Quadriceps Tendon

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Abbreviations

AIIS	Anterior Inferior Iliac Spine
ASIS	Anterior Superior Iliac Spine
MRI	Magnetic Resonance Imaging
NSAID	Nonsteroidal Anti-inflammatory Drugs
PRP	Platelet Rich Plasma
RF	Rectus femoris
VI	Vastus intermedius
VL	Vastus lateralis
VM	Vastus medialis

Introduction

The quadriceps is comprised of four distinct muscles that stabilize the lower extremity through knee extension and proper patellar tracking within the inter-condylar fossa of the femur, also known as the femoral groove. These actions are important for simple activities such as walking and standing upright. The quadriceps is critical to strenuous activities such as running, cutting, and traversing stairs or hills at an incline or decline. Injury to these muscles may result in increased stress on the proximal and distal tendons of the muscle group, thus predisposing to a wide array of tendon injury such as tendinitis, chronic tendinosis, partial tendon tear, or rupture. These types of injuries can range in prevalence from 2.5 to 14.4%, depending on the sport participated in by an athlete [1]. Recreational athletes and casual fitness seekers often are faced with issues stemming from repetitive motion of the quadriceps and strain on the tendon. Multiple intrinsic and extrinsic factors may play a role in predisposing someone to quadriceps tendinopathy and it is crucial to identify the correct diagnosis and degree of tendon pathology so that proper treatment modalities can be initiated and ultimately help prevent long-term sequelae of tendon injury.

Anatomy

The muscles that make up the quadriceps, from deep to superficial, include the vastus intermedius (VI), vastus medialis (VM), vastus lateralis (VL), and the rectus femoris (RF) (Fig. 10.1, Table 10.1). These muscles and their respective tendons must function in unison to allow for proper mechanics of the lower extremity.

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K. Onishi et al. (eds.), *Tendinopathy*, https://doi.org/10.1007/978-3-030-65335-4_10

