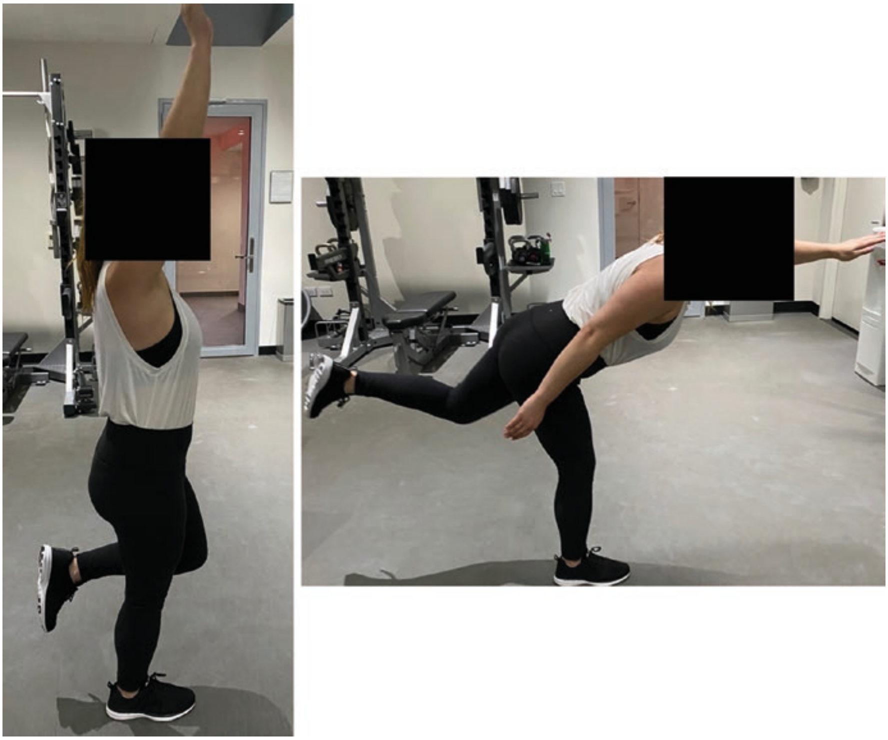

Fig. 3.11 Single-leg standing windmill: the athlete stands on the injured extremity with the knee near full extension, and transition from a neutral hip, to flexion as the trunk leans forward

extremity with the knee near full extension, and transition from a neutral hip, to flexion as the trunk leans forward (Fig. 3.11). A third technique is the lunge twist. This entails going into a standard lunge position, for instance, taking a step forward with the right foot, planting it, bending the right knee while keeping the left leg extended. The patient then turns the torso toward the right side, with both arms extended. The torso is then turned back to neutral, and a standing position is taken. The same is then done on the opposite side (Fig. 3.12) [38].

Fig. 3.12 Lunge twist: The patient enters a standard lunge position, for instance, taking a step forward with the right foot, planting it, bending the right knee while keeping the left leg extended. The patient then turns the torso toward the right side, with both arms extended. The torso is then turned back to neutral, and a standing position is taken. The same is then done on the opposite side (Fig. 3.12) [38]

Results of investigations evaluating the efficacy of trunk stabilization have been mixed. A 2004 prospective, randomized control trial performed by Sherry and Best compared patients with hamstring injuries (not proximal hamstring specific) that underwent either a traditional stretching and strengthening protocol or a trunk stabilization protocol. The sample was limited, with only a total of 24 athletes enrolled. The study found RTP duration was shorter for the trunk stabilization group compared to the standard rehabilitation group (22 vs 37 days), however, likely due to the small sample, statistical significance was not reached. Reinjury rate did reach significance, with the standard rehabilitation group having statistically more reinjuries both at the 2-week mark and 1-year mark following RTP. This study concluded that trunk stabilization was more effective than traditional rehabilitation in promoting return to play and preventing recurrent injury [37].

A 2013 follow-up prospective randomized control study from the same institution compared acute hamstring injury patients that underwent either an eccentric strengthening program or trunk stabilization protocol. Similar to the above study, this was a heterogeneous sample, including any location of hamstring injury. Again, a relatively small sample was recruited, with only 25 patients completing the rehabilitation program. No significant differences were found between the trunk stabilization group and eccentric group in terms of RTP (29 days vs 25 days), or reinjury rate (2 patients in each group). The study concluded that eccentric strengthening and trunk stabilization protocols were similarly effective but more study was required [38].

Rehabilitation Protocol

Numerous rehabilitation protocols exist for proximal hamstring injuries [13, 25, 34, 39]. While the specifics are marginally different, each follow a gradual ramp of activity based on the inflammatory healing process. Treatment is typically divided into phases.

Phase 1, or the acute phase, is designed to minimize pain, edema, and inflammation [34]. The goal is to restore neuromuscular control at low speeds, prevent excessive scar formation, and protect the nascent healing fibers. RICE therapy is started on day 0, with acetaminophen (see discussion on NSAIDS below). Activities include low intensity stationary biking and simple trunk stabilization exercises such as planks. Various benchmarks are used to evaluate when to progress from phase 1 to 2, but a common test is if the patient can walk with the same stride length and stance time on both limbs and a painless hamstring contraction at 90° of knee flexion [38]. Phase 1 typically lasts from 0 to 2 weeks [25].

Phase 2, or the recovery phase allows for increased exercise intensity, with faster speeds and larger amplitudes. It is during this phase that eccentric resistance training can begin [37]. Exercises such as the Diver and Nordic curls can be started but should only be done until pain is felt—protection of fibers is still required, and exercises should not be carried out to terminal length [34]. Criteria for progression should include full strength without pain during prone isometric contraction of the hamstrings while the knee is flexed to 30°, and painless jogging at 50% speed [29]. Phase 2 typically ranges from 2 to 6 weeks post-injury [25].

Phase 3 is the final phase prior to RTP. It includes eccentric resistance training in a lengthened position, simulated sporting activities, and gradual RTP. Full intensity should be avoided early, and eccentric exercises should continue to only be performed until pain is felt, particularly in the early part of this phase [40]. At this point, all exercises are allowed, with gradual progress to terminal end range of motion. Phase 3 lasts between 4 and 8 weeks post-injury [40].

Non-steroidal Anti-inflammatories

Non-steroidal anti-inflammatories (NSAIDS) are a class of drug that limits the inflammatory process at cyclooxygenase-1 and/or cyclooxygenase-2. NSAIDs are administered, as they can act as potent pain relievers, helping to reduce inflammation. Improved analgesia not only improves patient comfort but can also allow for more activity during physical therapy. Conversely, there is concern regarding an impairment of on the inflammatory milieu necessary for healing [41]. There have not been any studies evaluating the role of NSAIDS in proximal hamstring tendon tears but a few investigations have been carried out that may help provide guidance.

A 1995 double-blind randomized control trial by Reynolds et al. evaluated the use of meclofenamate and diclofenac in addition to PT, in a three-arm study. They assessed patients on days 1, 3, and 7 for pain, swelling, and isokinetic muscle performance. All groups significantly improved from baseline; however, there was no difference between treatment groups. The diclofenac and meclofenamate groups actually did significantly worse compared to the physical-therapy-only group when stratifying for more severe injuries [42].

Duchman et al. performed a systematic review in 2019 on the effect of NSAIDS on tendon-to-bone healing for multiple types of tendon injuries. They found 13 studies, 3 of which were clinical and 10 basic science. A poor methodological quality of clinical studies was found. Two studies found no clinical differences between the NSAID and non-NSAID group, and one found a higher rate of failure for rotator cuff repair. Ultimately, the study group determined the current literature does not provide sufficient evidence for or against the use of NSAIDS following acute injury or surgical repair of the tendon–bone interface [43].

It is unclear at this time, what if any, negative affects NSAIDS have on proximal hamstring injuries. The decision to use NSAIDS in conjuncture with physical therapy and other modalities should best be made after discussion of the risks and benefits is made between clinician and patient.

Corticosteroid Injections

Corticosteroids serve the same anti-inflammatory function as NSAIDS, but are more potent, and can be given as a direct injection to the zone of injury. Similar benefits and risks exist in terms of reduction of inflammation and pain but possible compromise to the healing process, or tendon rupture [4]. Again, evidence to guide decision-making is limited. Injections are typically given under guided imaging, such as ultrasound (Fig. 3.13) or fluoroscopic.

A 2010 retrospective study evaluated patients with non-complete proximal hamstring injuries that received ultrasound-guided corticosteroid injections of 1 mL of 40 mg/mL triamcinolonacetonide, with 5 mL of bupivacaine. The study population was heterozygous, with some patients trying other forms of nonoperative treatment prior to the steroid injection, while others got the injection at the same time as beginning their treatments. Patients also underwent different nonoperative treatments, with some receiving NSAIDS and physical therapy, while others did not. Results were collected from chart review and telephone survey at 4 years follow-up. Injections were given in the paratenon, but intratendinous injection was avoided. Of the 85 patients included, 76 reported immediate improvement, indicating the local anesthetic was placed appropriately. No significant complications were reported. About 50% of patients reported moderate-to-compete resolution of their symptoms at least 1 month after injection, and about 23% had no response. Despite the numerous limitations of this study, including lack of control group, retrospective telephone survey model, and heterozygous cohort, the study concluded corticosteroid injections were safe, and effective in at least some patients [44].

Nicholson et al. similarly, retrospectively reviewed proximal hamstring tear patients that received corticosteroid injections, though this was fluoroscopically guided as opposed to ultrasound. Similar to the Zissen study, the study population was small and heterogeneous. The same injectate was used as described above.

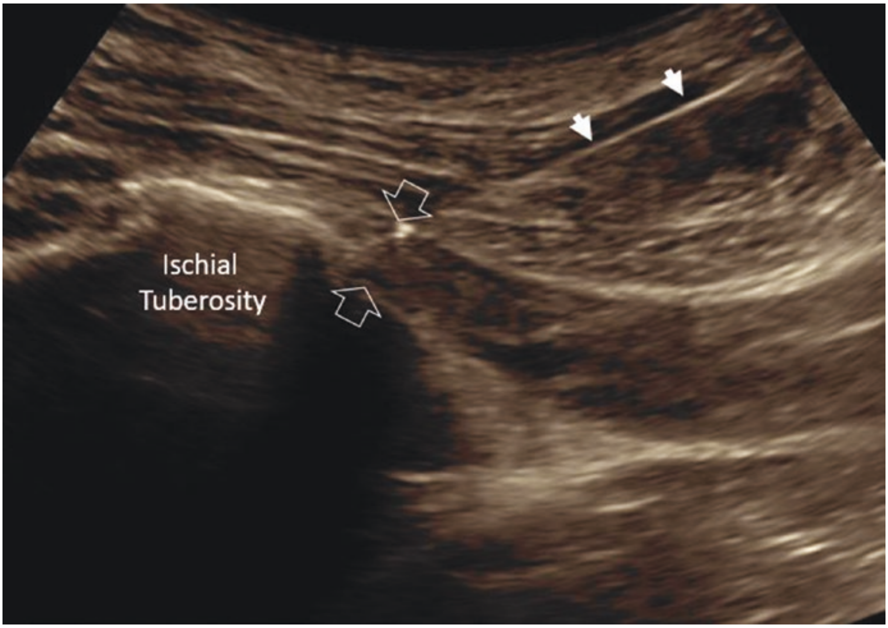

Fig. 3.13 Ultrasound-guided corticosteroid injection: Hollow arrows point to the hamstring origin. White arrows identify the needle immediately prior to injecting corticosteroid. This is a sagittal orientation view along the long axis of the tendon

Patients responded via online questionnaire. Visual analog scores significantly decreased, and athletic participation significantly decreased at a mean follow-up of 21 months. Similar to the Zissen study, about 22% of patients had no response to the injection. While the Zissen study found that 24% of patients will experience relief for greater than 6 months, this study found that 45% of patients will experience relief for greater than 3 months. Again, no serious complications were encountered [45].

Platelet-Rich Plasma

A more thorough discussion on platelet-rich plasma (PRP) can be found in Chap. 10, along with other biologic treatment options. A discussion on PRP's role in nonoperative treatment is provided below.

Platelets circulating in the blood carry regenerative potential via several factors they contain in their granules. These factors include TGF-beta (TGF-B), platelet-derived growth factor (PDGF), insulin-like growth factor 1 and 2 (ILGF-1 and -2), fibroblast growth factor (FGF), epidermal growth factor (EGF), and vascular endothelial growth factor (VEGF) [46–49]. Through the use of these factors, platelets can promote angiogenesis, inflammation, stimulation of precursor cells, and restoration of collagen orientation [49]. PRP requires taking a sample of blood from a patient, and concentrating the platelets in solution via centrifuge, then injecting the solution to the area of injury, thus potentially augmenting the healing process. It is thought it may be particularly helpful in tendon injuries, where the blood supply can be poor [50]. As this topic is relatively novel, it is an active area of research, with multiple investigations having been performed. Evidence is mixed as to the efficacy of PRP for proximal hamstring injuries. PRP is also extremely challenging to study, as there is no standardized formulation for injection. As a result, it makes comparisons between trials difficult.

Park et al. compared PRP with steroid injections for patients with proximal hamstring injuries. Patients either received PRP or steroid injections, and visual analog scores (VAS) and complications were recorded at 1-week and 4-week post-procedure. The PRP contained a sample between 300,000 and 500,000 platelets/μl. Injections were given either by ultrasound or fluoroscopic guidance. At 1-week follow-up, 72% of the PRP group had a positive response, compared with only 46% of the steroid group. At 4-week follow-up, the same 72% of the PRP group noted positive improvement compared with 54% of the steroid group. Neither group had any significant complications. Though they acknowledged the PRP group was significantly younger compared to the steroid group (34.5 years vs 50 years old), the authors concluded PRP was safe and at least as effective as steroids for proximal hamstring injuries [50].

Conversely, a 2013 study by Rettig et al. retrospectively compared ten NFL players with hamstring injuries (not proximal-specific), five that received conventional therapy alone and five that received therapy and PRP. The study found the PRP actually had a longer RTP compared to the conventional group (20 vs 17 days). While acknowledging the very small sample size and retrospective nature of the study, the author concluded PRP did not show any improvement [51].

Hamid et al. performed a randomized control study comparing patients with hamstring injuries (also not proximal-specific) that received either conventional rehabilitation alone or rehabilitation with PRP injections [52]. Unlike the Rettig investigation, this study group reported significantly earlier RTP in the interventional PRP group compared with the control group (27 vs 43 days). Significantly lower pain scores were also reported in the PRP group. As to why this study found PRP to be beneficial, when the Rettig study did not, they posited that they used an activating substance and local anesthetic in their study, neither of which was used in the Rettig investigation. They also believe the Rettig group used an excess amount of sodium bicarbonate [53].

Two small retrospective studies, one by Wetzel et al. in 2013 and one by Fader et al. in 2014, evaluated the use of PRP in chronic proximal hamstring injuries. Wetzel compared a PRP and physical therapy group to a physical therapy-only control group [54], while Fader reported on a cohort that received only PRP injections (level 4 case–control study) [49]. Both study populations contained patients that had failed an initial course of physical therapy alone. Both studies ultimately found PRP was safe and effective in cases of proximal hamstring tears refractory to initial conservative management.

Two well-done randomized control studies did not find PRP to be effective. Hamilton et performed a 3-arm study of PRP vs platelet-poor plasma vs rehab only for patients with hamstring injuries (not proximal-specific). They found no significant differences in return-to-play or reinjury rates at 2 or 6 months. No adverse effects were encountered [55]. Reurink et al. also evaluated patients with hamstring injuries (all types). They compared patients that received either PRP or a placebo injection. While no adverse events were recorded, no significant differences were found between groups in terms of RTP, reinjury rate at 1-year, subjective patient satisfaction, or hamstring outcome scores [56]. As to why their study did not find any significant results when the Hamid group's did [53], they attribute the discrepancy to lack of blinding on both the patient and investigator's parts, as well as limited sample sizes [56].

PRP is a new product with interesting biologic potential. However, given its various formulations and mixed reported efficacy, its exact role in treating proximal hamstring injuries remains unclear.

Shockwave Therapy

Shockwave therapy is still under investigation, and its clinical efficacy is hotly debated. A shockwave is an acoustic pressure wave with a specific wave form. Force is generated when a compressed air-driven projectile strikes an applicator, which is placed on the skin. This converts the kinetic energy of the projectile into a pressure wave, or shockwave, that is transmitted to the tissues [57]. The pressure waves spread in all directions from the surface, eventually reaching the affected zones. The initial shockwave is followed by a low tensile amplitude, or negative pressure. The lowered pressure results in locally dissolved gases forming cavitation bubbles [58]. Finally, there is a return to normal pressure, resulting in collapse of the bubbles, leading to the generation of additional, spherical shock waves. Though still under investigation, the purported biological effects of shockwaves include angiogenesis, anti-inflammatory effects, nociceptive changes, cell growth and replication, and collagen generation and organization [59].

Cacchio et al. performed a level 1 randomized controlled study comparing chronic proximal hamstring tendinopathy patients that received either shockwave therapy alone or a conventional physical rehabilitation program. The wave transmitter was placed at the area of maximal tenderness, and waves were applied in a circumferential pattern from this point. Patients received four shockwave sessions at weekly intervals, with 2500 shocks per session, at a pressure of 4 bar (energy flux density of 0.18mj/mm2), with total energy flux density of 450mj/mm2. At 3-month follow-up, visual analog scores (VAS) were significantly lower in the shockwave group (2 vs 5), as were the Nirschl phase rating scale (NPRS) (2 vs 6 points). There were no serious complications in either group. The study concluded that shockwave therapy was safe and effective in the treatment of chronic proximal hamstring tendinopathy [60].

Return to Play After Nonoperative Treatment

The decision to return to play after nonoperative treatment for a proximal hamstring injury is challenging. Given the extremely high incidence of reinjury, caution must be used before putting stress on the healed hamstring. Additionally, as the proximal hamstring is tendinous vs the myotendinous or pure muscle tears in middle hamstring injuries, recovery can be much longer. Askling et al. found proximal hamstring injuries (stretching type) had median recovery of 50 weeks, with 47% of patients giving up their sport for an extended period of time due to the severity of the injury [11].

There are no definitive criteria for return to play after proximal hamstring injury, and studies often poorly define their criteria. Van der Horst et al. performed a systematic review of definitions for RTP and found that non-objective terms such as "reaching the athlete's pre-injury level" and "being able to perform full sport activities" were the most common criteria [61]. Only half of the studies they queried even provided a definition for return to play. Sherry et al. provided some more objective criteria for RTP, though they were not specific to proximal hamstring injuries. These included no pain on palpation of the injured muscles, no difference in manual muscle strength testing between legs, and <10% difference in passive flexibility. Other metrics include hamstring-to-quadricep strength ratio, noting less than a 5% bilateral deficit should exist [62].

Several studies have investigated the potential role of MRI as an adjunct to clinical exam in evaluating safe RTP in hamstring injuries. While not proximal specific, a systematic review by Reurink et al. found no strong evidence for any MRI finding that can guide clinicians in predicting prognosis for RTP after an acute hamstring injury [63]. Jacobsen et al. also evaluated the role of acute injury MRI in hamstring injuries (also not proximal hamstring-specific). While injury physical exam and follow-up physical exam had some value in predicting safe RTP, they similarly determined MRI had no added benefit [64].

Outcomes Following Nonoperative Management

The indications for operative vs nonoperative are in part derived from a 2014 study by Hofman et al. retrospectively reviewing 19 patients with complete (3 tendon) proximal hamstring ruptures treated nonoperatively. At follow-up (average of 31 months), they found patients had 62% and 66% hamstring strength compared to the contralateral at 45° and 90° of knee flexion, respectively. Only 12 of 17 patients had returned to their sports. Conversely, there was only a 2% decrease in single-leg hop test compared to the contralateral. Ultimately, the group concluded nonoperative treatment for even complete tears is reasonable, though an extensive discussion must be had with the patient regarding RTP goals, as without surgery, their hamstring strength is likely to end up much weaker [65].

Two systematic reviews were performed comparing operative to nonoperative management for different types of proximal hamstring tears [66, 67]. Both studies are limited by small sample sizes of nonoperative patients. Harris et al. found 286 cases treated surgically compared to 14 cases treated nonoperatively. They did not separate severity of injury (complete vs partial tear). They found surgical repair resulted in significantly better subjective outcomes, greater rate of return to pre-injury level of sport, and greater strength than nonoperative management [66]. Bodendorfer et al. performed an updated systematic review and meta-analysis several years later in 2018. This study was also limited by a small number of nonoperatively treated patients. Overall, they found repairs had significantly higher patient satisfaction, hamstring strength, functional scores, and single-legged hop test. Partial avulsion repairs were also compared to complete tears. Complete avulsion repairs had higher patient satisfaction and less pain, though partial avulsion repair had significantly higher hamstring strength and less complications. They concluded that while partial hamstring repairs objectively do better than complete tear repairs, because the injury wasn't as severe, patients may not subjectively feel as if they improve as much after the surgery. Ultimately, while the authors conceded concrete conclusions cannot be drawn due to the small sample size, the group concluded that surgically treated patients do better, particularly for complete tears, though there is a higher complication rate [67].

Shambaugh et al. retrospectively compared 25 patients with complete proximal hamstring tears that received either operative (14 patients) or nonoperative management (11 patients) (not randomized, nonoperative was due to patient preference). No statistical significance was found between groups for any metric, though this was attributed to sample size. The operative group had higher mean functional scores, single-leg hop distances, and a greater strength compared to contralateral uninjured leg (57% strength of contralateral in nonoperative group, 91% in operative group). They concluded that for complete proximal hamstring ruptures, operative patients likely do better, but more study was required [68].

The same group performed a similar retrospective study comparing operative and nonoperative management for partial tears retracted less than 2 cm. Interestingly, they found no significant difference in objective measures, such as the single-leg hop distance or torque speeds but found higher subjective functional scores in the operative group. Neither group had significant complications. They concluded that both groups do well objectively, but surgically treated patients may feel as though they are doing better. They also found a high proportion of patients treated nonoperatively went onto surgical repair (40%), and thus a trial of nonoperative management is reasonable but after establishing goals and expectations [69].

Another retrospective comparative study was performed by Pihl et al. in 2019. They compared operative and nonoperative management for proximal hamstring avulsion injuries, though they included any type of avulsion (1–3 tendons) and any amount of retraction. They found no differences between the surgical and nonsurgical groups, but noted pre-treatment, that the surgical groups had more severe injuries. They thus concluded that a better randomized control study was needed, with more homogenous populations to draw any strong conclusions. As a result, the same group published a randomized control trial protocol that will prospectively compare operative and nonoperative management of proximal hamstring avulsions across multiple centers, in multiple countries [70].

Conclusion

Proximal hamstring injuries are challenging, with longer recovery times, than more distal muscular or myotendinous injuries. While there are guidelines based on prior investigations, the decision for operative or nonoperative management must be shared with the patient, as goals for activity level and return to sport must be clearly defined in order to come to a sensible agreed course of action. If nonoperative treatment is selected, numerous options exist, including various types of physical therapy, non-steroidal anti-inflammatories, steroid and platelet-rich plasma injections, and shockwave therapy. These can be used alone or in combination. Outcomes for appropriately selected nonoperative patients are generally moderate-to-good, though as noted recovery time can be extensive. Athletes must be counseled appropriately, and reasonable expectations should be set regarding prognosis and return to play.

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4 Surgical Treatment of Partial Proximal Hamstring Tendon Tears

Jonathan D. Haskel

Introduction

Hamstring injuries are extremely common in athletes and make up approximately 29% of all injuries [1, 2]. While hamstring injuries at the musculotendinous junction are relatively common, proximal hamstring injuries occur at a lower frequency. The most common mechanism of injury to the proximal hamstring origin is eccentric lengthening of the muscle unit during rapid acceleration and deceleration [3]. The mechanism of proximal avulsions, specifically, is through an eccentric contraction with the hip flexed and the knee extended. This occurs in sports with ballistic movements, such as skating, dancing, skiing, and weight lifting [4, 5]. The spectrum of proximal hamstring injury ranges from chronic insertional tendinopathy to partial-thickness injuries to complete proximal tendinous avulsion injuries with retraction. Acute tears of the hamstring origin can be distinguished from chronic insertional tendinopathy by history, physical examination, and supplemental imaging studies. As these injuries are not particularly common compounded by the fact that they present variably, proximal hamstring injuries are often under-diagnosed. Nonetheless, the frequency of proximal hamstring injuries appears to be increasing as patients continue to be physically active, and the diagnosis is increasingly recognized by clinicians.

The hamstring muscle group comprises three muscles, from medial to lateral: semimembranosus, semitendinosus, biceps femoris (long and short heads). These muscles originate on the ischial tuberosity (except for the short head of the biceps femoris, which originates on the linea aspera of the femur) and insert on the medial aspect of the tibia (semitendinosus and semimembranosus) and fibular head (biceps

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femoris), respectively. Tears of the hamstring origin most commonly involve the biceps femoris and semitendinosus insertions, with the semimembranosus least commonly involved [6, 7]. However, the semimembranosus origin is the most common site for tendinopathy [8, 9]. The most common pattern of partial-thickness injury is an avulsion of the conjoint tendon, while the semimembranosus remains intact. This can prevent significant retraction and produce a "hidden lesion," where injury to the conjoint tendon is not appreciated during repair unless the semimembranosus is incised [10].

History and Physical Exam

Partial-thickness proximal hamstring injuries can present either as chronic insertional tendinopathy without a specific event or alternatively as a single event with a strong eccentric contraction. The latter mechanism is more commonly associated with a complete avulsion. In a complete avulsion, patients describe the injury as the sensation of being shot in the posterior thigh and report subsequent difficulty ambulating [4]. Chronic insertional tendinopathy presents as poorly defined posterior thigh pain, particularly with terminal hip flexion and knee extension [11]. Less commonly, symptoms of sciatic nerve irritation can occur with radiating leg pain, along with posterior thigh pain [12]. Patients also report difficulty sitting due to pain at the avulsion site [13].

While visual inspection may not reveal any obvious abnormalities, occasionally patients will present with a latent area of ecchymosis in the posterior middle and distal thigh. However, more commonly, inspection fails to identify any significant findings [12]. Patients may have some reproducible tenderness over the ischium. Hip and knee range of motion is typically preserved, however pain may be elicited with passive hip flexion and knee extension. Moreover, the popliteal angle should be assessed on both lower extremities. The popliteal angle is determined by flexing the hip to 90° with the knee flexed to 90°, and then slowly extending the knee passively. The knee flexion angle at which posterior thigh pain and guarding occurs is compared with the uninjured extremity. An increase in this angle can suggest a hamstring injury [14]. Hamstring strength testing can elicit symptoms. With the patient in the prone position and knee flexed to 90°, resisted active knee flexion can precipitate hamstring pain.

Special tests have been described to support the diagnosis of proximal hamstring pathology. The Puranon–Orava test is positive if posterior thigh pain is elicited after flexing the hip to 90° while passively extending the knee until it is supported on a support. The bent-knee stretch test is performed in the supine position. The hip and knee are maximally flexed, and the knee is then passively extended by the examiner. A stiff-legged gait pattern is possibly, whereby patients avoid hip and knee flexion. Finally, a thorough neurovascular exam is warranted in these patients, who can develop a self-limiting peroneal nerve neuropraxia resulting in a subtle foot drop or eversion weakness [15].

Imaging

Standard anterior-posterior (AP) hip, AP pelvis, and cross-table lateral hip radiographs are recommended for all patients with suspected proximal hamstring injuries. Radiographs can demonstrate ischial apophyseal avulsion, ischial enthesopathy, or fracture, however plain radiographs are often negative in athletes with hamstring injuries [5]. In the acute injury phase, ultrasonography is extremely accurate to determine the location and extent of a hamstring injury [16]. Ultrasound can demonstrate fluid collection around the injured muscle and depicts areas of echogenicity, representing edema and/or hemorrhage.

