Operative Techniques in
Orthopaedics

Proximal Hamstring Tears and Syndrome

Elan J. Golan, MD,* and James P. Bradley, MD†

Proximal hamstring avulsion is an oft-encountered injury, frequently resulting in significant physical impairment, especially in athletes and other highly active individuals. Prompt and accurate diagnosis is essential to maximizing outcomes and facilitating return to play. MRI imaging allows for precise characterization of injury patterns and location, and may be predictive of return to play. While often managed nonoperatively, recent evidence has demonstrated clear improvements in postoperative strength and patient satisfaction with surgical repair, especially in the setting of highly-retracted partial or complete injuries. Chronic injury may also be successfully managed operatively, though with more tempered expectations.
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Introduction

Hamstring injuries are among the most common reasons for lost time of play in athletes, often occurring in individuals participating in sports requiring rapid cutting or acceleration moments.[1-3] Indeed, such injuries make up almost one third of lower extremity injuries in individuals participating in sports such as hurdling, soccer, rugby, and American football. Such injuries are often recurrent, with a noted risk of reinjury a high as 12%-31%.[4,5] The incidence of hamstring injury may also be on the rise, with one analysis of NCAA athletes demonstrating a 4% annual increase in reported hamstring injuries over the last decade, with 33% attributed to recurrence.[6]

Proximal hamstring injuries, in particular, are notorious for prolonged recovery and increased impairment with activities of daily living. Characterization of proximal injuries is highly variable; ranging from low-grade strains, to partial tears, to complete, retracted avulsions. Recent advances in diagnosis and imaging, along with an evolution of surgical techniques and indications have greatly assisted in maximizing outcomes while facilitating pain-free resumption of activity.

*Freddie Fu Sports Medicine Building, UPMC Department of Sports Medicine, University of Pittsburgh, Pittsburgh, PA.

†Burke and Bradley Orthopaedics, University of Pittsburgh Medical Center, UPMC St. Margaret, Pittsburgh, PA.

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Address reprint requests to James P Bradley, MD, Burke and Bradley Orthopaedics, University of Pittsburgh Medical Center, UPMC St. Margaret, Medical Arts 200 200 Delafield Rd., Suite 4010, Pittsburgh, PA 15215. E-mail: bradleyjp@upmc.edu

Anatomy

The hamstring complex is composed of 3 muscles, working synergistically to effect hip extension and knee flexion. With the exception of the short head of the biceps femoris, the remaining 3 hamstring muscles cross both the knee and hip, placing them at increased risk for proximal injury. These 3 muscles originate from a common proximal tendon on the ischial tuberosity, coursing distally as their tendons separate between 5-10 cm from their origin. [7] The semimembranosus, semitendinosus, and long head of the biceps femoris share a common innervation from the tibial portion of the sciatic nerve, while the biceps short head is innervated by the peroneal nerve.

In terms of individual function, the semimembranosus imparts stability by contributing to medial extremity rotation while assisting with both knee flexion as well as extension and adduction of the thigh. The semitendinosus acts to flex and internally rotate the tibia, while also imparting valgus stability to the knee. The long head of the biceps extends the femur and hip, while providing posterior stability to the pelvis and extremity. Finally, being unique in traversing only the hip joint, the short head of the biceps contributes to knee flexion in a position of hip extension.

The long head of the biceps femoris and semitendinosus combine to form a 'conjoined tendon', with an oval shaped insertion that lies more medial and posterior on the ischial

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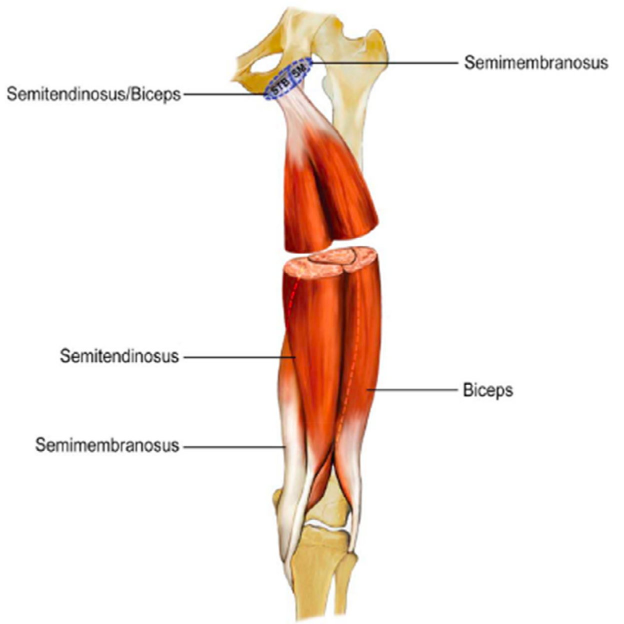

