Proximal hamstring tendon avulsion: state of the art

Pablo Bertiche,1 Nicholas Mohtadi,2 Denise Chan,2 Per Hölmich3,4

ABSTRACT

Complete proximal hamstring tendon avulsions from the ischial tuberosity, though infrequent, are the most severe type of hamstring muscle injury in the field of sport medicine. These serious injuries are commonly associated with a delayed or even misdiagnosis, despite obvious clinical findings. The published literature favours surgical repair even though the studies represent lower levels of evidence. Non-surgical treatment is a viable option for lower physical demand patients. This state-of-the-art article reviews the relevant anatomy, the clinical assessment including specific physical examination signs and diagnostic testing in patients suspected of a proximal hamstring avulsion. Up-to-date evidence is reviewed to address surgical and non-surgical treatment options and outcome assessment. The authors provide a detailed description of what would be considered the current worldwide standard of care; an open, suture-anchor-based repair of the avulsed tendon complex (semitendinosus, long head of biceps femoris and semimembranosus) securely to the ischial tuberosity. Also included are surgical tips and tricks, with advice on postsurgical management and rehabilitation. Future perspectives should involve higher quality, prospective research to better define the indications for surgery, evaluate the emerging role of endoscopic repair and disclose complications along with measuring patient-reported outcomes.

INTRODUCTION

Ishikawa was credited for publishing the first description of proximal hamstring avulsion (PHA) in 1988.1 He reported two cases in the young population who were treated by surgery.1 He sutured the three hamstring tendons to the ischial tuberosity through drill holes. The treatment was based solely on the clinical findings and X-ray to confirm the diagnosis. ‘An avulsion of the hamstring muscles from the ischial tuberosity should be considered in patients who have undergone trauma and have the following clinical characteristics: pain in the buttock and difficulty standing or walking; a palpable defect and tenderness in the area distal to the ischial tuberosity; weakness during flexion of the knee with a loss of normal outline of the hamstring muscles on the dorsal aspect of the knee and no roentgenologic evidence of fracture of the ischium.’

It is important to state upfront that there are no population-based studies to determine the true incidence of PHAs. Similarly, there is a publication bias in that most publications relate to surgical treatment and involve highly active patients.2–5 The largest and most recent series represents 263 patients over a 13-year period. The majority occurred during sporting activities, with soccer being the most common followed by tennis in this series.6

PHAs have been reported to represent approximately 12% (21/179) of all hamstring injuries in an athletic population.7 However, only 8% (14/179) were complete PHA, with the remainder being partial tears and avulsions of the ischial apophysis in skeletally immature patients.7 Most importantly, compared with one of the most common injuries, that is a hamstring strain, the PHA would be considered a rare injury overall.

The literature reflects that these injuries are most common in activities requiring rapid acceleration such as running, hurdling, water-skiing, jumping and kicking sports with forced hip hyperflexion and ipsilateral knee extension.3 8–10 PHAs can result in significant disability, prolonged absence from competition and a long period of rehabilitation in highly active individuals.7 In less active patients; the injury clearly has less of an impact.11

Relevant anatomy

The hamstrings muscle group occupies the back of the thigh and is composed of 3 muscles: semimembranosus (SM), semitendinosus (ST), and biceps femoris (BF). The hamstrings function primarily as knee flexors and hip extensors (SM, ST and long head of the BF). They originate from the ischial tuberosity. The anatomy of the insertion site is well defined in the publication by Steprien et al.12 However, when approaching these patients surgically the tendons typically avulse as one unit, revealing the tuberosity as a ‘bald’ spot, sometimes with some adjacent residual tendon fibres (figure 1A). Therefore, it is challenging to distinguish separate tendons and their respective insertion sites. The insertion site has two main components, one for the SM, which is deep, curvilinear and slightly laterally positioned (figure 1B). The second component includes the ST and long head of the BF, which form into a conjoint tendon (figure 1C) that attaches medially, superficially and slightly superior to the SM.12 The conjoint tendon of the ST and long head of the biceps separates into the two muscles roughly 10 cm distal to the ischial tuberosity. The ST and SM descend along the medial portion of the thigh to insert on the pes anserinus and postero-medial portion of the tibia, respectively. The long head of the BF joins to the short head, which originates from the lateral lip of the linea aspera of the femur to insert on the fibular head and the lateral plateau of the tibia.11–13 The ST, SM and long head of the BF are innervated by the tibial division of the sciatic nerve. The short head of the BF is innervated by the peroneal division of the sciatic nerve.10