Magnetic resonance imaging (MRI) is the modality of choice to evaluate the hamstring origin. MRI can accurately identify the injury location, proximal myotendinous junction, muscle belly, distal junction, or insertion. MRI can also portray the dimensions of abnormal T2 hyperintensity, percentage of abnormal cross-sectional muscle area, percentage of abnormal muscle volume [17], and chronicity of injury indicated by fibrosis [18]. Acute tears are characterized by a linear high T2 signal at the bone–tendon interface as well as fiber disruption, hypertrophy, and retraction if present [19]. Tendinopathy can be visualized as abnormal signal on T1- and proton density weighted images, and dark signal at the tendon origin on T2-weighted images. The "sickle sign" is a notable finding on MRI characterized by a crescent-shaped linear signal at the bone–tendon interface on T2-weighted images suggestive of a partial-thickness tear [19].

Treatment

In general, partial tears involving one or two tendons with less than 2 cm of retraction should be treated nonoperatively. Nonoperative modalities include activity modification, physical therapy, stretching program, non-steroidal anti-inflammatory medications (NSAIDs), shockwave therapy, and local injection with either corticosteroids or platelet-rich plasma [11]. Despite a dearth of substantial literature to support specific therapeutic exercises, eccentric exercises are considered to mainstay treatment for initial management of partial proximal hamstring injuries. Recently, heavy slow resistance training comprised of both eccentric and concentric exercises has been proposed as a possible superior alternative to isolated eccentric exercises for Achilles tendinopathy; however, further studies are needed to validate this in the context of hamstring injuries [20].

Ultrasound-guided corticosteroid injections have been utilized for initial management of these injuries. Two studies have demonstrated significant short-term improvement in pain control following injections; however, only a minority of patients (<38%) exhibited sustained relief 6 months after receiving the injection [21, 22]. More recently, platelet-rich plasma (PRP) is increasingly utilized as a treatment option; however, the quality of evidence to support its use is low. Davenport et al. [23] performed a double-blind, randomized controlled trial comparing injections of whole blood with PRP for the treatment of chronic insertional tendinopathy. Both groups exhibited improvement in pain and functional outcomes measures at 6 months; however, no significant differences between the groups were appreciated. Two other studies in the literature report the efficacy of PRP for pain and functional outcome improvement at 6 months; however, both studies are small cohort series without a control group [24, 25].

It is generally accepted that a high-grade partial proximal hamstring tear or 2-tendon injuries with retraction greater than 2 cm are best managed with surgery. Additionally, partial tears that remain symptomatic despite extensive conservative treatment can be considered for surgical treatment. Relative contraindications include limited surgeon familiarity with anatomy and technique, chronic tears with extensive scarring, and a high surgical risk patient. Surgical options include both open and endoscopic techniques.

Open Repair

Carmichael et al. published the first report of open surgical repair of proximal hamstring injuries in patients with complete avulsions from the ischial tuberosity [26]. This technique is well described by Bowman et al. [19]. The described technique for open proximal hamstring repair starts with prone positioning. After standard prepping and draping, a transverse incision is made along the gluteal crease, centered over the ischial tuberosity. Superficial dissection is performed while protecting sensory branches of the posterior femoral cutaneous nerve, followed by incision of the gluteal fascia in line with the skin incision. Gluteus maximus fibers are bluntly dissected down to the tuberosity. The sciatic nerve may be visualized and protected. Curved Deaver retractors are placed medially, laterally, superiorly, and inferiorly. Chronic-appearing injuries are debrided, and partial tendinous avulsions are revealed by elevating normal-appearing tissue overlying the injury. The ischial tuberosity footprint is then prepared by decortication using a curette or a rasp. Suture anchors are placed. The number and configuration of anchors depend on the amount of intact hamstring origin. Sutures are passed in a horizontal mattress configuration, and any side-to-side repair is performed if a longitudinal component is present. The gluteal fascia is closed in water-tight fashion to avoid hematoma formation followed by skin closure, and the extremity is placed in a hinged knee brace locked in 30° of flexion to protect the surgical repair. In general, isotonic hamstring strengthening starts at 6 weeks, and the brace is removed at 6–8 weeks postoperatively. Gentle sporting activities can be started at 12 weeks with unrestricted activity at 6 months postoperatively.

Authors recommend performing the surgery approximately 3–4 weeks after injury; any sooner, and the tissue is more friable and more difficult to repair. Any later, and the tissue is at risk of forming adhesions with the sciatic nerve. If patients have concomitant symptoms of sciatica, the surgeon should suspect possible adhesion formation between the nerve and the avulsed tendon. This can complicate the surgery, as the nerve requires formal mobilization from the scar. Therefore, loupe magnification should be readily available if sciatic nerve manipulation is required. Moreover, post-operatively patients should be monitored in the recovery room, as there is a risk for hematoma formation that can result in new neurological symptoms.

Lempainen et al. first reported open surgical management of partial proximal hamstring tears in 48 patients, with 42 patients treated after failing nonoperative therapy and 6 treated acutely [27]. At a mean follow-up of 3 years, 87.5% of patients reported good or excellent outcomes and 85.4% returning to their pre-injury level of sport participation. Authors performed an open suture anchor repair to the ischium with sciatic neurolysis in the majority of cases. Bowman et al. [19] retrospectively analyzed 14 patients with partial tears of the proximal hamstring origin treated with open debridement and tendon repair. At an average follow-up of 32 months, all patients had returned to their prior level of activity, no patient underwent subsequent surgery, and the average Marx score was 6.5 of a maximum of 16. Barnett et al. [28]. analyzed 36 patients who underwent open debridement and tendon repair of partial thickness proximal hamstring injuries and found that at an average follow-up of 58.8 months (acute injuries) and 47.7 months (chronic injuries), 21 (60%) returned to their pre-injury level of activity and 26 patients (74%) had good or excellent outcomes. In this cohort, patients operated on acutely were more likely to have a good or excellent result compared to those with a delayed repair. Moreover, patients who underwent repair of complete hamstring injuries were more likely to have a better subjective outcome compared to patients with partial hamstring injuries. Finally, Arner et al. recently analyzed their series of 64 patients who underwent open debridement and tendon repair at a mean follow-up period of 6.5 years and found an average Lower Extremity Functional Score (LEFS) of 96%, mean Marx score of 12.4, 97% satisfaction with surgery, and an average return to sport at 11.1 months (Table 4.1).

Endoscopic Repair

Endoscopic techniques have recently been introduced to address extraarticular hip pathologies [29–31]. Endoscopic repair may avoid morbidity and complications associated with open procedures. Advantages of endoscopic techniques include minimal disruption of normal anatomy, improved evaluation of partial-thickness tears, potentially decreased neurovascular complications due to improved visualization, and decreased bleeding/morbidity [32]. Potential complications of endoscopic techniques include damage to neurovascular structures, specifically the sciatic nerve during portal placement or during debridement, fluid extravasation into the pelvis, pressure points or neuropraxia depending on patient positioning and length of surgery, steep learning curve, and technical challenges of passing suture for repair. Surgical technique is outlined in our Authors' Preferred Technique section.

The literature on outcomes following endoscopic repair of partial thickness tears of the proximal hamstring origin is sparse. Linder et al. [33] was the first to report a case report of a partial proximal hamstring injury treated endoscopically in a 16-year-old female. At 3-months post-operatively, she had painless range of motion

Table 4.1 Details of published studies assessing surgical management of partial proximal hamstring tendon tears

Author (year)	No. of patients (no. of injuries)	Average age at surgery (y)	Intervention	Average nonoperative treatment duration	WB status post-op	Mean follow-up	Patient outcome
Lempainen et al. (2006) [27]	47 (48)	33	Open debridement and primary tendon repair	13 months	PWB ×2 wk	36 mo	33 excellent, 9 good, 4 fair, 2 poor
Bowman et al. (2013) [19]	14 (14)	43	Open debridement and primary tendon repair	–	TTWB crutches	32 mo	13 of 14 were satisfied, 71% can return to sport
Barnett et al. (2014) [28]	36 (36)	39.5 (acute partial), 44.5 (chronic partial)	Open debridement and primary tendon repair	31.6 days (acute partial), 509.8 days (chronic partial)	PWB ×6 wk	58.8 mo (acute partial), 47.7 mo (chronic partial)	60% return to sport, 74% with good or excellent result
Arner et al. (2019) [35]	64 (64)	47.3	Open debridement and primary tendon repair	–	TTWB ×4 wk	6.5 years	97% satisfied, 92.2% sports participation, 94% mean total proximal hamstring score
Kurowicki et al. (2020) [36]	20 (20)	49.5	Endoscopic debridement and primary tendon repair	3 months minimum	WBAT crutches	23 mo	mHHS 90.6, 42.1% with subjective hamstring weakness, 95% return to sport
Bowman et al. (2019)	6 (6)	51	Endoscopic debridement and primary tendon repair	176 days	PWB ×6 wk	29 mo	94% patient satisfaction, 88% return to sport by 7.6 months. Endoscopic scores equivalent to open

TTWB toe-touch weight-bearing, *PWB* partial-weight bearing, *mHHS* modified Harris hip score and return to strength. Korowicki et al. analyzed a series of 20 patients treated with endoscopic debridement and primary tendon repair with a mean follow-up period of 23 months. However, a large portion of the data analysis performed is not stratified between partial and complete proximal hamstring injuries. In this cohort, the modified Harris Hip Score (mHHS) average was 90.6 and return to sport rate was 95%. Patients with complete proximal hamstring tears demonstrated significantly higher mHHS post-operatively compared to partial proximal hamstring tears, corroborating with Barnett et al's data on open repairs [28]. Bowman et al. [34] analyzed a sub-cohort of 10 patients treated endoscopically, among an overall cohort of 58 patients treated with open and endoscopic techniques. Authors explained that the study was not adequately powered to detect any meaningful differences between the open and endoscopic sub-cohorts; however, the endoscopic cohort did well in terms of satisfaction, pain, complication rates, and patient-reported functional outcomes. Table 4.1 summarizes the existing literature on open and endoscopic repair of partial proximal hamstring tears.

Authors' Preferred Technique: Endoscopic Repair

The patient is positioned prone on a standard operating room table, with all bony prominences well padded. Fluoroscopy enters the surgical field from the contralateral side. The operative extremity is slightly abducted to protect the sciatic nerve. The palpable ischial tuberosity is used for portal placement and fluoroscopic visualization. The two portals utilized are marked at approximately 4 cm medial and 2 cm superior for the medial portal and 4 cm lateral and 2 cm superior for the lateral portal (Fig. 4.2). We then use fluoroscopic images to localize the portals to the ischial tuberosity, signifying the origin of the conjoint tendon. A 30° scope is introduced into the medial portal, and a shaver is used to perform an ischial bursectomy. Adhesions are then removed to identify the origin of the conjoint tendon on the ischial tuberosity. A probe is inserted and used to characterize the severity of tear. A shaver is then used to debride the ischial tuberosity footprint, followed by a burr to decorticate the tuberosity until bleeding bone is visualized. Next, an 8.5 mm cannula is inserted lateral to the endoscope through which a suture anchor is inserted into the bone. Suture is passed through the tendon in mattress configuration, and knots are tied using arthroscopic techniques. The sciatic nerve may be identified lateral to the ischium, and a neurolysis can be performed if indicated. An additional suture anchor may be inserted as needed. Finally, a probe is used to test the strength of the repair. The wound is irrigated and a sterile dressing is applied.

Post-operatively, patients are made foot-flat partial weight bearing with a hip abduction brace locked in full extension while standing. The brace is removed when sitting with the hip and knee in 90° of flexion. Crutches are used for assistance when ambulating. At 2 weeks, patients are made 50% partial weight bearing and their sutures are removed. At 4–6 weeks, patients are weight bearing as tolerated. Pearls and pitfalls of endoscopic repair are outlined in Table 4.2.

Table 4.2 Pearls and pitfalls of endoscopic partial proximal hamstring repair

Pearls	1. Minimal disruption of normal anatomy 2. Potentially decreased neurovascular complications due to improved visualization 3. Decreased bleeding/morbidity 4. Superior evaluation of partial-thickness tears
Pitfalls	1. Injury to neurovascular structures during portal placement 2. Injury to sciatic nerve if disoriented to arthroscopic anatomy 3. Technical challenges of suture passing during repair 4. Steep learning curve

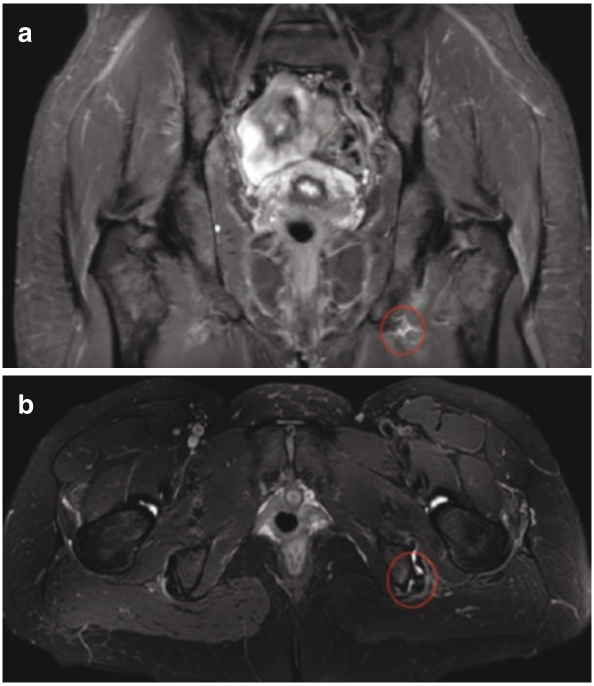

Fig. 4.1 (**a**) Coronal T1 MRI demonstrating a high grade partial tear of the hamstring tendon, with separation from the ischial tuberosity. (**b**) Axial T1 MRI demonstrating a high grade partial tear of the hamstring tendon, with separation from the ischial tuberosity

Case

A 45-year-old healthy female fitness instructor presented with left hip pain for approximately 7 months prior to presentation. Physical exam at presentation was notable for tenderness to palpation of the left proximal hamstring. She exhibited buttock pain with internal and external rotation of the hip and pain with hip flexion >100°. MRI imaging (Fig. 4.1a, b) demonstrated a high-grade partial thickness proximal hamstring tear. She underwent endoscopic debridement and primary tendon repair using two suture anchors (Fig. 4.2). By 6 months, the patient returned to full hip range of motion without pain and returned to her pre-injury activity level as a fitness instructor. Endoscopic images reveal a well-fixed proximal hamstring repair construct (Fig. 4.3a–d).

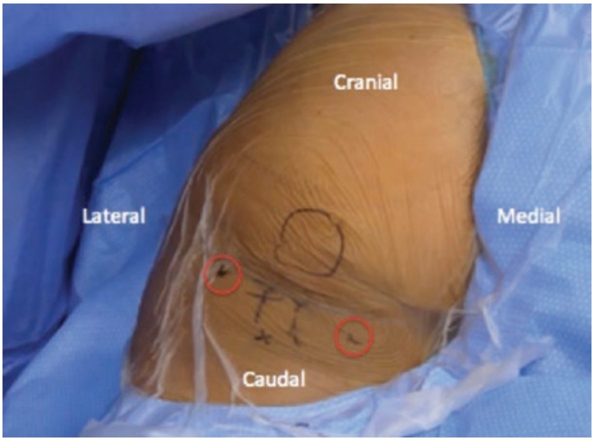

Fig. 4.2 Clinical photograph of marked medial and lateral portal sites

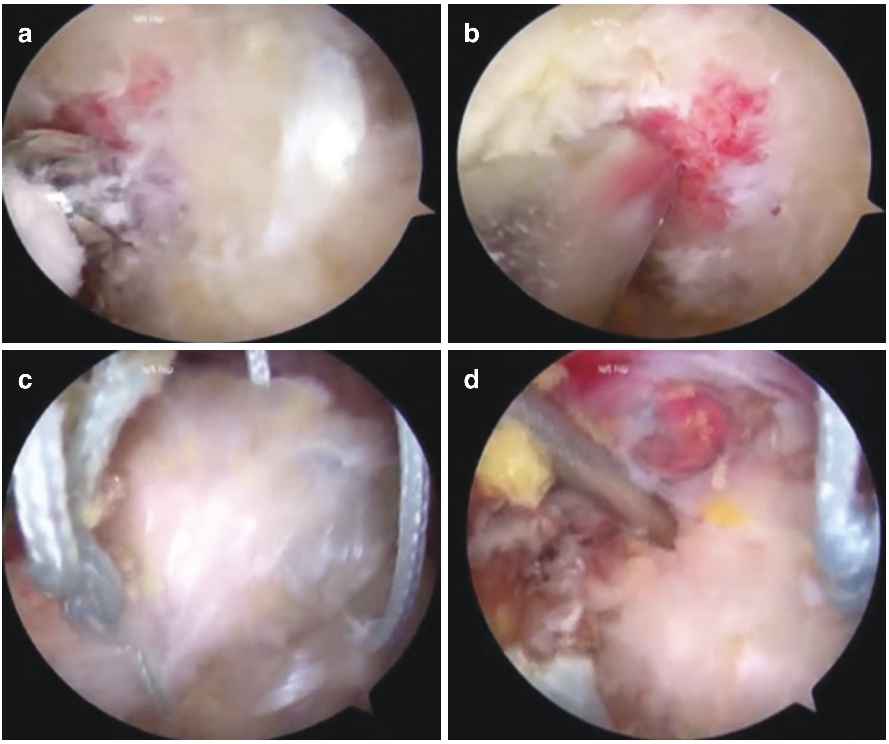

Fig. 4.3 (**a**) Decortication of the ischial tuberosity using a burr. (**b**) Insertion of suture anchor into decorticated ischial tuberosity. (**c**) Passage of suture through the proximal hamstring tendon. (**d**) Probing of final repair construct

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Surgical Treatment of Acute Proximal Hamstring Tendon Tears

5

Stephen A. Hunt

Indications for Acute Repair

As has been previously discussed, many hamstring injuries may respond to nonoperative management with acceptable outcomes. Both the extent of injury and patient factors serve a role in determining the best course of treatment (Table 5.1). While there are no absolute indications for surgical intervention, a review of the literature suggests that indications for surgical intervention include two tendon avulsions with greater than 2 cm of retraction and complete three tendon avulsions [1–6]. Patient factors such as age, activity level (including type of work and recreational activities), medical comorbidities, and potential compliance with postoperative precautions also factor into this decision-making process. Recently, sciatic nerve-related symptoms, such as pain, have also been cited as a relative indication for surgical intervention [7]. Once the extent of the injury has been defined, it is important to discuss the treatment options and expected functional outcomes with the patient. The literature has suggested that acute repairs may have better outcomes and fewer

Table 5.1 Indications for acute proximal hamstring repair

Injury factors
3 tendon avulsion
2 tendon avulsion >2 cm retraction
Patient Factors
High-level athlete
Active job/recreational activities
Pain (sciatic nerve)

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complications then repairs of chronic tears [6, 8–10]. It is also important to discuss potential surgical complications [7, 11] with the patient and known outcomes [2, 4–6, 9–13] so the patient's expectations are realistic.

Operating Room Setup

It is important to consider the setup of the operating room preoperatively. The best exposure for repair will be performed with the patient in the prone position. Adequate and careful padding of all body parts is recommended as these cases may require several hours to complete. Use of fluoroscopy intraoperatively is recommended to assess the position of anchor placement and to ensure the trajectory of anchors. Therefore, the patient shoulder should be positioned on a radiolucent portion of the OR table to ensure appropriate visualization of the tuberosities. Additionally, if the endoscopic repair technique is attempted, it is helpful to utilize fluoroscopic imaging while establishing portals. Endoscopic repair requires the use of the arthroscopic equipment tower, and this equipment may clutter the operating room, while also affecting the maneuverability of the C-arm. Finally, it is important to have appropriate deep retractors in the case of performing an open repair. A headlamp can be beneficial during visualization of the tendon footprint on the ischial tuberosity, especially in cases of muscular or larger patients.

It is preferable to break the OR bed to place the legs in a slight position of flexion at the hip to open up the gluteal crease. Additionally, it is important to drape the entire limb free to allow for knee flexion (Fig. 5.1). Knee flexion relaxes the retracted tendon and facilitates repairing the tendon to its footprint. Finally, sealing off the perineum during prep and draping is important to decrease risk of infection.

Sciatic nerve monitoring is controversial, and its benefit is unclear. It can be utilized to assess potential damage to the sciatic nerve during dissection of the

Fig. 5.1 (**a**, **b**) Patient is draped in the prone position with the injured right limb free for knee flexion and hip extension

tendon stump and sciatic nerve neurolysis. However, it may result in an added expense to the procedure and little data is available to support its routine use.

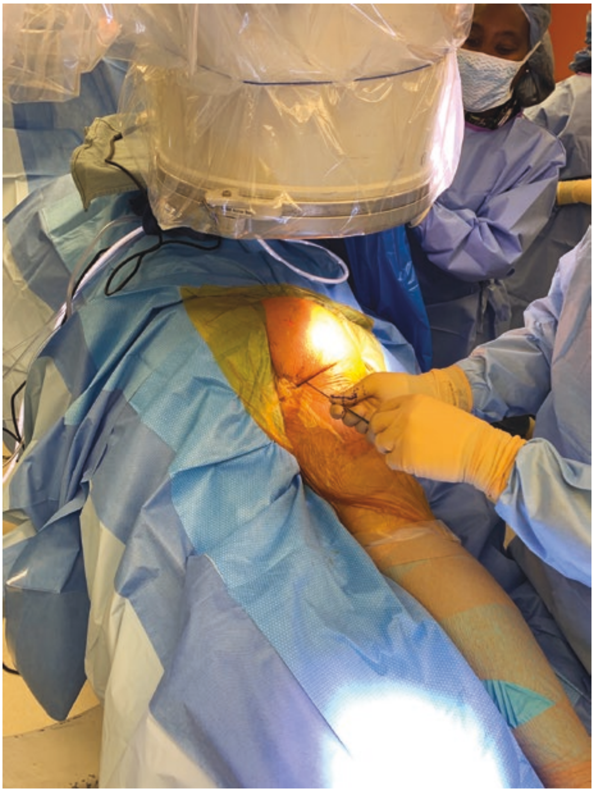
Endoscopic Repair

Endoscopic repair of proximal hamstring injuries is gaining popularity [13–15]. The benefit of endoscopic repair is that there is excellent visualization of the ischium and the footprint of the hamstring origin. Additionally, the portals split the fibers of the gluteus maximus which can be difficult to retract in open repairs. Finally, smaller incisions are generally perceived as cosmetically more appealing and *may* decrease complications seen in open repair such as dysethesias, wound complications, and potential infection. However, it is important to identify and protect the sciatic nerve during initial portal placement and while performing the repair during endoscopy. Additionally, the subgluteal space is a potential space and fluid extravasation may lead to compartment syndrome if the procedure is not performed efficiently or the fluid pressure is not managed appropriately.

At least three portals are required to complete an endoscopic repair. Marking out the superficial anatomy can be a helpful way to visualize the appropriate approach (Fig. 5.2). Palpable bony landmarks include the ischium medially, the posterior

Fig. 5.2 Superficial anatomy marked out for endoscopic portal placement

Fig. 5.3 Fluoroscopic assistance during initial portal placement



superior iliac spine superiorly, and the greater trochanter laterally. Generally, portals are created with fluoroscopic assistance using a nick and spread technique superficially and a switching stick placed to the tip of the ischial tuberosity (Fig. 5.3). The inferomedial portal is placed first using the aforementioned technique. Often times a rush of hematoma/seroma will confirm proper location of the trochar. Generally, standard length arthroscopes may be utilized; however, in larger patients, it may be necessary to utilize long arthroscopes. Both 30º and 70º arthrocopes may be used depending on surgeon preference. Initially, the ischium should be identified, as it serves as an important landmark for orientation during the procedure. Next, the inferolateral portal can be placed under direct visualization in order to diminish the risk of injury to the sciatic nerve. This portal is generally placed along 4–5 cm lateral to the inferomedial portal along in line with the gluteal crease. At this point, long screw-in trochars can be placed. It is important at this stage to monitor the inflow fluid pressure to allow adequate visualization while preventing severe extravasation in this subgluteal space. Anatomic studies have demonstrated these portals tracks to be safe, greater than 2 cm away from the sciatic nerve and inferior gluteal neurovasular bundles [15].

Once the first two portals are established, it is important to identify the sciatic nerve. The ischium is a constant and remains a useful reference point throughout the case. A blunt wissinger rod or a shaver (in an OFF position) may be utilized to bluntly dissect soft tissue and scar and bursa off the ischium. Once some of these adhesions and bursa have been released/resected, there is usually a strip of fat that can be visualized looking lateral and posterior from the ischium that identifies the course of the sciatic nerve (Fig. 5.4). Blunt dissection can confirm the position of the nerve and release any adhesions that may have developed during the early healing process.

Now that the sciatic nerve has been identified, attention is directed to identifying the proximal hamstring tendon stump to determine if it is amenable to endoscopic repair. The tendon is usually retracted inferiorly, although there may be a few fibers still attached to the ischium. Flexing the knee may help identify the stump as well. Once the stump is identified, it may be gently debrided to healthy tissue. At this point, placing a traction suture can be helpful in assess the quality of the proximal tendon as well as the ease of mobilization (Fig. 5.5). Often, it is

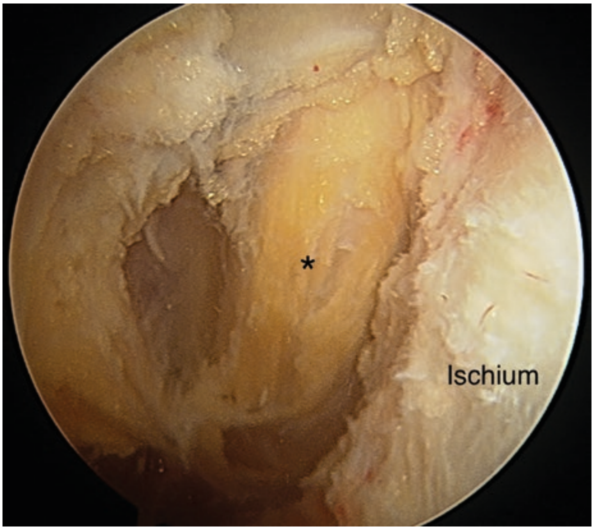


Fig. 5.4 Sciatic nerve (*) visualized during endoscopic repair

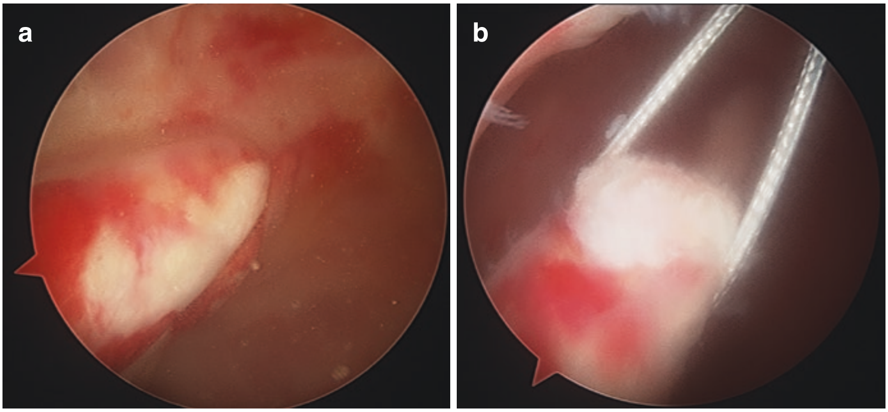


Fig. 5.5 (**a**) Proximal hamstring tendon stump identified. (**b**) Traction stitch placed through the hamstring tendon stump

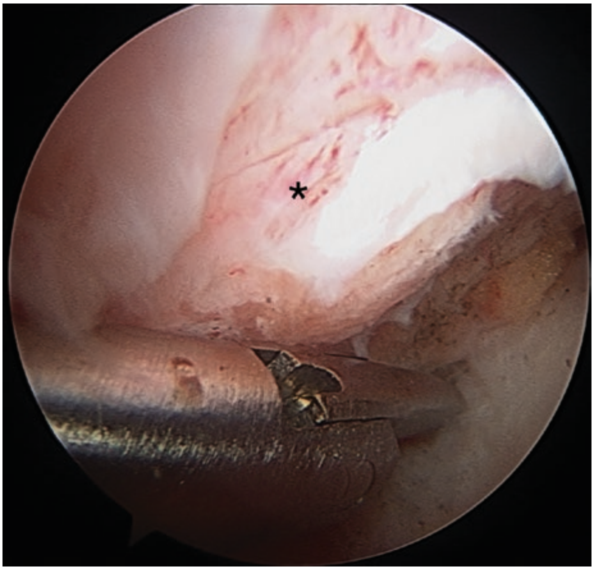


Fig. 5.6 Arthroscopic scissors releasing adhesions from hamstring tendon stump (*)

easier to place a traction suture through an accessory superior portal. This portal is placed in a similar manner as previously described. A self-retrieving suture passer is recommended for ease of passing the traction stitch. Depending on the quality of the tissue, more than one stitch may be passed. Next, the traction stitches are pulled to provide tension and identify and adhesions that require release in order to mobilize the tendon for repair. Arthroscopic scissors can be used to carefully dissect adhesions from the retracted stump in order to improve mobilization of the tendon (Fig. 5.6). Once adhesions have been released, the traction stitches are pulled to assess whether the proximal tendon will reach the ischial footprint without excessive tension.