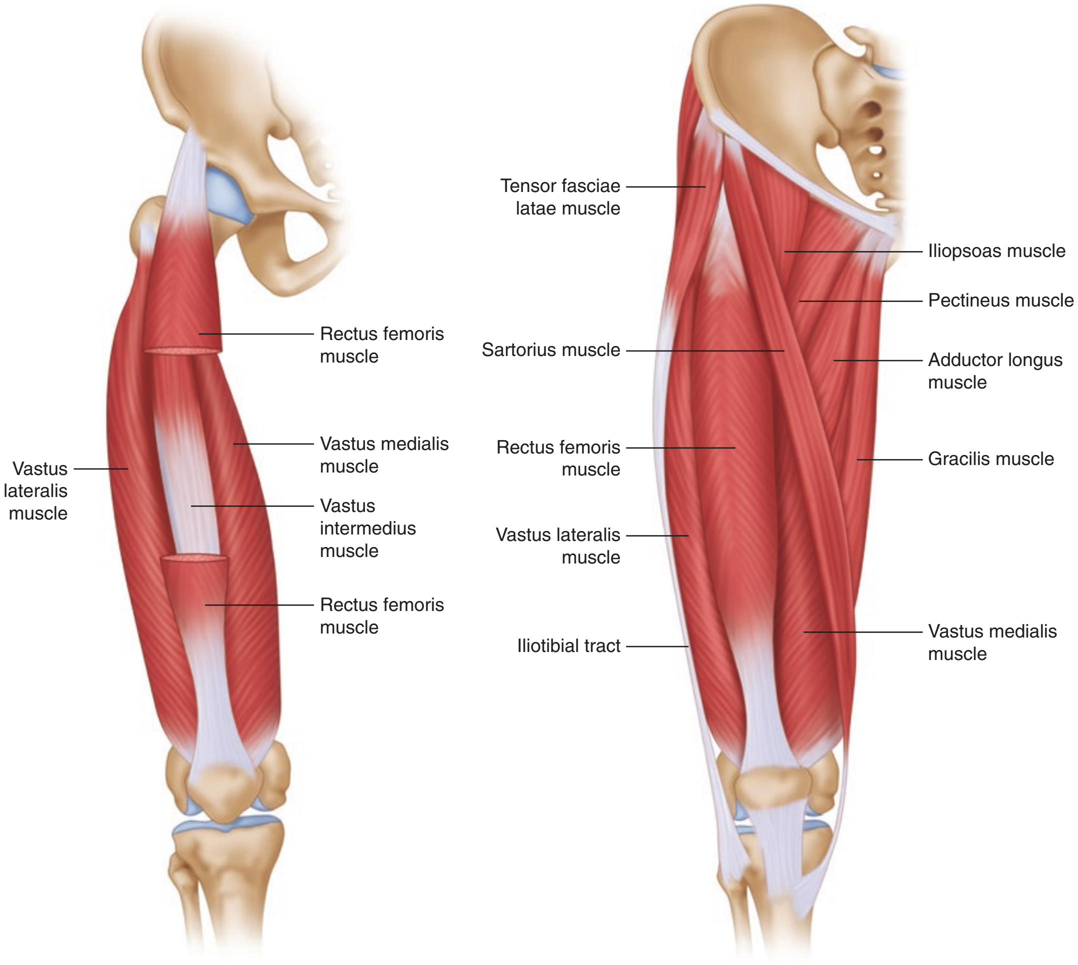

Fig. 10.1 Quadriceps anatomy

Table 10.1 Quadriceps anatomy

Muscle	Origin	Insertion	Arterial supply	Nerve innervation
Rectus femoris	Anterior inferior iliac spine & superior acetabulum	Superior patella and tibial tuberosity via the patellar tendon	Lateral circumflex femoral A.	Femoral N. (L2-L4)
Vastus medialis	Medial proximal femur	Superior medial patella and tibial tuberosity via patellar tendon	Lateral circumflex femoral A. and deep femoral A.	Femoral N. (L2-L4)
Vastus lateralis	Greater trochanter of the femur & gluteal tuberosity	Superior lateral patella and tibial tuberosity via patellar tendon	Transverse and lateral circumflex femoral A.	Femoral N. (L2-L4)
Vastus intermedius	Anterior and lateral femur	Superior patella and tibial tuberosity via patellar tendon	Lateral circumflex femoral A.	Femoral N. (L2-L4)

Proximally, the quadriceps musculature bind to their bony origins through fibrous tendons, which serve as anchors for muscle contraction and function. The vastus musculature arises from the femur, with the medialis primarily from the medial lip and lateralis from the lateral lip of the linea aspera. The intermedius has a more diverse origin, typically originating from the anterolateral aspect of the femur [54].

Detailed discussion of the rectus femoris is warranted given it is the most frequently implicated quadriceps muscle in injuries [64]. Multiple factors have been noted to play a role in RF injuries including its fusiform shape and extension across two joints [64]. Additionally, the RF may be subject to eccentric contraction and has a high percentage of type II fibers, both of which contribute to the RF relatively higher rate of injury [64]. A common mechanism of injury is kicking a ball due to the momentum-assisted transmission of force generated by the eccentrically loaded proximal muscles. This contraction pattern leaves the quadriceps vulnerable during various movements needed to kick a ball [6]. Predisposing factors for injury may include history of prior injury, poor conditioning, and fatigue [64]. Recent hamstring injury within the prior 8 weeks and any prior injury to the RF appears to be significant risk factors for RF injury as well [61].

The direct head of the rectus femoris originates from superior facet of the anterior inferior iliac spine (AIIS). The footprint on the AIIS has been described as broad based and “tear drop” shaped, situated just superior and anteromedial to the lateral most aspect of the acetabular rim. In normal morphology, a smooth concave wall of ilium is interposed between the acetabulum and AIIS, providing attachment site for the hip capsule, and the iliofemoral ligament on the lateral aspect [45]. The iliocapsularis muscle also arises from the AIIS along the inferior border, separated from the direct head of the RF by the AIIS ridge [45]. Cadaveric studies have revealed along the anterior medial region of the AIIS a “bare area” with no tendinous attachment, important to note as this may be a safe zone for surgical decompression without involving the tendon [45].

The indirect head of the rectus femoris originates, slightly more inferiorly, from the superior acetabular ridge and hip joint capsule. A few centimeters beyond their origins, they fuse to form a conjoined tendon, with the direct head being the more superficial component. The superficial component of the conjoined tendon blends into the anterior fascia of the recuts musculature. The posterior component of the conjoined tendon, primarily from the indirect head, gives rise to an intrasubstance myotendinous junction spanning approximately two-thirds of the rectus musculature [55].

At the distal aspect of the quadriceps, multiple structures form the densely packed single anchor quadriceps tendon. The anatomy of the quadriceps tendon, although often simply described as a fusion of the tendinous contributions of the quadriceps musculature, is complex and variable. Historically, the quadriceps tendon was described as tri-laminar with superficial fibers from the RF, intermediate layer from VL and VM, and deep layer from the VI [20, 66]. More recent studies have suggested a more complex bilaminar, trilaminar, or tetralaminar structure with unequal contributions from the contributing tendons [67]. Grob et al. in 2016 described the quadriceps tendon as having “onion-like” layering and fibers arranged similarly to the husk of corn, further described as a trilaminar structure formed by six elements: lateral, deep medial, and superficial medial aponeuroses of VI, the VL, tensor VI, and rectus femoris [66]. Depending on the level at which the tendon is transected, there may be two, three, or four layers, further complicated by the fact that depending on the plane, the corresponding layers may be complete or incomplete. The VM contribution is interesting as it contributes to the quadriceps tendon with its medial insertion into all layers of the tendon. The tendon becomes increasingly thick until maximal thickness is reached at its insertion onto the patella [66]. Grob et al. note the variability of descriptions of the distal quadriceps tendon is likely due to the variability of fusion points of superficial and deep layers as well as the oblique orientation of the two-layered intermediate layer [66]. As the distal quadriceps tendon is frequently utilized as a graft, further research into the tendon is warranted to determine appropriateness of full versus partial thickness graft, exact harvest sites, and how tendon defects should be closed [66]. The quadriceps tendon is occasionally referred to as the suprapatellar tendon in the literature [67]. The superficial layer, originating from the RF, offers fibers that are continuous over the patella to contribute to the patellar tendon, occasionally referred to as the patellar ligament or infrapatellar tendon [67].