Figure 1 Illustration showing the anatomy of the hamstring origin (STB = conjoined tendon of the semitendinosus and biceps, SM = semimembranosus) along with their anatomical relationships in the posterior thigh.

tuberosity. In contrast, the semimembranosus possesses a crescent shaped insertion that inserts anterior and lateral to the conjoined tendon. The semimembranosus tendon is the first to grow distinct, usually at about 30% of its proximal to distal course, and represents the most medial component of the hamstring complex as it courses distally and anteriorly[1,8,9] (Fig. 1).

An understanding of several key anatomical relationships is crucial for successful intraoperative evaluation and management of proximal hamstring injury. Most importantly, the sciatic nerve lies an average of 1.2 cm lateral to the ischial facet and must be protected at all times. Once identified, the inferior edge of the Gluteus maximus muscle can also aid in guiding dissection, lying 6.3 cm caudal to the insertion of hamstring's conjoined tendon, and 5 cm caudal to the inferior gluteal nerve.[9]

Pathomechanics

The hamstrings' myotendinous junction experiences the highest eccentric loads during activity, and is the most common site of proximal injury.[10] The most common mechanism for proximal avulsion is a sudden, ballistic force experienced in a position of combined knee extension and hip flexion. This combination of forces is most commonly experienced during the terminal swing phase of gait cycle. In this position, the hamstring complex is particularly vulnerable, contributing to both maximal hip extension, while beginning to flex and decelerate the knee. Indeed, on analysis of sprint mechanics, maximal eccentric hamstring contraction is noted at terminal swing, just prior to heel strike.[11] Proximal hamstring avulsion may also occur in setting a sudden, extreme deceleration moment, with falls during skiing activities reported as the most common mechanism of injury in multiple series.[12,13]

Patient Presentation

Patients will often present with pain of variable course and intensity along the posterior extremity and pelvis. This pain is often exacerbated by activities necessitating some combination of hip extension or knee flexion and is commonly noted with prolonged sitting, especially in more chronic injuries.[14] Some, but not all, will recall a discrete pop during the injury. Especially in the setting of a complete rupture, ecchymosis from dependent hematoma may be readily appreciable at variable location along the course of the hamstring complex.

Following a thorough history, initial physical examination should begin with an assessment of strength and range of motion. It is imperative to perform a complete neurovascular exam in all patients with suspected proximal hamstring injury, as involvement of the sciatic nerve should not be overlooked. An increased popliteal angle, when compared to the contralateral side, is highly suggestive of tendinous injury. Patients will often demonstrate discomfort and decreased strength during prone, resisted knee flexion. A palpable gap may also be appreciated along the hamstring tendons' course.

Multiple special exam maneuvers have been described and validated to assess for proximal hamstring injury including the Puranen-Orava test and Bent Knee-Stretch or Hamstring Active tests. In a recent retrospective review, the hamstring active test performed at 30° and 90° was noted to be most sensitive and specific for the diagnosis of hamstring tear.[15] Others commonly employed exam maneuvers include the hamstring curl, standing heel drag, and plank tests.

In addition to the hamstring active test, we find a modification of the plank maneuver to be of particular clinical utility. The effected heel is first supported while the patient assumes a plank position, employing the contralateral side for support. Next, the patient is asked to replicate the maneuver on the contralateral side, attempting to support themselves only with the injured extremity. Pain or an inability to assume a plank position is considered positive,[1,16] and affords the added benefit of pinpointing the location of pathology for patients who often present with vague posterior pain that can be hard to localize (Fig. 2).