If the tendon is adequately mobile, then preparation for endoscopic repair continues. A shaver or burr is utilized to resect residual soft tissue on the footprint and to decorticate the bone for enhanced healing (Fig. 5.7). At this point, suture anchors are inserted, and sutures are passed in a variety of patterns and configurations depending on surgeon experience and skill. Fluoroscopy is recommended during anchor insertion to ensure against penetration of the far cortex of the ischium. Often the suture anchors placed in the inferior aspect of the footprint are passed in a mattress configuration and a knotless style anchor may be placed more superiorly in order to avoid prominence of knots on the superficial surface of the tendon which may cause irritation with sitting.

If the tendon cannot be well mobilized or the quality is questionable for this type of repair, conversion to an open repair is recommended. It can still be advantageous to use a shaver or burr to debride and decorticate the ischial footprint because of the excellent visualization with the arthroscope.

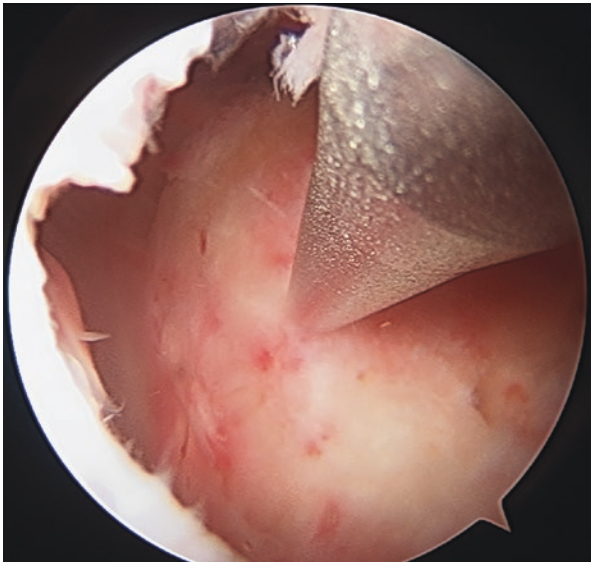


Fig. 5.7 Ischial footprint is decorticated and healing response performed prior to anchor placement

Open Repair

Some acute repair cases require open repair, particularly in situations where the tendon has poor quality or has already scarred and cannot be adequately mobilized or visualized endoscopically. In open repairs, patient positioning is the same as in an endoscopic repair. The skin incision may be made transversely or longitudinally [1, 4]. Both have advantages and disadvantages. The transverse skin incision is more cosmetic than the longitudinal incision, as it is placed in the gluteal crease. However, it may place the superficial cluneal nerves at more risk for injury during subcutaneous dissection and retraction. Additionally, because the incision is in an existing skin crease, it may be more prone to infection. The longitudinal incision allows for an extensile approach to hamstring tendon mobilization and sciatic nerve neurolysis. However, it is not cosmetically appealing, and if it crosses the gluteal skin, crease may create some residual tightness during hip flexion.

The deep dissection involves identifying the inferior border of the gluteus maximus and incision the deep facia inferior to the tendon. It is important to develop this plane as this large muscle and tendon must be elevated superiorly to visualize the hamstring tendon origin on the ischium. Cadaveric studies have placed the hamstring footprint approximately 6.3 centimeters proximal to the inferior border of the gluteus maximus [16]. One technique has been described where the inferior raphe of the gluteus maximus is identified and split in line with the muscle fiber orientation with good results and no complications [12]. If the operation is performed within a few weeks from injury, a hematoma will soon be encountered after elevating the gluteus maximus. If it has been several weeks, a retracted hamstring tendon stump will often form a pseudo-capsule which will encase the hematoma and can also serve as a plane to protect the sciatic nerve. In chronic tears, the hematoma usually has resorbed and created abundant scar about the retracted tendon. At this point, it is extremely important to identify and protect the sciatic nerve as it courses along the lateral border of the hamstring tendons and muscle bellies. While less common in acute repairs, sometimes neurolysis may be required to mobilize both the sciatic nerve and the proximal hamstring tendon as adhesions can quickly form between the two structures [4]. A penrose drain may be utilized to tag the nerve and for gentle retraction of the nerve if needed. In general, it is best not to frequently handle the nerve once it has been identified and found to be free of adhesions.

Once the sciatic nerve is identified, degenerative tissue in the tendon stump is debrided (Fig. 5.8) . At this point, a # 5 suture is placed in a Krackow stitch configuration. Using this stitch for tension, blunt dissection may be performed distally to ensure adequate mobilization for repair. At this point, the ischial footprint is exposed. Retractors are placed underneath the gluteus maximus and the tract proximally is usually palpable with a finger. Hohmann retractors may be placed posterosuperiorly and inferolaterally. Care must be taken to avoid excessive force of either retractor position as the pudendal and sciatic nerves may be at risk, respectively [17]. The ischial bursa and any other soft tissue remnant should be debrided at this

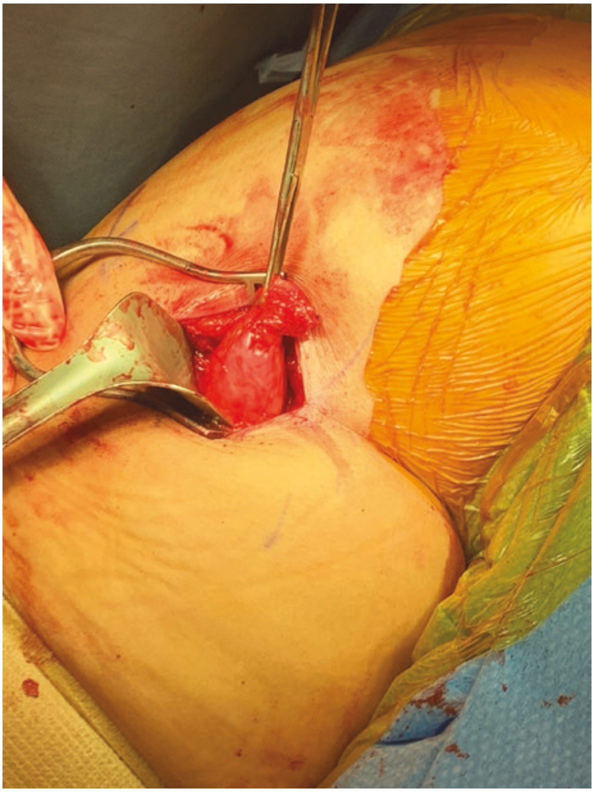


Fig. 5.8 Tendon stump is debrided through a transverse incision during open repair

time, and the footprint should be decorticated or drilled to promote a robust healing response. Next, anchors are placed in the desired configuration. As stated during the endoscopic section, a mattress configuration may be utilized at the inferior border of the footprint and a knotless anchor incorporating the Krackow stitch(es) is placed superiorly. The knee may need to be flexed during knot tying to reduce the tendon to the footprint. After thorough irrigation, a layered closure is performed, and local anesthetic may be judiciously insufflated in the deep and superficial tissues with care to avoid direct injection of the sciatic nerve. A subcuticular closure of the skin and occlusive dressing is recommended given the proximity of this incision to the perineum.

Tendon Fixation

In either the endoscopic or the open repair, it is important to restore strong fixation of the tendon to the ischial footprint. This can be performed with a combination of suture anchors. Hamming et al. [18] performed a biomechanical analysis of various repair configurations in cadaveric specimen. Specifically, they analyzed the use of small anchors (2.9 × 11.5 mm) versus large anchors (5.5 × 18.5 mm) in combinations. They concluded that five small anchors provided the closest cyclic failure load to intact tendons as compared to two small or two large anchors. While this is important information, it can be technically challenging to place that many anchors on the ischial footprint. However, it is certainly important to achieve multiple points of fixation on the ischium to ensure healing of the tendon to the footprint [14]. In the open repair technique, it is generally easier to achieve multiple points of fixation as it can be difficult to manage multiple sutures endoscopically.

Postoperative Care

Bracing is recommended postoperatively. The purpose of the brace is to prevent excessive tension on the repair that occurs during hip flexion with simultaneous knee extension. A variety of braces may be utilized including hip-based or knee braces. Regardless of the brace type, the patient should be educated to avoid quick movements and concomitant hip flexion with an extended knee. Protected toe touch or foot-flat weightbearing is recommended with assistive devices such as a walker or crutches to avoid excessive muscle contraction required by non-weight-bearing. Pain is generally managed by a combination of acute anti-inflammatory, muscle relaxer, acetaminophen, and narcotic pain medication as needed. Ice packs are utilized in the first 72 hours to control local soft tissue inflammation from the surgical insult. Deep venous thrombosis prophylaxis is also recommended for the first 2 weeks or until the patient is sufficiently mobilized. The patient should be instructed basic home exercises in the form of ankle pumps and quad/gluteal/rectus abdominus isometrics. The timing of initiating formal physical therapy depends on surgeon preference and quality of the repair. Patients may also benefit from using devices traditionally used for total hip arthroplasty patients, such as a long shoehorn, a sock aid, a long grasper, and a dressing stick to assist in activities of daily living.

Outcomes

Most reported outcomes on acute surgical repair rely on case series, reviewed retrospectively or systemic reviews of lower quality studies. Many of these cohorts report on both acute and chronic cases and include a variety of surgical techniques. The general trend of these studies suggests that patients undergoing acute surgical repair of proximal hamstring injuries can have improved symptoms, high satisfaction, and return to sport rates with overall low complication rates [2, 6, 8–13].

Kurowicki et al. [13] reported on short-term outcomes of endoscopic proximal hamstring repair. In this cohort of 20 patients with a minimum of 1-year follow-up, improvements were reported in visual analogue pain score, UCLA activity score, and modified Harris hip score. All 20 patients were able to return to work, and 95% returned to sport. In spite of these high rates of return to activity, eight patients reported subjective hamstring weakness, while three patients reported persistent pain with sitting. Unfortunately, this study blended partial tears and complete avulsions in the outcome data, limiting some of the strength of the conclusions.

Willinger et al. [11] reported on 94 of 120 patients at a mean of 56 months postop. Return to sport was significantly higher after acute treatment with an overall rate of 86%. Complications were reported in 8.5%, but they were statistically higher in complete tears and delayed surgeries. Of note, 22% of the cohort was lost to follow-up which may affect the validity of these conclusions. Rust et al. [9] compared the outcomes and return to sport after surgery for acute and chronic proximal traumatic hamstring ruptures in 72 patients. All acute tears (51 patients) underwent open repair, while in chronic tears, a bridging Achilles allograft with a bone plug was used in 14 patients with chronic tears if a primary repair could not be performed. At mean follow-up of 45 months, acute repairs had superior sports activity scores (80.3% vs. 70.2%) and higher Activities of Daily Living (ADL) scores (93.3% vs. 86.5%) when compared with the chronic cohort. Also, there were no significant differences in the complication rate between acute and chronic repairs. The authors concluded that although 87% of the group returned to normal ADLs, patients who desire to return to sports should undergo acute repair.

Cohen et al. [2] reported on 40 patients undergoing acute repair and with a mean follow-up of 33 months. The authors reported a 98% satisfaction rate after surgery. They demonstrated that patients reported high outcome scores in the Lower Extremity Functional Scale (LEFS), the custom LEFS, the Marx Activity Scale, the custom Marx scale, and the proximal hamstring score. Additionally, in comparison with 12 patients undergoing chronic repairs, acute repairs had higher custom Marx scale scores. Finally, two patients (5%) undergoing acute repairs reported neuralgic pain and 16 patients (40%) reported some discomfort while sitting.

Subbu et al. [10] compared the outcomes of acute (<6 weeks; 78 patients), delayed (6 weeks to 6 months; 24 patients), and chronic (>6 months; 10 patients) repairs in 112 athletes (56% elite). The authors noted in spite of there being a similar degree of tendon retraction in all three groups, the delayed and chronic groups had significantly more tension requiring use of a protective postoperative knee brace lock at 90° for 6 weeks, whereas only 41% of acute repairs required such protection. The authors reported a high return to sport of 96.4%. Patients undergoing acute repairs returned to sport at an average of 16 weeks, 9 and 13 weeks faster than delayed and chronic repairs, respectively. Furthermore, nerve symptoms were experienced by five patients in the delayed (21%) and five in the late (50%) groups, compared to only two in the early group (3%).

Skaara et al. [5] reported on self-reported and performance-based functional outcomes of 31 patients (28 acute, 3 chronic) at mean follow-up of 30 months. Most patients experienced little to no pain or limitations during ADLs. While they reported a 94% satisfaction rate, only 58% of patients reported that they had returned to their preinjury activity level. In fact, significant differences in mean hamstring strength and single-legged hop test between the involved and uninvolved legs. Additionally, 71% did not fully trust their operated leg and feared reinjury. These findings were reiterated by van der Made et al. [6], who performed a systemic review in 2014 including 13 studies with 387 patients. They concluded that in spite of a high subjective satisfaction rate, many patients reported decreased strength, residual pain, and decreased activity levels. Bowman et al. [8] also found that many runners failed to return to their preinjury activity levels.

Complications

Complications will be covered in detail in a later chapter. Reported complications include nerve injury or dysfunction, incomplete healing or recurrent tearing, pain with sitting, and persistent muscle weakness, atrophy and loss of power [2, 6, 8–13].

Conclusion

Acute repair of proximal hamstring avulsions is recommended for two tendon injuries with greater than 2 cm retraction and three tendon avulsions. Both endoscopic and open approaches can be safely performed with high patient satisfaction rates and low complication rates. While a large majority may return to normal ADLs, many patients may have some residual weakness and loss of power. Most studies suggest that acute repairs have favorable outcomes and lower complication rates versus chronic repairs.

Case Report #1

A 42-year-old active male with no medical history was at a work retreat when he tried to "do the splits" while dancing. He heard an audible "Pop" and had immediate pain in his left buttock region. He went to the emergency room where radiographs were obtained and were negative. An MRI was obtained which demonstrated a complete avulsion with 3 cm of retraction (Fig. 5.9). After discussing treatment options and outcomes, he underwent an endoscopic repair. At the time of surgery, the tendon was mobilized and a two anchor repair was performed (Fig. 5.10).

Case Report #2

A 48-year-old active female with no medical history was waterskiing on vacation when she felt a "pop" and sharp pain in her left buttock. She was evaluated by a local orthopedist who ordered an MRI confirming a three tendon avulsion injuries with 5 cm of retraction (Fig. 5.11). She returned from vacation and presented for consultation at the 2 weeks post-injury. She was indicated for surgery but had to

Fig. 5.9 Coronal MRI image demonstrating left hamstring avulsion with 3 cm of retraction and large hematoma

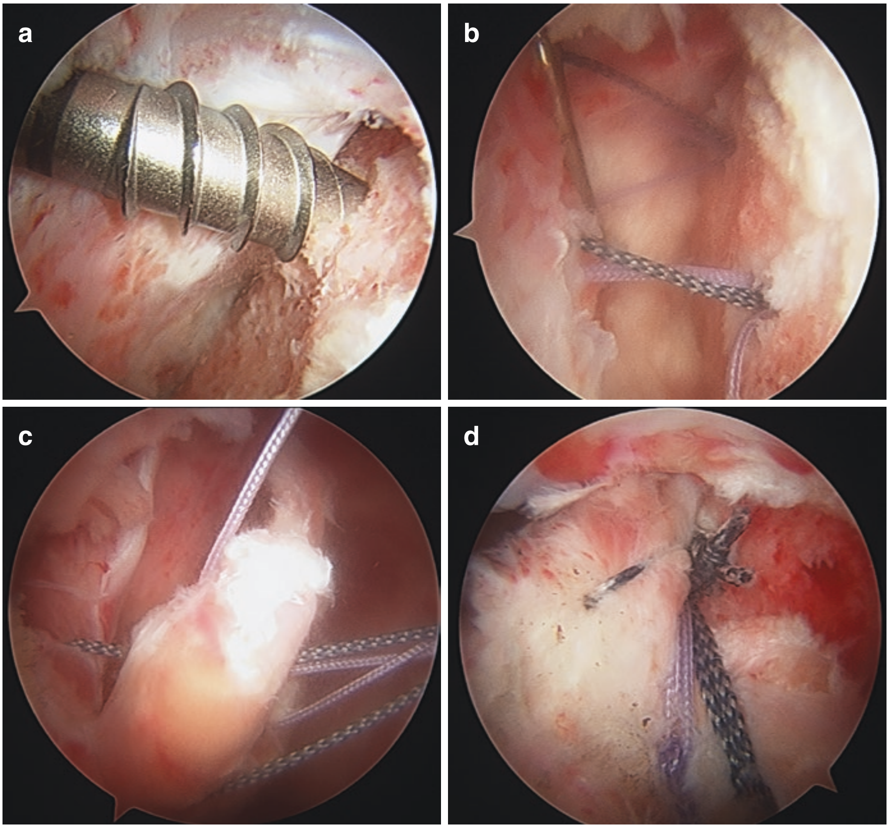


Fig. 5.10 Endoscopic repair. (**a**) Tap inserted in preparation for anchor placement. (**b**) Sutures passed through undersurface of hamstring tendon. (**c**) Sutures passed through hamstring tendon. (**d**) Final double row repair

delay for work and personal reasons until 6 weeks postinjury. Initially, an endoscopic approach was performed. However, the tendon stump was thickened and difficult to mobilize. A traction stitch was placed in the stump, but the tissue quality was poor and the tendon was scarred distally. The decision was made to convert to an open technique. A transverse incision was made in the gluteal crease and a two anchor double-loaded repair with the addition of a Krackow stitch in the mobilized and debrided tendon was performed (Fig. 5.12).

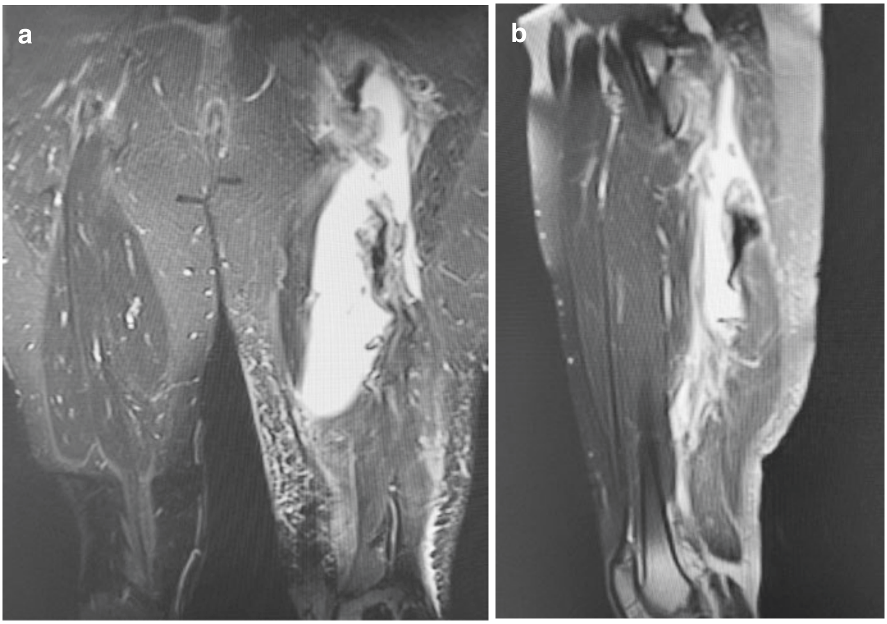
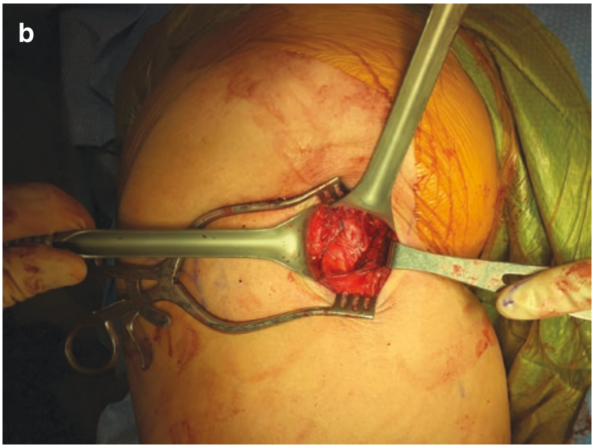


Fig. 5.11 (**a**) Coronal MRI image demonstrating left hamstring avulsion with 5 cm of retraction. (**b**) Sagittal MRI image demonstrating left hamstring avulsion with 5 cm of retraction

Fig. 5.12 Open repair performed after initial endoscopy found the tendon not amenable to endoscopic repair. (**a**) Tendon stump was found to be of poor quality. (**b**) Final open repair

Fig. 5.12 (continued)



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6 Surgical Management of Chronic Proximal Hamstring Tendon Tears

Bogdan A. Matache and Laith Jazrawi

Introduction

Hamstrings comprise the most commonly injured muscle group in running and jumping athletes [1–3]. In these athletes, the injury is most often localized to the musculotendinous junction [4]. Conversely, proximal hamstring tears make up the majority of hamstring injuries (12%) in water skiers, dancers, skaters, and bodybuilders [4–6]. In most cases, it is either completely torn or avulsed, but partial ruptures and ischial apophyseal avulsion fractures also contribute to the spectrum of proximal hamstring injuries [6]. While nonsurgical management of intrasubstance tears results in an acceptable level of pain relief and functional improvement in most patients, complete proximal ruptures are generally indicated for repair, owing to the residual cramping and weakness found in 80% of these injuries managed nonoperatively [7–9].

Proximal hamstring injuries can be differentiated by the number of tendons involved, tear location, presence of a bony avulsion, degree of retraction, and sciatic nerve involvement. In their anatomical classification system, Wood et al. [5] described Type-1 tears as osseous avulsion, Type-2 tears as musculotendinous injuries, Type-3 tears as incomplete avulsions, Type-4 tears as complete tears with no retraction, and Type-5 tears as complete tears with retraction and with (Type-5a) or without (Type-5b) sciatic nerve involvement. Complete tears involve the entire conjoint tendon, comprising the long head of biceps femoris and semitendinosus tendons, and the semimembranosus tendon [10].

Despite an improved understanding of the radiographic anatomy of the ischial region and the ability to confidently identify which muscle is injured and to what degree, delays in diagnosis and referral persist. As a result, patients may present for

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initial orthopedic consultation with a chronic tear, which has different surgical considerations than an acute tear. The definition of a chronic tear has been inconsistently described in the literature, but acute tears generally comprise those <4–6 weeks old, and those >4–6 weeks old represent delayed or chronic injuries [11–13]. While acute tears are technically easier to repair, owing to the preservation of native tissue planes and absence of scarring, many studies have demonstrated favorable outcomes in the repair of chronic proximal hamstring ruptures [7, 14–19]. This chapter will discuss the diagnosis of chronic proximal hamstring tears, indications for repair, surgical technique, rehabilitation, and outcomes.

Indications and Contraindications

Indications

Proximal hamstring repair is generally indicated for active patients with acute 2-tendon avulsions with >2 cm of retraction, and 3-tendon tears irrespective of the amount of retraction [10, 11, 20, 21]. Patients with chronic proximal hamstring tears will often present with persistent pain and weakness after a failed initial course of nonsurgical treatment. It is also not uncommon for these patients to have been inappropriately advised against surgery by a previous physician, this despite improvements in diagnosis and surgical management of these injuries.

In addition to the above-listed surgical indications, chronic tears are indicated for repair if they cause deep buttock pain due to scarring and adhesions between the torn hamstring tendon(s) and the sciatic nerve; this has been termed the "hamstring syndrome" [22]. Patients with this will often complain of unrelenting pain that is exacerbated by prolonged sitting, such as when driving. In such cases, an extensive neurolysis of the sciatic nerve at the time of surgery should be anticipated and performed in addition to hamstring repair.

Contraindications

There are no absolute contraindications to surgical repair of proximal hamstring tears. Relative contraindications include single tendon avulsions, 2-tendon tears with minimal retraction, a poor soft tissue envelope, a high Charleston comorbidity index resultant of multiple medical comorbidities, a sedentary lifestyle, and advanced physiologic age. Furthermore, patients should be cautioned that they may not be able to return to the same level of activity they experienced prior to their injury. This is especially true for runners, where although 82% returned to running after proximal hamstring repair, only 50% were able to return to the same activity level [23]. In contrast, cyclists, surfers, and water skiers returned to their preinjury level of activity 81% of the time. As with any surgical procedure, unreasonable patient expectations may be a relative contraindication to surgery.

Surgical Technique

Positioning

Surgery is performed with the patient positioned prone over chest rolls. General anesthesia is preferred to permit muscle paralysis during the case that will allow for improved mobilization of the retracted tendons. A distal bump under the feet is used to maintain the knee at 30° of flexion to de-tension the hamstrings. The leg is freely prepped and draped in a sterile manner to the level of the buttock crease medially and the iliac crest proximally. The ischial tuberosity is palpated and marked. Given the amount of surgical dissection often required in the setting of a chronic rupture, a 10–15-cm longitudinal vertical incision extending from the ischial tuberosity down the middle of the posterior thigh is used to facilitate surgical exposure.

Approach

The surgical approach can be broken down into three segments: (1) superficial dissection, (2) sciatic neurolysis, and (3) deep dissection.

Superficial Dissection

Dissection is carried through the subcutaneous tissues to the level of the cluneal fascia, which is a very thin fascial layer that can inadvertently be cut if care is not taken to identify it. The fascia is then incised in line with the incision and along the inferior gluteal fold and tagged for easy identification at the time of closure. The posterior femoral cutaneous nerve is next found emerging deep to gluteus maximus and protected for the duration of the case. Injury to this nerve may result in temporary or permanent posterior thigh pain and dysesthesia. The first portion of the approach is concluded by proximal retraction of the gluteus maximus muscle to identify the ischial tuberosity, sciatic nerve, and torn hamstring tendons.

Sciatic Neurolysis

In acute repairs, neurolysis of the sciatic nerve is usually not required as the nerve can usually be bluntly dissected off of the hamstrings. However, in the setting of a chronic tear, the nerve is often encased in scar tissue and requires a formal neurolysis to allow for a safe repair and to prevent tethering of the nerve as the retracted tendons are mobilized proximally for repair (Fig. 6.1). The easiest and safest location to find the sciatic nerve is out of the zone of injury in the distal aspect of the approach, approximately 20–25 cm distal to the ischial tuberosity [9, 24]. A nerve stimulator can be helpful in identifying the nerve, which is located lateral and deep to the hamstrings [25, 26], and surgical loupes may improve visualization and preservation of its branches to the hamstrings muscles [18, 24, 26]. Neurolysis is performed in a distal-to-proximal direction, carefully dissecting the torn hamstrings muscles off of the nerve. If an extensive amount of dissection is required around the

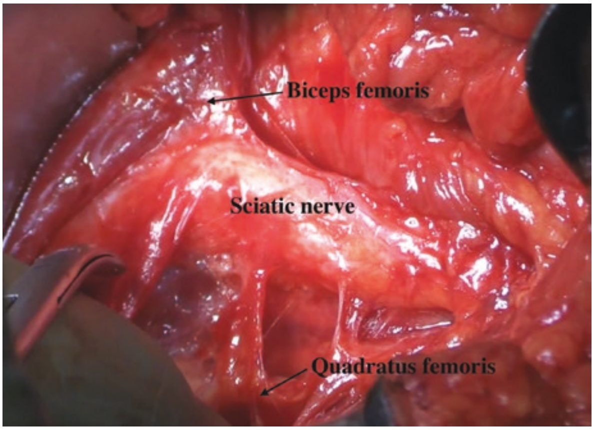

Fig. 6.1 Extensive fibrous adhesions surrounding the sciatic nerve in the setting of a chronic proximal hamstring injury

sciatic nerve, a piece of acellular dermal matrix can be wrapped around it after repair of the hamstrings to theoretically improve gliding and prevent scarring [25].