Adjacent to but distinct from the quadriceps musculature is the articularis genu, originating from the distal third of the femur and inserting on the proximal aspect of the supra-patellar bursa. The articularis genu acts as a tensor of the vastus intermedius during extension of the knee to retract the suprapatellar bursa proximally to prevent impingement of the synovial membrane within the patellofemoral joint space [2]. Recent research has confirmed the articularis genu does not contribute to the distal quadriceps tendon in any capacity [66].

Anterior Inferior Iliac Spine Apophysitis and Avulsion

A 12-year -old female presents with 2 months of progressive right anterior hip pain. There is no history of trauma or injury. She plays club soccer as a midfielder and is otherwise healthy. She initially noticed the pain while running and with kicking in practice. The pain is gradually worsening, limiting her ability to participate in sport. She denies feeling a "pop," and is able to ambulate with minimal discomfort. On physical exam, there is point tenderness over the AIIS with painful end range flexion of the hip and weakness with quadriceps testing.

Clinical Presentation

Pediatric and adolescent athletes are subject to chronic traction and repetitive microtrauma of the apophysis, leading to pain and inflammation termed apophysitis. The direct tendon of the rectus femoris originates from the apophyseal ossification center of the anterior inferior iliac spine. The indirect tendon, originating from the supra-acetabular ridge, is rarely involved in pediatric rectus injuries [44, 49, 52]. Unlike epiphyses, which are located at the ends of long bones and are responsible for longitudinal growth and circumferential remodeling, apophyses (also termed traction epiphyses) serve as the attachment site for tendons onto bone. Chronic loading of the apophyseal physes causes chondrocyte proliferation, hypertrophy, and inflammatory changes [42]. Additionally, explosive activities may result in the avulsion of the unfused apophysis due to strong contraction of the rectus femoris. These injuries are due to forceful contraction when transitioning from hip hyperextension and knee flexion to hip flexion with knee extension. The indirect head of the rectus femoris becomes more taut with increased hip flexion and is rarely involved in younger athletes [49]. Activities commonly associated with AIIS apophysitis and avulsion include kicking a ball, sprinting, and jumping [46, 48–51]. Historically, AIIS avulsions have been termed "sprinter's fractures" [45, 49]. The interval between appearance and closure of the apophysis serves as a window of vulnerability due to relative biomechanical weakness [44].

The median appearance AIIS apophysis for males is at 13.6 years of age and for females 14.0 years of age [43]. Table 10.2 describes the chronological age at appearance and closure of

Table 10.2 Age at appearance and closure of AIIS apophysis

Sex	First appearance	Median appearance	All appeared	First closure	Median closure	All closed
Male	11.1	13.6	15.3	13.9	16.3	17.5
Female	9.8	14.0	15.9	11.3	14.5	15.9

Adapted from Parvaresh et al. [43]

the AIIS apophysis. The general trend for pelvic apophyses is that of earlier appearance and closure for females than males, consistent with other areas of skeletal development. Importantly, younger patients are more likely to injury apophyses that appear earlier (i.e., AIIS) whereas older adolescents are more likely to injure later appearing ossifications centers (i.e., anterior superior iliac spine [ASIS]) [43, 44]. AIIS apophyseal avulsions are the second most common pelvic avulsion injury suffered by youth athletes, behind ischial tuberosity avulsions [51].

In AIIS apophysitis, symptoms will gradually worsen over time as the athlete continues to load the affected apophysis and microtrauma accumulates. On physical exam, there will be tenderness over the anterior hip along the AIIS but symptoms may be vague compared to the immediate disability seen in AIIS avulsion. The athlete may have minimal pain with walking, but as the quadriceps musculature is engaged with more vigorous activity such as sprinting, pain is reported. Hip range of motion is typically well maintained, although pain at end range flexion may be reported. If hip range of motion is asymmetrical, other etiologies should be considered. Strength will be reduced compared to the contralateral side.

In a more severe iteration of the above scenario, a true avulsion may occur at the apophysis. For AIIS avulsions, physical exam will reveal tenderness over the AIIS with variable presence of swelling and limited flexion of the hip. Strength will be more limited than with apophysitis given the added severity. Athletes should be queried regarding the presence of antecedent pain as avulsions may occur either on previously normal apophyses or in the setting of preexisting apophysitis [44].

Imaging

Radiographs

In cases where apophysitis is suggested by history and physical exam, radiographs may be considered unnecessary, as the findings are often nonspecific. If the diagnosis is in doubt, or if the patient has not responded to a typical treatment, radiographs may be obtained. In longer standing cases of apophysitis, radiographs may reveal irregularity or fragmentation of the apophyseal plate. Occasionally widening and sclerosis may be noted [52].

Radiographs will readily show avulsion injuries and are usually sufficient for diagnosis. The anteroposterior (AP) pelvis view allows for comparison of the affected and unaffected sides and normal apophyseal development. Of note, gonadal shields should not be used when performing radiography of the pediatric and adolescent pelvis [53]. In cases where AIIS injury has led to extra-articular impingement, AP pelvis with false-profile view may be utilized. The AP pelvis view may show low lying or prominent AIIS, associated with a “double cross-over sign” [45].

