Review Article

Hamstring Injuries in Athletes: Evidence-based Treatment

Justin W. Arner, MD
Michael P. McClincy, MD
James P. Bradley, MD

Abstract

Hamstring injuries are common in athletes and can cause notable disability. They can be separated based on proximal, muscle belly, and distal injuries, with proximal and distal injuries more commonly requiring surgical intervention. Most injuries do not require acute MRI; however, MRI is useful in proximal and distal injuries as well as muscle belly tears that fail to respond to nonsurgical treatment. Acute repair of proximal avulsions, both partial and complete, result in successful outcomes, whereas chronic complete repairs are more difficult and less reliable. Muscle belly injuries have predictable outcomes but recurrence is common. Nonsurgical treatments focus on eccentric strengthening with the possible addition of low WBC platelet-rich plasma, which may have the potential to hasten recovery and decrease re-rupture. Distal injuries are relatively rare but may require surgical intervention. Hamstring reinjury is common, making continuation of preventive therapies after return to sport essential. Future research with larger sample sizes are required to determine how to decrease injury and reinjury rates, to evaluate the efficacy of platelet-rich plasma and to determine other treatments that may accelerate recovery after injury.

From the Department of Orthopaedic Surgery, University of Pittsburgh (Dr. Arner and Dr. McClincy), and Burke and Bradley Orthopedics, University of Pittsburgh Medical Center, UPMC St. Margaret (Dr. Bradley), Pittsburgh, PA.

Dr. Bradley has received royalties from Arthrex. None of the following authors or any immediate family member has received anything of value from or has stock or stock options held in a commercial company or institution related directly or indirectly to the subject of this article: Dr. Arner and Dr. McClincy.

Supplemental digital content is available for this article. Direct URL citation appears in the printed text and is provided in the HTML and PDF versions of this article on the journal's Web site (www.jaaos.org).

J Am Acad Orthop Surg 2019;27: 868-877

DOI: 10.5435/JAAOS-D-18-00741

Hamstring injuries are common and can account for notable disability in athletic patients, with male athletes being more commonly affected. Hamstring injuries makes up nearly 30% of new lower extremity pathology, and are at a notable risk of becoming chronic issues, with reinjury rates between 12% and 31%.[1] Typically, rapid acceleration sports produce the highest injury rates. Particularly high injury rates are seen in hurdling, soccer, American football speed positions, as well as other running, jumping, and kicking sports. Professional soccer players are among the athletes at greatest risk for this injury, and a 20% rate of hamstring injury per season has been reported, with 20% of injuries becoming chronic. Hamstring injuries are most commonly muscular, with severity ranging from mild disruptions to complete loss of fiber organization. Although less frequent than muscle and myotendinous injuries, proximal hamstring tendinous avulsions are commonly encountered in water-skiing, skating, and weight lifting patients.[2] Proximal injuries can more severely affect activities of daily living and have prolonged recoveries.

Despite the increase in attention and knowledge of these injuries, rates and recurrences have not improved. In fact, one cohort of elite soccer players reported a 4% annual increase in hamstring injuries over a 13-year period and 33% of National Collegiate Athletic Assocaition (NCAA) hamstring tears are recurrences.[3] Timely and appropriate diagnosis and treatment are essential, with physical therapy, biologic treatments, and surgical repairs offering promise.

Anatomy and Function

Three muscles make up the hamstring complex: the biceps femoris (long and short heads), semitendinosus, and semimembranosus. All but the short head of the biceps originate on the lateral ischial tuberosity, with the semimembranosus being most lateral and deep with a crescent-shaped origin. The common semitendinosus/biceps femoris origin is oval in shape and originates on the medial aspect of the hamstring footprint (Figure 1). Knowledge of adjacent anatomy is vital and provides landmarks for appropriate image interpretation and safe surgical approach. The average distance from the proximal semitendinosus/biceps origin to the inferior border of the overlying gluteus maximus is 6.3 cm.[4,5] Most importantly, the sciatic nerve is 1.2 cm from the lateral bony aspect of the hamstring origin, and the inferior gluteal nerve travels 5 cm cephalad to the inferior border of the gluteus maximus.[4,5] Knowledge of these relationships is essential to protect neural anatomy during surgical repair.

After originating on the lateral ischial tuberosity, the semimembranosus tendon passes anteriorly (deep) to the common semitendinosus/biceps tendon and becomes the most medial muscle of the hamstring complex with the semitendinosus overlying it. The long head of the biceps has the most proximal muscle belly, arising 6 cm from its origin and proceeding distally with a long myotendinous junction. The long head of the biceps becomes the most lateral muscle of the posterior thigh (Figure 1). The short head of the biceps origin lies on the posterior femur just medial to the linea aspera. Distally, the semimembranosus has multiple insertions on the posteromedial tibia, whereas the semitendinosus becomes the most distal portion of the pes anserinus triad. The long head of the biceps attaches on the lateral fibular head and tibia. Similar to the semimembranosus, the short head of the biceps has many insertions including the long head of the biceps tendon as well as the posterolateral capsule, iliotibial band, fibular head, and lateral tibia.[4,5]