Imaging

Initial radiologic assessment begins with plain films of the pelvis. As bony avulsion injury is almost uniformly encountered in the skeletally-immature, x-rays are often noncontributory, with further imaging necessary to aid in diagnosis. Ultrasound represents a readily available and cost-effective method for initial evaluation. Indeed, ultrasound has been demonstrated to be as sensitive as MRI in detecting hamstring tears, though achieving such sensitivity it is highly dependent on user proficiency.[17]

It is our practice to routinely obtain MRI imaging in patients with a clinical exam suggestive of proximal hamstring injury.

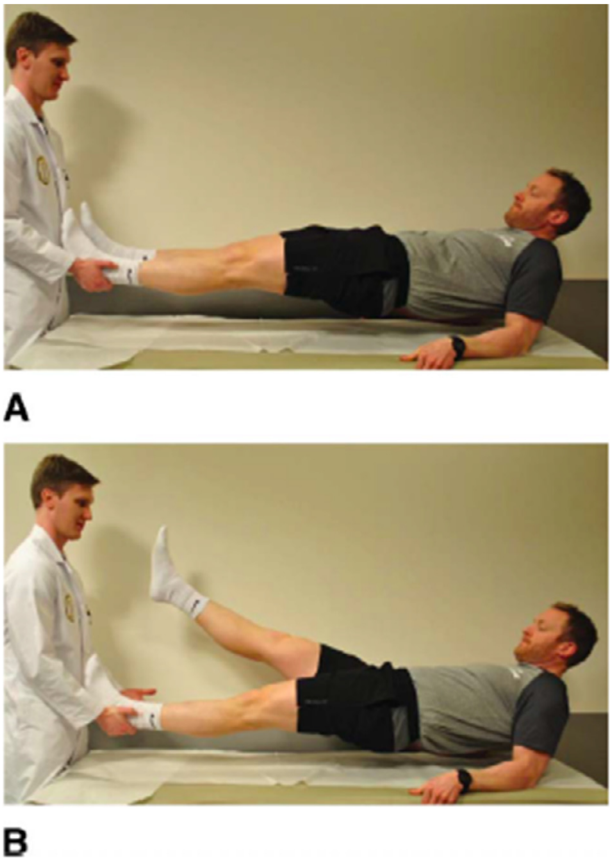

Figure 2 Photographs showing plank modification 2: (A) the examiner supports both heels in the air while the patient extends both hips so their pelvis is elevated off the table, (B) then the examiner releases the unaffected heel so the affected leg alone is supporting the pelvis.

MRI offers several distinct advantages over other modalities including; readily distinguishing between a discrete tear and tendinopathy, precise localization of the site of injury, easy identification of the number of involved tendons, and allowing for an immediate measure of tendon retraction. A 'sickle sign' appreciated on coronal T2 imaging often helps in appreciation of partial, proximal tears (Fig. 3).

Of course, practitioners should be cognizant of the fact that an MRI represents a single 'snapshot' in time and may mislead in cases of delayed tendon retraction, emphasizing the importance of reliance on history and clinical exam in those being considered for nonoperative management.

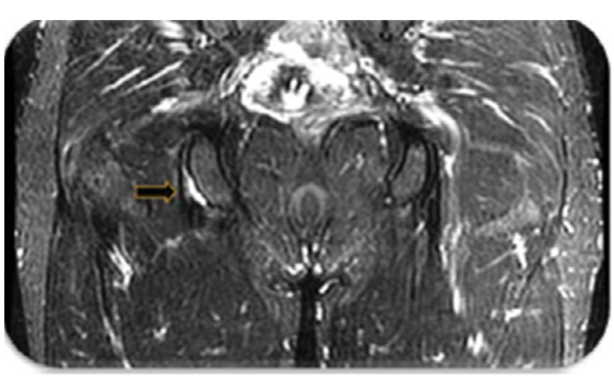

Figure 3 Sagittal T2 Imaging demonstrating partial tear of right proximal hamstring with a positive 'Sickle Sign' (arrow).