Ultrasound

Ultrasonography (US) may be employed in diagnosing and screening AIIS apophysitis and avulsions. The apophysis may appear as a “hetereogeneous vascularized psuedomass” in cases of apophysitis, due to underlying inflammation [52]. The AIIS ossification center will be displaced inferiorly in the case of avulsion. In younger athletes where the AIIS has yet to ossify and the apophysis cannot be visualized on radiographs, US may be of particular use. The cartilaginous AIIS may be visualized and compared to the unaffected side. Apophysitis and avulsions at multiple sites may exist simultaneously, and if screening with US, a thorough investigation of bilateral pelvic apophyses should be undertaken [44].

MRI

Magnetic resonance imaging (MRI) is not typically obtained for cases of uncomplicated apophysitis. If atypical in presentation, or in cases of treatment failure, MRI may be performed that will reveal enlargement and widening of the apophysis with conservation of the original shape of the AIIS apophysis. Increased signal intensity is expected on T2-weighted sequences about the apophysis, bone marrow, and adjacent soft tissue structures [52].

In cases of AIIS avulsion, those with ossified apophyses that have yet to fuse, MRI will reveal avulsion of the apophysis with associated marrow and soft tissue edema [49]. The size of the avulsed apophysis and measurement of gap should be noted [61]. In younger athletes, if the apophysis has yet to completely ossify, MRI may be considered the modality of choice to fully characterize these injuries. Fat suppressed T2-weighted and STIR sequences best image acute apophyseal injuries and will reveal edema. Osseous and musculotendinous involvement is also well characterized on these sequences [49]. In chronic injuries, T1-weighted sequences provide better anatomic detail and may reveal displaced osseous fragments [49]. Chronic apophyseal avulsion injuries may simulate aggressive bone lesions but the typical location in skeletally immature patients help to avoid misdiagnosis [61]. Recommended MRI protocol consists of "axial fat-suppressed T2-weighted or STIR series, coronal T1-weighted and fat-suppressed T2-weighted or STIR series, and a sagittal T2-weighted series" [49].

Treatment

AIIS apophysitis is treated conservatively and has an excellent prognosis. Often after a short period of rest, symptoms subside and the athlete may begin a gradual return to sport. Rehabilitative programs are commonly utilized, often under the direction of physical therapists. Pain control in the short term may be managed with topical application of ice and with use of nonsteroidal anti-inflammatory drugs (NSAIDs). Patients and parents should be counseled that the normal course of AIIS apophysitis is that of gradual improvement with time and complications are uncommon [52]. Traction hypertrophy is rarely seen in apophysitis, but can be associated with bony hypertrophy and development of prominence leading to restriction of hip motion and extra-articular impingement [45].

Acute AIIS avulsions are typically managed conservatively as well, unless avulsed beyond 2 cm. Initially, analgesia with NSAIDs, local application of ice, and rest are recommended. Crutches are initially used to assist in limiting weight bearing. Once able to walk with minimal discomfort crutches are discontinued and a progressive strengthening program may begin, often under the supervision of a physical therapist. Duration of time before return to play is variable, ranging from 3 weeks to 4 months. The variability is influenced by the patient's age, degree of displacement, and level of sport in which they participate. Additionally, compliance and commitment to rehabilitative protocols are important to maximize function and early return to sport [46].

The literature reveals little support for surgical treatment of AIIS apophysitis. However, a displaced AIIS avulsion can necessitate open surgical repair in certain populations such as high-level adolescent soccer players. Surgery may be indicated for AIIS avulsions beyond 2 cm or if severe rotational deformity is noted [45]. A Smith-Petersen anterior approach sparing the lateral femoral cutaneous nerve has been described [39]. The incision is carried distally from the ASIS toward the lateral border of the patella. The interval between the sartorius and tensor fascia lata is utilized to uncover the anterior surface of the rectus femoris. Careful identification of the indirect and direct heads of the rectus should be performed after clearing hematoma and debriding degenerative tissue. Techniques for fixation depend on the site of injury. Side-to-side repairs with nonabsorbable suture for mid-substance injuries can be performed [39]. Suture anchor fixation may be required for injuries at the enthesis, whereas avulsion-type injuries are typically repaired with cannulated screw fixation of the apophysis back down to the AIIS.

There have been case reports of bony exostoses developing after avulsion of the AIIS requiring arthroscopic debridement or open surgical resection [47]. This may be due to hematoma formation and subsequent exostoses formation within the tendon sheath itself, or from myositis ossificans within the rectus musculature. The development of hip impingement is a late complication and there may only be a remote history of injury as a youth [45].

Proximal Rectus Femoris Partial Tears, Avulsions, and Tendinopathy

A 32-year-old recreational athlete presents with acute onset of pain over the groin after kicking during a pick-up soccer game. He notes there was some mild aching pain over the area in the preceding 2 weeks. On physical exam, there is tenderness over the groin directly inferior to the AIIS. Pain is worsened with resisted knee extension. Passive range of motion is well maintained with mild discomfort at end range flexion.

Clinical Presentation

Proximal RF injuries are most commonly myotendinous or myoaponeurotic in nature, but occasionally proximal tendon tears and avulsions are encountered [44]. Proximal RF tendon avulsions account for approximately 1.5% of all hip lesions occurring during sport, and are more common in sports requiring sprinting and kicking [65, 68]. Accurate diagnosis is critical because long rehabilitation times may be required for proximal tendon tears [44, 61]. There is debate as to whether the direct or indirect head is more commonly implicated in proximal tendon tears and avulsions, partially due to the relative infrequency of these injuries [44, 64]. Regardless, either may be involved and conjoined tendon injuries may also be observed [44].