Anatomically, the relationship between the hamstrings and the sciatic nerve is very important. Approximately 1.2 ± 0.2 cm separate the nerve from the hamstring origin at the ischial tuberosity.14
The close proximity of the sciatic nerve has implications associated with acute injuries, with patients presenting with neurological symptoms distal to the level of injury. Similarly, in chronic tendinopathy/hamstring syndrome, local neurological complaints, particularly pain, can be attributed to this relationship. Most importantly, the sciatic nerve needs to be identified and protected as a critical part of surgical approach in this area. The three hamstring muscles attached to the ischial tuberosity act across both the hip and knee joints. These two-joint muscle tendon units are at risk of injury since they contract concentrically by flexing the knee and extending the hip and eccentrically in the opposite mode. The short head of the BF is unaffected in hamstring avulsions since it is anatomically distinct and crosses only the knee joint.

Hamstring injury

Hamstring injuries can range in severity from a minor muscle injury, which represents 25% to 30% of all muscle strains, to a complete avulsion of three tendinous insertions on the ischial tuberosity; the focus of this article. The most common mechanism of injury is a sudden hyperflexion of the hip with the knee in extension during sport activities. With ageing, the susceptibility for injury increases. Therefore, hamstring avulsions can simply occur because of a fall on a slippery surface during activities of daily living.6 9 14 17 18

Current evidence

Five systematic reviews addressing the topic of hamstring avulsions have been published to date.5 9 18-20 These reviews include publications only up to 2017. Harris (2011), included 18 publications, English language only, and case reports and series.20 One publication was considered level 2 evidence, but this was also a case series. The conclusion suggested better outcomes for acute versus chronic repairs and surgical compared with non-surgical treatment. However, there were only 14 (out of 300) patients treated non-surgically.20 van der Made (2015) reported on 13 publications, some of which were reported as cohort and case control studies, but on further appraisal we consider these to be retrospective case series. They performed a quality assessment which confirmed that all studies were of ‘low-quality’ due to ‘lack of randomization and controls’.18

Bodendorfer (2018) included 24 publications (including one abstract subsequently published), and used a validated quality assessment tool designed for non-randomised trials. They concluded that there is a ‘paucity of high-quality studies’ and that acute surgically treated patients essentially have better outcomes.9

Coughlin (2018) and Belk (2019) addressed the issue of returning to sport in their systematic reviews. Coughlin included 21 publications and performed both a quality assessment and meta-analysis of the available data. They concluded that both the non-comparative and comparative studies were of fair quality. Their main outcome was a return to sport, which was achieved in the majority of patients treated surgically.3 Belk (2019) included 16 studies and had similar conclusions with a return to sport in greater than 90% of the patients having a hamstring repair.

These systematic reviews have similar conclusions. The main concern is the lack of high-quality evidence, heterogeneity of patient populations, non-validated outcome assessment and lack of non-surgical comparisons.

The most recent publications included the largest surgical series and an international survey.6 22 The survey included members of the International Society of Arthroscopy, Knee Surgery and Sports Medicine (ISAKOS) and the European College of Sport and Exercise Medicine (ECOSEP).22 This survey echoed the concerns regarding the surgical bias in the literature and the ‘scarcity of controlled studies’.22 Irger et al (2019) provided information on 263 surgically treated patients from one institution. They concluded that PHAs most commonly occur in the 45–59 years old age group and have a similar male-female distribution, with older women being injured as a result of activities of daily living and younger men being injured during sports.6

The purpose of this article is to review all aspects of PHAs in adults and to provide a detailed description of surgical techniques and postsurgical management. Future evidence-based perspectives on the development of diagnosis and treatment for hamstring proximal avulsions will also be discussed.

CLINICAL EVALUATION

At the exact moment of injury, patients will often feel or hear a ‘pop’ rip or tearing sensation and experience severe pain in the posterior thigh/lower buttock. This may or may not be associated...
with sciatic nerve symptoms; that is, numbness and tingling in the sciatic nerve distribution. They will have difficulty doing most functions involving the affected extremity. Weight-bearing is possible, walking tentative and usually requires support, but sitting is more problematic. 23 24 Complete avulsions universally result in bleeding with haematoma formation and obvious bruising (figure 2). The authors have seen upwards of a litre of blood in the posterior thigh. Bruising will progress distally and is most commonly seen around the posterior distal thigh and the knee, and rarely around the ankle and foot. Unfortunately, what may seem to be an obvious problem on history is often discounted leading to a missed or delayed diagnosis.