In an attempt to provide guidance for return to play based on radiologic findings, Cohen and Towers reviewed MRI imaging in professional football players following acute hamstring injury.[10] All individuals received an MRI within 3 days of injury, which were initially graded based on a traditional MRI scale. A more in depth analysis of imaging was then performed accounting for factors including: the number and location of injured muscles, percent cross sectional area involved, presence of retraction, degree of edema or presence of tendinopathy, and the overall craniocaudal extent of visualized pathology. Each finding was assigned a point value, with a score of <10 shown to correlate with a return to play of less than 1 week. In contrast, a score of >15 points was found to be predictive of a player missing a minimum of 2-3 games (Figs. 4, 5).

Based on such analysis, the authors were able to identify several radiologic factors independently predictive of return to play following a hamstring injury. For example, players with 100% tendon involvement averaged 7 games missed vs 6 or less with only 2 tendon involvement. Increasing retraction also correlated with time to return, as players missing 2 or more games averaged 1.1 cm of retraction, vs 0.1 cm averaged by players missing 1 game or less. The authors concluded that individual factors readily discernable on MRI imaging may help guide expectations in terms of return to athletic competition.

Indications

While the need for operative intervention in the setting of a proximal hamstring injury has been previously questioned, increasing recent evidence clearly supports improved outcomes with early surgical repair.[1,13,18-20] Further, several studies have noted nonoperative management to result in a debilitated state in some individuals,[21,22] with a high percent of active individuals initially choosing nonoperative

Grade	Description
I	T2 hyperintense signal about a tendon or muscle without visible disruption of fibers
II	T2 hyperintense signal around and within a tendon or muscle with fiber disruption spanning less than half the tendon or muscle width
III	Disruption of muscle or tendon fibers over more than half the muscle or tendon width as manifest by T2 hyperintense signal occupying the position of the injured tendon

Figure 4 Table of traditional MRI grading of musuclo-tendinous strains.

	Missed Games			
	0 or 1	≥ 2	Odds Ratio (95% CI)[a]	*P*
MRI score	7.9	11.9	1.5 (1.2, 1.9)	< 0.01
MRI grade II or III, %	25.0[b]	75.0[c]	0.10 (0.03, 0.35)	< 0.01
Age, years	26.7	26.9	1.02 (0.86, 1.2)	0.84
Retraction length, cm	0.1	1.1	2.9 (1.02, 8.4)	0.01
T2 signal length, mm	8.9	13.0	1.1 (1.02, 1.23)	0.02
Reinjury, %	0[d]	100[e]	N/A[f]	0.01

Figure 5 Univerate analysis demonstrating independent factors on MRI imaging of hamstring injury predictive of time missed (NFL games).

management eventually undergoing surgical repair.[23] Given such findings, our indications for operative management have expanded with increasing publication of clinical outcomes, especially when hamstring avulsions are encountered in athletes or other highly active individuals.[8]

Initially, operative management was reserved for injuries involving 2 or more tendons or demonstrating >2cm of retraction on imaging.[20] However, there are several potential drawbacks to this approach. Firstly, a tear exhibiting less than 2 cm of retraction at initial evaluation, may grow more retracted with continued activity. Further, tearing of 2 out of 3 hamstring tendons likely places increased forces on the lone tendon remaining intact, possibly leading to degenerative changes or even delayed rupture. Indeed, in one study, 40% of patients initially opting for nonoperative management of partial hamstring injuries exhibiting <2cm retraction ultimately required surgical repair.[23]

Our current approach is to treat 2 tendon tears with <2cm of retraction on a patient to patient basis, with operative management more likely to be recommended in athletes and other highly active individuals. While a wait-and-see approach can also be chosen, it is important to counsel patients as to the well-documented potential for worse outcomes in the setting of chronic injuries, should they eventually elect for a delay repair.[13,18,24]

Fortunately, an operative approach in injuries failing to respond to a trial of conservative treatment has been shown to be successful. In a series of 17 athletes with partial hamstring tears remaining symptomatic after a minimum of 6 months of conservative management, Bowman et al[25] reported an average postoperative custom-LEFS score of 66.7 out of a maximum of 80 points. No patient was found to have any interference with 20 surveyed activities of daily living. All but one individual were symptom free following intervention, with no patient requiring a subsequent procedure at final follow-up.