Figure 1

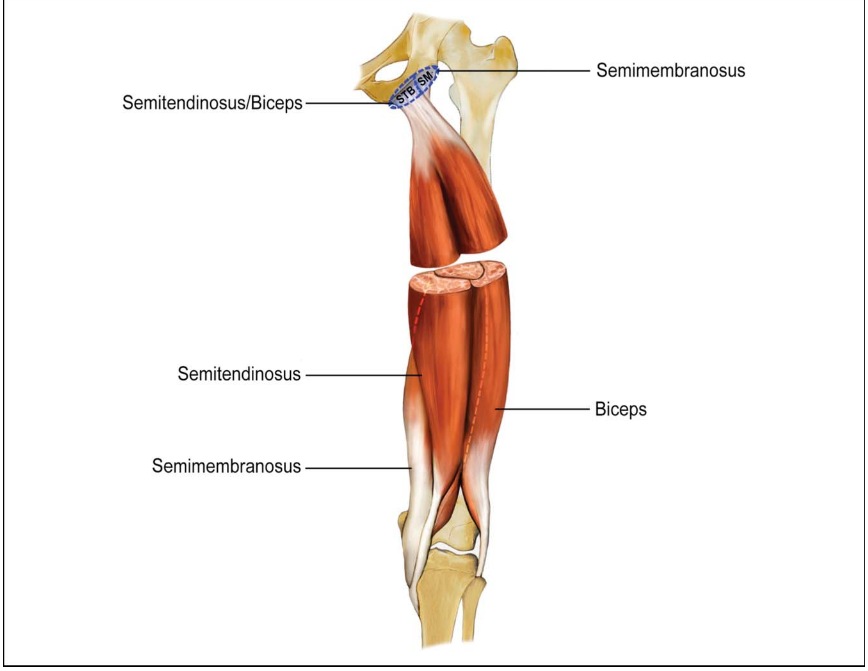


Illustration showing the anatomy of the hamstring origin (STB = conjoined tendon of the semitendinosus and biceps, SM = semimembranosus) along with their anatomic relationships in the posterior thigh.

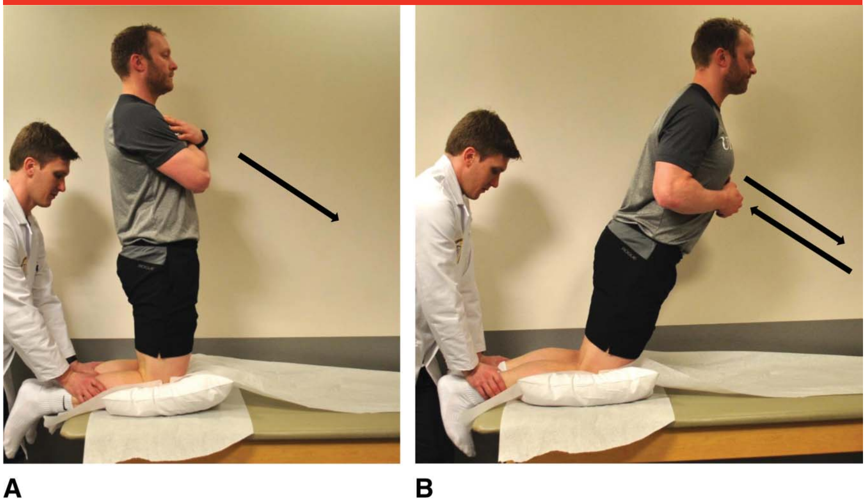
The hamstrings (with the exception of the short head of the biceps) traverse both the hip and knee joints allowing the muscles to both extend the hip and flex the knee. The muscle complex also limits knee extension just before and during heel strike to provide dynamic stability. A complex interplay exists between eccentric contraction of the hamstrings and concentric contraction of the quadriceps.[6]

Mechanisms of Injury and Risk Factors

The hamstrings are at increased injury risk because they cross both the hip and knee joints. Injury most commonly occurs during eccentric contraction. The greatest strain occurs at the end of swing phase when the hamstrings eccentrically contract at their maximal elongation before heel strike. Eccentric contraction extends the hip and decreases knee extension from heel strike through stance phase. Intramuscular or musculotendinous injuries most commonly occur during the takeoff phase of running, with the biceps femoris being most commonly injured.[2] In contrast, proximal hamstring avulsions typically occur during eccentric contraction with the hip flexed and knee extended, putting the muscle on maximum tension. The semimembranosus origin is the least likely to rupture, and its intact tissue can help prevent notable tendon retraction.[7]

Common risk factors for injury are listed in Table 1 (Supplemental

Figure 2



Photographs showing Nordic hamstring exercise: an eccentric exercise where (**A**) the athlete kneels while his heels are held to the ground by an assistant, (**B**) then the athlete leans forward allowing his knees to extend in a controlled manner until he or she is laying prone. A hamstring curl is then performed so the athlete's body is again in the kneeling position with his knees at 90°.

Digital Content 1, http://links.lww.com/JAAOS/A370) as are factors shown not to affect injury.[2,8,9] Risk factors can be grouped into three categories: inadequate preparation (deconditioning, inadequate warm-up, fatigue, dehydration), muscular dysfunction/imbalance (hamstring-quadricep imbalance, hamstring strength deficits, core weakness, muscular recruitment issues), and anatomic abnormalities (leg length inequality, short fascicle length, previous injury).[10] It is postulated that a previous injury leads to a notable recurrence risk because the reparative scar serves as a stress riser adjacent to normal muscle, lowering the threshold for reinjury in areas adjacent to scaring. The quality of scar formation and remodeling is the single most important determinant of subsequent muscle function and risk of reinjury.[2]

Injury Prevention

Hamstring strength training is an important aspect of injury prevention. Exercises focusing on improved eccentric knee flexion have been shown to decrease injury recurrence.[11] Further injury prevention may be possible through isolated targeting of specific hamstring muscles, with the long head of the biceps femoris and semimembranosus being more active during hip extension and the semitendinosus and short head of the biceps femoris preferentially assisting knee flexion. Eccentric exercises such as the Nordic hamstring exercise have been shown to reduce hamstring injuries by 50% to 70% in large athletic populations; however, its use is not widespread.[3,12,13] This is an eccentric exercise where the athlete kneels while his heels are held to the ground by an assistant and then the athlete leans forward allowing his knees to extend in a controlled manner until he or she is laying prone. Then, a hamstring curl is performed so the athlete's body is again in the kneeling position with his knees at 90° (Figure 2). The greater education of sports medicine health care teams and further evidence-based outcome studies are needed to determine when and how preventive measures can be successful.[11]

Evaluation of Injuries

History and physical examination are the cornerstones for proper evaluation. Knowledge of the mechanism of injury, location of pain, and history of previous injuries are vital. Typically, athletes complain of acute pain in the posterior thigh during running, kicking, or jumping motions. Occasionally these athletes will recall an audible or palpable pop. After injury, an abnormal gait is common. Athletes with nonsevere recurrences or chronic issues frequently have hamstring tightness. In proximal avulsions, pain with sitting is common.