On physical examination, the patient presents with an altered gait, avoiding simultaneous flexion of the hip and extension of the knee; the so-called ‘hurdler’s position’, due to the pain it generates. The bruising will be present after a day or two. In the case of a complete rupture, a depression can be felt in the proximal posterior thigh, just below the ischial tuberosity. However, due to the local response to the injury and significant tenderness, deep palpation is often compromised precluding identification of the defect. A valid strength assessment is not possible due to the pain generated when the patient activates their hamstrings against resistance. One common physical examination finding is that when the patient is asked to flex their knee while lying prone, they will use their gastrocnemius to compensate for the loss of hamstring function. The examiner may be fooled into thinking that the hamstrings are not avulsed since active knee flexion against gravity is indeed possible using the gastrocnemius and short head of the biceps. However, weakness is universally present. The bowstring sign is an absence of palpable tension in the distal part of the hamstrings with the patient prone and the knee flexed 90° (figure 3). In the supine position, the popliteal angle can be measured with the hip and knee flexed 90° and then slowly extending the knee passively. The knee flexion angle at which posterior thigh pain and guarding occur is compared then slowly extending the knee passively. The knee flexion angle can be measured with the hip and knee flex 90° and the pain generated when the patient activates their hamstrings

![Figure 2](image2.png)

**Figure 2** Bruising after proximal hamstring avulsion.

![Figure 3](image3.png)

**Figure 3** (A) Bowstring sign negative; (B) Bowstring sign positive.
hamstring function and most patients have difficulty doing this in the acute situation. This test is also helpful when monitoring functional progress over time, particularly when managing this injury non-operatively (figure 6). Another helpful functional test is the ‘Hip Extension Test’, in which the patient is asked to actively extend the hip in a prone position (figure 7). This test has been described as a useful way to determine whether or not hamstring function may be adequate enough to avoid surgery in the case of a complete avulsion.11 However, this is more likely the case in delayed rather than acute (<6 weeks) presentations (figure 7).

Finally, clinical evaluation of the sciatic nerve is very important, because of its proximity with the hamstring muscle insertion and the direct innervation of the ST, SM and long head of the BF. In a series of 162 patients with a partial or complete avulsion of the hamstring muscle group, 45 patients (27.8%) had neurological symptoms in the distribution of the sciatic nerve; 8 patients (4.9%) had motor deficits, 11 (6.8%) sensory deficits and 36 (22.2%) neuropathic pain.10 A careful neurological evaluation should be performed to assess for sciatic nerve irritation, including posterior thigh sensation and distal motor and sensory function of the tibial and peroneal nerves.24

**Diagnosis**

Standard radiography of the affected hip (AP pelvis and lateral view) is routinely used, even though the X-rays are usually negative. Radiographs are particularly important in younger skeletally immature patients to rule out an avulsion fracture of the ischial apophysis.

Diagnostic ultrasound is a readily accessible, inexpensive and non-invasive test that is useful for diagnosing hamstring soft tissue injuries. Relatively high-resolution imaging can be directly correlated with the physical examination findings to confirm the diagnosis.28 However, the information may not be considered precise or detailed enough for surgical planning purposes.

MRI, is considered the gold standard test for hamstring avulsion injuries. MRI can differentiate between partial or complete avulsions, and acute or chronic injuries, and identify the number of tendons involved, tendon retraction and muscle quality in terms of fatty infiltration and atrophy28 (figure 8). MRI can also provide information on the exact location of the sciatic nerve, whether the nerve is normal in appearance or deviated in any way due to the mass effect of the haematoma.28

In summary, the diagnosis of a PHA is made by eliciting the history of an acute injury (a mechanism resulting in a ‘high’ tensile force sustained by the hamstrings), a physical examination that identifies a defect in the proximal tendon insertion with an associated loss of hamstring function, typically an absence of X-ray findings except in skeletally immature individuals, and confirmatory MRI.
CLASSIFICATION

Hamstring injuries in general have traditionally been classified according to their pathoanatomical presentation as follows: a mild strain (Grade 1), a moderate/partial or incomplete tear (Grade 2) and severe or complete rupture (Grade 3). This classification applies to the most everyday hamstring injuries, which typically occur at the muscle tendon interface. The most commonly used classification for the PHA is the one established by Wood et al.\(^{29}\) He described five types of avulsions on the basis of the anatomical location of the injury, the degree of avulsion (incomplete or complete), the degree of muscle retraction (if avulsion is complete), and the presence or absence of sciatic nerve tethering.\(^{29}\)