The direct head is under increased tension in early hip flexion. As hip flexion increases, the indirect head becomes more taut, and the direct head is placed under less tension [64]. Proximal RF injuries have been noted to occur during hip hyperextension and knee flexion or as a consequence of sudden eccentric contraction of the quadriceps [65]. Patients may describe a pop or tearing sensation at the time of injury. This may be accompanied by pain over the groin and anterior thigh with variable presence of ecchymosis and swelling depending on degree of injury [64]. The location of pain depends on which head of the RF is involved, with direct head injuries localized over the groin and indirect heard injuries presenting with more lateral or anterolateral pain [44, 64]. Given the lateral presentation of pain in indirect tendon injuries, misdiagnosis is common, especially in cases of chronic injury where initial trauma may be remote or the injury may be neglected [44].

On physical exam, ecchymosis may be present in acute cases and the patient will report tenderness at the origin of the tendons along the anterior hip accompanied by decreased function of the extensor tendon mechanism [64, 65]. In chronic cases, patients may report weakness with hip flexion and knee extension [65]. In cases of avulsions where significant muscle retraction has occurred, a palpable defect along the proximal RF may be appreciated. The retracted musculature may present as an anterior thigh mass, accentuated during quadriceps contraction [64].

Painful enthesopathic changes at the direct tendon due to overuse and repetitive trauma are uncommon. These patients may present with chronic hip pain and nonspecific clinic findings [44]. Patients with osteoarthritis of the femoroacetabular joint may develop paralabral and arthrosynovial cysts adjacent to or within the indirect tendon the RF leading to tendinopathy. These patients may report classic groin pain in addition to lateral or anterolateral hip pain. As with chronic indirect tendon tears and avulsions, the lateral nature of the symptoms may lead to initial misdiagnosis with the condition masquerading as gluteal tendinopathy [44]. Ultrasound can be utilized and will reveal hypoechoic thickening of the involved tendon, and occasionally intratendinous cysts [44].

Calcific tendinitis can affect the RF tendons, but is also rare. Apatite calcific densities may be identified on radiographs or advanced imaging, most commonly identified within the indirect head, just lateral to the tip of the acetabulum. The direct head is less commonly involved—calcification would be seen just inferior to the AIIS [44]. Calcific deposits in the direct head of the RF have been implicated in cases of internal snapping hip due to impingement with the overlying iliacus muscle [62]. Snapping due to calcific tendinitis of the direct head may be visualized dynamically under ultrasound [44]. Acute phase resorption of may present with acute onset of pain and limited motion of the hip. Visualizing tendinous calcifications under ultrasound, in addition to normal laboratory analysis, can help to differentiate acute resorption from more serious causes of hip pain such as septic arthritis [44].

Imaging

Radiographs

Radiographs are frequently the initial diagnostic study obtained in cases of proximal quadriceps tendon injury and are helpful in constructing a differential diagnosis. In adults, degenerative changes, femoroacetabular impingement, heterotopic ossification, and calcific tendinitis may be identified on plain radiographs [44]. Standard anteroposterior views are useful for visualizing the supra-acetabular rim, but the AIIS is not well delineated. The addition of false-profile or frog leg views allow for further characterization of the AIIS [44].

On plain radiographs, acute avulsions may reveal displaced osseous fragments, originating most commonly from the AIIS, and less commonly from the superior acetabular ridge [64]. Subsequent healing of these avulsed injuries may demonstrate sclerosis and osteolysis, not to be confused with infectious or malignant processes [64]. With time, heterotopic bone formation may be noted that can lead to impingement [45, 64].

Ultrasound

Evaluation of the proximal origins of the RF requires precise knowledge of underlying anatomy and thorough evaluation of both the affected and unaffected hip. The patient should be placed supine with the hip in neutral position. A high-frequency linear transducer is recommended for evaluation. After static scanning is performed, dynamic scanning may be considered to evaluate for snapping hip [44].

The direct tendon is best visualized in the axial plane scanning from ASIS to the AIIS. The probe may then be rotated 90 degrees in the sagittal plane to obtain long axis images of the direct tendon, which will appear as a hyperechoic fibrillary structure deep to the iliopsoas and sartorius musculature, originating from the AIIS. The indirect tendon is poorly visualized from this plane appearing as a hypoechoic structure along the lateral border of the direct tendon [44].

A lateral approach has recently been described to visualize the indirect tendon under ultrasound, but given the depth of the tendon, characterization may be difficult. Additionally, comparison views of the contralateral hip are recommended to evaluate for subtle changes consistent with tendinopathy or when chronic tearing is suspected. Sonographic evaluation of the indirect tendon via the lateral approach may be limited in the elderly due to fatty degeneration of the gluteal musculature [44]. The lateral approach to evaluate the indirect head is well described below by Moraux et al. [44]:

> Scanning the lateral hip in the axial plane, lateral to the anteroinferior iliac spine, localizing the indirect tendon underneath the gluteus muscles and overlying the supra-acetabular ridge and lateral iliofemoral ligament. When the tendon is identified, the transducer is positioned in an axial oblique plane with 30° obliquity on the lateral aspect of the hip. The indirect tendon appears as a convex thin echoic or hypoechoic structure underlying the gluteus minimus muscle, arising from the acetabular posterosuperior ridge and posterior capsule. In a case of insufficiently lateral transducer positioning, the tendon will appear hypoechoic because of its convexity and an anisotropy artifact. Then, the shor-axis view is obtained with a 90° transducer rotation; the tendon will appear as a thin and flat structure.