Deep Dissection

Once the sciatic nerve has been dissected and protected, the focus shifts to completely exposing the torn hamstring tendons. This involves excising any scar tissue and mobilizing the hamstrings as distally as possible from adjacent tissue. Two nonabsorbable high-tensile sutures are then passed through the tendon stumps in a locking Krakow fashion to achieve proximal control of the torn hamstrings. Once this has been achieved, a Hohmann retractor is placed behind the ischial tuberosity [25], and the tuberosity is debrided of fibrotic tissue and prepared for bony repair. The decision to perform a primary repair versus reconstruction is influenced by a number of intraoperative cues. After maximal mobilization of the hamstrings, the knee is flexed to 90°, the position of postoperative immobilization, and the gap between the tendons and the ischial tuberosity is measured [18, 24, 27]. If there is no residual gap with good tendon tissue, a primary repair can be performed following the principles described in Chap. 5. If there is no residual gap, but the tissue is tenuous, a primary repair with graft augmentation is recommended [17]. If there is any residual gap present, it is recommended that a bridging graft be used for repair [9, 17, 18, 24, 27]. The choice of graft and technique used for augmented and bridging repair are described below.

Graft Selection

The graft most commonly utilized in the repair of chronic proximal hamstring tears is the Achilles allograft [17, 18, 26, 27]. The benefits of using this graft include its absence of associated donor site morbidity, ease of procurement, versatility, and relatively low cost [28]. Furthermore, as will be described below, it can be used either with a bone plug, or as an all-soft tissue graft. Other graft options described

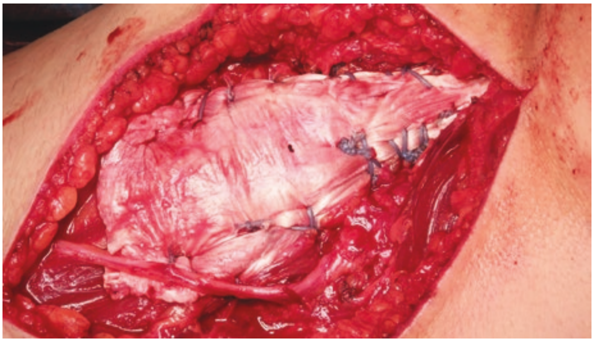

Fig. 6.2 Achilles allograft augmentation of a chronic proximal hamstring repair

in the literature include semitendinosus and gracilis autograft, obtained either from the ipsilateral [29] or contralateral [24] knee, and iliotibial band autograft [9].

Graft Augmentation

As alluded to above, the decision to augment a repair resides on the quality of the tissue in the tendon stump that is reapproximated to the ischial tuberosity (Fig. 6.2). The more chronic the repair, the less likely it is that the tendon stump can be primarily repaired to the tuberosity, and the higher the likelihood is of necessitating a bridging construct. However, in delayed repairs, such as those between 4 and 8 weeks from the time of injury, primary repair is potentially achievable. This is further facilitated by the use of an allograft to augment the repair when the tissue quality is poor. The decision to do so is surgeon-dependent, but factors such as a short residual tendon stump, suture cut-through, and tendon delamination can serve as intraoperative cues to prompt allograft augmentation of the repair.

Proximal fixation of an Achilles allograft used for augmentation is performed in a similar fashion to a bridging repair, which will be described below in detail. After the graft is secured proximally and primary repair is performed, the knee is flexed to 40° and the broad distal allograft is folded over both the conjoint and semimembranosus tendons and secured with nonabsorbable suture [17]. The knee is then taken through a full range-of-motion to ensure that the integrity of construct is maintained.

Bridging Repair

The key aspect of a bridging construct is the graft fixation on the ischial tuberosity, and a number of different techniques for this have been described. When an Achilles allograft is used, the two main options are to either use bone plug [17, 26], or suture anchors [17, 18, 27]. A bone plug is a good option since it allows for bone-to-bone healing to occur, which has been shown to be advantageous in other procedures, such as anterior cruciate ligament (ACL) reconstruction [30, 31]. However, in the setting of a large gluteus maximus impairing complete visualization of the ischial tuberosity, suture anchors provide an easier solution to proximal fixation of the graft.

Bone Plug

The bone plug technique involves fashioning the calcaneal bone block of an Achilles allograft into a 7–8-mm plug and securing it into a unicortical drill tunnel centered in the ischial tuberosity with an interference screw. If this technique is used, our preference is to use a metal screw, owing to the reliable fixation achieved using this implant and ability to visualize the screw on postoperative radiography. However, polyether ether ketone (PEEK) screws have recently been shown to provide equivalent clinical performance to titanium screws for interference fixation of ACL grafts, and may provide a reasonable alternative to metal screws [24, 32]. They also carry the added benefit of avoiding metal artefact on postoperative magnetic resonance imaging. Regardless of the choice of implant used for interference fixation, the screw should be placed medial to the bone plug to better replicate the anatomy of the hamstrings origin on the ischial tuberosity [17]. Care should also be taken to seat the screw flush or slightly recessed relative to the cortical bone on the ischial tuberosity to reduce the risk of a painful prominence postoperatively.

After securing the bone plug, the knee is flexed to approximately 45° and the locking traction sutures that were previously passed through the tendon stump are tensioned maximally in the direction of the ischial tuberosity. The broad tendinous portion of the Achilles allograft is then fanned out over and sutured to the hamstrings' musculotendinous unit using a combination of nonabsorbable and absorbable locking sutures until secure fixation is achieved [17, 26, 27]. The knee is then taken through a gentle range of motion to ensure that full extension can be achieved.

Suture Anchors

Achilles allograft fixation to the ischial tuberosity using suture anchors is an alternative technique for bridging repair of a chronic proximal hamstring tear. This may be preferred over the use of a bone plug in certain settings, such as in the setting of a muscular gluteus maximus impairing proper visualization of the footprint, as mentioned previously. It is also the technique more familiar to most surgeons, since most acute repairs are performed in a similar manner. Many different anchor options have been described in the context of proximal hamstring repair, including PEEK [24, 29] and bioabsorbable [27] implants. The anchors are inserted into the lateral aspect of the ischial tuberosity, 1 cm apart, and are incorporated into the repair as described below.

The bridging repair technique using suture anchors can be used for Achilles allograft or autograft options. When an Achilles allograft and iliotibial autograft are used, one suture limb from each anchor is passed through the tendinous portion of the graft in a locking Krakow fashion, while the other limb of the suture is passed in a vertical mattress configuration and used to reduce the graft to the ischial tuberosity [9, 27]. The distal repair is then completed in a similar manner as the bone plug technique detailed above. When a semitendinosus autograft is used, one of two methods of graft incorporation can be employed. The first consists of using the graft to reinforce the torn tendon stump with successive passes, each at a 90° angle to the previous (Pulvertaft weave), which allows for improved tissue integrity and greater stump length [29]. The reinforced stump can then be repaired to the ischial tuberosity in the same way as a primary repair. Alternatively, one can insert one end of the autograft with the suture anchor into a drill hole in the tuberosity, and weave its other limb through the tendon stump as described above [24]. The fixation can then be reinforced with additional suture anchors.

Postoperative Rehabilitation

To date, there is no well-established postoperative rehabilitation protocol that has demonstrated superior outcomes over other protocols. Most studies that describe the postoperative management after repair of a chronic proximal hamstring tear include elements of limitations of hip flexion, knee extension, and weight-bearing for a duration of 3–8 weeks after surgery [17–19, 24, 26, 27, 29]. This can be achieved using a variety of hip, knee, or combined orthoses.

In our practice, we have found that a limitation of weight-bearing for a duration of 6 weeks, in conjunction with a knee brace limiting knee extension past 45°, unless excessive tension on the repair was encountered intraoperatively, provides adequate protection of the repair. Further, we have found the use of hip extension braces to be rather cumbersome for patients, and many are unable to tolerate these altogether. Instead, we prefer advising patients to avoid postoperative hip flexion greater than 45° and active hamstring contraction. Our detailed postoperative rehabilitation protocol can be found in Table 6.1.

Outcomes

Improved recognition of chronic proximal hamstring tendon injuries as surgical injuries has led to a recent increase in the number of studies assessing the outcomes of repair. So far, chronic proximal hamstring repair has shown to be a safe and efficacious procedure for reducing pain and restoring function in patients with this injury. However, given the general low level of evidence in the literature, short duration of follow-up, heterogeneity of graft choices and fixation methods, and variable postoperative rehabilitation protocols used, conclusions about the success of chronic proximal hamstring repair must be tempered.

Only a few small case series have reported specifically on the surgical outcomes of chronic proximal hamstring tendon repair. The largest such series belongs to Cross et al. [33], who presented their outcomes of surgical repair of chronic proximal hamstring ruptures in nine patients. Their results were encouraging, with hamstring strength and endurance testing after surgery scoring approximately 60% compared to the contralateral side, all patients reporting satisfaction with their surgery, and 7/9 being able to return to their preinjury sport. Of note, all repairs were performed with the knee flexed to 90° and without the use of a graft. Murray [27]

Table 6.1 Recommended postoperative rehabilitation protocol following repair of chronic proximal hamstring injuries

Phase 1 (weeks 0–6)	
Weight-bearing	
No weight-bearing with crutches	Weeks 0–6
No active hamstring contraction	Weeks 0–6
No hip flexion >45°	Weeks 0–6
No knee extension >45°	Weeks 0–6
Hinged knee brace	
Locked at 45° for ambulation and sleeping, remove for hygiene	Weeks 0–2
Set to range from 45° to 140° for ambulation, remove for sleeping and hygiene	Weeks 2–6
Discontinue brace	Week 6
Range of motion (ROM)	
45°	Weeks 0–2
45–140°	Weeks 2–6
Therapeutic exercises	
Heel props with quadriceps sets (supine position only)	Weeks 2–6
Phase 2 (weeks 6–12)	
Weight-bearing	
As tolerated	Weeks 6–12
Range of motion	
Progress by 30° per week to full active ROM	Weeks 6–12
Therapeutic exercises	
Progress to closed chain extension exercises, begin quadriceps strengthening	Weeks 8–12
Lunges (0–90°), leg press (0–90°)	Weeks 8–12
Proprioception exercises	Weeks 8–12
Stationary bike	Weeks 8–12
Phase 3 (months 3–6)	
Weight-bearing	
Full weight-bearing with normal gait patterns	Months 3–6
Range of motion	
Full ROM	Months 3–6
Therapeutic exercises	
Continue quadriceps and hamstring strengthening	Months 3–6
Focus on single-leg strength	Months 3–6
Sport-specific drills	Months 4–6
Begin maintenance program for strength and endurance	Month 6
Activity goals	
Begin jogging	Month 3–4
Return to sport	Months 6–9

and Marx [18] were some of the first to report on their technique of chronic proximal hamstring repair using Achilles allograft. Their series consisted of one and two patients, respectively, and demonstrated encouraging results in terms of isokinetic strength testing compared to the contralateral side. More recently, Ebert et al. [29]

reported on six patients with chronic proximal hamstring avulsions treated with ipsilateral distal hamstring tendon autograft reconstruction. At 2 years following surgery, mean ipsilateral knee flexion peak and average torque strength were at least 90% of the contralateral limb, but knee flexor total work was still significantly greater on the operative side. However, this could at least partially be explained by the authors' graft choice, since harvesting ipsilateral distal hamstrings could certainly result in a sustained knee flexion weakness, especially in the setting of a chronic proximal avulsion. Nevertheless, 5/6 patients were satisfied with the results of their surgery and with their ability to return to their previous activities.

A number of retrospective studies have compared the outcomes of chronic repairs without the use of a graft to acute repairs, although all were heavily skewed in terms of patient numbers toward acute repairs. Birmingham et al. [14] reported their outcomes of proximal hamstring repairs in 23 patients (14 chronic), and found excellent outcomes in 18/23, good results in 4/23, and fair results in 1/23. Hamstring strength and endurance were an average > 81% of the contralateral side at 43-month follow-up, and 21/23 patients were able to return to >95% of their preinjury activity levels by 10 months after surgery. All chronic repairs did not require a graft, and there were no significant differences between acute and chronic repairs, although the only patient who reported a fair outcome was a chronic repair. In a similar study by Cohen et al. [10], 98% of patients were satisfied with their outcomes at 33 months and all demonstrated improved Lower Extremity Functional Scale and Marx Activity Scale scores compared to baseline, with no differences found between the acute and chronic repairs.

An elegant study by Subbu et al. [12] compared the outcomes of acute (<6 weeks; 78 patients), delayed (6 weeks–6 months; 24 patients), and chronic (>6 months; 10 patients) repairs in 112 athletes (56% elite). The authors found that 96.4% of patients returned to sport at an average of 19 weeks, with the acute repairs returning 9 and 13 weeks faster than delayed and chronic repairs, respectively. If the authors felt that there was any tension on the repair intraoperatively, they prescribed a postoperative knee brace locked at 90° for 6 weeks. Interestingly, although there was no significant difference in the degree of tendon retraction between the groups, all patients in the delayed and chronic groups required a knee brace, compared to only 41% of acute repairs. Furthermore, nerve symptoms were experienced by five patients in the delayed (21%) and five in the late (50%) groups, compared to only two in the early group (3%).

Similar findings are echoed by Blakeney et al. [8] and Willinger et al. [34] in both of their series, with improved outcomes from baseline after chronic primary repairs, but statistically greater improvement and lower complication rates following acute repairs compared to chronic ones. In a recent systematic review, Bodendorfer et al. [7] compared the outcomes of surgical repair of complete acute versus chronic (>8 weeks) proximal tears, and identified 213 chronic avulsions. While chronic repairs generally improved with surgery, acute repairs had significantly improved satisfaction (95.5% vs. 84.4%), sitting pain (0.3% vs. 2.2%), and strength testing as a percentage of the contralateral leg (85.2% vs. 82.8%) compared to chronic repairs.

Patient-reported outcome measures, complications, and re-ruptures were generally similar between the two groups. Unfortunately, the studies were all of low methodological quality with variable definitions of the factors that comprise a chronic tear, so conclusions can't be generalized.

Even fewer comparative studies have been published looking at the surgical outcomes following chronic proximal hamstring repair using a bridging graft or graft augmentation. One such study was conducted by Folsom et al. [17], who evaluated 26 patients, who underwent surgical treatment of complete proximal hamstring ruptures, five of which were chronic (>4 months). Four of the five chronic repairs required an Achilles allograft (one augmentation, three bridging), and 2/4 grafts were fixed using a bone plug, while the other two were fixed with suture anchors. Three patients in the chronic repair group (60%) achieved a full recovery, and all were satisfied with their results. No difference was observed in terms of mean hamstring strength deficits between acute and chronic repairs, although the numbers for comparison were small. Rust et al. [26] compared the outcomes and return to sport after surgery for acute and chronic proximal hamstring ruptures. In chronic tears, a bridging Achilles allograft with a bone plug was used if a primary repair could not be performed. There were 21 patients with chronic repairs (mean time from surgery: 441.4 days), of which 14 required a bridging graft. Eighty percent of chronic reconstructions were satisfied with their outcome, and chronic reconstructions scored 86.4% on the Single Assessment Numeric Evaluation (SANE) – Activities of Daily Living (ADL) and 71.5% on the SANE – Sports Activity scores. Interestingly, the patients who required allograft reconstruction tended to report worse preoperative function and showed greater overall improvement after surgery in the SANE-ADL (33.4% vs. 28%) and SANE-Sports Activity (46.5% vs. 36%) scores compared to chronic repairs. Also, there were no significant differences in the complication rate between acute and chronic repairs.

Conclusion

Based on the best available evidence to date, surgical management of chronic proximal hamstring tears, involving at least two tendons, results in improved patient outcomes and an acceptably low complication rate compared to nonsurgical treatment. The decision to use a graft is made intraoperatively, based on tendon quality and the ability to perform a tension-free repair of the torn tendons. If a graft is used to augment or bridge the repair, Achilles allograft is the most commonly utilized option. Postoperative rehabilitation is not uniformly agreed upon, the use of a knee orthosis limiting knee extension is generally recommended for a short period of time. Although there is a need for higher quality studies incorporating newer techniques and longer-term follow-up, surgeons should be aware of the literature currently available supporting the surgical management of chronic proximal hamstring tears in order to appropriately counsel patients.

Case Report #1

A 34-year-old active female with no medical history was at work 2 months prior to presentation, when she extended her right hip trying to stop a soda cart from rolling down an incline. She heard an audible "pop" and had immediate pain in her right buttock region. She initially attempted to manage her symptoms conservatively, but due to persistent difficulty sitting on that side and progressive paresthesias down the back of her thigh, she decided to consult with her primary care physician. An MRI and EMG study were obtained that demonstrated avulsion of the semimembransus tendon with 6 cm of retraction (Fig. 6.3a), and evidence of posterior tibial neuropathy. After discussing treatment options and outcomes, she underwent an open repair with sciatic neurolysis. An L-shaped incision based in the buttock crease was used (Fig. 6.3b), a neurolysis of the sciatic nerve was performed (Fig. 6.3c), the semimembranosus tendon was mobilized (Fig. 6.3d), and a 2-anchor repair was performed.

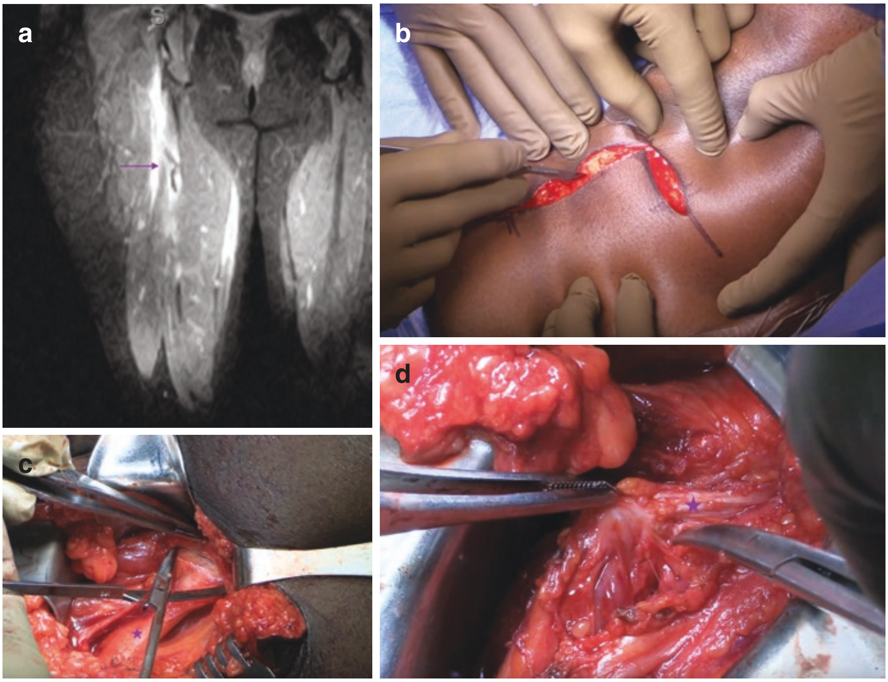

Fig. 6.3 Case report #1: A chronic semimembranosus tear with retraction, as seen on coronal T2-weighted MRI (**a**); the incision used for repair (**b**); identification and neurolysis of the sciatic nerve (**c**); and mobilization of the semimembranosus tendon prior to repair (**d**). (**a**) T2-weighted coronal MRI of the right thigh demonstrating a chronic, retracted semimembranosus tear (→). (**b**) Incision used for repair of a chronic proximal hamstrings tear. The horizontal limb of the incision is based in the buttock crease, while the vertical limb extends longitudinally down the thigh in-line with the ischial tuberosity. (**c**) Neurolysis of the sciatic nerve (*) being performed in the setting of a chronic proximal hamstring tear with fibrous adhesions. (**d**) Identification and mobilization of the semimembranosus tendon (*) prior to repair

Case Report #2

A 44-year-old active male with no medical history injured his right hamstring 3 years prior to presentation while playing ultimate frisbee. He was evaluated at another hospital, diagnosed with a partial proximal hamstring tear, and managed conservatively. Over the past few years, he had noticed worsening activity-related cramping pain, fatigue, and weakness in his right posterior thigh region. An MRI obtained at our institution revealed a complete proximal hamstring tear with 15 cm of retraction (Fig. 6.4a, b). After discussion treatment options and outcomes, he underwent an open repair augmented with an Achilles allograft. Deep dissection revealed a complete intratendinous tear that could not be primarily repaired to the ischial tuberosity after mobilization (Fig. 6.4c). Two 4.75-mm PEEK suture anchors were inserted into the ischial tuberosity (Fig. 6.4d), and an all-soft-tissue bridging construct was performed using Achilles allograft (Fig. 6.4e, f).

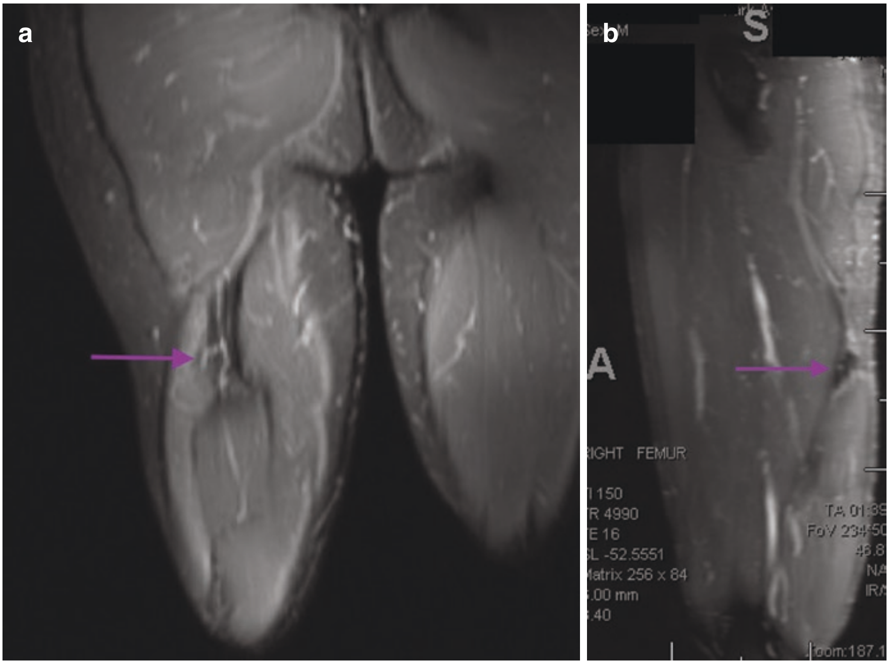

Fig. 6.4 Case report #2: A chronic, complete proximal hamstring tear with retraction, as seen on coronal (**a**) and saggital (**b**) T2-weighted MRI; dissection identified a complete intratendinous tear that could not be primarily repaired to the ischial tuberosity after mobilization (**c**); two 4.75-mm PEEK suture anchors were used for repair (**d**); an all-soft-tissue bridging construct was performed using Achilles allograft (**e**, **f**). (**a**) T2-weighted coronal MRI of the right thigh demonstrating the tendon stump of a chronic, retracted complete proximal hamstring tear. (**b**) T2-weighted saggital MRI of the right thigh (left is anterior) demonstrating the tendon stump of a chronic, retracted complete proximal hamstring tear. (**c**) The distal (left) and proximal (right) stumps of the intratendinous tear (*). (**d**) Two 4.75-mm PEEK suture anchors inserted into the ischial tuberosity after debridement of the residual proximal stump. (**e**) Achilles allograft fixed proximally to the ischial tuberosity for bridging repair. (**f**) Achilles allograft folded over and repaired to the residual distal stump and myotendinous junction

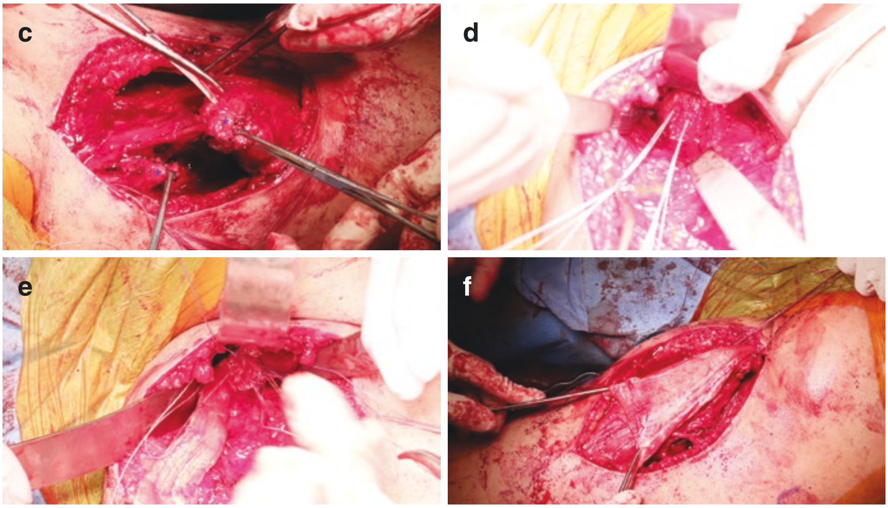

Fig. 6.4 (continued)

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Endoscopic Treatment of Proximal Hamstring Tendon Tears

7

Anthony A. Essilfie and Thomas Youm

Introduction

As mentioned in previous chapters, the indications for operative management for proximal hamstring repair are bony avulsion of the ischium with retraction greater than 2 cm, complete tears of all three tendons with or without retraction, and partial tears that remain symptomatic despite a course of conservative management [1–4]. With recent advancement of technique and equipment, more pathology can be treated endoscopically, including the proximal hamstring. There is a paucity of literature on endoscopic repair of complete and partial proximal hamstring tears. Currently, there are surgical techniques reporting the methods of endoscopic repair of complete and partial proximal hamstring tears [5–8]. There is no consensus for the appropriate indications and patient selection for proximal hamstring repair using an endoscopic technique as opposed to the more traditional open approach. At present, the decision to utilize an endoscopic technique to repair the proximal hamstring is up to the surgeon's discretion, expertise, and familiarity with the technique. A table of advantages and disadvantages associated with endoscopic proximal hamstring repair can be seen in Table 7.1.

Open fixation of the proximal hamstring has a 23% complication rate with wound infections, neurological complications, and peri-incisional numbness being the most commonly reported complications [9]. The risk of infection is particularly concerning given the proximity of the gluteal fold to urine and fecal material. Decreasing the size of the incision needed for the procedure should theoretically reduce the infection risk. A potential disadvantage of the endoscopic approach is the possibility of neurovascular injury when creating the portals. However, a benefit of the endoscopic approach is the ability to access the proximal hamstring without

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Table 7.1 Advantages and disadvantages associated with endoscopic proximal hamstring repair

Advantages	Disadvantages
Smaller incisions	Fluid extravasation
No gluteus maximus retraction	Learning curve
Magnified visualization	Technical challenge of passing and shuttling sutures through the tendon.
	Injury to the neurovascular structures during portal placement and during repair of the tendon

requiring retractors used in open proximal hamstring repair that could result in neuropraxia, particularly to the sciatic nerve.

Currently, there is no study comparing endoscopic to open proximal hamstring repair. Bowman et al. stated that there was no difference in outcomes for the open versus endoscopic technique; however, only 10% of the patients in their study underwent endoscopic hamstring repair and the study was not designed to detect a difference in outcomes [10]. Recently, the first publication on the short term outcomes of endoscopic proximal hamstring was published. Kurowicki et al. performed a retrospective case series on 20 patients that underwent an endoscopic proximal hamstring repair [11]. At an average of 23 months follow-up, there was significant improvement in objective hamstring strength, hip flexion passive range of motion, UCLA activity score and VAS pain scores. There were no baseline modified Harris Hip Scores (mHHS); however, it was noted that patients that underwent repair of complete proximal hamstring tears had significantly better postoperative mHHS compared to patients that had repair of partial proximal hamstring tears, 95.5 vs. 85.7, respectively, $p = 0.03$. Further investigation into the outcomes of endoscopic proximal hamstring repair is warranted to optimize patient outcomes through more refined patient selection.