Type 2 and 3 tendon avulsions can be further described based on which specific muscles are involved. PHAs can also be classified according to the time elapsed from the incident injury. However, there is no consensus with respect to the definition of acute versus chronic and why a specific cut point is used.\(^{4,27,30-33}\) The authors would suggest an empirical approach to the temporal classification: Acute <6 weeks; Subacute up to 12 weeks and Chronic >12 weeks. This provides direction with respect to the surgical approach. The acute avulsions can be managed with a transverse buttock crease incision, and the subacute/chronic with a surgical approach using a longitudinal incision. In chronic significantly retracted tears, a consideration for allograft reconstruction may be rarely necessary.\(^{23}\) The acute/chronic designation also helps as a prognostic indicator as acute injuries and repairs typically do better than subacute/chronic injuries.\(^{20,27}\)

OUTCOME MEASURES

There are several different scores that have been used to measure the clinical results of proximal hamstring ruptures. These include the Short Form-12 (SF-12) generic health survey, the region-specific Lower Extremity Functional Scale (LEFS) and two disease-specific scales, the Proximal Hamstring Injury Questionnaire (PIHQ) and the Perth Hamstring Assessment Tool (PHAT).\(^{20,34,35}\)

The PIHQ was created by Sallay et al\(^{35}\) to evaluate the functional results in patients who received surgical repair for a complete proximal hamstring tendon rupture. This patient-reported questionnaire is based on the most common complaints of patients who had chronic non-repaired tears. The patient-reported questionnaire measures: pain, stiffness, strength, previous and current activity levels, and surgical satisfaction.\(^{15}\) This score has not been validated with respect to current standards.\(^{36,37}\)

The only validated outcome measure for assessing patients with PHAs is the PHAT.\(^{14}\) It is designed to assess the preoperative disability and postoperative outcome. The questionnaire uses a 0 to 10 Visual Analogue Scale for pain assessment in three different activities (‘pain when sitting; pain with stride-out stretch and pain at rest’). It uses a five-point categorical scale to determine the maximum amount of time that the patient can perform ‘sitting in a chair; driving a car; and running’ without discomfort, a four-point categorical scale to describe their current level of activity, and a three-point categorical scale to describe whether or not they experience tenderness over the hamstring buttock.\(^{24}\)

The PHAT was designed by Blakeney et al\(^{14}\) based on a published prospective series of 74 consecutive proximal hamstring surgical repairs in 72 patients, with a median age of 50.5 years (range 16–74). Patients completed the PHAT, SF-12 Health Survey and LEFS. The scoring system was validated by calculating its internal consistency, reproducibility, reliability and sensitivity to change. The results showed high completion rate (100%), high internal consistency (Cronbach’s alpha 0.8), high reproducibility (intra-class correlation coefficient 0.84) and high

---

**Box 2** Physical examination signs

- Increased pain with simultaneous hip flexion and knee extension.
- Prone knee flexion against gravity using the gastrocnemius muscle.
- Bowstring sign.
- Active shoe removal sign.
- Hip extension test.
- Increased passive hip flexion.
- Popliteal angle sign.

---

**Box 3** Validated outcome measures and classifications

'Validated' outcome measure:

- Perth Hamstring Assessment Tool (PHAT; disease-specific)

Wood’s classification of proximal hamstring avulsions:

- **Type-1**: Osseous avulsions, which typically represent apophysial injuries in skeletally immature patients.
- **Type-2**: Avulsions at the musculotendinous junction.
- **Type-3**: Incomplete tendon avulsions from bone.
- **Type-4**: Complete tendon avulsions with no or minimal retraction of the tendon ends.
- **Type-5**: Complete tendon avulsions from bone with retraction of the tendon ends.
  - **Type-5a**: not associated with sciatic nerve involvement.
  - **Type-5b**: associated with sciatic nerve signs.
sensitivity to change, with a moderate correlation with the LEFS and lower correlation with the Physical Component Score of the SF-12.34

MANAGEMENT
The most important factor in the treatment of PHA is recognition of the problem and early diagnosis. Patients should be seen by knowledgeable practitioners who are able to evaluate the patient, and investigate and confirm the diagnosis. Early referral to a surgeon comfortable in repairing these injuries is optimal. Most orthopaedic surgeons have not been specifically trained to manage this injury.