Author's Preferred Technique

Proximal hamstring repair is performed in the prone position under general anesthesia. After ensuring that all bony prominences are well-padded, the bed is flexed between 20° to 30° to facilitate visualization of the hamstring insertion at the ischial tuberosity. The operative leg is prepped and draped free in a manner allowing for intraoperative knee flexion to assist with tension-free reduction of the avulsed tendon(s).

Operative approach begins with a transverse incision made within the gluteal fold. This incision is preferred for cosmesis, and to allow for tension-free retraction of the laterally lying sciatic nerve. It is imperative to remain mindful of the sciatic nerve's location throughout the duration of the procedure, avoiding over vigorous lateral retraction that could result in postoperative palsy.[26] The skin incision can also be extended distally in a 'T' like configuration if more extensile exposure is required, though, in our experience, this is rarely necessary.[27]

Dissection is carried down to the gluteal fascia which is split longitudinally, in-line with the skin incision, using caution to protect the posterior gluteal nerve, which may be encountered crossing the operative field. Following division of the fascia, the inferior border of the gluteus maximus muscle is accessed and visualized. It is our preference to split the muscle rather than retract it superiorly, as difficulty with superior retraction may hinder visualization, especially in larger or muscular individuals. Splitting of the Gluteus maximus is facilitated by localization of a raphe beginning just distal to the easily palpable ischial tuberosity and running in line with the muscle's fibers. Employing this raphe, the hamstring fascia is easily exposed and split longitudinally, with a sudden rush of blood often encountered from evacuation of the acute injury hematoma.

Successful evacuation of hematoma assists in confirming that the hamstring fascia has indeed been entered, as upon initial inspection, the intact fascia may be mistaken for intact hamstring tendons. Blunt dissection is then employed to identify the hamstring facet. Such dissection should be performed in a proximal medial to distal lateral direction, with the facet often encountered more inferior and lateral than anticipated. Rotation of the operative extremity can assist in verifying that the encountered bony prominence is indeed the ischium, and has not been mistaken for the lesser trochanter.

Precise identification and mobilization of the torn hamstring tendons is especially critical in the case of more chronic injuries, as a layer of fibrous scar tissue may often be encountered adjacent to the site of initial injury.[26] In such cases, slow and meticulous dissection should be employed, proceeding with caution while always remaining within the hamstring pseudo-sheath to prevent lateral migration and possible sciatic injury.

The torn hamstrings are then identified with knee flexion assisting in delivering the tendons in more retracted injuries. A heavy suture is used to gain control of each tendon, and the avulsed stumps are cautiously debrided of all terminal, fibrotic tissue. Care should be taken to remove only the minimum amount of terminal tissue to prevent complications from tendon shortening. Next, blunt lateral retraction of the sciatic nerve is again verified to allow for preparation of the proximal insertion at the ischial tuberosity. A combination of a rongeur, periosteal elevators, or curettes can be employed to decorticate the tuberosity prior to anchor insertion with the use of any motorized instruments avoided due to the proximity of the sciatic nerve.

Our preferred anchor configuration has evolved with practice from 5 anchors arranged in an "X" like configuration, to 3 rows of 2 anchors (3.0 mm PushLock; Arthrex) situated like the face of a die. Additionally, we will often opt for 2 additional sutures in a luggage-tag configuration along the medial leading edge of larger, 3-tendon tears. These medial sutures are then dunked into 2 smaller anchors (2.4 mm PushLock, Arthrex) to maximize the repair footprint surface, especially in cases where an early range of motion rehabilitation protocol is anticipated. Simple mattress sutures are employed to secure the tendon, avoiding Mason-Allen or Kessler type configurations, which may result in tendon bunching or shortening. Fixation is performed from distal to proximal, with the knee flexed between 30° to 60° throughout fixation (Fig. 6).