Physical examination should first include visualization for ecchymosis as well as palpation for defects and for maximal tenderness in three distinct locations: the ischial tuberosity, myotendinous junction, and distal tendinous insertions. Bruising is most commonly seen in proximal avulsions and high-grade myotendinous tears, whereas defects can sometimes be felt in muscle belly injuries. The popliteal angle should be measured bilaterally, with the uninjured leg offering insight into hamstring flexibility. Motor evaluation should evaluate knee flexion strength at varying degrees of flexion, including 90°, 45°, and 15°. A complete neuromotor examination is essential for distal function of the peroneal nerve distributions (ankle dorsiflexion/eversion). Peroneal nerve injuries are most common and present as neurapraxias; however, on occasion foot drop or eversion weakness can occur.

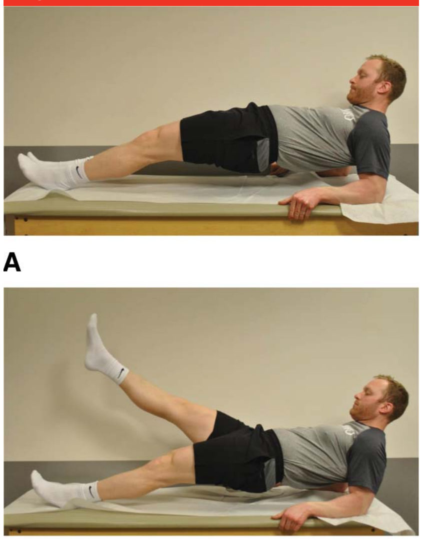
Special hamstring tests include the Puranen-Orava test (heel on an elevated surface and patient touches toes), the bent-knee stretch test (knee to chest stretch), modified bent-knee stretch test (examiner extends the knee during knee to chest stretch), all

Figure 3

Photograph showing standing heel-drag test: single leg squat with the contralateral foot placed anteriorly on the ground, and then, the foot is dragged back to midline.

which are validated and shown to be highly reliable to identify tendinopathy and strains. Other tests that the authors find useful include the resisted hamstring curl, the standing heel-drag test (single leg squat with contralateral foot placed anteriorly on the ground and then the foot dragged back to midline) (Figure 3), and the plank test (supine patient rises on elbows and raises the uninjured leg off examination table and then extends the hip of the injured side to elevate the pelvis) (Figure 4). The authors also find two modifications of the plank test to be helpful: (1) the affected hip is flexed off the table and the examiner holds the heel and then instructs the patient to extend their hip to raise their pelvis off the table (Figure 5) and (2) the examiner supports both heels in

Figure 4



A

B

Photographs showing plank test: (**A**) the patient in supine position rises on elbows, (**B**) raises the uninjured leg off the examination table, and then extends the hip of the injured side to elevate the pelvis.

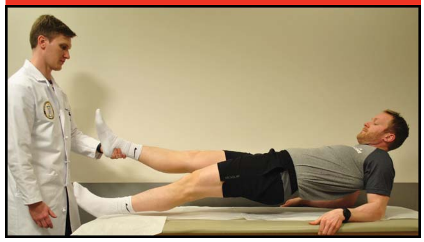
the air while the patient extends both hips so their pelvis is elevated off the table, and then, the examiner releases the unaffected heel so the affected leg alone is supporting the pelvis (Figure 6). If pain is elicited, these are considered positive.[2,14,15] Evaluation of gait is also important, particularly in proximal avulsions because these patients typically attempt to avoid both hip flexion and knee extension, resulting in a stiff-legged gait.

Treatment and Outcomes

Proximal Hamstring Avulsions

Patients with a suspected proximal avulsion injury are initially imaged with an AP pelvis radiograph to evaluate for possible bony avulsion, which is most commonly seen in skeletally immature patients. MRI is recommended when a hamstring avulsion is suspected to evaluate the

Figure 5

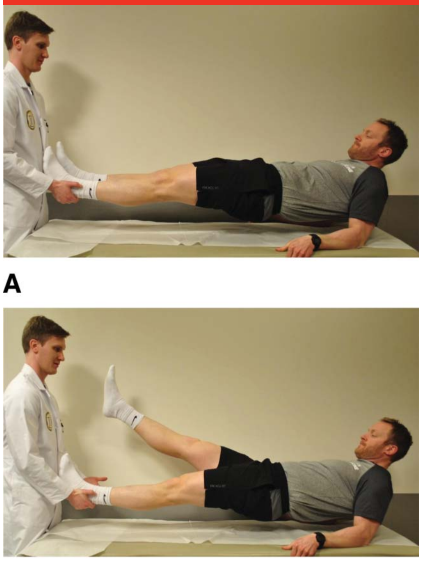


Photograph showing plank modification 1: the affected hip is flexed off the table, and the examiner holds the heel and then instructs the patient to extend their hip to raise their pelvis off the table.

insertion site and quantify the number of involved tendons as well as their degree of retraction. A careful examination of the sciatic nerve is essential because scaring in chronic proximal hamstring injuries may cause neuropathy. MRI is also useful in these cases because the sciatic nerve can be traced to identify points of potential tethering to the retracted tendons.[16] A recent meta-analysis reported a 23.17% complication rate with surgical fixation, 7.99% being neurologic.[17]

Multiple studies with small patient numbers have evaluated surgical repair of hamstring avulsions with many reporting good outcomes in acute ruptures, whereas chronic cases showed more variable improvement.[16,18-20] In a seminal article in 2008, Wood et al[21] evaluated 72 patients with proximal hamstring avulsions at an average 2-year follow-up using a three-anchor modified Mason-Allen suture technique. They reported 84% return of strength and 89% return in endurance, with poorer prognosis in severe retracted tears or with scaring to the sciatic nerve, both causing a more technically challenging repair. However, repair afforded an improved prognosis even in chronic cases where 80% returned to their preinjury level at 6 months. In the first study to use validated outcome measures, our

Figure 6



A

B

Photographs showing plank modification 2: (**A**) the examiner supports both heels in the air while the patient extends both hips so their pelvis is elevated off the table, (**B**) then the examiner releases the unaffected heel so the affected leg alone is supporting the pelvis.