In general, non-operative treatment is always an option since it will likely avoid any possible complications, return to activity will be earlier compared with surgical repair and the patient may have a satisfactory outcome. However, it is likely that non-operative treatment of a retracted PHA will lead to an outcome that results in a loss of function.21,38

The authors use the following analogy to describe what functional deficit to be expected: ‘A sprinter will become a runner; a runner will become a jogger; a jogger will become a walker and a walker will lose length and speed in their stride’. Similarly, the patient will lose their ‘high’ gear.

Surgery is typically indicated in active individuals with PHAs when there are two or three tendons involved with more than 2 cm of retraction (Wood type 5) or in cases of failed conservative treatment after 3–6 months.20,27,31

Recent studies demonstrated that the surgical repair of a PHA is associated with good functional outcomes and fewer complications, particularly when the repair occurs acutely. These studies show better strength testing, endurance levels, return to sport activities and higher patient satisfaction.8,23,35

Non-operative treatment
The conventional conservative treatment consists of rest, ice, activity modification, non-steroidal anti-inflammatories, eccentric strengthening exercises and physiotherapy.17,24,25 Additional treatments such as shock wave therapy, corticosteroid and platelet-rich plasma injections have no place in the treatment of acute PHAs. These treatments may be considered for patients with chronic hamstring insertional tendinopathy.19–41

Non-operative management is considered the preferred option for partial avulsions, tears involving one or two tendons only, for sedentary individuals, patients with medical comorbidities, or those that are unable to adhere to postoperative rehabilitation.24 Aggressive strengthening to optimize function is recommended.

Surgical techniques
The principles of surgical treatment are independent of surgical approach or technique. These include the following: (1) Adequate exposure of the ischial tuberosity; (2) Identification and protection of the regional nerves (posterior cutaneous nerve of the thigh and sciatic nerve); (3) Mobilisation of the injured muscle tendon units; (4) Secure fixation of the avulsed tendons to the ischial tuberosity; and (5) Intraoperative testing of the repair.

Different surgical techniques have been described in the literature. These range from large longitudinal open incisions to localised transverse buttock crease incisions to an endoscopic approach.

The authors recommend an open surgical approach. A transverse buttock crease incision is used for acute repairs (<6 weeks) and a longitudinal incision for more chronic injuries with retraction. Chronic repairs with <5 cm retraction can be managed with either incision, but the longitudinal incision is the recommended default approach.29 Some authors have described a ‘T’ shaped incision to accommodate better exposure.14

Open surgery is performed with the patient in a prone position under general anaesthesia.29 A horizontal incision in the gluteal crease is generally used in patients who have acute ruptures, or where the MRI suggests there is minimal tendon retraction.46 In patients with chronic retracted tears, we prefer a longitudinal incision from the ischial tuberosity for at least 10 cm. Dissection is carried down through skin and subcutaneous tissue. A concerted effort should be made to locate the posterior femoral cutaneous nerve. The nerve is identified exiting through the deep fascia roughly in the midline of the posterior thigh. There are two reasons to identify the posterior cutaneous nerve: (1) To minimise the chance of postoperative numbness in the posterior thigh, and (2) To follow the nerve deep to its origin, the sciatic nerve. Once the deep dissection has been performed, the avulsed tendon ends can be identified distally and the ischial tuberosity (figure 9A) palpated proximally, deep to the gluteus maximus which covers the entire region. A ‘Hohmann’ retractor is then placed directly into the bone of the ischial tuberosity. Correct positioning of this retractor(s) superiorly and medial to the hamstring insertion facilitates optimum exposure and allows for anchor insertion (figure 9).

State of the art review
It is always necessary to identify and protect the sciatic nerve (figure 9B) during the repair. A formal neurolysis is only necessary in chronic situations or where there are unresolved neurological symptoms preoperatively. The avulsed hamstring tendons are identified and mobilised accordingly. It is not necessary to identify each tendon separately since they remain together or congeal as one unit. In chronic situations it may be necessary to separately identify each tendon (figure 9).