Alternatively, the indirect tendon may be visualized by scanning at the level of the conjoined tendon, just distal to the direct tendon, in the sagittal plane. The conjoined tendon will appear as a short echoic fusion of the direct and indirect tendons just inferior to the AIIS. Once identified, an ascending curvilinear sweeping motion along the course of the indirect tendon from distal aspect to origin on the supraacetabular ridge allows for visualization of the indirect tendon [44].

Limited literature exists describing acute proximal RF avulsion injuries under ultrasound.

Ultrasound should be considered to differentiate strains from partial tears or avulsions allowing for early accurate diagnosis, including field-side evaluation [44, 63]. Esser, et al., have described a case of proximal RF avulsion in a collegiate soccer player confirmed by ultrasound. Visualization of torn and retracted direct head of the RF was noted and dynamic scanning with active knee extension caused retraction of distal rectus femoris [63]. Chronic tears will appear thickened and hypoechoic with possible calcification noted [44].

In cases of tendinopathy, under ultrasound the affected tendon will appear hypoechoic and there will be increased tendon volume. Hyperemia may be noted within the tendon as well under power Doppler [19, 44]. In calcific tendinitis, calcification is well defined and hyperechoic in appearance. Large calcifications may present with posterior acoustic shadowing. Hyperemia under Doppler is variably present [44].

MRI

MRI is useful in confirming diagnosis of proximal RF tendon avulsion, grading tears and determining length of retraction [64]. Although tendon tears may be visible on axial images, oblique sagittal images parallel to the iliac wing are superior for delineating the exact nature of the tear and gap if present [61]. Proximal tendon injuries should be classified as partial or complete tears and if complete, margin quality and gap should be noted. Additionally, involvement of the direct, indirect or both heads should be specified [61]. Displaced osseous fragments are not well characterized on MRI [64]. For chronic injuries, MRI is also helpful for assessing tissue fibrosis as well as identifying pseudocyst formation that has been described [64].

Treatment

Most proximal RF tendon tears and avulsions are treated nonoperatively. High-level athletes, especially those whose sports involve repetitive kicking and sprinting, may be considered for earlier surgical intervention. Additionally, for patients who fail greater than 3 months of conservative treatment and exhibit continued pain or weakness, surgery may be considered. Surgery is not indicated in patients with nondisplaced or minimally displaced avulsions and chronic tears in elderly patients [65]. There is no consensus on operative protocols [65].

Nonoperative

The largest case series of nonoperative management of proximal RF avulsions in athletes is Gamradt et al. series of 11 in the National Football League (NFL). These injuries, as previously noted, were found to be uncommon occurring approximately once per year in the NFL, and accounting for 1.5% of all hip injuries. Average return to play when excluding a single outlying athlete was 55.3 days, ranging from 21 to 84 days [68]. Gamradt et al. describe two cases with varying degrees of intervention to illustrate the lack of consensus on rehabilitation and differing impact on athletes. In one case, the athlete initially required a short period of protected weight bearing with crutches and use of NSAID, ice, and modalities. By week two, they progressed to active range of motion and isometrics, advancing to a resistance-training program by week four and a return to play with continued symptoms at week six. The athlete required a corticosteroid injection due to lingering symptoms the following season. To contrast, the other case presented was able to tolerate ambulation without difficulty and was able to resume light jogging at 9 days post injury. Full and unrestricted return to practice took place 2 weeks after injury and returned to games shortly thereafter with no long-term complications or limitations reported [68]. It would seem an individualized approach tailored to each patients' demands and degree of limitation is warranted with gradual progression back to sport as function normalizes.

Operative

Although there are no standardized protocols for proximal rectus femoris repair, Dean et al. describe one approach as follows. The patient is placed supine and the contralateral leg placed into full extension with sequential compression devices. The patient is draped, proximal to the

ASIS and distal to the knee. After identifying landmarks including the ASIS and greater trochanter, a 6-cm longitudinal incision just distal and lateral to the ASIS is made. This is extended distally using a Smith Petersen approach. Care should be taken to avoid the lateral femoral cutaneous nerve (LFCN) running medially to the ASIS deep to the inguinal ligament. Although the LFCN anatomy is variable, it most frequently crosses the interval between the tensor fascia lata and the sartorius 2–4 cm distal to the ASIS. The tensor fascia lata is retracted laterally, and in general, the sartorius and LFCN area retracted medially. The deep fascia is then identified and incised and the rectus femoris is identified. Once identified, the degree of retraction is assessed and the tendon and any adhesions are released from the surrounding tissues. Most often, the direct head is affected at the insertion on the AIIS. If both heads are affected, repair is performed on each separately. Devitalized tissue is removed from the tendon stump and a suture is passed through the direct head to assist with mobilization. The footprint on the AIIS is prepared by exposing the subchondral bone and a bleeding bed is created with a rasp to support healing. Suture anchors are placed over the footprint and the tendon is retracted to its origin. Of note, due to the small footprint on the AIIS, it may only be possible to place 1–2 anchors. The tendon is reattached in a double row fashion, initially placing an all suture anchor to establish the medial row. The suture from the anchor is passed deep to superficial through the tendon. Previously placed mobilization suture is then removed. Tension is applied while holding the sutures from the suture anchor to that tissue is well reduced against the bone. The sutures are tied over the tendon. A hole is drilled and the second anchor is then placed proximal to the first. Both strands are then passed through the second anchor and tissue tension should be assessed. Once satisfied, the anchor is placed into the bone socket and appropriate tension is obtained. If necessary, the hip can be flexed to decrease tension on the rectus tendon while being reattached. The tendon should cover both the anterior and inferior surfaces of the AIIS without excessive tension [65].