Figure 7

A

B

A, Radiograph showing a bony avulsion fracture of the right ischial tuberosity. **B**, Radiograph status after acute open reduction and internal fixation of the avulsion fracture.

group reported on 40 acute and 12 chronic avulsions at an average 2.8-year follow-up. We found both acute and chronic repairs to be successful regarding outcome scoring, with 67% of patients participating in strenuous activities and 98% of patients reporting satisfaction with their outcome.[22] At midterm follow-up, Sandmann et al[23] reported that functional outcomes returned to baseline, knee strength was equivalent to the uninjured leg, and high levels of return to sport were achieved in 15 patients at an average 4.6-year follow-up.

In the skeletally immature patient, ischial tuberosity avulsion fractures account for 10% to 11% of all pelvic avulsion fractures.[24] These are the most common pelvic apophyseal avulsion fractures to undergo surgical fixation, typically by acute open reduction and internal fixation (Figure 7). Case reports have described symptomatic nonunions in cases with >2 cm of fracture displacement, so this degree of displacement is now considered a relative indication for acute repair.[25] Delayed symptoms caused by ischial malunions have also been reported after conservative treatment of ischial tuberosity avulsion, with delayed fragment excision with or without hamstring repair showing notable clinical improvement.[24,25]

Overall the authors recommend surgical repair if more than one tendon is involved in a soft-tissue injury or if a bony avulsion is displaced >2 cm.[21,26] There is good evidence that if tendon retraction is >2 cm, surgical fixation leads to improved outcomes; however, no studies exist comparing different distances of retraction. Yet, higher amounts of retraction have been linked to poorer outcomes.[21] One study found that 40% of nonsurgically treated proximal hamstring avulsions of <2 cm eventually required surgical intervention.[26] We think that if proximal hamstring retraction is <2 cm, an individualized treatment decision should be made in concert with the patient. Although no studies have yet evaluated the number of avulsed tendons to failure rates, we think that if more than one tendon is torn, greater tension is likely placed on the remaining poor quality tendon thus making surgery necessary. Discussed below are our current techniques for soft-tissue repair of proximal hamstring ruptures.

Surgical Technique

The patient is placed prone on the operating table with the bed slightly flexed at the hips to improve exposure. The leg is prepped free so the knee can be flexed to relieve hamstring tension during reduction and repair. A transverse incision is made in the gluteal crease which can be extended distally in a "T" configuration to access large retracted tears; however, the authors find this rarely necessary. After dissection through the subcutaneous tissues, the gluteal fascia is transversely incised to reveal the gluteus maximus. The authors prefer to split the muscle rather than to dissect inferior to its border because superior retraction of the entire gluteus maximus makes exposure and anatomic repair more difficult.

A longitudinal incision is then made in the hamstring septum over the ischium with care to avoid injury to the sciatic nerve. The hamstring

Figure 8

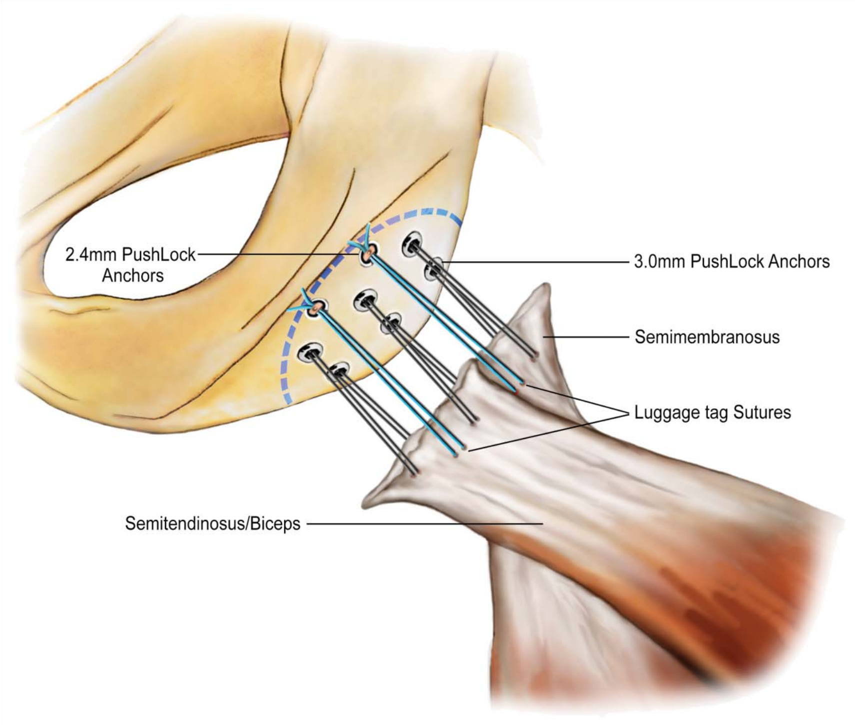


Illustration showing the authors' preferred proximal hamstring avulsion fixation technique with six anchors (3.0-mm PushLock; Arthrex) on the ischial tuberosity, in an anatomic simple mattress suture configuration, tying them distal to proximal with the knee flexed. Then, two luggage tag sutures are placed at the medial leading edge of the tendon and dunked into their own smaller suture anchors (2.4-mm PushLock).