The ischial tuberosity is prepared by debriding the remaining soft tissue at the insertion site to expose the hamstring footprint. Decortication of the bone is not at all necessary but creating a bleeding bony surface is important for optimal healing. Two or three double or triple loaded suture (non-absorbable) anchors are inserted strategically into the footprint (figure 9A). Ideally, one anchor for each of the tendons. However, this distinction is not always possible, and the goal should be a secure repair. One suture arm is passed into the tendon(s) end with any locking type technique. This allows the tendons to be reduced anatomically onto the tuberosity. Flexing the knee reduces the tension on the repair. The knee should then be slowly extended while both visualising and palpating the repair. This ‘testing’ of the repair will help to determine a safe position of knee flexion postoperatively. Over the past 20 years, the authors have evolved the repair technique from using sutures directly into the bone, to metal anchors, to now using biocomposite triple loaded suture anchors.

The wound is thoroughly irrigated, all bleeders are cauterised, and the sciatic nerve is re-examined to ensure that it is intact and not involved in the repair. The deep fascia is closed followed by the skin.

The authors also recommend deep venous thrombosis prophylaxis for all patients and non-steroidal inflammatory medication for prophylaxis against heterotopic ossification.

**Endoscopic repair**

Endoscopic repair of PHAs has been described in the literature.\(^4\)\(^{3}\)\(^{4}\)\(^{6}\) Clear indications for this technique are yet to be determined, as this is an evolving procedure. Endoscopic repair is not currently recommended for patients with chronic retracted tears.\(^4\)\(^5\)

The authors would state that the open surgical repair for avulsed hamstrings, independent of chronicity and retraction, is the standard of care. Endoscopic repair should be considered a technique in evolution for experts only at this time.

**POSTOPERATIVE CARE**

Postoperative rehabilitation is an essential part of obtaining a successful outcome. Much of what is required is introduced at the first visit with the surgeon. This discussion will include the initial limitations, protection of the repair, avoidance of stretching out of the repair and expected timelines. One of the things that is demonstrated is the so-called ‘hurdler’s position’ that is, hip flexed, knee extended and forward flexion of the trunk. This image is easily understood by the patients as the position to avoid. The patient should be engaged at the start to be in control of their rehabilitation.

The initial phase of postoperative care is to allow for wound healing, pain control and to accommodate the patient in returning to basic daily activity. Once this has been achieved the formal rehabilitation can proceed.

**Rehabilitation**

The principles that need to be addressed and understood in order to achieve optimal adherence are the following:

1. A secure repair that has been tested intraoperatively to determine the tension on the repair.
2. Protection of the repair until there has been adequate healing (6–8 weeks).
3. Early activation of the hamstrings with initial active assisted range of motion, then against gravity and subsequently with progressive resistance (1–6 months).
4. Avoidance of stretching the repair (the tendons heal with a scar which is susceptible to permanent stretching and loss of...
the normal length-tension relationship of the muscle tendon units).

Immediately after surgery, the authors would typically recommend that a brace is used to provide additional protection. The brace may be optional in acute situations where a surgeon achieves a secure tension-free repair. A hinged range-of-motion knee brace is likely to be available to most practitioners rather than a hip-specific brace, and it is less costly. The brace is intended to limit knee extension to reduce the tension on the repair. The actual limit is estimated in the operating room based on visualisation and palpation of the repair as described above. However, since the patient is in the prone position this is merely an estimate, as it is not possible to account for hip flexion. The brace is typically set with an extension block of 30°–60°. Rarely the brace is set at 90°, but this is in chronic avulsions with significant retraction of the muscle tendon units. The brace does not need to limit knee flexion in any way. Patients can activate their hamstrings and bend their knees with gravity eliminated. Weight-bearing is allowed with the assistance of crutches and within the confines of the brace. The rehabilitation protocol changes roughly at 2-week intervals. The first postoperative visit allows for the assessment of the wound, checking for complications and most importantly to determine what restrictions are necessary. The brace is carefully removed with the patient in the prone position and the knee is passively extended to the point where the patient will feel tension/pain in their buttock/repair site. The brace is adjusted to this point; that is, restricting extension beyond this position. Typically, this is 30° or less. The surgeon can palpate the hamstrings distally and the repair site proximally. The patient is then instructed to actively flex their knee with assistance. The surgeon can determine if the hamstrings are providing the force or whether the gastrocnemius is compensating. This is the second phase of rehabilitation, that is, active flexion against gravity. Usually this requires some initial assistance, which can be provided either by the patient’s spouse/partner or with a physiotherapist if they are a part of the surgeon’s team. Weight-bearing is allowed as tolerated and crutches for protection. The same process is followed at the fourth weekly visit. If full extension was achieved at the second week, then the brace may be discontinued at the fourth week; if not, then bracing is continued to the sixth week. The patient should be more comfortable with daily activities and sitting tolerance should be evaluated. If the patient can tolerate sitting, they can start on a stationary bike in a reclined position. Beyond 6 weeks, the brace can usually be discontinued, and active exercise progresses accordingly. At this point formal physiotherapy can be introduced provided there is good communication between the therapist, the patient and the surgeon. If this is not possible or optimal, it is better to have the patient direct the rehabilitation with the surgeon providing the guidance. Stretching should be avoided for at least 3 months and progression to activities is determined on an individual basis. Return to sport is challenging and will require more intense rehabilitation and monitoring.