Surgical Technique

The patient is positioned in the prone position. Care is taken to ensure that all bony prominences are well padded and that arm and neck positioning are appropriate. The injured leg is then prepped and draped in a standard sterile fashion. The ischial tuberosity is palpated, and then inferior medial, central, and lateral markings are made for portal sites (Fig. 7.1). Spinal needles are used at the portal sites and directed toward the ischial tuberosity using fluoroscopic guidance (Fig. 7.2). After a viewing portal is created, a shaver is introduced and an ischial bursectomy is performed. Adhesions are then removed to identify the origin of the conjoint tendon on the ischial tuberosity. Next, a probe is used to assess the delaminated tendon and the defect (Fig. 7.3). The tendon is then split in line with its fibers in the defect (Fig. 7.4). The shaver and bur are used to decorticate the ischial tuberosity to promote healing of the proximal hamstring tendon (Fig. 7.5). Two suture anchors are inserted in the tuberosity (Fig. 7.6). The sutures from the anchor were passed in mattress

Fig. 7.1 Prone positioning of the left hip with markings of the ischial tuberosity and the inferior medial, central, and lateral portal markings

Fig. 7.2 The fluoroscopy image confirms the appropriate trajectory of the inferior medial and lateral portals to the ischial tuberosity

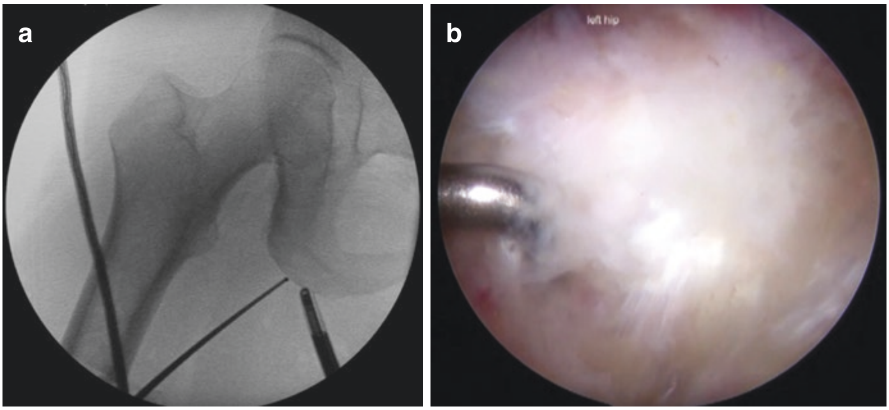

Fig. 7.3 (**a**) The fluoroscopy image confirms that the probe is on the ischial tuberosity. (**b**) An endoscopic view of the probe on the delaminated proximal hamstring tissue

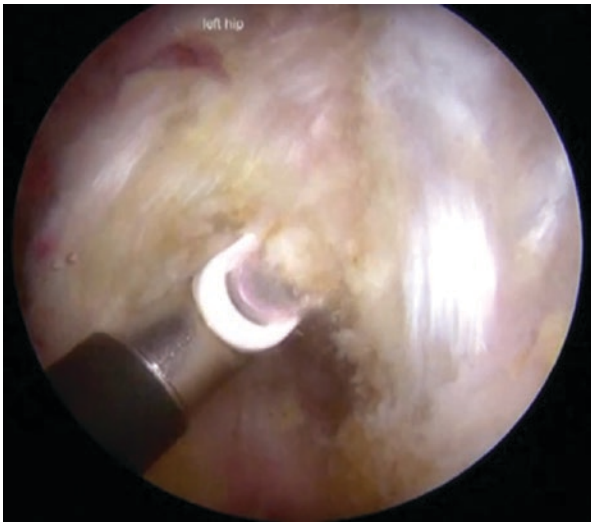

Fig. 7.4 An endoscopic image of splitting delaminated fibers of the conjoint tendon

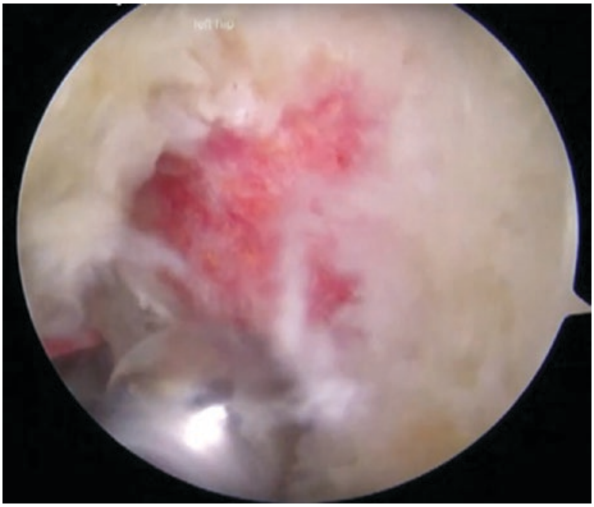

Fig. 7.5 An endoscopic image of the decorticated ischial tuberosity

configuration through the medial and lateral leaflets of the tear to create a side to side repair. Arthroscopic knot-tying technique is used to secure the hamstring to the ischial tuberosity (Fig. 7.7). Additional anchors can be used as needed depending on the size of the tear. Often the sciatic nerve is encased with adhesions so a lysis of adhesions and sciatic nerve decompression can be performed to address the concomitant pathology. Table 7.2 is a summary of pearls and pitfalls for endoscopic proximal hamstring repair.

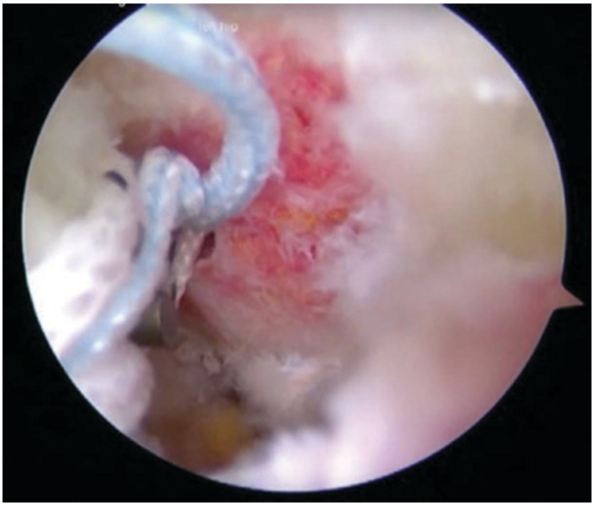

Fig. 7.6 An endoscopic image showing the placement of a suture anchor in the decorticated ischial tuberosity

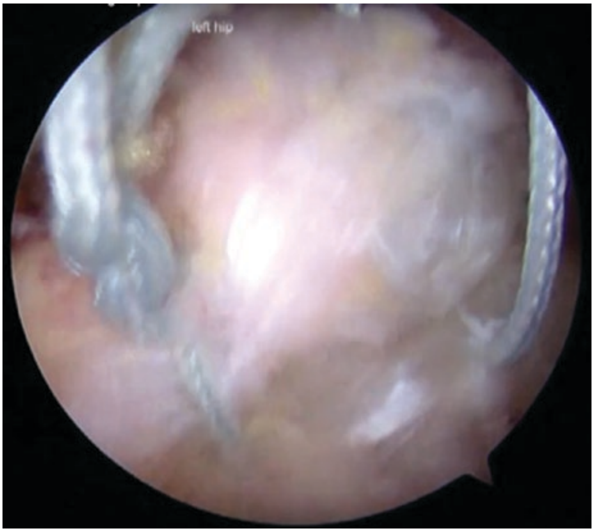

Fig. 7.7 An endoscopic view of the completed proximal hamstring repair

Table 7.2 Pearls and pitfalls of employing an endoscopic approach to proximal hamstring repair

Pearls and pitfalls:
Chronic cases with extensive retraction may not be amenable to endoscopic repair.
Portals should be established using fluoroscopic guidance to avoid injuring neurovascular structures.
The sciatic nerve must be identified and protected throughout the procedure.
Familiarity with arthroscopic techniques is essential to keeping operative time low and reducing risk of fluid extravasation.
Additional portals can be made to assist with suture management.
Sciatic nerve paresthesia is often seen in patients with proximal hamstring tears. Meticulous decompression of the sciatic nerve can be done to address the concomitant pathology.

Postoperative Management

The patient is made flat foot partial weight-bearing, with hip abduction brace locked in full extension for the first 6 weeks. At the 2-week postoperative appointment, the portal sites are assessed and the patient is transitioned to 50% weight-bearing. Also the patient begins formal physical therapy. At the 6-week postoperative appointment, the patient begins weight-bearing as tolerated with full range of motion to the hip. By the 3-month postoperative appointment, the patient is allowed to further strengthen the hamstring with the goal to return to sport by 4–6 months after surgery.

Summary

Endoscopic treatment of proximal hamstring tears is a burgeoning technique. Several technique articles have been written, but further studies comparing open versus endoscopic proximal hamstring repair with long-term follow-up are needed. The results of these studies would help refine the appropriate technique for patients that have sustained complete proximal hamstring tears or partial hamstring tears that are symptomatic despite conservative treatment.

Case Study

A 49-year-old female was dancing and did a split sustaining an acute rupture of her right proximal hamstring tendon. The patient felt instant pain proximally at the ischial tuberosity at the time of injury. Ecchymosis developed in the next few days. Her MRI films demonstrated a complete 3-tendon tear (Fig. 7.8a–c). She presented 3 weeks after injury and was given the option of endoscopic versus open repair. She chose endoscopic repair with the understanding that if visualization or any aspect of the procedure would potentially compromise results, the surgery would be converted to open. The patient was very much interested in the more minimally invasive nature of the endoscopic procedure.

Positioning, portal placement, and fluoroscopy were used as previously described in the surgical technique section of this chapter. The operating table was jack-knifed for endoscopic presentation of the ischial tuberosity. C-arm fluoroscopy was used to localize spinal needles at the ischial tuberosity and appropriate portals were created. The operating room setup is the same whether the proximal hamstring tear is a partial tear or a complete tear.

The stump of the proximal hamstring tendon tear at the ischial tuberosity is exposed (Fig. 7.9). After identification, exposure, and protection of the sciatic nerve, the footprint was abraded with a shaver and a burr (Fig. 7.10). A suture passer was then used to pass a traction stitch through an accessory portal into the proximal torn tendon. The tendon was then manually reduced to check for tension before proceeding with the repair (Fig. 7.11).

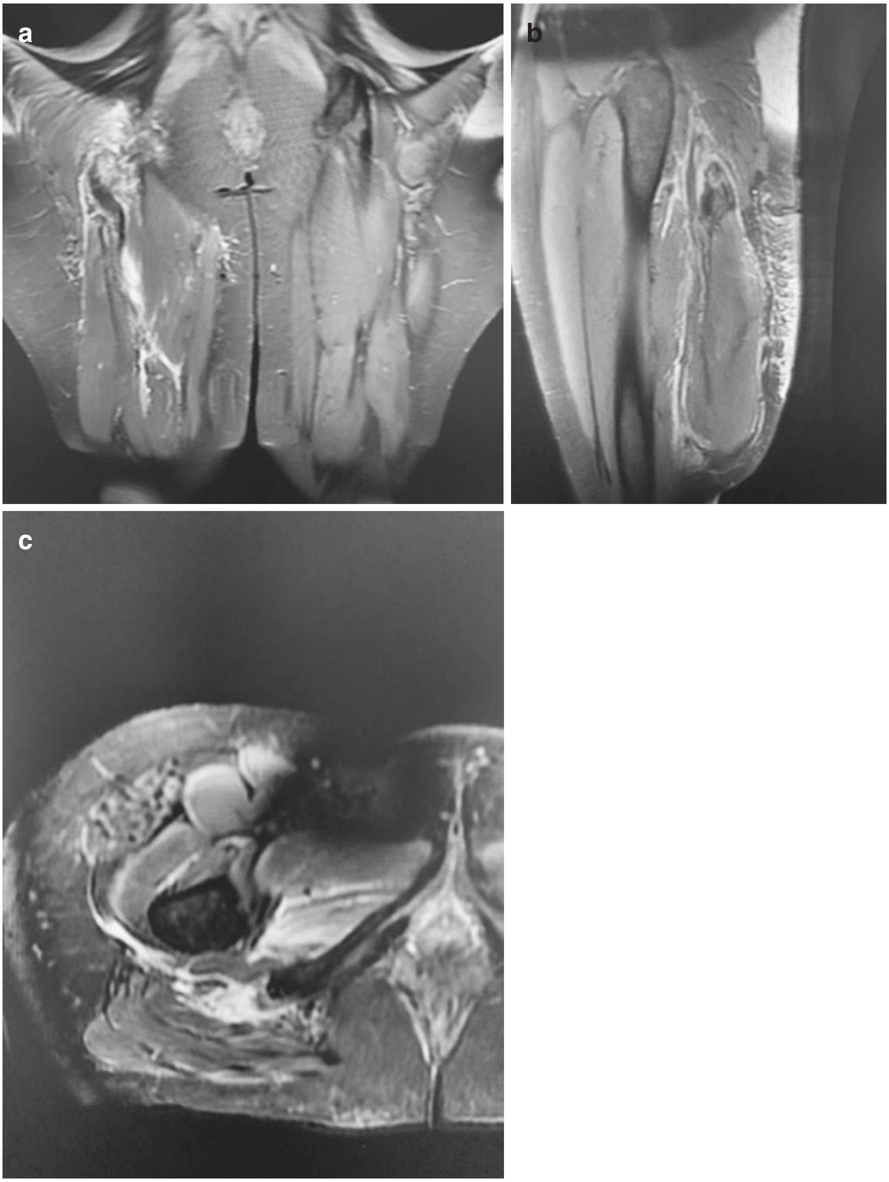

Fig. 7.8 (**a**) Coronal MRI images showing a complete tear of the proximal hamstring tendons. (**b**) Sagittal MRI images showing a complete tear of the proximal hamstring tendons. (**c**) Axial MRI images showing a complete tear of the proximal hamstring tendons

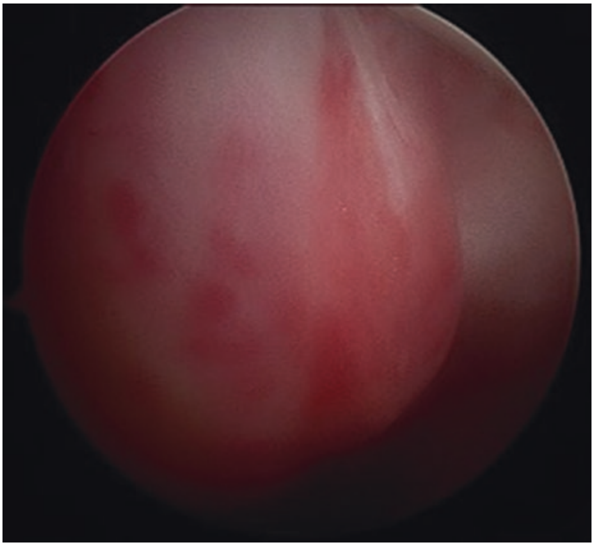

Fig. 7.9 Endoscopic view of the stump of the ruptured proximal hamstring tendons

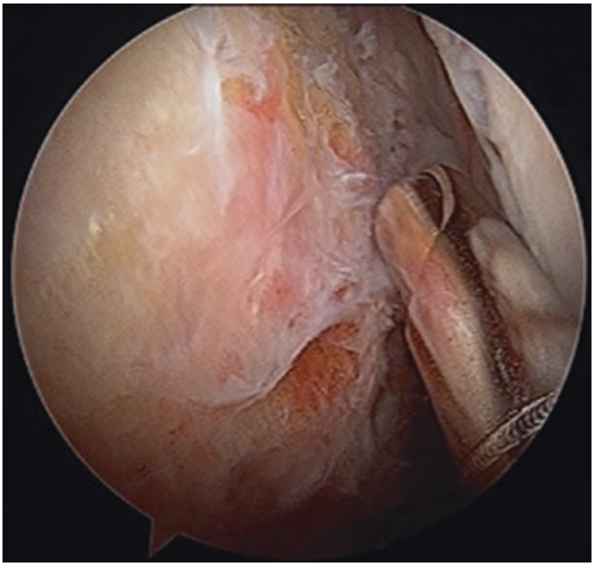

Fig. 7.10 The footprint of the torn proximal hamstring tendon was exposed. Soft tissue was debrided with a shaver and then abraded to achieve bleeding bone with a burr

Once we were satisfied with our planned endoscopic repair, a double-loaded screw-in type suture anchor was inserted into the footprint. The tuberosity was prepared with abrasion of the bone, a pilot hole was created for anchor insertion, and then the pilot hole was tapped, as the bone in this area is typically very strong. A PEEK anchor, which was felt to have more strength than a biocomposite anchor, was used (Fig. 7.12). PEEK was preferred to a metal anchor to allow for future MRI imaging. Sutures from the anchor were then passed into the torn tendon tissue and then arthroscopic knots were used to provide secure fixation of the repair (Fig. 7.13).

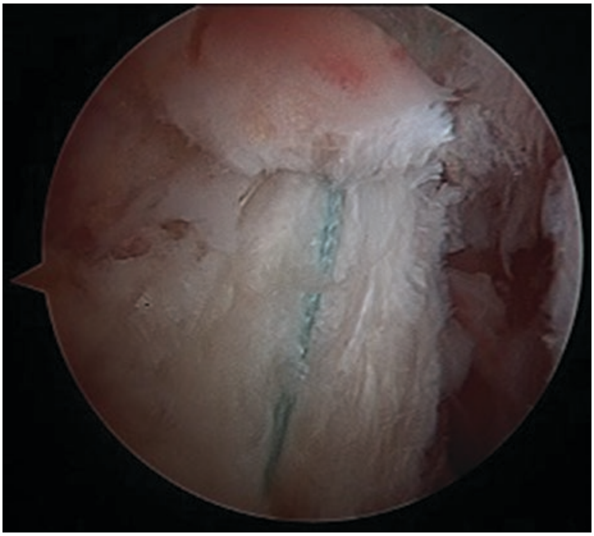

Fig. 7.11 A traction stitch was placed through the torn proximal tendon to reduce the tear and check the tension of the planned repair. The proximal non-viable tissue was debrided

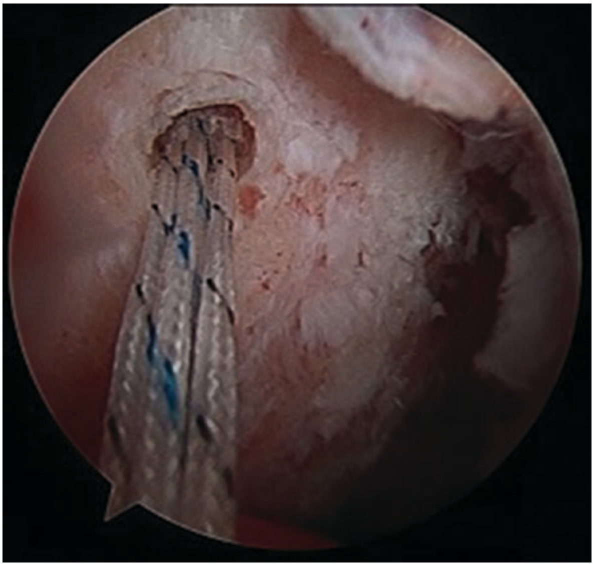

Fig. 7.12 A double-loaded twist-in anchor was punched, tapped, and then inserted into the ischial tuberosity

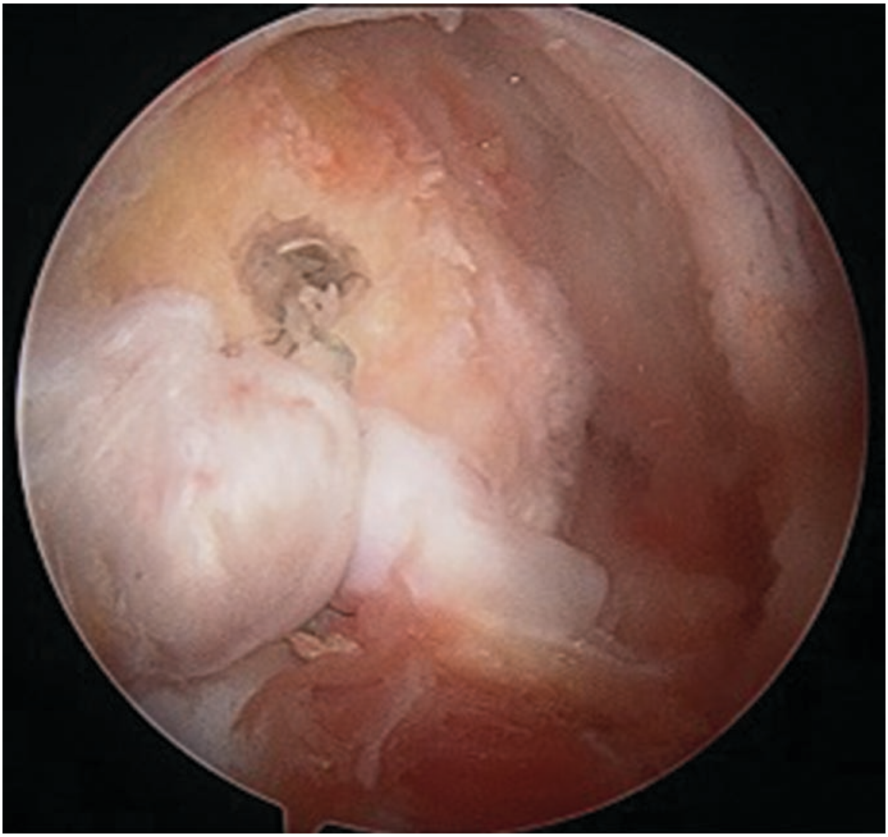

Fig. 7.13 Completed endoscopic repair of the proximal hamstring tendon

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8 Open Versus Endoscopic Approaches to Proximal Hamstring Tendon Tears: Techniques, Pearls, and Pitfalls

Guillem Gonzalez-Lomas and Kamali Thompson

Introduction

Surgical treatment of proximal hamstring injuries is recommended for (a) complete tears involving all three tendons (semimembranosus, semitendinosus, biceps femoris) with retraction greater than 2 cm [1–3], (b) partial or complete tears that fail to improve with conservative treatment, and (c) osseous avulsions with retraction [2–4]. Avulsions indicated for surgical repair are optimally treated within the first 4 weeks of the injury, before chronic fibrotic tissue encases the injured area, increasing difficulty of the procedure [5–7]. Both endoscopic and open repair techniques have been described in the literature and in earlier chapters [2, 5, 6, 8–14]. This chapter seeks to discuss the decision algorithm involving both techniques.

When to Do Open Surgery Versus Endoscopic Surgery

The surgeon faces two main forks in the decision tree of how to treat a patient with a proximal hamstring rupture. The first is whether or not to operate at all. As stated in earlier chapters, partial tears, even those classified as high grade, typically undergo at least 3 months of nonoperative treatment. A fair number of these will resolve with time, physical therapy, and modalities. The decision to surgically intervene in a partial tear rests on evaluating the grade of tear, how well the patient is tolerating and evolving with nonoperative treatment, and what activity level they expect to achieve. Traditionally, this latter criterion was interpreted to recommend conservative management alone for older patients >65 years of age. Our approach has since become much more patient-centric. Older patients can be very active with

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some even involved in competitive athletics. These physiologically young patients will remain in pain and incapacitated without a repair. Conversely, younger sedentary patients in their 40s with low activity requirements will often meet their activity expectations with nonoperative treatment.

Full thickness tears with retraction are typically indicated for surgery. Even in these cases, however, patient-specific characteristics including age, overall health, body habitus, and activity level have to be balanced in order to optimize the treatment plan.

Once operative management is recommended, surgical technique options are weighed. Open repair remains the mainstay of surgical treatment for proximal hamstring ruptures. Even when an endoscopic approach is elected, every case should be set up for possible conversion to open if visualization deteriorates or fluid extravasation becomes excessive. Tables 8.1 and 8.2 summarize the pearls and pitfalls of open and arthroscopic proximal hamstring repair.

Table 8.1 Open repair pearls and pitfalls [5, 14]

	Pearls	Pitfalls
Timing	Operation *3–4 weeks* after injury avoids issues seen in chronic cases	Surgery within *1 week* usually yields friable tissue and hematoma Waiting >*3 months* in retracted cases may require allograft reconstruction
Positioning	*Drape out operative limb* to allow for free mobilization	Communicate with *anesthesiologist* given greater complexity of general anesthesia in *prone position*
Incision	A *vertical or inverted L incision* along the gluteal fold allows for full exposure, preferable skin healing	*Transverse incisions* have a *higher rate of posterior femoral cutaneous nerve injury* than vertical incisions
Initial exposure	In chronic cases, *identify and release sciatic nerve first* as it is often encased in scar tissue If *seroma* present, identify and release it in order to access tendon stump	Identify *posterior femoral cutaneous nerve* Meticulously go through layers of fibrotic tissue to avoid iatrogenic neurovascular injury
Tuberosity exposure	*Spiked Bankart retractors* from a shoulder arthroplasty tray help expose the ischial tuberosity *Blunt Deaver retractors* are a good alternative that may pose less risk to inadvertent iatrogenic sciatic nerve trauma	Avoid placing *deep retractors blindly*, as they may injure neurovascular structures *Superior gluteal nerve injuries* can occur with over-exuberant retraction
Footprint preparation	Remove soft tissue from bony attachment to expose osseous surface	*Do not over-decorticate bone* as this can weaken anchor pull-out strength
Tendon preparation	Resect friable tissue Use *tapered needles* to pass suture so as to not cut other suture limbs Be honest about *tendon quality*	If suture pullout strength is not satisfactory, construct may fail *Removal of too much tendon* tissue can lead to increased tension on repair
Repair	*Tap prior to using corkscrew-type anchors*, especially in young patients, as the ischial tuberosity has dense bone	*Suture management* can become challenging if multiple anchors with multiple limbs. Need to have system in place

Table 8.2 Endoscopic repair pearls and pitfalls [4, 15–17]

	Pearls	Pitfalls
Timing	*Acute tears* and those retracted *<2 cm* may be amenable to endoscopic repair	*Chronic, retracted tears* may not be repairable endoscopically
Positioning	Place patient in prone position, *jack-knife* bed to expose tuberosity	Patient placed in *prone position* requires extra precaution from all surgical team members
Exposure	Identify *neurovascular structures* after portals established	Neurovascular structures are at risk while placing *blind portals*
	Maintain *adequate visualization* and hemostasis throughout the procedure *Limit suction* on shaver when debriding around neurovascular structures. Keep electrocautery at low levels throughout debridement process to limit potential damage	Failing to obtain *adequate visualization* of neurovascular structures can lead to iatrogenic injury
Repair	*Use cannulas* for suture management *Use long cannulas* in patients with *large body habitus* Consider *superior portal* to improve suture management. *Tap prior to using corkscrew-type anchors*, especially in young patients	*Suture management* can become challenging. Need to have system in place
Footprint preparation	Establish footprint first In *partial tears*, make longitudinal exposure through intact bursal side through which to access footprint, decorticate with bur and insert anchors	Endoscopic technique requires a steep learning curve
Overall	Recommend *practice on a cadaveric specimen* before one's first case *Dry scope* used during a standard open case can help familiarize with how structures will appear endoscopically	Endoscopic technique may increase operative time with resultant decreased visualization from fluid extravasation. Compartment syndrome is a possibility with excessive time/pump pressure

Learning Curve

Endoscopic repair has gained in popularity recently for reasons including ease of visualization, obviating gluteus maximus retraction, decreasing infection risks, and minimizing surrounding tissue trauma. Its learning curve, however, remains quite steep. Unlike arthroscopy, where fluid is confined by capsule and solid joint, proximal hamstring endoscopy requires careful anatomic plane localization and neurovascular structure identification. Most notably, the sciatic nerve requires constant attention, as the soft tissues around it retain fluid quickly, visualization worsens, and structures become less recognizable. Even advanced arthroscopists will require some familiarization before attempting endoscopic repair. A recent description of a dry, endoscopically assisted approach offers a compromise between gaining the advantages of endoscopic visualization and magnification and avoiding the pitfalls of endoscopic fluid extravasation while still allowing mini-open access to the ischial tuberosity [18]. As a trial run, using a dry scope during an open repair can help orient the surgeon to the appropriate instrumentation angles as well as how the structures will appear during future endoscopic cases. Before attempting on a live patient for the first time, we recommend that surgeons practice their selected endoscopic technique on a cadaveric specimen if possible.