Postoperatively, to prevent active contraction of the rectus femoris, the patient is placed into a knee brace locked in extension for 6 weeks. The patient is restricted to nonweight bearing status during this period. Additionally, the patient is instructed to avoid active hip flexion. Postoperative arthrofibrosis is prevented with the use of a continuous passive motion machine from 0° to 90° for 6–8 hours per day. Formal physical therapy begins approximately 4 weeks postoperative with a focus on range of motion. Partial progressive weight bearing is started in week six and crutches are progressively weaned. The patient may discontinue crutches when able to walk without a limp and minimal pain. Eccentric strength training and running begin approximately 8 weeks after the procedure. Return to play is expected 4–6 months after surgery [65].

Proximal Quadriceps Myotendinous Injury

A 20-year-old male, collegiate soccer player presents post-match with acute onset of pain over the proximal right thigh after kicking the ball late in the second half. There was no antecedent pain and he is otherwise healthy. He is right leg dominant. He was able to continue playing with discomfort. In the training room post-match, he has a mildly antalgic gait. There is tenderness to palpation over the anterior third of the right thigh but no obvious defect or deformity. Manual muscle testing reveals relative weakness about the quadriceps.

Clinical Presentation

As previously discussed, the rectus femoris anatomy is complex with contributions from a direct and indirect tendinous origin proximally. There is intramuscular extension of the indirect tendon extending distally referred to as the central tendon or intramuscular tendon, and occasionally referenced as an intramuscular septum or central aponeurosis [26, 59, 69], This indirect myotendinous extension within the bipennate portion of the rectus is surrounded by the unipennate portion of the rectus, giving rise to unique “muscle-within-a-muscle” configuration [59]. Of note, a bipennate muscle has muscle fibers originating from two sides of a tendon (i.e., indirect head RF). A unipennate muscle has muscle fibers originating solely from one side of the tendon (i.e., direct head RF), and the tendon remains on one side of the muscle, blending superficially with the aponeurosis [59]. The indirect tendon of the RF is initially rounded in appearance and located within the medial aspect of the muscle. As it progresses distally, it flattens, rotates laterally and moves to the middle of the muscle belly. Distally, the deep tendon of the indirect tendon is flat and oriented more vertically, lying within the anterior muscle belly [26]. Given the long intermuscular myotendinous extension, the indirect head of the RF is subject to injury longitudinally. This can involve the myotendinous junction itself, or can result in an uncommon injury pattern called intramuscular degloving, where there is dissociation of the inner bipennate portion from the outer unipennate potion of the rectus femoris [59].

Rectus femoris myotendinous injuries occur most frequently in late adolescent and young adult males (average 18 years old, range 15–22) and are seen most commonly in soccer. The injury is typically sustained while kicking but has also been reported while sprinting. Myotendinous and intramuscular degloving injuries of the RF may occur on the dominant or nondominant leg [59]. Risk factors for RF injuries include short stature, preseason training, and recent injury to either the RF or hamstring musculature [61]. Additionally, environmental factors may contribute as RF injuries are seen more frequently in cold conditions [61].

Physical exam of patient who have sustained proximal RF myotendinous injuries is variable depending on the degree of injury. Less severe myotendinous injuries may present only with mild discomfort and slight weakness. More severe injuries, including intramuscular degloving injuries, can present with anterior thigh swelling due to intramuscular hematoma and retracted muscle fibers.

Imaging

Radiographs

There is limited literature available on utility of radiographs in evaluation of myotendinous RF injuries but they would be expected to be normal. Radiographs may be helpful in the evaluation of concomitant or alternate pathology such as AIIS avulsions.

Ultrasound

The literature on US evaluation of central tendon injuries is somewhat limited. Balius et al. identified 35 high-level Spanish soccer players with central tendon injuries evaluated under ultrasound. Only one patient suffered a grade III or degloving type injury. Grade I injuries revealed “ill-defined hyper or hypoechoic area without objective fibrillary discontinuity or inflammation of the fascia.” Grade II injuries were notable for partial discontinuity of fibers [60]. For degloving injuries of the RF, correlating with MRI, one may expect to see a “bull’s-eye” type pattern with discontinuity of the normal architecture: hyperechoic, rounded central bipennate fibers surrounded by anechoic fluid collection, finally surrounded around the periphery by the unipennate fibers (Fig. 10.2). Hyperemia may also be expected.