**RESULTS**

Harris et al performed a systematic review and concluded that operative patients reported significantly better strength testing, endurance levels and return to sports than the non-operative group.

Blakeney et al found in a prospective case series, that the surgical repair of proximal hamstring tendon ruptures leads to improved patient function for both acute and chronic injuries.48

Bodendorfer et al in their systematic review compared the outcomes after operative and non-operative treatment of PHA and published 90.8% satisfaction for the surgical group, which was significantly greater (p<0.001) than the non-operative group (52.9%). However, the number of non-surgically treated patients was at most 28 compared with 767 operatively treated patients. The 28 non-surgical patients were from only two studies, Hoffman (2014) and Olsen (2015). The Olsen reference, an abstract that was subsequently published by Shambaugh (2017), was published from the same institution as Hoffmann (2014) and had overlapping time periods. This suggests that Bodendorfer may have included some patients more than once in their analysis. While no complications were reported in the non-operative patients, the operative group reported a 23.2% complication incidence, including 2.2% rerupture and 2.6% reoperation rates. With respect to the time from injury to surgery, acute patients had significantly higher satisfaction (95.4%) and less pain than the chronic group (83.7%). Postoperatively, 0.3% of the acute and 2.2% of the chronic group reported sitting pain, which was significantly different (p=0.036). The acute and chronic groups demonstrated similar results with respect to return to sport. Acutely treated patients reported significantly better results in strength testing versus the contralateral leg, compared with the chronic group.49

Bodendorfer et al also compared complete versus partial tears. The results were significantly better for the complete compared with partial avulsion repairs in overall patient satisfaction (89.6% vs 81.4%) and pain scores.9 Partial avulsion repairs had significantly higher strength testing and endurance scores. These results may be influenced based on the chronicity of the injury. Partial tears were initially managed conservatively, which delays the surgical treatment. Cohen, Sallay, Birmingham and Wood published similar results.

Belk et al and Couglin et al performed systematic reviews to look specifically at return to sport after surgical treatment of proximal hamstring tears. Both studies had similar conclusions suggesting a high rate of sport participation. The average age of the patients included was very similar at 39.6 years and 41.4 years.3

Three recent studies were published after the previous systematic reviews and meta-analyses were performed. Piposar et al compared the clinical and functional outcomes of 15 non-operatively and 10 operatively treated patients that were retrospectively identified with a high-grade partial or complete proximal hamstring tear (with <2 cm retraction) and failed non-operative treatment. Functional scores were statistically greater for the operative patients. However, the side-to-side differences on the single-legged hop test for distance, and the torque deficits measuring isokinetic hamstring strength were not statistically different between the non-operative and operative groups.46 The study concluded that with proper rehabilitation, strength
can be recovered on the injured side after a mean 30–35 months of follow-up, with or without surgical repair.\textsuperscript{49}

Kayani et al\textsuperscript{50} prospectively evaluated muscle strength, functional performance and return to preinjury level in a series of 41 patients treated operatively for chronic incomplete PHA injuries. All patients returned to preinjury level of sporting activity and there were no episodes of injury recurrence within the mean 28.2-month postoperative follow-up period.\textsuperscript{50}

In a retrospective study of 94 patients (mean age 53.8 years) with an acute or chronic, partial or complete proximal hamstring tendon avulsion, Willinger et al\textsuperscript{41} reported 49% of patients returning to the same level of sport at a mean 56.2 months following surgical treatment. Clinical outcomes of partial and complete avulsions were similar, but the overall postoperative complication rate was higher in patients with chronic and complete avulsions (5.3%).\textsuperscript{51}

In summary, PHAs are not very common. These injuries occur in athletes of different ages and competition levels as well as those involved in activities of daily living. The average age of those patients undergoing surgery is roughly 40 years. The current evidence supports surgical treatment of a complete PHA in the active athletic population. Acute repairs appear to have better overall outcomes in terms of pain, strength tests, satisfaction and return to sport, and less complications. Non-surgical treatment can be recommended for partial tendon avulsions, and complete avulsions with less than 2 cm of retraction. A conservative approach is preferable for patients with medical comorbidities and those who are willing to reduce their physical demands.