Figure 9

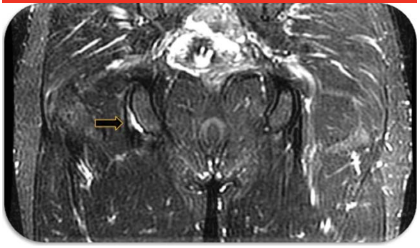
Illustration showing postfixation of proximal hamstring avulsion repair showing the authors' preferred technique with six anchors tied in an anatomic simple mattress suture configuration with two luggage tag sutures placed at the medial leading edge of the tendon.

fascia is typically intact; the surgeon must not allow this to mislead them into believing that the hamstrings are intact. A fluid collection or hematoma is often encountered after a vertical fascial incision. Evacuation of fluid and blood allows identification of the torn hamstring tendons which are then tagged, then edges débrided to healthy tissue. Next, the hamstring insertional anatomy at the ischium is identified with the facet being more inferior and lateral than most appreciate. The leg may be rotated during dissection to confirm the ischium is indeed encountered and not the lesser trochanter. Subperiosteal dissection starts proximal and medial and then goes distal and lateral where the tear is typically appreciated. Once the ischium is exposed, the insertion site is curetted and an osteotome is used to fish scale the cortical bone to improve the healing environment. No motorized instruments are used to decrease risk of injury to the sciatic nerve.

Like many repair techniques, bone tunnels with suture have been abandoned in favor of multiple bioabsorbable suture anchors. Miller et al first described using four anchors in a box configuration with simple mattress sutures. The authors have transitioned from five anchors in an "X" pattern to six anchors (3.0 mm PushLock; Arthrex) positioned like the face on a die. Sutures are tied in a simple mattress configuration distal to proximal with the knee flexed. More recently, the authors have also placed two luggage tag sutures at the medial leading edge of the tendon, which are dunked into smaller suture anchors (2.4 mm PushLock; Arthrex) to help improve bony contact (Figures 8 and 9). After a layered closure, patients are made toe-touch weight bearing and placed in a knee brace flexed to 40° for 4 weeks. The brace is then discontinued allowing progressive weight bearing over the next 4 weeks with pain-free arch of motion against gravity. We prefer a knee brace rather than a hip brace because these are too cumbersome for the patient and we do not think they provide a notable advantage. The authors think a knee brace locked at 40° sufficiently decreases tension on the repair and adequately slows patient's activity. A progressive return to sport protocol is then carried out over the ensuing 6 months as previously described.[2]

Timing of surgical intervention appears to be critical, with studies reporting more difficult exposure and fixation as well as more sciatic nerve neurolysis being required in chronic complete tears. Subbu et al[27] defined early repair as within 6 weeks of injury and found those patients to

Figure 10



Sagittal pelvis T2 MRI showing a right partial avulsion of the proximal hamstring origin with the sickle sign.

have quicker return to sport and better outcomes, whereas the chronic group displayed increased morbidity and complications. Similarly, Blakeney et al[28] defined chronic as over 3 months from injury, and found both acute and chronic repairs had improved outcomes. However, early repairs did have better outcomes in comparison with chronic repairs in their cohort of 94 patients.

Overall, good results have been reported in acute repairs when matched with those treated nonsurgically with increased strength, less pain, improved return to sport, and higher patient satisfaction. Chronic complete retracted repairs are less predictable and more difficult technically, with added challenges of mobilizing the tendons to the ischium and freeing tendons that may have scarred to the nearby sciatic nerve. Furthermore, chronic tears have higher rates of re-rupture and chronic pain. Despite these difficulties, studies have reported improved outcomes with surgical fixation when compared with those treated nonsurgically.[22,29]

Partial Proximal Hamstring Tears

Partial proximal hamstring ruptures are less well studied, but typically are attributed to chronic overload, commonly encountered in running and Pilates activities. One source of confusion is the differentiation between tendinopathy and partial tears. The literature is unclear regarding the progression of hamstring tendinopathy to partial tendon rupture, but the authors think these injuries begin as tendinosis/tendinopathy patterns, which progress to partial tears with continued stress. MRI is useful to distinguish these pathologies. Tendinopathy is seen as increased signal on T1 but not on proton density sequences, whereas partial tears have an increased signal focus on T2 as the classic sickle sign on coronal cuts, which indicates a poor scar response[2] (Figure 10).