Similarly, when performing one's first endoscopic repair on a patient, ample time should be allotted for optimal positioning and for possible longer than expected operative times. Earlier chapters have discussed bed, positioning, and imaging requirements. Time pressures related to doing cases in multiple rooms or tightly packing a daily surgical schedule should be consciously limited for the first few endoscopic cases, until the surgeon becomes facile with the technique.

How to Decide Between Open and Endoscopic Approaches?

Given the relatively recent inception of endoscopic surgery as a proximal hamstring repair option, the indications for it remain controversial. Table 8.3 shows a basic overview of appropriate indications for each technique.

Partial Tears and Techniques

Partial tears have been treated successfully with an open approach. Bowman et al. [19] reported on a cohort of 17 patients treated with an open repair of a partial tear. Patients were predominantly female with a mean age of 43. The authors' operative approach consisted in identifying and exposing the ischial tuberosity with blunt Deaver retractors. In many instances, they found normal appearing tendon on the "bursal" side. In these cases, they sharply elevated the tendon attachment to access and prepare the tuberosity. They then repaired the torn tissue back to the tuberosity and performed a side-to-side repair of the torn portion of the tendon stump to any intact footprint tendon as available. In this study, all patients returned to athletic activity with a maximum score on the Marx Activity Scale.

Table 8.3 Indications for open vs endoscopic approach

Indications	Open approach	Endoscopic approach
>2 cm retracted, 2 or 3 tendon tear, acute	Indicated	Indicated if visualization is adequate
>2 cm retracted 2 or 3 tendon tear, chronic	Indicated, may require allograft reconstruction	Not indicated
Partial tear, acute	Not indicated, trial of nonoperative treatment first	Not indicated, trial of nonoperative treatment first
Partial tear, chronic	Indicated	Indicated

The endoscopic approach has also been used for partial repairs with reported success. Domb et al. [15] described a successful endoscopic repair of a partial tear in a cheerleader who had failed extensive nonoperative treatment. Their technique involved using a combination of fluoroscopic guidance and tactile feedback to create posteromedial and posterolateral portals and identify the ischium, the sciatic nerve, and the conjoint tendon. Once the tendon was identified, a longitudinal split through the intact bursal portion made with a beaver blade exposed the bare tuberosity bone underneath. An arthroscopic burr was used to decorticate the bone and 5.5 mm metal corkscrew anchors were used in a mattress fashion, with one suture limb on each leaflet of split tendon. This allowed preservation of the still-attached tendon portion while repairing the avulsed portion back to bone.

Full Thickness Tears and Techniques

Bowman et al. [20] published a cohort of 86 hamstring repairs and reported good outcomes with an overall satisfaction rate of 94%. The vast majority of the repairs were done through an open approach. The tendon sheath was incised, exposing the tendon underneath. A modified Krackow suture was used to enhance pullout strength, and a tension slide technique pulled the tendon down to the bone. Patients older than 50, those with surgery within 3 weeks for acute tears and those with complete tears had greater satisfaction than their counterparts. Runners returned to running 80% of the time but only 50% returned to their previous level. This study falls in line with previous reports of successful open hamstring repair. Sarimo et al. [2], for example, found 29/41 good to excellent results with a full thickness open repair. Successful outcomes typically had a mean time from injury to surgery of 2.4 months while poor outcomes had a wait of nearly 12 months. They recommended early intervention in acute cases.

Studies examining outcomes of endoscopic full thickness proximal hamstring repair have shown promising results. Kurowicki et al. [21] reported 1 year outcomes in a series of 20 patients undergoing endoscopic hamstring repair. Their technique consisted in jack-knifing the OR table, using a 30° scope, a distal ischial portal at the gluteal fold, and a direct ischial portal directly over the ischial tuberosity. They reported a return to work and sport of 100% and 95% respectively. However, subjective hamstring weakness was reported in 42%, and 15% had pain with sitting. More recently, Mehta et al. [4] described an endoscopic repair technique using direct posterior and posterolateral portals and a double row suture bridge.

Patient Characteristics That May Help Guide Selection of Endoscopic Versus Open Technique

Age

Successful hamstring repairs have been reported in patients as young as 12 and as old as 76 [20, 22]. A recent epidemiological analysis [22] of 263 cases showed a peak in injury and surgery rate between 45 and 59 for both males and females but with males having a higher representation than females in other age groups. In theory, age should not influence indications for endoscopic or open repair. However, several issues should be taken into account when deciding on a technique in older patients. First, the more friable and less high quality tendon tissue encountered in older patients can pose challenges in terms of achieving robust sutures bites of tissue. With an open technique, a running or Krackow stitch can often improve suture pullout strength. This is not as technically feasible endoscopically where only one to three suture passes are possible even with a self-retrieving suture passer. Second, older patients may have other comorbidities, such as hypertension, that affect their ability to tolerate epinephrine, often added to endoscopy fluid to minimize bleeding and improve visualization. Third, the ischial tuberosity tends to lose bone density commensurate with age. In older patients, corkscrew-type anchors may be preferable to tack-like anchors. Corkscrew anchor insertion typically entails inserting the anchor into the tuberosity bone without a guide. When done endoscopically, using a canula or skid to orient the anchor placement can avoid time wasted in trying to find the anchor hole. We recommend that the physiologic age be incorporated into the technique decision-making algorithm.

Body Habitus

Body habitus can influence exposure both in endoscopic and in open techniques. A large pannus in the buttock area can be difficult in ischial tuberosity exposure during open approaches. Often, the surgeon will find the structures so deep that exposure using levering-type retractors like Homans, Bankarts, or Deavers places tremendous tension on the surrounding tissue. Iatrogenic injury from overenthusiastic retraction should not be underestimated. Motor branches of the sciatic nerve have been shown to innervate the long head of the biceps femoris and the semitendinosus as close as 4 cm from the ischial tuberosity and superior gluteal nerve branches lay under the gluteus maximus muscle belly [23]. These areas may be vulnerable to traction or crush neuropraxia. Furthermore, visualization and repair through this deep hole can become grueling. In these cases, a vertical incision either alone or in combination with a horizontal gluteal fold limb can help facilitate exposure. Benefits of endoscopy in patients with large body habitus include no need for large pannus retraction and potentially improved visualization. The disadvantages of endoscopy in these patients, however, should be emphasized. First, triangulation in large patients can become extremely challenging. Second, fluid extravasation can quickly obliterate good visualization. Furthermore, if the case gets converted to open, the resultant boggy tissue will complicate the identification of structures. Third, the surgeon should request longer cannulas in advance, for example, from a hip arthroscopy kit. The tissue expansion as the case progresses can render shorter cannulas unusable. Ultimately, which approach to use rests on the surgeon's judgment. We do not recommend a large body habitus patient as a surgeon's first endoscopic case.

Tear Retraction and Chronicity

Acute tears avulsed off the ischium often have fairly malleable tissue that can be approximated with almost no tension, even when retracted >2 cm. Tears with retraction of less than 2 cm, whether acute or chronic, can be managed reliably with endoscopy. Retraction >2 cm renders acute tears still amenable to fixation using either technique, but the more retracted the tear, the more technically challenging it is to reduce anatomically via endoscopy. These more retracted tears should only be attempted after the surgeon considers themselves facile with endoscopy in the subgluteal area.

Chronic, retracted tears will often have fibrous connections to or encasement of the sciatic nerve. We do not recommend endoscopy in these cases as they require meticulous dissection that is often impractical endoscopically.

Location of Tear

Proximal hamstring avulsions can be treated using either technique but central tendon injuries [24, 25] often occur 10–20 cm from the hamstring origin. These should be treated with an open approach if surgical management is ultimately selected as endoscopic landmarks are distal and hard to find.

Outcomes

There are currently no studies comparing endoscopic to open repair. The initial postoperative restrictions and rehabilitation are typically similar regardless of the technique used as they are contingent on the other characteristics of the tear: chronicity, retraction, repair tension, tendon quality, and patient body habitus. We recommend either a hip brace limiting hip flexion to no more than 30°, or a knee brace limiting knee extension to no more than 60° in the immediate postoperative period. The remainder of the postoperative rehabilitation protocol has been elucidated in the chapters describing open and endoscopic repair techniques.

Cases

Case 1

A 29-year-old female runner presented with chronic left buttock pain that was acutely worsened by a pop. On exam, she had tenderness over the ischial tuberosity, a positive straight leg raise and pain and weakness with heel drag and with resisted flexion at 30° of knee flexion. MRI (Fig. 8.1) showed a mildly retracted full thickness avulsion of the left conjoint tendon. Given her desire to return to running,

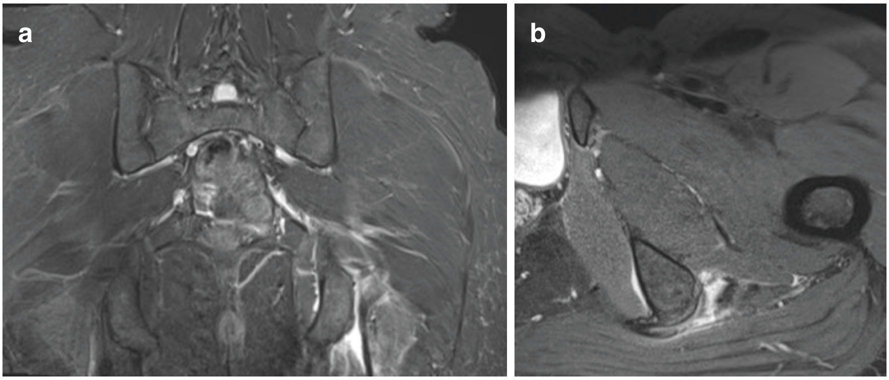

Fig. 8.1 Coronal (**a**) and Axial (**b**) T2-weighted cuts of left hip MR arthrogram showing near complete detachment with 1–2 cm retraction of conjoint tendon

failure of nonoperative treatment, and acute worsening of an already symptomatic area, operative options were discussed.

Management

The case met indications for both endoscopic and open approaches. An open approach was selected. The tendon was identified and two 4.5 mm corkscrew-like anchors were inserted into the ischial tuberosity and used to repair the tendon to the bone.

Case 2

A 55-year-old physical education instructor and active recreational athlete sustained an injury slipping on wet surface. She was treated with physical therapy, activity modification, and NSAIDs for 6 months but continued to have pain and a positive straight leg raise as well as weakness on hamstring flexion at 30°. MRI showed a high-grade partial tear (Fig. 8.2). It was felt that the morphology of the partial tear was amenable to endoscopic repair.

Management

Figure 8.3 illustrates the repair sequence. (a) the bursal side of the tendon appears intact. (b) upon probing, the undersurface can be seen to have avulsed off the ischium. (c) The ischial tuberosity bone is then decorticated with a bur or bone cutter. (d) A tap is used to prepare the suture anchor hole since this bone tends to be quite dense and resistant. (e) The suture anchor is inserted. (f) Two suture anchors are placed and a suture passer is used to pass the suture limbs through the tendon in mattress fashion. (g) The suture limbs are tied, reducing the tendon to the bone.

Figure 8.4 shows an alternative partial repair alternative technique. (a) The sciatic nerve is identified and protected. (b) The superficial tendon still attached to the

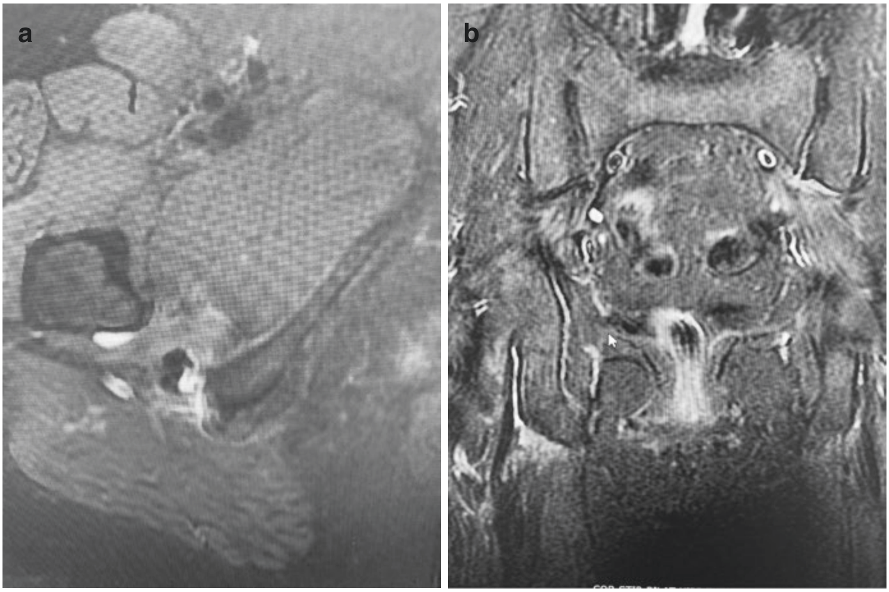

Fig. 8.2 (**a**) Axial T2-weighted MRI image showing near complete avulsion of the conjoint tendon off the ischial tuberosity. (**b**) Coronal T2-weighted MRI image showing near complete avulsion of the right proximal hamstring conjoint tendon off the ischial tuberosity

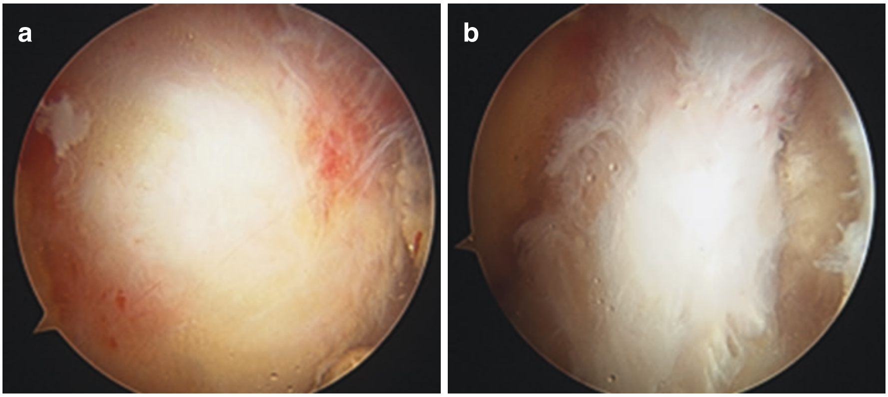

Fig. 8.3 Endoscopic repair sequence

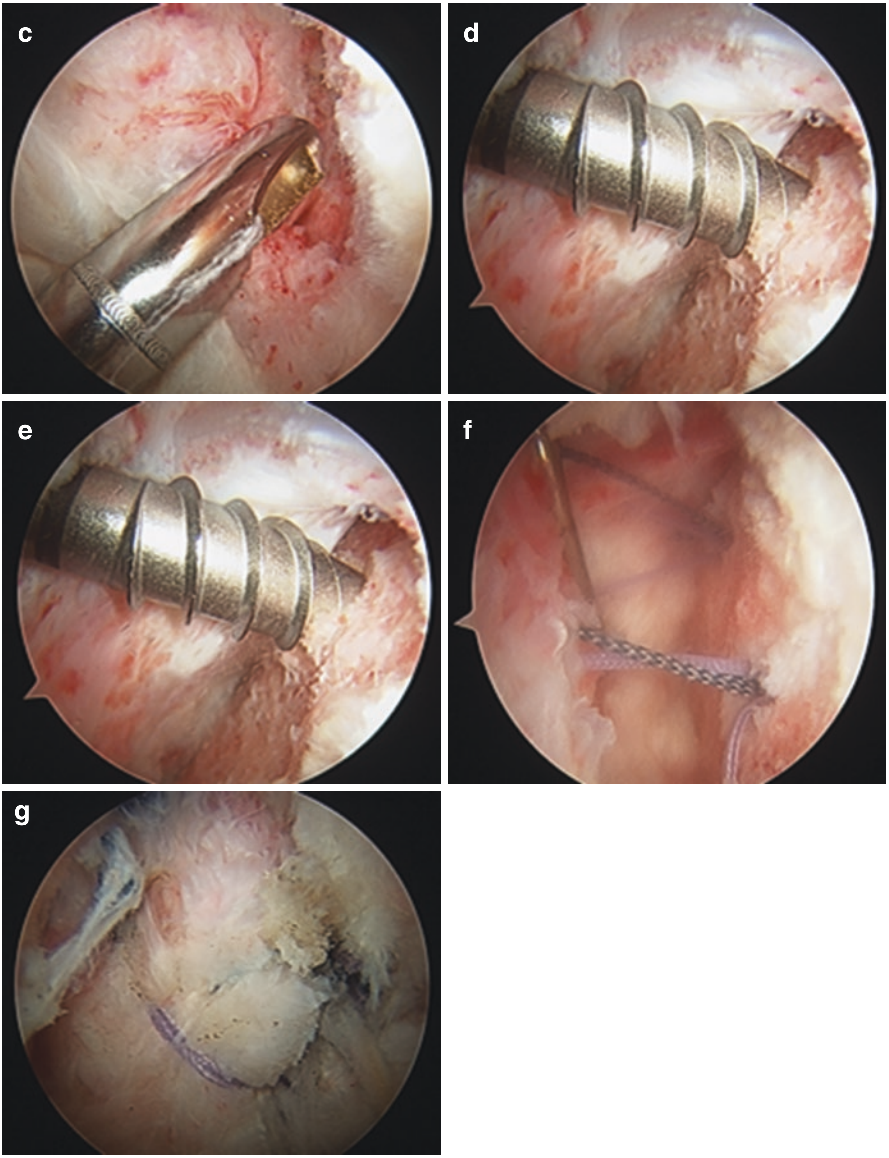

Fig. 8.3 (continued)

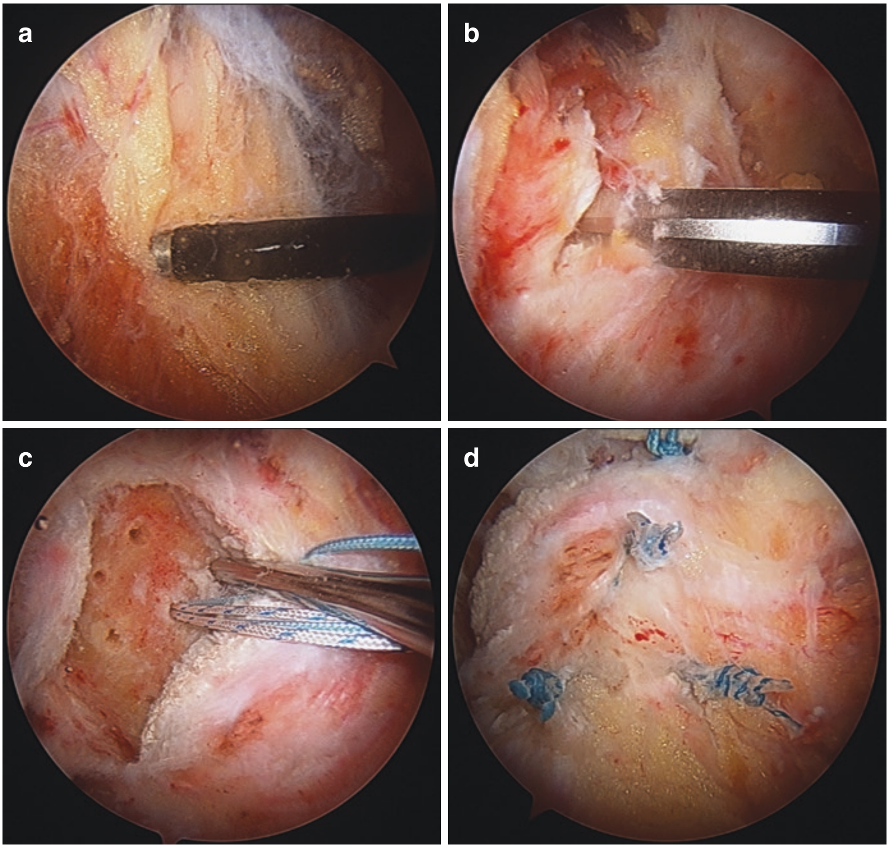

Fig. 8.4 Alternative partial repair alternative technique

bone is divided into line with its fibers. (c) The ischial tuberosity is decorticated and suture anchors are placed in the bone through the split tendon. (d) The tendon is repaired using a double row technique with mattress sutures passed through either tendon leaflet.

Conclusion

Both open and endoscopic management are viable proximal hamstring repair options. Currently, endoscopy is indicated for acute or chronic tears with <2 cm retraction or for partial tears. Open repair is still considered the gold standard, but as endoscopic techniques gain in popularity, we will have to incorporate new data about their medium- and long-term effectiveness. There are technical advantages that may allow endoscopy to eventually supplant open repair in select cases.

Notably, however, endoscopy has a steep learning curve. With rigorous preparation and practice, both techniques can become useful implements in a surgeon's armamentarium.

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Surgical Complications of Proximal Hamstring Tendon Tears

9

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Introduction

Complications associated with the surgical repair of proximal hamstring tears have been reported in academic literature for some time. While relatively rare, these injuries (and their complications) are severe, and operative repair has been utilized by orthopedic surgeons to treat patients for several decades. The largest individual case series of surgically repaired proximal hamstring tears reported a complication rate of 21.2%, similar to the rate of 23.17% reported in the largest systematic review on these injuries [2, 4]. It is important to note however, that both of these studies, and others on the matter, stress the low methodological quality of evidence among most published papers on the subject, as well as the general heterogeneity of complication reporting.

The first case report of surgical repairs of proximal hamstring tears was by Ishikawa et al. in 1988 [10]. However, it was Sallay and Cross who built on prior work and widened our knowledge of the injury, the operative repair, and associated complications with their reports in 1996 and 1998, respectively [7, 18]. Sallay noted that approximately 50% of his patients, all waterskiers, complained of protracted, pain-related complications following surgery, which he attributed to the nature of surgical procedure about the ischial tuberosity [18]. Additionally, Sallay found that only 58% of his cohort was able to return to sport, though it was at a lower level.

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Additionally, only 25% of patients were was able to return to some level of water-skiing, thus highlighting the lasting impact of these injuries and their associated repairs [18].

In the 30 years since the first published report on proximal hamstring tears, there have been a multitude of original scientific reports, systematic reviews, and meta-analyses on the subjects of proximal hamstring tear injuries, treatments, and outcomes. Using these scientific publications as a guide, this chapter will describe the various complications associated with the surgical repair of proximal hamstrings tears, in an effort to better prepare surgeons for what they can expect when treating these patients.

Nonspecific Surgical Complications

Wound-Related Complications

The available literature endorses low rates of wound-related complications (infection, dehiscence, and seroma) following proximal hamstring repairs—the overall rate of these complications is approximately 3.25% [4]. As much of the available literature on proximal hamstring repairs focuses on the management of acute vs. chronic tears, it is worth noting that there is no statistically significant difference in complications between these cohorts overall [4].

A more subtle, though worthwhile, wound-related complication associated with these repairs is peri-incisional numbness. While it is difficult to ascertain the true rate of this complication (as data regarding these rare injuries is generally limited), the largest available systematic review estimates their incidence to be approximately 5.42% [4]. However, it is worth noting that peri-incisional numbness has been reported in up to 61% of patients postoperatively among individual case series [3].

Additionally, there is an isolated report of keloid formation following proximal hamstring repair, and while this should not be cause for concern, it should be noted by all surgeons performing this procedure [13]. Similarly, there is an isolated report of seroma formation following proximal hamstring repair [19].

Repair of proximal hamstring tears is associated with a low rate of wound-related complications. As with any other surgical procedure, there is a low, nonzero risk of infection postoperatively, and the severity of these infections may be limited by regular postoperative communication and patient follow-up.

Deep Venous Thrombosis and Pulmonary Embolus

As with most other orthopedic surgeries, there is a risk of deep vein thrombosis and/or pulmonary embolus following surgical repair of proximal hamstring tears [6, 19]. Fortunately, this surgery has extremely good outcomes with respect to these complications, and there have only been a handful of DVT/PE's reported in the literature.

The rate of occurrence of both pulmonary embolus and deep vein thrombosis has been reported at less than 1% [22].

Additionally, the thromboprophylaxis currently used to mitigate the risk of encountering these postoperative complications may predispose patients to postoperative hematoma formation. There has been at least one reported case of postoperative hematoma formation requiring surgical evacuation [12].

In short, proximal hamstring repairs are associated with low rates of postoperative deep vein thrombosis, pulmonary embolus, and hematoma formation. Despite their rare occurrence, it is imperative that all surgeons conduct a thorough preoperative history and physical exam to further reduce the incidence of these devastating complications.

Specific Proximal Hamstring Complications

Neurological Injury

There are three neurological structures at risk during the surgical repair of proximal hamstring injuries; complications involving these nerves are the most common among all known complications associated with proximal hamstring repair. In the largest published systematic review of open operative repair, Bodendorfer et al. reported neurologic complications in 7.99% of patients [4]. The posterior femoral cutaneous nerve is most at risk during the surgical approach and is associated with numbness over the posterior thigh [14, 20]. Some literature reports a frequency of posterior femoral cutaneous nerve injury as high as 9.6% of patients undergoing proximal hamstring repair [6]. Additionally, the inferior gluteal nerve may be injured during the surgical approach or during the gluteal muscle retraction [14].

The sciatic nerve is at risk during the mobilization and identification of the detached conjoint tendon, which often displays scarring around the sciatic nerve. This scar tissue formation can oftentimes cause the ruptured tendon to develop intertwining adhesions with the nerve itself. Sciatic nerve injury has also been reported during retraction of the ischial tuberosity, owing to its close proximity to this anatomic landmark. Rates of postoperative sciatica are highly variable in the available literature and have ranged from 0% to 17% [3, 11].

The delayed repair of proximal hamstring tears may be a risk factor associated with an increased risk of iatrogenic neurologic injury. One of the larger case series on these injuries, published by Subbu et al., demonstrated a statistically significant association between increased risk of sciatic nerve injury and time from injury to surgical treatment [21].

In conclusion, neurologic injury, especially involving the sciatic nerve, should be an important surgical consideration that must be not be overlooked when planning these procedures. Many orthopedic surgeons utilize neurosurgeons specializing in peripheral nerve dissection and repair to assist them with these procedures [23]. These surgeons can be invaluable in gaining initial surgical exposure and should, in many cases, perform the sciatic neurolysis.

Muscular Complications

Recent systematic reviews have demonstrated a low rate of re-rupture following proximal hamstring repairs [4]. While rates of re-rupture are conservative due to under-reporting, large systematic reviews have concluded that the rate of re-rupture is 2–3% [4, 9]. These re-ruptures, though rare, are devastating for the patient and are generally treated with reoperation [8].

The impact of surgical timing on the rate of re-rupture is a source of some debate in the literature on proximal hamstring repairs. The results of Harris' systematic review concluded that early repair (<4 weeks injury to surgery) was statistically favorable for reducing postoperative re-rupture when compared to delayed (>4 weeks injury to surgery) repair [9]. These results have since been redemonstrated by Subbu et al., with the results of his large case series also demonstrating the superiority (with respect to rates of re-rupture) of acutely managed proximal hamstring tears versus tears managed in a delayed fashion [21].

It should be noted, however, that a more recent systematic review by Van Der Made et al. was unable to arrive at the same conclusion as Harris—finding "no to minimal differences in outcome between acute and delayed repairs" [22]. This sentiment has been echoed in several large case series, making it even harder to understand the differences between these two patient populations [16].

Fortunately, there is a low rate of reoperation associated with the surgical treatment of proximal hamstring tears. Reoperation, most recently reported at 2.57%, is likely due to a multitude of factors [4]. In some cases, reoperation is required following postoperative dislocation of the suture anchors used to secure tendon to the ischial tuberosity [5].

Re-rupture following proximal hamstring repair is a rare but potentially serious complication that can be limited by various interventions throughout the surgical course. Preoperatively, physicians should discuss postoperative rehabilitation with patients to limit this risk. Intra-operatively, it is essential to ensure adequate fixation of suture anchors. Postoperatively, patients must adhere to a strict course of rehabilitation.