REGIONAL DIFFERENCES
The authors are not aware of significant regional differences with respect to the management PHAs. This injury was first reported in 1988.\textsuperscript{1} It is likely that there are regional nuances with respect to patient selection, idiosyncratic surgical details and rehabilitation protocols, but these are not evident in the available literature. The principles of evaluation and management would remain the same worldwide.

FUTURE PERSPECTIVES
With the recent development of new technologies and the goal to have minimally invasive surgical procedures, different authors have published new techniques to repair the proximal avulsion of the hamstrings endoscopically. These techniques require a lot of endoscopic experience. Future research will show if they result in less complications and better outcomes.\textsuperscript{43,45}

Currently, these techniques are used in acute partial or total injuries without excessive retraction, so the indications are very restricted.\textsuperscript{45} We believe that future high-level prospective studies should be performed to accurately assess the outcome after non-operative and operative treatments, and also the results of open repair versus endoscopic techniques in all types of hamstring injuries.

Box 8 Major pitfalls of proximal hamstring avulsion surgery

- Sciatic nerve injury.
- Deep venous thrombosis.
- Inability to restore the length-tension relationship of the hamstring muscle tendon unit.

Box 9 Future perspectives

- Future research is required to determine the complication rates of new technologies for repairing proximal hamstring avulsions.
- High-level prospective studies are needed to accurately assess outcomes of non-operative and operative treatments.
- Patient outcomes following endoscopic techniques need to be compared with current standard open suture-anchor-based repair in high-quality prospective studies to guide evidence-based medicine.

Contributors PB performed the initial literature search, initial formatting, created the figures and the original draft of the manuscript. NM performed an additional literature search, re-drafted the manuscript and performed the final revisions. DC coordinated the process of creating this manuscript, formatted the drafts and final submission and revisions, including the figures and references. PH contributed to the re-drafted manuscript, provided additional references and contributed to the final revisions.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient consent for publication Not required.

Ethics approval Approval from the University of Calgary Conjoint Health Research Ethics Board is not required because research on human participants at the University of Calgary was not conducted for the purposes of this review.

Provenance and peer review Commissioned; externally peer reviewed.

Data availability statement There are no data in this work.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, an indication of whether changes were made, and the use is non-commercial. See: http://creativecommons.org/licenses/by-nc/4.0/.

REFERENCES
The proximal hamstring muscle-tendon complex of the hamstrings is the primary contributor to hip extension. The anatomic structure and function of the hamstrings were described in a review article by Bertiche et al. [13]. The proximal hamstring muscles and tendons are subjected to high forces during athletic activities, leading to muscle strains and tendon tears. Miller et al. [14] provided a detailed description of the proximal hamstring muscle-tendon unit, including the anatomy, biomechanics, and pathophysiology.


Surgical repair is often necessary for complete proximal hamstring ruptures. Ahmad et al. [21] reported outcomes of surgical repair in a retrospective cohort study. Subbur et al. [22] described the timing of surgery for complete proximal hamstring ruptures in a prospective study. Laskovski et al. [23] reviewed the outcomes of nonsurgical treatment for proximal hamstring avulsions.

Avulsion injuries are a common type of proximal hamstring injury, and several studies have evaluated the surgical management of these injuries. Ahmad et al. [24] provided a systematic review of surgical techniques for proximal hamstring avulsions. Chahla et al. [25] reviewed the outcomes of surgical treatment for proximal hamstring avulsions.

Platelet-rich plasma (PRP) has been used in the treatment of complete proximal hamstring avulsions. Ahmad et al. [26] studied the outcomes of PRP injection in a randomized controlled trial. Laskovski et al. [27] reviewed the outcomes of nonsurgical and surgical treatments for proximal hamstring avulsions.

Chahla et al. [28] provided a comprehensive review of the surgical management of complete proximal hamstring avulsions. Ahmad et al. [29] evaluated the outcomes of surgical treatment for proximal hamstring avulsions in a systematic review. Milovanovic et al. [30] evaluated the outcomes of surgical treatments for proximal hamstring avulsions in a meta-analysis.

In summary, the proximal hamstring muscle-tendon complex is a vital component of the lower extremity and must be carefully evaluated and treated to optimize patient outcomes.