Once the tendon has been a repaired the wound is copiously irrigated and a layered closure is performed, beginning with the gluteal fascia. The patient is initially placed in a knee brace locked at 40° of flexion. A hip orthosis is avoided as they

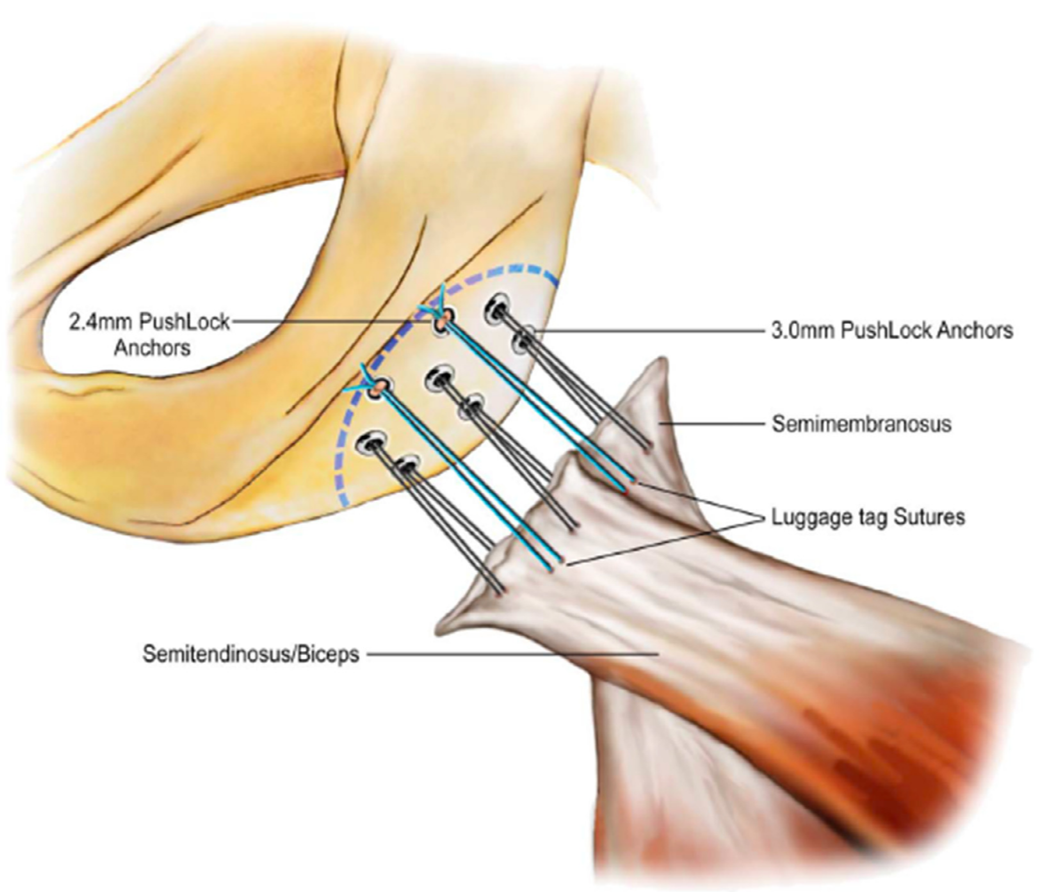

Figure 6 Diagram of the authors preferred 6 ± 2 anchor configuration for proximal hamstring repair. Six anchors (3.0-mm PushLock; Arthrex) are situated like the face of a die on the ischial tuberosity. Two luggage tag sutures may also be placed at the medial leading edge if additional fixation is desired in larger tears. These are dunked into their own smaller anchors (2.4-mm PushLock; Arthrex). After passage in a simple mattress configuration, sutures are tied sequentially from distal to proximal.

are a common source of patient discomfort, and in our experience do not provide any benefit to postoperative recovery.

Number of Anchors

One technical consideration warranting further discussion is the number and configuration of suture anchors employed for proximal hamstring repair. Current literature contains many reported techniques with a high degree of variability in anchor size and placement, ranging from 2 larger anchors to our preferred technique of 6 anchors with the option for additional luggage tag fixation.[3,8,13,18,24]

In a recent cadaveric study, Hamming et al[28] provided a biomechanical justification for the preferential use of multiple, smaller anchors. In this study, cyclical loading of various anchor configurations and sizes were compared. The authors noted that an increased number of anchors directly correlated with a higher force to failure, while no benefit was demonstrated from increasing individual anchor size. Based on these findings, the authors concluded that preferential use of a greater number of anchors over a larger repair footprint was most important in optimizing construct strength. We have noted similar findings in our clinical practice, especially in cases of complete, 3-tendon proximal hamstring tears, leading to the adaptation of the 6 ± 2 anchor configuration described above.