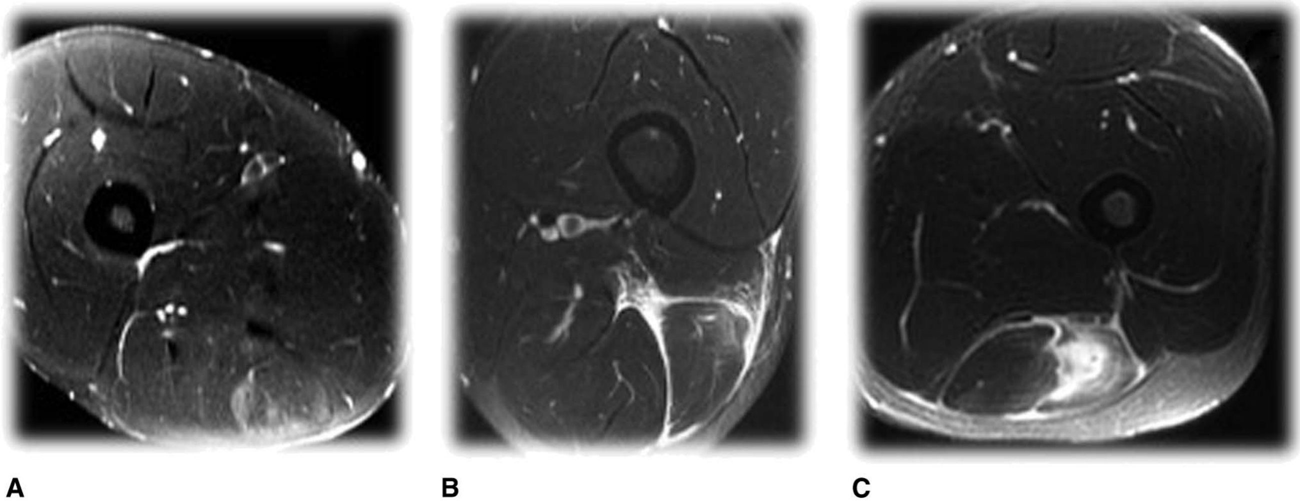
Our group published the first cohort of partial repairs in 2013 that included 17 patients with an average 32-month follow-up. All 17 patients who had a tear intraoperatively had a sickle sign on MRI. The authors found improvements in all outcome scores with surgical repair. All returned to sport at the same level; however, one had persistent symptoms during competitive distance running.[15] More recently, Piposar et al[26] compared 15 patients undergoing nonsurgical and 10 undergoing surgical treatment for high-grade partial or complete ruptures and found both groups had acceptable subjective and objective outcomes. However, 40% (4/10) of those treated nonsurgically required future surgery for persistent pain or loss of function, indicating that more aggressive early operative treatment may be beneficial. A recent meta-analysis compared partial and complete avulsion repairs and found better strength and endurance in partial tears, but higher patient satisfaction, less pain, and higher complication rates in complete tears.[17]

Adjuncts to nonsurgical treatment, including platelet-rich plasma (PRP), have shown promise in partial hamstring avulsions. Fader et al[30] found that 10 of 18 patients who previously failed physical therapy had greater than 80% improvement in their visual analogue score after leukocyte-reduced PRP injections. They concluded that leukocyte-reduced PRP treatment was safe and benefited most patients, with the major adverse reaction being 72 hours of postinjection soreness. Park et al[31] compared 32 patients who received PRP and 24 who received steroid injections for grade 2 proximal hamstring injuries and found a more favorable response in the PRP group at 1 week. At 4 weeks, PRP had better outcome scores but did not reach statistical significance. The authors' protocol for PRP treatment is one double dose with injection under CT or ultrasonography. Anecdotally, the authors have observed that approximately 50% are able to return to their preinjury level after injection, whereas those with a sickle sign on MRI receive little benefit. Partial tears that fail injections, physical therapy, activity modifications, or patients who want to continue a very active lifestyle are typically recommended for surgical intervention.

Muscle Belly Injuries

Hamstring muscle belly injuries are common and can cause notable pain and prolonged disability. The biceps femoris is most commonly injured (84%), with the semimembranosus making up 12% and semitendinosus 4% of injuries.[32] MRI grade and size of tear have been shown to be useful in predicting return to sport; however, Reurink et al reported that many of these studies have a risk of bias.[2,32,33] T2 hyperintensity is the basis of the most common classification, where grade I is signal of a tendon or muscle without disruption, grade II is disruption of less than half of the width, and grade III being over half disrupted (Figure 11). A more detailed MRI scoring system was developed by our group that has been found to be highly predictive in

Figure 11



T2 axial MRIs showing (**A**) grade 1 hamstring strain without disruption, (**B**) grade 2 hamstring strain with tearing <50%, and (**C**) grade 3 hamstring strain with >50% tearing.

determining time missed by assigning points based on (1) age, (2) number of muscles involved, (2) location, (3) if the insertion was involved, (4) percent of cross-sectional injury, (5) amount of retraction, and (6) proximal to distal length of injury (Table 2, Supplemental Digital Content 1, http://links.lww.com/JAAOS/A370). These data were based on data from two National Football League (NFL) teams with 43 injuries. Our group was able to separate players by rapid (<1 week), intermediate (2 to 3 weeks), or prolonged return to play (>3 weeks) and correlated these with MRI scores of <10 for rapid return and >15 in those with prolonged return to play. Table 3 (Supplemental Digital Content 1, http://links.lww.com/JAAOS/A370) shows more detailed findings of this study regarding MRI parameters and return to play in these three categories.[8]

Conservative treatment of muscle belly injuries is well established including rest, ice, compression, modalities, and NSAIDs with gradual return to activities. The use of steroid injections is controversial, with some reporting quicker return to play and better recovery of contractile tension without ill effects.[8] A recent meta-analysis found rehab to produce the best results with limited evidence to support PRP, agility, or trunk stabilization. Specifically, eccentric strengthening was shown to decrease reinjury and improve muscle fiber length in 14 days; however, many of these studies were markedly underpowered and of fair or poor quality.[34] With data from our group and the authors' experience, Table 4 (Supplemental Digital Content 1, http://links.lww.com/JAAOS/A370) shows the expected time off for in-season hamstring injuries.[8] The authors' protocol for treatment of elite athletes typically involves MRI to localize and grade the injury, followed by a PRP injection within 24 to 48 hours. Second and third injections are repeated 5 to 7 days apart based on response to preceding injections. Physical therapy is instituted and functional testing (ie, plank strength, knee flexion strength at 15 degrees, etc.) is used to determine when the athlete can return to sport. The authors also now incorporate and compare baseline Catapult GPS (Melbourne, Australia) data as RTP criteria where NFL players must be within 1 mile per hour of running speed, have the same work load, and same angular velocity before being released to full play.