Pain and Stiffness

Various reports have described postoperative pain in slightly different terms, making the true incidence of this complication difficult to ascertain. One commonly described type of pain, pain while sitting, is an extremely common complication following surgical repair of these injuries. This pain, which is more than likely due to the incision, tissue trauma, and subsequent scarring over the ischial tuberosity, was reported at 7% in Bodendorfer's systematic review [4]. However, this type of pain has been reported at rates of up to 61% in individual case series [3, 6, 12]. Additionally, available literature suggests that patients who undergo delayed repair of these injuries are statistically more likely to experience postoperative sitting pain than those whose injuries are repaired acutely—likely because of the increased tissue dissection associated with delayed repair [4].

The postoperative experience, from a pain perspective, is further muddied by the predominantly small size of these case series. For example, 48% of patients from a 23-patient series on by Aldridge reported either persistent stiffness or pain while sitting following repair of partially torn proximal hamstrings [1]. Reports by Sallay et al. and Folsom et al. describe "daily postoperative pain as having an 8–20% incidence" [8, 17]. Additionally, other studies have examined the incidence of postoperative pain during activity and reports suggest that activity-induced pain occurs in 17–39% of patients [3, 20].

As previously mentioned, chronic repairs are made more challenging by the increased scar tissue associated with the injury and, oftentimes, the intermingling of the sciatic nerve. These scars are generally associated with a persistent localized pain (hamstring syndrome) about the ischial tuberosity that is exacerbated by repetitive use [15].

Postoperative pain is one of, if not the, the most common complications associated with these injuries and should be discussed at length with the patient perioperatively. Though there is a lack of uniformity in the literature, it is abundantly clear that a substantial portion of patients continue to experience pain long after surgical repair—with any luck, future management may be more successful with respect to limiting this complication.

Complications Related to Endoscopic Management

There is limited available literature on the outcomes, including complications, of endoscopic proximal hamstring repairs (ePHR). To date, there is only one published case series on these injuries, and although there has yet to be a comparative study, this case series suggests that there may be advantages associated with endoscopic repair over the more commonly utilized open approach [11].

Endoscopic repair mitigates the risk of excessive gluteus maximus retraction during dissection and limits disturbance of normal anatomy. This may be a factor in the lower (15.8%) rate of persistent pain while sitting following ePHR [11]. While many of the neurologic complications associated with open repair are inflicted during the approach, the theoretical advantage of endoscopic dissection must be weighed against the fluid pressure (and theoretical risk to the very same structures). This minimally invasive dissection may be a contributing factor as to the 0% rate of both iatrogenic nerve injury and infection associated with literature on ePHR [11].

Another advantage of ePHR is that it affords enhanced visualization of tissues throughout the procedure, which should allow for superior anatomic repair and a theoretically reduced rate of re-rupture, which was reported at 0% among this lone patient cohort [11].

Endoscopic repair represents the latest iteration of an evolving operative toolkit for the treatment of proximal hamstring tears. Though preliminary data on the outcomes of these procedures is promising, it is imperative that further research is conducted on the long-term efficacy of ePHR before it is recommended as the standard of care surgical repair modality.

Conclusion

In conclusion, the various operative repairs of proximal hamstring tears are complex but manageable procedures for many practicing orthopedists. A careful physical examination, combined with a thorough history and associated imaging, should be enough to ensure accurate diagnosis of most proximal hamstring tears. Fortunately, operative repair of these injuries is associated with a limited, and specific, set of postoperative complications such as postoperative sciatica, pain, and re-rupture. It is imperative that surgeons discuss the differences between acute and chronic tears, as these injuries each present their unique sets of challenges to caregivers. All surgeons should remain mindful of complications while discussing their treatment plan, and its associated risks, with their patients.

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Biological Treatment of Proximal Hamstring Tendon Tears

10

David Kirby

Introduction

Hamstring injuries account for about 30% of all sports-related injuries and can be difficult to treat [1]. Unfortunately, these injuries often develop into chronic conditions with high rates of reinjury [1, 2]. Identifying the injury early and implementing a proper treatment are key to improving outcomes. Studies on the surgical repair of hamstring tendon tears have demonstrated encouraging results, with improved strength, improved patient satisfaction, and decreased pain when compared to nonoperative management [3]. However, surgery is not without risks and open repair of proximal hamstring tears is associated with a high complication rate [4]. Additionally, chronic tendon repairs have not demonstrated the same robust outcomes [4]. This leads to an increased need for nonoperative treatment options targeted at patients who do not make for good operative candidates.

Nonoperative management is limited to partial tendon tears with minimal tendon retraction. As increased retraction has been associated with poorer outcomes, a 2 cm cutoff has been proposed as the indication for nonoperative treatment [5]. Clinicians should make patients aware that even with optimal nonsurgical treatment of proximal tendon tears <2 cm, 40% of patients will require future repair [6]. Given this high rate of progression, every effort should be made to optimize treatment if nonoperative management is chosen. Biological enhancement of tendon healing has demonstrated encouraging early results as an adjunct to nonoperative management in partial proximal tendon tear. Platelet-rich plasma (PRP) is the most well-studied and widely implemented biologic used in proximal tendon tears, however, other biologics have also shown promise.

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Basic Science of Tendon Healing

Biologics have been suggested as a way to enhance the endogenous tendon healing process that occurs naturally. This is in an effort to decrease healing time and improve tendon strength. Tendon healing occurs in a concerted set of stages that can take 1–2 years to complete. The first phase is the inflammatory stage. The initial injury will create localized tissue bleeding via the damaged vessels and capillary beds. The exposed tissue basement membrane will start the clotting cascade through platelet activation. This will result in hematoma clot formation and produce inflammatory cytokines to attract the cellular components of the innate immune system (neutrophils, macrophages, monocytes) to the site of injury. These cells work to remove local damaged tissue and will secondarilly recruit fibroblast and activate regenerative cells. Secreted angiogenic factors will stimulate an ingrowth of new blood vessels into the forming clot, which will further assist in the cellular emmigration. The recruited fibroblasts tip off the next phase of the repair, which is the proliferation phase. During this phase, fibroblasts create an extracellular matrix rich in collagen, predominantly type III. Much of the activity up until this point has been driven by the catabolic inflammatory response which actually weakens the tendon initially. The tendon strength will start to increase as the fibroblast produces the extracellar matrix. The proliferation phase typically lasts about 6–8 weeks, after which tendon strength will be near its maximum. The next phase is remodeling, which has consolidation and maturation subphases. During the consolidation phase, the extracellular matrix, which is predominantly type III collagen at this point, is converted to type I collagen. Finally, at around 3 months, the maturation stage of the remodeling phase will begin with collagen fibers remodeling to align with the length of the tendon [7].

Each of the phases of tendon healing are accompanied by influxes of proteins that modulate cellular activity. The initial phase is driven predominantly by inflammatory factors that are essential for attracting the initial cellular infiltrate and stimulating the process of angiogenesis. Too vigorous of an inflammatory response has been associated with excessive fibrous tissue formation which has been shown to inhibit overall tendon healing [2]. In addition to the inflammatory cascade, a host of local factors are produced that stimulate mesenchymal stromal cell differentiation, tenocyte proliferation, fibroblast proliferation, and extracellular matrix production. Some notable factors are fibroblast growth factor (FGF), bone morphogenic protein (BMP) 12–14, vascular endothelial growth factor (VEGF), transforming growth factor beta (TGF-β), epidermal growth factor (EGF), insulin-like growth factor (IGF), and platelet-derived growth factor (PDGF) [7]. Given their involvement in the healing process, these factors provide an attractive target for nonoperative therapy.

Platelet-Rich Plasma

Platelet-rich plasma (PRP) has been proposed as an augment for wound healing since the 1980s [8]. PRP is a therapy derived from one's own blood with contents, which are separated based on density via centrifugation to create the platelet concentrate. This separation creates a layer that is enriched in platelet content with relatively decreased amounts of other cell types. The platelets secrete a host of factors that make the PRP layer rich with growth hormones. Specifically, PRP contains increased amounts of vascular endothelial growth factor (VEGF), transforming growth factor beta (TGF-β), epidermal growth factor (EGF), insulin-like growth factor (IGF), and platelet-derived growth factor (PDGF). These proteins facilitate healing through chemotaxis of cells to the injury site, neoangiogenesis, directing cellular proliferation, increasing matrix formation, and promoting collagen synthesis [9–12]. Additionally, the cytokines in PRP have been shown to stimulate tenocyte proliferation and collagen production and may dampen the formation of fibrous scar tissue [13]. This is important as one of the key factors associated with recurrent injury is the presence of extensive scar tissue [2]. Although PRP does not contain stem cells, it has been shown to attract and stimulate the stem cells in surrounding tissue which may further benefit tendon healing [14–16].

The platelets in PRP provide the metabolically active components responsible for wound healing; however, they need to be activated to degranulate these contents. In the body, platelets become active when exposed to collagen in the basement membrane of injured blood vessels. In vitro, calcium and thrombin are added to the PRP mixture, which maximizes the extrusion of growth factors. In addition to growth factors, platelet granules contain large amounts of adenosine, serotonin, and histamine which have all been shown to modulate and support the initial local immune response [17–19]. The contents of all granules are released within an hour of activation, with low levels of growth factors continued to be produced by the remnant platelets [20].

There is a large heterogeneity between PRP separation systems regarding concentrations of platelets, leukocytes, and growth factors in PRP [21]. Notably, PRP samples can vary significantly on platelet concentration, which is directly correlated to the concentration of growth factors present in the sample. Clinicians have recommended that PRP samples should have a concentration of platelets five times that of endogenous blood content [22].

Platelet-rich plasma (PRP) has shown encouraging results for the treatment of tendon tears. Animal models have demonstrated that PRP enhances the initial tendon-to-bone remodeling and benefits overall healing. In a study by Hapa et al., a rat model of rotator cuff tears revealed decreased initial inflammation and improved 2 week tendon continuity and tendon strength with PRP injection when compared to saline injection [23]. In another animal study in rats, patellar tendon injuries supplemented with PRP recruited more circulation-derived cells and had increased collagen I and III production relative to control [24]. Preclinical trials in humans have also indicated the potential therapeutic benefits of PRP. In the presence of PRP, human tenocytes demonstrate increased cellular proliferation and collagen production [25].

Human clinical studies have not demonstrated the same homogenous results as in vitro studies. A systematic review on the use of PRP in sports medicine by Filardo et al. exemplified this lack of consensus among the various injuries. In their review they found that while PRP may be beneficial in certain cases, such as patellar tendonopathy and lateral elbow tendinopathy, other studies involving PRP fail to show superiority over other conservative treatment options [26]. The data from multiple meta analyses of PRP treatment in human rotator cuffs also demonstrated ambiguous results, specifically in relation to pain outcomes and function [12, 27, 28]. Interestingly, these studies revealed that PRP may have an impact on retear rates. When retear rates were evaluated for all patients treated with PRP, no significant difference was found compared to control [12]. However, when tears were subdivided based upon size, PRP reduced the risk of re-tear by 40% in patients with tears ≤3 cm [27, 28]. A randomized controlled trial more recent than Filardo's meta-analysis evaluated PRP injections in Achilles tendinopathy and found that patients treated with PRP have significantly improved Victorian Institute of Sports Assessment-Achilles (VISA-A) and visual analog pain scale (VAS) scores and have reduced tendon thickness relative to placebo. However, in the same study, a cohort receiving a steroid base injection had a more significant improvement in all measurements relative to PRP treatment [29].

Hamstring proximal tendon tears have been on particular focus for the utilization for PRP. The biological rationale supporting the use of PRP and the strong demand for a nonoperative treatment option for hamstring injuries has catalyzed the widespread use of PRP clinically. Although early preclinical trials have supported this use, more recent trials in humans have not been as clear. To date, there have been five clinical trials published on the use of PRP in proximal hamstring tendon tears (Table 10.1). Of the five studies, one was a case series, three were cohort studies, and one was a randomized controlled trial [30–34].

The first study was published in 2013 by Wetzel et al. This retrospective cohort study included 15 patients with 17 hips and compared patients treated with leukocyte-rich PRP to patients treated conservatively with physical therapy. Both groups experienced significant improvements in visual analog score (VAS) and Nirschl Phase Rating Scale (NPRS) score at 4.5 months; however, no differences were noted between PRP and conservative treatment. One significant limitation of the study was that the control group consisted of patients who successfully responded to physical therapy without the need for further treatment, while the PRP treatment group relied on patients who had failed physical therapy and conservative measures [30].

Fader et al. published on a series of 18 patients treated with ultrasound guided leukocyte-poor PRP injection who had failed conservative therapy and found a 63% improvement in VAS [31]. Davenport et al. published the highest level study in 2015 in a randomized controlled trial of 17 patients (19 hips) with grade I-II tendon tears who had failed 6 weeks of conservative treatment. This study compared leukocyte-rich PRP injections to whole blood injection. While both whole blood and PRP demonstrated improved outcomes, only PRP had significantly improved ADL and IHOT-33 scores at 6 months [34]. Levy et al. evaluated the impact of tendon tear severity on outcomes. In patients who with chronic tendon tears, they found no statistically significant outcome differences in overall pre- vs post-injection scores or between the different injury severities [32].

More recently, and with the largest study to date, Park et al. evaluated 56 patients with grade II proximal tendon tears, comparing leukocyte-poor PRP injection to

Table 10.1 Details of published studies of PRP treatment of chronic proximal hamstring tendon tears

Date	Study type	No. of patients	Avg. age at injection (years)	Variable	PRP volume (mL)	US guidance	Mean follow-up	Outcomes
2013	Cohort study	15 patients (17 hips)	37.1 (PRP)/42.8 (no injection)	Leukocyte-rich PRP vs conservative therapy	6	N	4.5 months	Significant improvement in VAS and NPRS score of both treatment groups; no difference in outcomes between groups, although there was trend for improvement in the PRP-treated group
2015	Case series	18 patients	42.6	Leukocyte-poor PRP	2.5–4	Y	6 months	63% improvement in VAS
2015	RCT	17 patients (19 hips)	46.6 (PRP)/45.4 (WB)	Leukocyte- rich PRP vs whole blood	3	Y	6 months	PRP had significantly improved ADL and IHOT-33 scores at 6 months, while WB had no significant improvement; no difference in ultrasound appearance was seen
2019	Cohort study	29 patients	45.2	Tear severity	6	Y	2 months	No statistically significant outcome difference in overall pre- vs post-injection scores or between the different injury severities
2019	Cohort study	56 patients	34.4 (PRP)/49.7 (no injection)	PRP vs corticosteroid	2–5	Y	4 weeks	At week 1, PRP demonstrated a significantly improved VAS over corticosteroid; at 4 weeks, the PRP group still reported a greater improvement in VAS, although this was not significant

corticosteroid injection. At first week, PRP demonstrated a significant improvement in VAS over corticosteroid injection. In the PRP group, 71.9% reported an improvement of 2 or greater in VAS while 45.8% reported the same improvement in the corticosteroid group. At 4 weeks, the PRP group still reported a greater improvement in VAS, although this was not significant [33]. More high-quality studies are needed on PRP injections in proximal hamstring injury before a consensus can be declared, but there does appear to be a trend for improvement in pain and function. As the studies are largely in patients who have failed conservative therapy, PRP is a good option for patients with chronic tendinopathy who are not surgical candidates but whom have failed other conservative options. Additionally, PRP may provide better short-term outcomes that corticosteroid options. Looking toward outcomes in other tendon types, PRP also appears to positively impact retear rates, but this remains to be evaluated in hamstring tendon injuries.

Other Injected Biologics

A host of injectable biologics have been proposed that take advantage of the native tendon healing process. Just as with PRP, these agents seek to improve certain aspects tendon repair to speed recovery and improve outcomes. The scientific support for the majority of these is preclinical but promising:

- Bone marrow aspirate concentrate (BMAC): BMAC is produced by aspirating a marrow containing cavity and concentrating the cells via centrifugation. The end product is rich in platelets and mesenchymal stem cells (MSCs). The stem cells provide potential pluripotent cells to aid in tissue regeneration but also act as trophic producing agents which can stimulate local tissue healing. Preclinical trials in rabbits that underwent repair after iatrogenic rotator cuff tendon tear demonstrate that BMAC injections increase tendon repair load-to-failure and have improved collagen fiber formation and orientation [35]. Kim et al. performed a randomized controlled trial evaluating how BMAC injections (in conjuncture with PRP) impacted rotator cuff healing and found that BMAC injection significantly improved patient reported pain and function at 3 months [36]. A recent study out of New York University reported on a series of patients who underwent ultrasound guided BMAC injection for hamstring origin tendinosis. Three months after a single PRP injection, four of five patients reported symptomatic improvement [37].
- Hyaluronic acid (HA): HA is a high-molecular-weight glycosaminoglycan that is highly expressed in cartilage, ligaments, and tendons. Side chains on the molecule attract and bind water, making the molecule a useful biologic lubricant and structural component. HA creates an environment that facilitates cellular migration and has been suggested to promote cellular proliferation [38, 39]. In an animal model of tendon-bone healing, HA increased the maximum failure load after anterior cruciate ligament (ACL) reconstruction with histology confirming improved tendon healing [40].

- Insulin-like growth factor 1 (IGF-1): IGF-1 has proven to be a powerful chemotactic and mitogen for fibroblasts and tenocytes, increasing collagen formation [41]. It has been studied in animal models with intriguing results for muscle injury repair. In an animal model of severe hamstring tear, IGF-1 gene transfer therapy, which increases the local expression of IGF-1, resulted in larger muscle fibers and improved muscle action potentials relative to systemic therapy [42] and has been found to be significantly elevated in tendon healing [43].

Authors' Preferred Treatment

Patients with grade I–II proximal tendon tears who have failed conservative therapy can benefit from a trial of injectable biologic therapy. Our preferred agent is leukocyte- poor PRP. To prepare PRP, peripheral blood is harvested and is then centrifuged to separate the contents. The top clear layer is plasma, the middle layer is the buffy coat and contains white blood cells and platelets, and the bottom layer is the erythrocyte layer (Fig. 10.1). The buffy coat layer can be further centrifuged

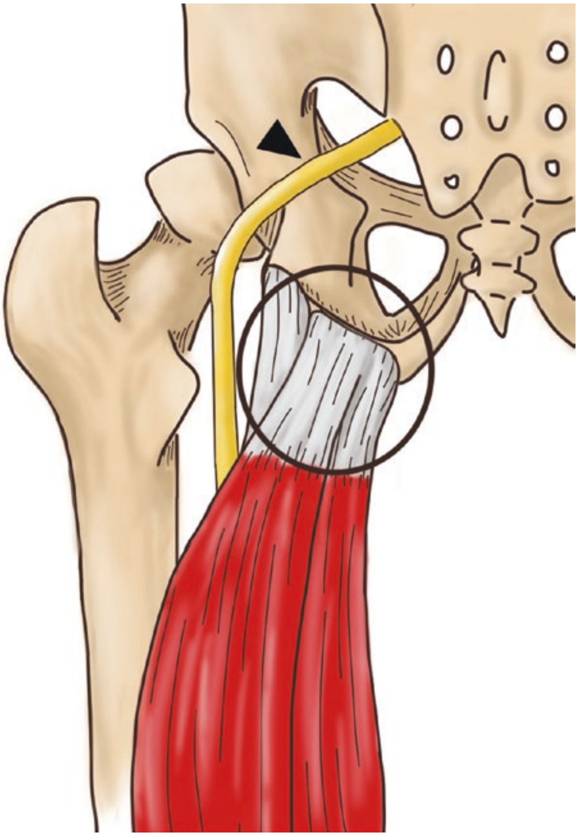

Fig. 10.1 Fractionated blood components. Blood separated by centrifugation results in a top layer of platelet-poor plasma, a middle layer (buffy layer) from which PRP is derived, and a bottom layer of packed red blood cells

to separate the platelets from the white blood cells to form PRP. This typically yields 10% of the initial blood volume (i.e., 50 mL of blood will result in 5 mL of PRP). Citrate is used as an anticoagulant and as a sink for calcium ions. Calcium is a trigger for activating platelets and if not chelated will result in premature degranulation. PRP is stable for up to 8 hours in this state. PRP can be administered in this state without further preparation, but this depends upon local tissue factors to activate the platelets. This also means that PRP will be in fluid-like state when injected, which can disperse from the intended site. Alternatively, the PRP sample can be activated by mixing with calcium chloride and thrombin. The platelets will then begin to form clot and will degranulate a majority of the factor containing α-granules within 10 minutes [20, 22]. As the clot forms, the viscosity of the sample will increase which contains the aliquot to the injury site upon injection. This is the author's preferred method. If platelet preactivation is chosen, the clinician must perform the injection within 10 minutes of mixing [22]. A brief technique guide is described below.

Equipment

- PRP preparation:
  - Peripheral blood collection kit
  - 18–20 gauge needles
  - 10 mL syringes
  - Commercial PRP preparation system
  - Blood collection tubes with acid citrate dextrose anticoagulant
  - Thrombin/calcium mix (1000 units of thrombin with 10% calcium chloride per mL, mixed with PRP at a 1:10 ratio for activation)
- PRP administration:
  - Ultrasound machine
  - 6–10 MHz linear transducer – lower frequency for obese or muscular patients
  - 22-gauge needle (local anesthetic administration)
  - Lidocaine hydrochloride (or preferred local anesthetic)
  - 20-gauge 3.5 inch spinal needle (PRP administration)

Positioning and Technique

- The patient is positioned prone with the feet hanging off the edge of the table. Of note, the PRP should be prepared prior to positioning.
- After the patient is positioned, the injection site should be cleaned and prepped. Lidocaine is injected locally in the subcutaneous tissues. A sterile technique is used throughout the procedure with a sterile transducer cover and sterile gel.
- The PRP sample can then be mixed with the thrombin/calcium mixture for activation.

- Using a 20-gauge spinal needle, the proximal hamstring tendon is injected under direct ultrasound visualization. The needle tip should always be visualized before advancement. To accomplish the injection, the ischial tuberosity is first identified on US, which helps with identification of the common tendon origin. Both long and short axes are used to confirm anatomy. The sciatic nerve will be seen just lateral to this structure (Fig. 10.2). Tendinosis and intrasubstance tears will

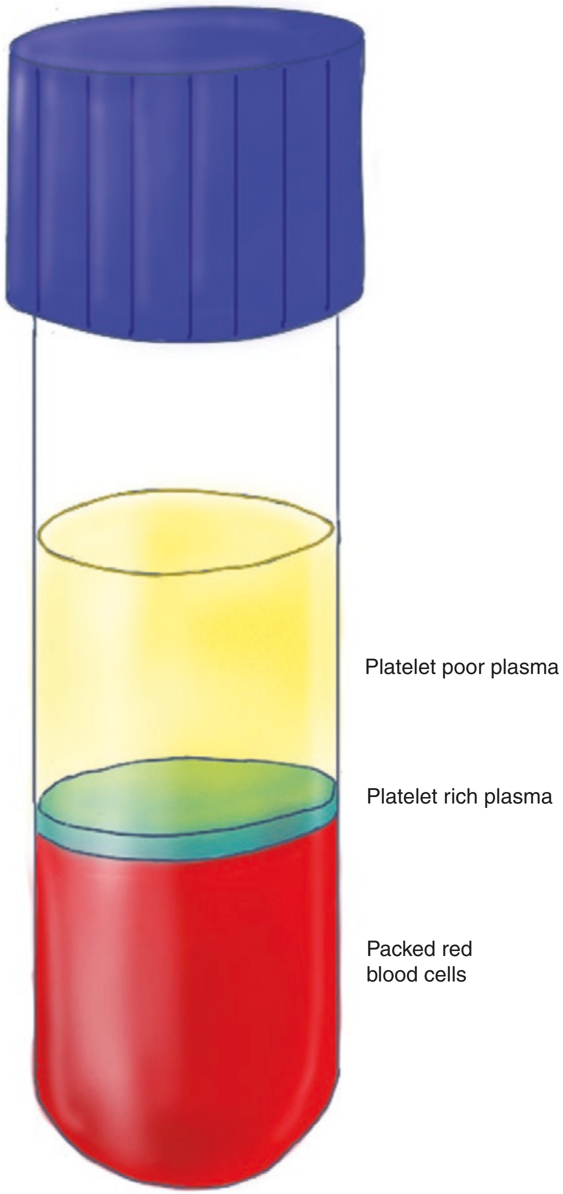

Fig. 10.2 Illustration demonstrating proximal hamstring anatomy pertinent to intratendinous injection. The proximal hamstring tendon originates at the ischial tuberosity (black circle) and is the target for the injection. The sciatic nerve (black arrow) courses just lateral to the tendon at this level

appear as hypoechoic areas on US, aiding in targeting administration. Use of the sagittal plane is recommended for the approach as this minimizes the risk of encountering the sciatic nerve. The PRP is then injected intratendinously under direct visualization.
- The technique outline is described for the administration of PRP, however, it can be adapted for any locally injected agents.

Risks and Complications

- Risks of injection site pain, infection, and bleeding should be discussed with the patient. Additionally, the risk for allergic reaction should be considered and monitored.
- The sciatic nerve courses near the origin of the hamstring. To avoid injury, the nerve should be visualized on ultrasound to insure it is not violated by the needle on injection.

Conclusion

Proximal hamstring tendon injuries are common in athletes and can be difficult to manage. Nonsurgical treatment options currently focus on complex physical therapy regimens, but biologics are becoming an evolving field to augment tendon healing. Early preclinical studies have demonstrated that PRP and other biologics improve the normal tendon healing process. In clinical studies, these effects have translated into a trend for improved pain and function during recovery from partial tendon tears; however, higher–quality studies are required to define the true impact.

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Rehabilitation After Surgery for Proximal Hamstring Tendon Tears

11

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Principles of Rehabilitation

The principles of rehabilitation following proximal hamstring tendon repair have not changed significantly in recent years. While it is important to perform the repair with precision, equal care must be taken to strengthen the hamstring muscles and prevent adhesions, all while preserving the integrity of the repair. A good rehabilitation program is critical for restoring form and function and giving the patient the best possible chance of returning to his/her pre-injury level of activity. This is especially important following a hamstring injury, as these have been associated with extensive rehabilitation timelines. The myotendinous junction of the hamstring muscle is the most vulnerable portion for injury, with more proximal injuries being associated with longer times to return to sport activity [4, 34]. Following injury, competitive runners require 16 weeks, on average, to return to sport without restriction, while dancers may require up to 50 weeks, thus highlighting the importance of a well-structured rehabilitation protocol [8, 19, 22, 35].

A patient's rehabilitation protocol begins pre-operatively when the patient and surgeon discuss the operative, peri-operative, and postoperative courses. During this time, the surgeon must answer the patient's questions and, more importantly, ensure that the patient's expectations are reasonable and achievable. Expectations should not only encompass the patient's ultimate surgical outcome but also their expected time for rehabilitation and the surgeon's clinical opinion on the patient's risk of retearing the tendon. In the past, athletes have reported marked frustration with hamstring injuries as they are correlated with long rehabilitation periods, unpredictable rates of return to pre-injury level of sports, and have a higher-than-desired tendency to recur [1, 8].

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The main goals of postoperative rehabilitation should be to protect the site of repair during its healing process, ensure restoration of function, prevent the recurrence of symptoms, and control the patient's pain. While these basic principles of rehabilitation can be generalized among all patients having a torn hamstring tendon repaired, the approach to rehabilitating a young, active patient with healthy tendon and strong bones should differ from that of an older patient with weaker tissue integrity and lower levels of activity. Thus, each patient's rehabilitation should be approached in an individualized fashion.

Multiple postoperative adjunctive therapies, such as bracing, cryotherapy, and neuromuscular electric stimulation (NMES), have been cited throughout literature to assist in rehabilitation and augment the healing process. Postoperative bracing involves a precisely fitted apparatus that limits joint range of motion (ROM) in order to minimize pain, improve recovery, and prevent further injury. Cryotherapy involves the utilization of low temperatures to provide anti-inflammatory and analgesic effects to a localized region [27]. NMES involves the application of electric currents to neuromuscular tissue to elicit a muscle contraction, with the goal of strengthening muscles through repetitive contractions [26]. A cross-sectional study of postoperative rehabilitation protocols following hamstring tendon repair by Lightsey et al. found that the majority of protocols (71%) suggested immediate postoperative bracing of the hip and/or knee [23]. Of those recommending hip bracing, 53% of protocols suggested limiting hip flexion to 45°, with the mean time to discontinuation being 6.0 weeks; similarly, of those recommending knee bracing, 64% of protocols recommended keeping the knee locked at 90° flexion, with the mean time to discontinuation being 5.5 weeks. A lower, but substantial proportion of studies from the cross-sectional study recommended cryotherapy (54%) and NMES (20%) [23].