Outcomes for Proximal Hamstring Repair

Regardless of technique, 1 factor consistently reported to result in less favorable outcomes is an individual presenting with a chronic, vs acute, proximal hamstring injury. While no consensus definition exists, a 'chronic' injury is often defined as greater than 4 and sometimes up to as many as 12 weeks after injury,[1,13,20] the current literature almost uniformly demonstrates inferior results with delayed surgical management.[13,18,24] However, what is also clear is that even chronic injuries fair better with operative treatment when persistently symptomatic.[13,20,29]

In a landmark article, Wood et al[13] reported on repair of both acute and chronic hamstring injuries. The authors defined chronic as >12 weeks from the time of injury, preferring to perform a repair by 4 to 6 weeks with injury hematoma allowing for a tract to easily identify the tendon edges. The authors noted difficulties with identification of retracted tendons after 6 weeks, with increasing concern for scaring to adjacent tissue, such as the sciatic, by 3 months. Overall, both acute and chronic injuries that underwent surgical repair were determined to fair better than patients managed nonoperatively, a finding that has since been reproduced by subsequent authors.[12,20,29,30] However, the degree of overall improvement was significantly less following repair of chronic cases, with significant decreases in speed of recovery and strength and endurance noted in those undergoing delayed repair.

One possible explanation for the delayed adoption of surgical repair as standard of care for hamstring injury likely stems from the fact that much of the initial literature was limited to smaller studies with variable end points reported. In the first large series to employ validated outcome measures, Cohen et al[20] reported on 63 patients undergoing proximal hamstring repair for both acute and chronic tears. All patients were diagnosed with either a retracted tear or partial tears failing to respond to nonoperative management, with the majority of cases comprised of complete avulsions. Outcomes were assessed with validated Lower Extremity Functional Scale (LEFS) scoring. At a mean follow-up of 33 months, 98% reported satisfaction following surgical treatment with an LEFS score in the highly functional range averaging between 75.2 to 80.

In a recent meta-analysis combining 24 studies, Bodendorfer et al reviewed of outcomes of both operative and nonoperatively managed hamstring injuries. Pooled results demonstrated significantly higher patient-satisfaction (90.81% vs 52.94%), LEFS Scores (75.64 vs 71.5), and hamstring strength (85.01% vs 63.95% of contralateral) in those electing for operative repair. Sub analysis of acute vs delayed repair demonstrated more favorable outcomes for early surgery in terms of strength, LEFS scores, and pain-scale. Interestingly, repair of partial avulsions resulted in greater final strength and endurance, but less patient satisfaction than repair of complete or retracted tears. The authors concluded that operative management resulted in improved objective outcomes, but did acknowledge a high rate of all-comer complications at 23.17%.

In terms of recovery of preinjury strength, in a retrospective comparison of operative and nonoperatively managed complete proximal injuries, Shambaugh et al[29] demonstrated superior outcomes in terms of LEFS scores with operative repair. The authors further noted significant strength deficits in those electing for nonoperative management as compared to the uninjured, contralateral extremity. Proximal hamstring injuries undergoing repair demonstrated 90.87% ± 16.3% of the strength of the contralateral side during isokinetic testing in contrast to those that were managed nonoperatively, which demonstrated just 57.54% ± 7.8% and 67.73% ± 18.8% of contralateral strength with isometric testing at 45° and 90°.

In a similar series of patients treated with surgical repair, Sandmann et al[30] further demonstrated the success of operative management in restoring isokinetic strength. At an average follow up of 56 months, the authors noted similar values for knee flexion and extension strength as in the uninjured, contralateral extremity. Further, all patients reported successful return to sport without differences in their pre and post repair activity tolerances.

Conclusion

A clear appreciation of the complex anatomy of the proximal hamstring tendons is crucial to successful surgical management, facilitating a safe operative approach while allowing for avoidance of surgical complications. With increasing evidence of improved outcomes following surgical management of both acute and chronic injuries, it is our belief that early operative repair should be preferentially considered in complete or highly retracted tears. The treatment of a partial injury remains complex and should be evaluated on a case-by-case basis, with risks and benefits of both operative and nonoperative approaches weighed against individualized patient goals and expectations.

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