A study currently in progress by our group compared 31 NFL football players who received PRP with 30 who did not for grade 2 hamstring injuries. We found PRP injections allowed NFL players to return 1 game sooner ($P < 0.05$) compared with those who received rehabilitation alone. No re-tears occurred in the PRP group, which is noteworthy because RTP is prolonged if a re-tearing occurs at the same location. Because of the potential financial impact of expedited return to play and decreased re-tear rates, PRP injections for treatment of grade 2 hamstring injuries may be advantageous in professional athletes. The authors believe the use of leukocyte-poor PRP is essential and is the main contributor of the varied results regarding the efficacy of PRP in the literature.[35,36]

Distal Hamstring Injuries

Literature regarding distal hamstring injuries is sparse. Isolated distal biceps femoris tears typically occur from noncontact mechanisms and are commonly part of a multiligament knee injury. Case reports of isolated injuries suggest that acute repair results in improved outcomes.[37] Repair techniques include suture, suture anchors, or transosseous, with the latter having the highest load to failure.[38]

Isolated distal semimembranosus ruptures are rare and have even more limited literature. Case reports indicate that acute surgical repair is indicated and yields good results, while myotendinous junction repairs results in poor outcomes.[39] Distal semitendinosus injuries typically occur during sprinting and present with popliteal tenderness and skin puckering following retraction. Treatments include rest followed by physical therapy, débridement, or surgical repair. The literature is unclear regarding what factors may predict success of nonsurgical treatment. Cooper and Conway[40] evaluated 25 elite athletes and found nonsurgical treatment resulted in poor outcomes with 42% unable to recover, whereas acute débridement quickened recovery in those with a painful mass and issues with knee extension. Although rarely isolated, surgical intervention of distal hamstring injuries should be considered in athletes.

Summary

Hamstring injuries are common in athletes and can cause notable disability. They can be separated based on proximal, muscle belly, and distal injuries, with proximal and distal injuries more commonly requiring surgical intervention. Most injuries do not require acute MRI; however, MRI is useful in proximal and distal injuries as well as muscle belly tears that fail to respond to nonsurgical treatment. Acute repair of proximal avulsions, both partial and complete, result in successful outcomes, whereas chronic complete repairs are more difficult and less reliable. Muscle belly injuries have predictable outcomes but recurrence is common. Nonsurgical treatments focus on eccentric strengthening with the possible addition of leukocyte-poor PRP, which may have the potential to hasten recovery and decrease re-rupture. Distal injuries are relatively rare but may require surgical intervention. Hamstring reinjury is common, making continuation of preventive therapies after return to sport essential. Future research with larger sample sizes are required to determine how to decrease injury and reinjury rates, to evaluate the efficacy of PRP, and to determine other treatments that may accelerate recovery after injury.

References

Levels of evidence are described in the table of contents. In this article, references 12, 13, 35 are level I studies. References 10 and 32 are level 2 studies. References 3, 6, 8, 9, 15, 18, 19, 22, 23, 24, 26, and 27 are level III studies. References 1, 2, 4, 5, 7, 11, 14, 16, 17, 20, 21, 25, 28, 29, 30, 31, 33, 34, 36, 37, 38, 39, and 40 are level IV studies.

References printed in **bold type** are those published within the past 5 years.

1. Croisier JL: Factors associated with recurrent hamstring injuries. *Sports Med* 2004;34:681-695.
2. Ahmad CS, Redler LH, Ciccotti MG, Maffulli N, Longo UG, Bradley J: Evaluation and management of hamstring injuries. *Am J Sports Med* 2013;41: 2933-2947.
3. **Ekstrand J, Walden M, Hagglund M: Hamstring injuries have increased by 4% annually in men's professional football, since 2001: A 13-year longitudinal analysis of the UEFA elite club injury study. *Br J Sports Med* 2016;50:731-737.**
4. Miller SL, Webb GR: The proximal origin of the hamstrings and surrounding anatomy encountered during repair: Surgical technique. *J Bone Joint Surg Am* 2008;90(suppl 2 pt 1):108-116.
5. **Stepien K, Smigielski R, Mouton C, Ciszek B, Engelhardt M, Seil R: Anatomy of proximal attachment, course, and innervation of hamstring muscles: A pictorial essay. *Knee Surg Sports Traumatol Arthrosc* 2019;27:673-684.**
6. Jonhagen S, Ericson MO, Nemeth G, Eriksson E: Amplitude and timing of electromyographic activity during sprinting. *Scand J Med Sci Sports* 1996;6: 15-21.
7. **Wangensteen A, Tol JL, Witvrouw E, et al: Hamstring reinjuries occur at the same location and early after return to sport: A descriptive study of MRI-confirmed reinjuries. *Am J Sports Med* 2016;44: 2112-2121.**
8. Cohen SB, Towers JD, Zoga A, et al: Hamstring injuries in professional football players: Magnetic resonance imaging correlation with return to play. *Sports Health* 2011;3:423-430.
9. Elliott MC, Zarins B, Powell JW, Kenyon CD: Hamstring muscle strains in professional football players: A 10-year review. *Am J Sports Med* 2011;39:843-850.
10. **Schuermans J, Van Tiggelen D, Danneels L, Witvrouw E: Susceptibility to hamstring injuries in soccer: A prospective study using muscle functional magnetic resonance imaging. *Am J Sports Med* 2016;44: 1276-1285.**
11. **Bourne MN, Timmins RG, Opar DA, et al: An evidence-based framework for strengthening exercises to prevent hamstring injury. *Sports Med* 2018;48: 251-267.**
12. Petersen J, Thorborg K, Nielsen MB, Budtz-Jorgensen E, Holmich P: Preventive effect of eccentric training on acute hamstring injuries in men's soccer: A cluster-randomized controlled trial. *Am J Sports Med* 2011;39:2296-2303.
13. **van der Horst N, Smits DW, Petersen J, Goedhart EA, Backx FJ: The preventive effect of the Nordic hamstring exercise on hamstring injuries in amateur soccer players: A randomized controlled trial. *Am J Sports Med* 2015;43:1316-1323.**
14. Cacchio A, Borra F, Severini G, et al: Reliability and validity of three pain provocation tests used for the diagnosis of chronic proximal hamstring tendinopathy. *Br J Sports Med* 2012;46:883-887.
15. Bowman KF Jr, Cohen SB, Bradley JP: Operative management of partial-thickness tears of the proximal hamstring muscles in athletes. *Am J Sports Med* 2013;41: 1363-1371.
16. Bucknor MD, Steinbach LS, Saloner D, Chin CT: Magnetic resonance neurography evaluation of chronic extraspinal sciatica after remote proximal hamstring injury: A

preliminary retrospective analysis. *J Neurosurg* 2014;121:408-414.