Progression of a patient's ROM and weight-bearing (WB) status are also important factors to consider in their rehabilitation process. While initial immobilization postoperatively is theorized to accelerate granulation tissue formation, early resumption of range of motion is essential for promoting collagen penetration and orientation of the regenerating muscle fibers, promoting muscle strength, preventing atrophy, resorbing scar tissue, and reperfusing damaged tissue [10, 18, 21, 23]. There is currently limited and variable data in literature outlining specific postoperative ROM milestones for proximal hamstring tears, but the majority of available protocols recommend early, gentle passive ROM at a mean of 1.4 weeks, and active ROM at a mean of 4.0 weeks [23]. A patient's WB status postoperatively is equally important as WB can cause muscle activation and lengthening, which can compromise the integrity of the repair. Thus, it comes as no surprise that the majority of available protocols online suggest either non-WB or "toe-touch" WB with crutches in the immediate postoperative period, with mean resumption of WB reported at 7.1 weeks [23]. These findings are in agreement with data from scientific literature, with non-WB status recommendations ranging from 4 to 8 weeks or toe-touch WB status recommendations ranging from 2 to 6 weeks [3, 6, 9, 11, 20, 24, 30].

Hamstring stretching, while present in a number of protocols for nonoperative management of low-grade hamstring tears, is a point of debate among postoperative protocols. Although the cross-sectional study by Lightsey et al. found that nearly half of all protocols found online recommended initiation of hamstring-specific stretches at a mean of 10.1 weeks postoperatively, numerous studies found in literature either have no recommendation or explicitly recommend against performing hamstring stretches [3, 15, 23, 30]. The latter group stated that hamstring stretches were avoided in an effort to prevent elongation of repair tissue. Ultimately, evidence to strongly support or refute stretching the hamstring muscle during postoperative rehabilitation is currently lacking, and thus should be further studied.

Following return of complete ROM and full WB status, goals of rehabilitation then transition to restoring normal gait and regaining hamstring strength. Prolonged periods of immobilization early on in rehabilitation can lead to atrophy of the operative hamstring muscle. This, in conjunction with the compensatory load taken on by the contralateral limb, creates an imbalance that can manifest as an altered gait. It is vital to regain strength in the operative limb as it not only allows for restoration of a normal gait but can also be protective against reinjury of the ipsilateral proximal hamstring [12, 17]. While eccentric strength training is emphasized in rehabilitation of the hamstring, a common criticism of these protocols is a lack of attention paid to musculature adjacent to the hamstrings [17]. Adequate neuromuscular control of the lumbopelvic region has been implicated in achieving optimal control of the hamstrings during athletic activities [25]. While literature involving postoperative rehabilitation is limited, studies on nonoperative management of proximal hamstring injuries have found significant reduction in injury recurrence when eccentric strength training was combined with exercises focused on trunk stabilization [31].

Similar to strength training, it is vital to ensure that patients regain their proprioceptive sense of the operative limb. Not only is proprioception important in allowing the patient to perform activities of daily living and/or athletic activities but it is also essential in giving the patient the best possible chance of preventing recurrence of injury. Exercises that are commonly used to optimize proprioceptive sense include weight shifting, single-leg balance, impact control exercises, balance board, advanced proprioception [23].

It is important to note that the above discussion applies solely to rehabilitation following open proximal hamstring repair. In recent years, this procedure has been achieved using an endoscopic approach, which has separate rehabilitation considerations [13, 14].

While it comes as no surprise that neglected proximal hamstring ruptures can lead to significant functional impairment, appropriate surgical intervention with extensive rehabilitation should allow patients to return to their pre-injury level of activity [10, 23, 33]. However, there is currently a lack of high-quality evidence to support object guidelines or criteria for an athlete safe return to play and remains an important area for future research. Based on current literature, athletes should at least be able to perform functional, sports-specific skills (e.g., dribbling, running, jumping) at full speed without complaining of stiffness or pain prior to being cleared for resumption of their sporting activities without restriction [17, 25, 29, 36]. Athletes should also have their strength assessed using maximal-effort knee flexion tests, using both eccentric and concentric motions, to ensure they are pain free and have less than a 10% deficit when compared to the nonoperative limb. Flexibility should similarly be compared to the contralateral limb, ensuring similar ranges of motion without complaints of pain or stiffness.

Suggested Postoperative Protocol

Below is a proposed guide to the rehabilitation of proximal hamstring tears requiring surgical intervention, based on our institution's experience. The protocol is broadly grouped into three phases: phase I (0–6 weeks), phase II (6–8 weeks), and phase III (8–12+ weeks).

Phase I begins immediately postoperatively, where the patient is placed into a hip range of motion brace locked at 0°. The goals of this phase are to protect surgical repair while carefully resuming full ROM. The patient's brace is gradually advanced in 30° increments until full range of motion is achieved. The patient is maintained in non-weight-bearing status for at least 4 weeks and is then progressed to ambulation as tolerated. Additional precautions during this time include no active hamstring contraction, no hip flexion greater than 45°, and potentially limited knee extension depending on the intraoperative tension of the repair. Early exercises include transfer training, heel props, and quad sets. The surgeon may suggest cryotherapy for pain and swelling control, light desensitization massages for the incision and posterior hip, and/or scar massages to the patient if it is deemed appropriate.

Phase II is implemented between weeks 6–8, in which full range of motion is allowed as tolerated. The goals of this phase are to restore normal gait and the ability to perform activities of daily living in a pain-free and functional manner. The patient is allowed to progress to normal weight bearing and ambulation. Additional precautions during this time include monitoring for tenderness around the surgical site and minimizing any hamstring stretching exercises to avoid premature lengthening of the repair. Exercises such as light supine and seated hamstring strengthening (beginning at 0 lbs and progressing in 1 lb increments as tolerated while pain free) are initiated. Other therapeutic exercises include heel raises, quadricep sets, short arc squats, and single leg balance may also be employed.

Phase III is implemented between weeks 8 and 12, in which prone hamstring exercises (e.g., low weight hamstring curls) and non-impact aerobic conditioning (e.g., stationary bike, elliptical, aquatic therapy) are begun. The goal of this phase is to achieve pain-free performance of non-impact aerobic activities and unrestricted activities of daily living at home or work. Precautions to be taken during this time include monitoring for hamstring flexibility and tenderness of the surgical site. Finally, between weeks 12 and 16, patients begin a gentle hamstring stretching protocol until range of motion is symmetric. The patient is allowed to progress back to their normal activity and return to pre-injury level of activity as long as they are pain-free.

Outcomes Following Rehabilitation

While the primary objection of rehabilitation is to ensure patients can return to their prior level of activity, the high rates of reinjury have led to speculation surrounding the appropriateness of currently employed rehabilitation strategies [17]. A variety of factors can dictate how a patient should follow their procedure and rehabilitation protocol. These factors can be subdivided into categories such as character of the injury, postoperative complications, and post-rehabilitation deficits that may increase the risk of reinjury. It is the duty of the surgeon and physical therapist to be mindful of these as accounting from them early can maximize the patient's chances of returning to their pre-injury level of activity.

A hamstring injury can be categorized in many ways: these included (but are not limited to) the extent of the tear, chronicity of the tear, presence of an avulsion injury, presence of concomitant injuries, and/or characterization as a primary or recurrent tear. Depending on the characterization of the injury, surgical technique and extent of postoperative rehabilitation can vary significantly, and thus dictate long-term outcomes. For instance, a systematic review by Harris et al. found that surgical repair of acute proximal hamstring tears resulting in significantly better subjective outcomes, greater rate of return to pre-injury level of sport, and greater strength/endurance than non-surgical management [16]. Similarly, another study by Pombo et al. noted that proximal hamstring injuries with avulsions should be categorized as a distinct type of injury, given that they tend to have greater delays in returning to activity while also possibly having long-lasting functional impairments [28]. It has also been noted in the literature that the history of ipsilateral hamstring injuries is the most common risk factor for reinjury [2, 7, 22, 37].

A patient's postoperative complications can also be an important factor in dictating their rehabilitation protocol as well as their risk of reinjury. Minor postoperative complications can include (but are not limited to) minor wound infections, hematoma formation, arthrofibrosis, continued paresthesia at the surgical site, cramping, or pain; major complications can include (but are not limited to) wound dehiscence, major infection, or retear [5]. Presence of these complications can create delays in a patient's rehabilitation timeline and may even require reoperation. This may hinder patients from achieving important rehabilitation milestones, which can ultimately result in long-term function deficits.

Finally, post-rehabilitation deficits play an obvious role in long-term outcomes following surgical repair. As mentioned earlier, the goals of rehabilitation are to protect the site of repair during its healing process, ensure restoration of function, prevent the recurrence of symptoms, and control the patient's pain. These are achieved through various adjunctive therapies and exercises. However, utilization of improper rehabilitation techniques that lead to deficit can lead to issues such as persistent muscle atrophy, immature proprioceptive sense, and thus a higher risk of reinjury and poorer long-term outcomes. A study by Heiderscheit et al. listed several factors that contribute to a high rate of reinjury—persistent weakness of the injured muscle, reduced extensibility of the musculotendon unit due to residual scar tissue, and changes in the motor and biomechanical patterns of agile movements [17]. Similarly, a study by Valle et al. mentioned various potential maladaptations associated with initial hamstring injuries that can predispose patients to reinjury, namely, scar tissue formation, reduced flexibility, strength deficits, selective hamstring atrophy, and shifts in the torque–joint angle relationship [32].

Conclusion

Hamstring injuries are common, especially among athletes, and have a high rate of recurrence. In order to allow patients to have the best chance of returning, focus must be placed not only on the operative stage but also on their postoperative rehabilitation. Guidelines for rehabilitation must be adapted to each patient and the characterization of their tear in order to optimize their outcomes. The main goals of postoperative rehabilitation should be to protect the site of repair during its healing process, ensure restoration of function, prevent the recurrence of symptoms, and control the patient's pain.

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12 Proximal Hamstring Injury Rehabilitation and Injury Prevention

Jordan W. Fried, Graeme Whyte, and Thomas Youm

Introduction

Return-to-play and return to pre-injury status are extremely important to athletes. For patients who qualify for nonoperative treatment, a rehabilitation protocol must be structured appropriately to prevent delayed healing or reinjury. In some instances, patients do not heal at the rate that is expected and may require a second opinion and surgical consideration. To fully understand nonoperative rehabilitation, identifying risk factors and preventive measures for proximal hamstring injuries will have a significant impact on the return to activity.

Risk Factors

Injury prevention requires recognition and understanding of both modifiable and non-modifiable risk factors. Few studies have reviewed potential causes and predisposed states that put an individual at risk for an injury to the proximal hamstring. Older age, genetics, and variance in anatomy are some of the more common non-modifiable risk factors for all hamstring injuries [1–7]. Age has always been suggested as a risk for injury, with proposed mechanisms of change in muscle cells and structure due to the natural aging process [1, 2]. However, several studies showed either the opposite trend—younger players developing injuries—or no difference dependent on age [8–13]. A study conducted in 2002 concluded younger football players (17–25 years) were more likely to sustain an injury than older players

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(26–35+ years). This study evaluated athletes during the preseason, and experience most likely contributes to the discrepancy in rates of injury [8]. A study performed in 2006 prospectively evaluated professional rugby players and found no statistical significance correlating age and hamstring development [13].

The more common modifiable risk factors for all hamstring injuries include body mass index (BMI), prior hamstring injury, insufficient warm-up and stretch, and an imbalance of muscular strength with a low hamstring to quadriceps ratio (H:Q) [6, 14]. Agre reviewed hamstring injuries, attempting to identify proposed etiological factors, preventative measures, and good treatment options. His review examined all hamstring injuries and stated several factors related to hamstring injury development, including poor flexibility, muscle fatigue, inadequate and inequality of strength of both legs, strength imbalance, inadequate warm-up and stretching, previous injury, and premature return to play [15].

In 1994, Worrell studied factors associated with all hamstring injuries. Muscle fatigue, lack of flexibility, muscle imbalance, and improper stretching were all identified several years prior but were thought to contribute as individual factors. Worrell concluded that the previously mentioned risk factors contribute to the complex nature of hamstring injuries, and prevention and rehabilitation must focus on an all-inclusive management plan incorporating identified risk factors [16].

Body mass index (BMI), a modifiable risk factor, has been reviewed by several studies [1, 4, 11, 13, 17–20], and most concluded no significant association between BMI and hamstring injury rates. However, Gabbe et al. demonstrated an association between a BMI > 25 and hamstring injuries among elite Australian football players [4]. A couple of studies proposed poor flexibility and improper stretching as mechanisms that increase the chance of injury [21, 22]. Verrall et al. concluded that if athletes improve their flexibility, the muscle would be capable of handling greater stress and force, and the number of stretch injuries would decrease [22].

Several systematic reviews evaluated and reported associated risk factors for all hamstring injuries [14, 23, 24]. However, there were some discrepancies between the studies and what was found to have a significant effect on injury development. Hamstring muscle weakness and an imbalance between the hamstrings and quadriceps muscle [5, 12, 15, 16, 20, 25–32] have been postulated to be risk factors for injury. A systematic review [23] discussed two studies [12, 26], finding a significant relationship between injury and muscle weakness, referencing measured H:Q ratios. Besides the results of these studies, the systematic review found no other significant association between injury and measured H:Q ratios. Prior et al. concluded that many modifiable and nonmodifiable risk factors have been implicated in hamstring injuries, but the extent to which modifiable factors are true risks remained unclear [24]. A systematic review and meta-analysis [14] discussed risk factors for hamstring strain injuries in sports. The review encompassed all hamstring muscle strain-types and concluded age [1–4, 8–11, 13, 17, 33, 34], previous hamstring injury [18, 26, 32], and an increased quadriceps peak torque [5, 12, 25, 26] were associated with hamstring muscle strains.

Drezner reviewed several aspects of all hamstring injuries, including mechanism, healing, and risk factors, in order to formulate appropriate treatment plans.

Previous hamstring injuries, reinjury in the same location of the affected hamstring, and premature return-to-play predispose athletes to lower leg injuries [1, 25, 31, 35–37]. Structured rehabilitation and employment of preventive measures may help reduce the incidence of hamstring injuries and allow athletes to return to play more efficiently.

Proximal hamstring strains and tears may be attributed to previously studied etiological factors encompassing all hamstring injuries, but few studies have identified unique factors to this population. Sudden forced hip flexion with knee extension predisposes athletes to developing a proximal hamstring injury [38–40]. This mechanism of injury is commonly found in water skiers, running sports, high energy ballistic exercise, weightlifting, judo, soccer, and rugby, and also seen in the occasional slip and fall accident [39–51]. Additionally, forceful hip flexion in combination with hip abduction and knee extension has been reported as another potential mechanism for proximal hamstring injuries [52].

Water skiing is a dangerous activity when not performed properly and can result in serious injury [53]. Several studies have reported on water skiers and the incidence of all hamstring injuries, specifically proximal injuries [40, 43, 45–47, 49, 54–58]. A case series [56] evaluating the surgical repair of a chronic tear in the proximal hamstring identified five water skiers, suggesting extreme flexion at the hip and extension of the knee as a risk factor.

A couple of studies discussed clinical cases involving Judo performers and their subsequent hamstring injuries. The Judo performers suffered complete avulsions of the tendon from the ischial tuberosity as a result of extreme hip flexion and knee extension during different maneuvers [42, 43]. A case series reviewed patients with proximal hamstring injuries from a diverse group of athletes, with a majority participating in water skiing and ballet/dance, and also several patients suffering from falls. A majority of the 71 patients suffered their injury from the common mechanism: forceful hip flexion with total knee extension [57]. Cohen et al. post-operatively assessed surgical outcomes in cohorts composed of sports-related and non-sports-related mechanisms. 27 of the 29 patients in the non-sports-related cohort experienced their injury via eccentric hip flexion with knee extension. Of the 23 patients who were injured during sports, more than half participated in water skiing and running [47].

Prevention

Hamstring injuries are commonly encountered in athletes, and many studies have attempted to understand and theorize ways to prevent the initial injury or reinjury. Risk factors such as muscle fatigue, poor core-stability, poor lumbar posture, limited flexibility, strength deficits, and lack of a proper warm-up have been studied [15, 16], in hopes of fully understanding and preventing future injuries. Prevention of all hamstring injuries, including strains and partial and complete avulsions, has been explored in several studies [6, 13, 30, 32, 38, 59–61], but not much data is available solely on proximal hamstring injuries.

Worrell studied etiological factors and preventive methods, aimed at better understanding all hamstring injuries [16]. Warm-up exercises and recognition of the importance of muscle fatigue were assessed. In the early 1980s, Beaulieu reviewed stretching exercises and developed a program focusing on the importance of flexibility and its implications. Heavy emphasis was placed on developing a safe and effective stretching program, knowing which stretches were considered safe and unsafe for the hamstring muscles, and employing proper execution [62].

Beaulieu discussed the positives and negatives of several stretching techniques and what a proper stretching plan should look like for an athlete. The four techniques explained and evaluated were ballistic, passive, contract relax, and static. Ballistic stretching involves bouncing movements, lengthening the muscle. It is considered the least desirable technique as it increases the tension experienced by the muscle and represents twice the amount of tension when compared to a slower, controlled stretch. Passive stretching requires a partner, providing an external force. This maneuver has merit when performed correctly; however, when performed incorrectly, it can overstretch the muscles and tendons and cause injury. Contract relaxing involves a muscle isometrically contracted for 5–10 seconds before any stretching is applied. Studies and clinical observations have suggested that this technique is not recommended, as it is easy to develop an injury. Finally, static stretching is the recommended method and performed in a gentle and slow manner. The stretch position is held for 30–60 seconds, allowing the contraction from the stretch reflex to be mild and controlled. Static stretch, when compared to the previously mentioned maneuvers, produces lower levels of tension and proves to be the safest method [62–64].

Designing a stretching plan requires the understanding that attaining flexibility is a gradual process and must be performed properly to help prevent injury or reinjury. The ideal stretching plan focuses on the following: mild warm-up preceding stretching; using static stretches; allowing time to stretch before and after all workouts and events; starting with easier exercises and progressing to more difficult ones; alternating muscle groups; assuming the stretch position slowly until tightness is felt and not pain; and holding the designated position for at least 30–60 seconds. The ideal warm-up consists of stretching exercises and a course of active muscle contraction. The warm-up increases the range of motion of both joints and muscles as well as increases the muscular temperature, providing more efficient muscle contractions [62, 65].

A study in 1997 analyzed trends in treatment and prevention across all hamstring injuries [32]. Increased muscle tension, lending to decreased elasticity, decreases the capability of all muscles to absorb pull forces without injury [66]. To combat the increase in muscular tension, warm-up regimens and pre-exercise stretching help reduce the tension and reduce the chance of injury [67, 68]. Williford et al. conducted a study that compared three groups of patients: jogging and utilizing static stretching, solely utilizing static stretching, and a control group [65]. The study team concluded that both the group using jogging and static stretching and the group solely utilizing static stretching achieved a significant increase in flexibility in multiple joints and muscle groups, aiding the assumption that controlled warm-ups and stretching may prevent future injuries [62, 65].

A biomechanical study reviewed the impact of warm-up prior to physical exercise on muscular injury and prevention and concluded all failures localized to the musculotendinous junction. Review of the muscle failures also revealed a greater force and increase in length of the muscle are required to cause an injury. The non-stimulated, or lack of warm-up group, required less force and decreased muscle stretch to cause an injury. The muscles that did not warm-up also proved to be inelastic compared to the warm-up group, predisposing them to injury [67].

A study in 1984 monitored intercollegiate football players, who were highly susceptible to hamstring strains. Players were separated into two groups based on the years they played, each receiving a supervised winter running program. The older group was instructed to construct a year-long stretching, running, and weightlifting program. The younger group received a staff-designed year-long stretching, running, and weightlifting program in addition to high speed isokinetic workouts. The study team observed a significant drop in primary hamstring strains; the first group experienced a 7.7% primary hamstring injury opposed to the second group, which experienced a 1.1% primary hamstring injury rate. Isokinetic exercise seemed to reduce primary injury rates, correcting muscle imbalances and aiding the nonoperative rehabilitation [69].

Sallay et al. reviewed proximal hamstring injuries and suggested preventive measures in water skiers. A majority of the patients were injured during takeoff, potentially because of improper technique. Novice skiers should be instructed and supervised by an experienced water skier, ensuring proper positioning to help avoid injury due to technique. Experienced skiers were also at risk of injury, potentially due to fatigue or equipment-related issues. However, after collecting their data, the study team reasoned that with such a violent mechanism of injury (hip flexion with full knee extension), even the most experienced water skiers may still be susceptible to injury [60].

Two groups of military basic trainees were followed and reported the number of lower extremity overuse injuries experienced. The control group (148 trainees) performed basic training as originally planned, where the interventional group (150 trainees) added extra hamstring stretching sessions to their scheduled fitness program. The hamstring stretches were performed paired, one person standing with the other person supporting the leg with the hip flexed at 90°. The standing trainee angled his trunk forward with a pelvic anterior tilt, maintaining a straight back and the head in a neutral position. This position was kept until the trainee felt a hamstring muscle stretching sensation with no pain. The stretch was executed five times for each limb and held for a total of 30 seconds. Hamstring flexibility was measured at the beginning and end of the study, concluding an injury incidence rate of 29.1% and 16.7% in the control and interventional groups, respectively [59].

A review was completed on the available evidence for eccentric strengthening and lumbo-pelvic training preventing hamstring injuries. Lumbo-pelvic stability has been defined by several studies, but a less vague definition describes lumbo-pelvic stability as "the ability of the lumbo-pelvic hip complex to return to equilibrium following a perturbation without buckling of the vertebral column" [61]. This concept has been tested in a biomechanical study, highlighting small increases in hip flexor activation, displaying an increase in the stretch experienced by the contralateral biceps femoris and other hamstring muscles during the late swing phase of gait, which has been implicated in hamstring injuries [70].

Fatigue and muscle weakness have always been implicated in hamstring injuries, suggesting a place for eccentric strengthening [61]. A few studies have proven in animal models a reduction in the amount of energy absorbed prior to muscle failure in fatigued or weakened muscles [66, 71]. The Nordic Hamstring Exercises (NHE) were designed to strengthen and reduce hamstring injuries, as most injuries occur during eccentric contraction [72]. Eccentric training improves muscle mass and has been proven to minimize injury risk, when combined with a warm-up regimen in a group of elite soccer players [73, 74]. Eccentric exercise interventions seem to reduce hamstring injury rates, but results are dependent on compliance [61].

In conclusion, preventive stretches and exercise programs have shown a degree of impact in reducing initial hamstring injury and reinjury rates. In the early treatment of hamstring injuries, few studies reviewed the preventive measures and, instead, relied more heavily on theoretical assumptions including flexibility, warm-up, strength, and fatigue awareness. Current literature has now expanded on prior protocols and added to the foundation of hamstring injury prevention. However, athletes of all levels still experience hamstring injuries, suggesting that further research is necessary.

Nonoperative Rehabilitation

Treatment and rehabilitation for proximal hamstring injuries is dependent on several variables including degree of injury, comorbidities, compliance with post-operative protocols, and patient preference [75]. Proximal hamstring strains may be treated either operatively or nonoperatively, but partial and full thickness avulsions generally proceed with surgery [50]. Nonoperative treatment for proximal hamstring tears has been recommended for a specific group of patients who meet the following criteria: single tendon tear with or without retraction; multiple tendon tears with less than two centimeters of retraction; comorbidities; or sense of poor patient compliance [39, 76]. However, few studies have analyzed and compared nonoperative to operative outcomes of proximal hamstring injury, and even fewer studies have reported a standardized nonoperative rehabilitation protocol.

Most muscular injuries are initially treated with the RICE regimen: rest, ice, compression, and elevation. Buckwalter et al. reviewed operative and nonoperative management of proximal hamstring injuries. Patients who qualified for nonsurgical treatment were initially started on symptom-driven management, utilizing RICE and avoidance of any activities that may provoke the symptoms. Isometric exercises were encouraged to maintain hamstring strength and activation [51]. Once the painful post-injury period resolves, rehabilitation protocols usually commence. Protocols have been developed for hamstring injuries but none made specifically for proximal hamstring avulsions.

Degen et al. reviewed the management for proximal hamstring tendinopathy and avulsions [75]. Eccentric physiotherapy exercises mainly constitute rehabilitation for proximal hamstring tendinopathy, though these methods lack supportive literature [41, 77]. Recently, Beyer et al. investigated the use of heavy slow resistance (HSR) training comprised of both concentric and eccentric exercises. HSR training has shown positive data suggesting an area for use [78]. Extracorporeal shock wave therapy, corticosteroid injection, and platelet-rich plasma (PRP) have all been applied adjunctly to the traditional conservative management of physical therapy and NSAIDs [75].

Nonoperative treatment for partial proximal hamstring tears is generally indicated for single-tendon tears, or 2-tendon tears with less than 2 centimeters of retraction. Traditionally, nonoperative management starts with activity modification and anti-inflammatories, followed by a structured physical therapy protocol. Piposar et al. compared operative to nonoperative outcomes in patients with high grade partial and retracted proximal hamstring ruptures. Patients who proceeded with nonoperative treatment were instructed to modify their activities, take NSAIDS when symptoms presented, and follow a personalized physical therapy regimen. For patients with continued pain for at least 3 months, they were offered surgical resolution [79].

Approximately 60% of the nonoperative group had acceptable outcomes with respect to outcome scores. However, the nonoperative group reported more difficulty with activities of daily living such as walking, standing, and using the staircase. A significant limitation of this study was the lack of a standardized nonoperative treatment protocol for each patient [79]. Nonoperative treatment resulted in acceptable outcomes, but surgery may be more beneficial in the long-term, as 40% nonoperative patients were converted to surgery.

Complete proximal hamstring ruptures are generally treated with early surgery, especially in the active and athletic population [47, 80]. Nonoperative treatment for complete tears is only considered in the relatively sedentary patient, someone with substantial medical comorbidities, or patients who cannot comply with post-operative restrictions [39]. Hofmann et al. discussed nonsurgical outcomes in patients after complete proximal hamstring ruptures. After comparing to a cohort of surgical patients, the study team concluded patients may experience success without surgery, but patients may see a decrease in hamstring strength in addition to a decline in their previous athletic activities. An extended course of physiotherapy for at least 4 months is recommended, but patients should be well informed of the discrepancies between their subjective assessment of the recovery and their overall functional status [81].

Shambaugh et al. retrospectively reviewed surgical and nonsurgical proximal hamstring injuries, comparing their respective clinical outcomes [58]. Patients who were treated nonoperatively incorporated RICE with physical therapy and corticosteroids, if necessary, with a gradual return to sports at 4 months. Each patient followed a structured, standardized physical therapy program consisting of "early mobilization, gentle range of motion, and flexibility exercises with progression to strengthening and return to sport within 6 to 12 weeks." Every 6 weeks, patients were seen to monitor their rehabilitation and recovery, and no patients in the nonoperative group required surgery throughout their treatment. However, nonsurgical patients reported slightly lower patient-reported outcome scores, muscular weakness, and lower rates of return-to-play when compared to surgical patients.

Receiving nonoperative treatment avoids the associated risks of surgery; however, the patient is susceptible to injury-associated complications that develop without surgical correction. Nonoperative rehabilitation is performed to help prevent these complications from developing but is not always successful. Knee flexion and hip extension weakness, lower limb deformity, difficulty sitting, and the increased risk to develop symptom-like hamstring syndrome are all potential consequences of failed rehabilitation [76].

Overall, rehabilitation outcomes and return-to-play are most important to active individuals. With regard to nonoperative treatment and rehabilitation, patients experience success but a good percentage either convert to surgery or adjust life activities. Few studies have evaluated a standardized nonoperative rehabilitation protocol, thus suggesting for future research and improvements to increase outcome scores and return athletes at the pre-injury level.

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