17. **Bodendorfer BM, Curley AJ, Kotler JA, et al: Outcomes after operative and nonoperative treatment of proximal hamstring avulsions: A systematic review and meta-analysis. *Am J Sports Med* 2018; 46:2798-2808.**

18. Brucker PU, Imhoff AB: Functional assessment after acute and chronic complete ruptures of the proximal hamstring tendons. *Knee Surg Sports Traumatol Arthrosc* 2005;13:411-418.

19. Cross MJ, Vandersluis R, Wood D, Banff M: Surgical repair of chronic complete hamstring tendon rupture in the adult patient. *Am J Sports Med* 1998;26: 785-788.

20. Klingele KE, Sallay PI: Surgical repair of complete proximal hamstring tendon rupture. *Am J Sports Med* 2002;30: 742-747.

21. Wood DG, Packham I, Trikha SP, Linklater J: Avulsion of the proximal hamstring origin. *J Bone Joint Surg Am* 2008;90: 2365-2374.

22. Cohen SB, Rangavajjula A, Vyas D, Bradley JP: Functional results and outcomes after repair of proximal hamstring avulsions. *Am J Sports Med* 2012;40:2092-2098.

23. **Sandmann GH, Hahn D, Amereller M, et al: Mid-term functional outcome and return to sports after proximal hamstring tendon repair. *Int J Sports Med* 2016;37: 570-576.**

24. **Schuett DJ, Bomar JD, Pennock AT: Pelvic apophyseal avulsion fractures: A retrospective review of 228 cases. *J Pediatr Orthop* 2015;35:617-623.**

25. Servant CT, Jones CB: Displaced avulsion of the ischial apophysis: A hamstring injury requiring internal fixation. *Br J Sports Med* 1998;32:255-257.

26. **Piposar JR, Vinod AV, Olsen JR, Lacerte E, Miller SL: High-grade partial and retracted (<2 cm) proximal hamstring ruptures: Nonsurgical treatment revisited. *Orthop J Sports Med* 2017;5:2325967117692507.**

27. **Subbu R, Benjamin-Laing H, Haddad F: Timing of surgery for complete proximal hamstring avulsion injuries: Successful clinical outcomes at 6 weeks, 6 months, and after 6 months of injury. *Am J Sports Med* 2015;43:385-391.**

28. **Blakeney WG, Zilko SR, Edmonston SJ, Schupp NE, Annear PT: A prospective evaluation of proximal hamstring tendon avulsions: Improved functional outcomes following surgical repair. *Knee Surg Sports Traumatol Arthrosc* 2017;25:1943-1950.**

29. **van der Made AD, Reurink G, Gouttebarge V, Tol JL, Kerkhoffs GM: Outcome after surgical repair of proximal hamstring avulsions: A systematic review. *Am J Sports Med* 2015;43:2841-2851.**

30. Fader RR, Mitchell JJ, Traub S, et al: Platelet-rich plasma treatment improves outcomes for chronic proximal hamstring injuries in an athletic population. *Muscles, Ligaments Tendons J* 2014;4:461-466.

31. **Park PYS, Cai C, Bawa P, Kumaravel M: Platelet-rich plasma vs. steroid injections for hamstring injury-is there really a choice? *Skeletal Radiol* 2019;48:577-582.**

32. **Ekstrand J, Lee JC, Healy JC: MRI findings and return to play in football: A prospective analysis of 255 hamstring injuries in the UEFA elite club injury study. *Br J Sports Med* 2016;50:738-743.**

33. **Reurink G, Brilman EG, de Vos RJ, et al: Magnetic resonance imaging in acute hamstring injury: Can we provide a return to play prognosis? *Sports Med* 2015;45: 133-146.**

34. **Pas HI, Reurink G, Tol JL, Weir A, Winters M, Moen MH: Efficacy of rehabilitation (lengthening) exercises, platelet-rich plasma injections, and other conservative interventions in acute hamstring injuries: An updated systematic review and meta-analysis. *Br J Sports Med* 2015;49: 1197-1205.**

35. **Hamilton B, Tol JL, Almusa E, et al: Platelet-rich plasma does not enhance return to play in hamstring injuries: A randomised controlled trial. *Br J Sports Med* 2015;49:943-950.**

36. **Sheth U, Dwyer T, Smith I, et al: Does platelet-rich plasma lead to earlier return to sport when compared with conservative treatment in acute muscle injuries? A systematic review and meta-analysis. *Arthroscopy* 2018;34:281-288. e281.**

37. **Knapik DM, Metcalf KB, Voos JE: Isolated tearing and avulsion of the distal biceps femoris tendon during sporting activities: A systematic review. *Orthop J Sports Med* 2018;6:2325967118781828.**

38. **Branch EA, Loveland D, Sadeghpour S, Anz AW: A biomechanical assessment of biceps femoris repair techniques. *Orthop J Sports Med* 2018;6:2325967117748891.**

39. **Blakeney WG, Thaunat M, Ouanezar H, de Campos GC, de Padua VBC, Sonnery-Cottet B: Distal semimembranosus tendon avulsions: Acute surgical repair in a professional rugby player. *Orthop J Sports Med* 2017;5:2325967117731102.**

40. Cooper DE, Conway JE: Distal semitendinosus ruptures in elite-level athletes: Low success rates of nonoperative treatment. *Am J Sports Med* 2010;38: 1174-1178.