MRI

MRI may be utilized to fully characterize myotendinous and intramuscular degloving inju-

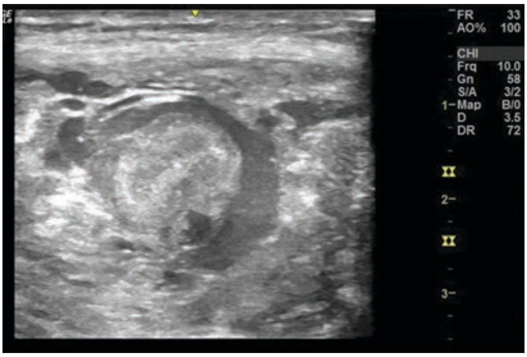

Fig. 10.2 Short axis ultrasound rectus femoris intramuscular degloving

ries of the RF. Kassarjian et al., recommended the following protocol in evaluation of myotendinous RF injuries:

> initial wide field of view images that include both hips and thigh and consists of: axial T1, axial STIR, and axial gradient echo sequences all of which extend from the anterior inferior iliac spine to the distal myotendinous junction of the rectus femoris. These images are not meant to be of high resolution but serve to accurately localize both acute and chronic injuries and allow evaluation of the contra-lateral hip and thigh both for comparison (e.g., of muscle bulk) and to assess for occult additional injuries. Subsequently, higher resolution images with a smaller field of view are obtained of the symptomatic rectus femoris. This includes T2 weighted sequences with fat suppression in the following planes: axial images in all cases, sagittal oblique images (paralleling the anterior inferior iliac spine) when proximal tendinous injuries are suspected, sagittal images when myotendinous injuries of the direct (superficial) component are suspected or when myofascial injuries are suspected, and coronal images when myotendinous injuries to the indirect (deep) component are suspected [61].

The tendon of the direct head is short and quickly fans to blend with the anterior fascia. This anatomy and quick transition make differentiation between grade I and II injuries difficult as well as differentiating between myotendinous versus myofascial injuries. High quality axial, sagittal and sagittal oblique images can facilitate in delineating the grade of these injuries. The tendon of the direct head may appear more hypointense than the fascia allowing for differentiation. Myotendinous injuries of the direct head will appear as edema along the intersection between the anterior fascia and muscle belly of the RF. Fluid and hematoma may track distally along the deep surface of the anterior fascia. This may be of importance if the collection is in close proximity to the sartorius crossing superficially. It is suggested that injuries in this area may carry a worse prognosis as the sartorius may compress and prevent clearance of breakdown products and prevent healing of the underlying injury [61].

The indirect head anatomy and long central extension is well described above. The complex anatomy and long course of the indirect head makes assessment with the classic three-point grading system traditionally used to classify injuries difficult. Grade I injuries may reveal edema extending into the musculature on both sides of the intact tendon. This resembles a feather due to the underlying bipennate architecture and is best visualized on coronal fat suppressed T2 images [26, 61].

Grade II injuries will reveal distortion of the muscle fibers and variable involvement of the tendon itself although the myotendinous junction will have fibers remaining [61]. Grade III injuries represent complete tears and there will be gapping of the myotendinous junction with variable degrees of retraction of the muscle and tendon themselves. Depending on the age of the injury the gap may be filled acutely with fluid, blood and debris or later with granulation tissue [61]. Kassarjian et al., noted the following poor prognostic factors that may be visualized on MRI: proximal injuries, the presence of perifascial fluid, changes visualized on T1-weighted images, and involvement of greater than 50% of cross-sectional area of the muscle [61]. The presence of perifascial fluid and lesions visible on T1-weighted images were associated with significantly longer recovery times [61]. Intramuscular degloving injuries on axial T2-weighted images will reveal separation of the outer unipennate from the inner bipennate myotendinous complex with associated intramuscular edema [59]. True myotendinous injuries of the indirect portion of the RF are relatively more common and appear as edema and fluid centered at the myotendinous junction [59]. On axial images this has been described as a “bull’s-eye lesion” with edema surrounding the central tendon [61]. This injury is illustrated in Fig. 10.3. There is frequently evidence of edema in surrounding muscle groups as well. The average length of intramuscular RF degloving injuries is 9.9 cm, located 15.5 cm from the acetabular rim to the proximal most portion of the injury. On average, there is 1.2 cm of retraction [59]. The presence of atrophy and fatty infiltration may be observed in older injuries [6].

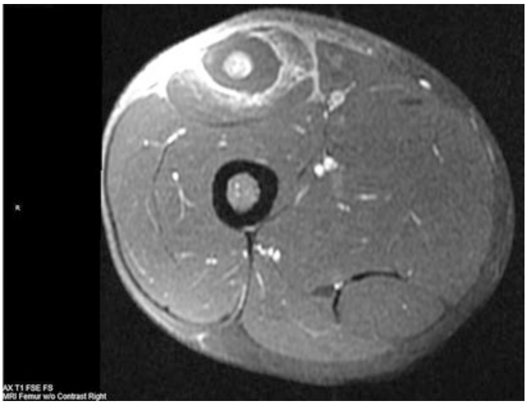

Fig. 10.3 Axial T1 MRI femur without contrast showing typical "bull's-eye lesion"

Treatment

Rehabilitative protocols are not standardized for proximal RF myotendinous injuries. Intramuscular tendon involvement often requires longer periods of rehabilitation compared to more peripheral injuries of the RF [26]. Return to play time for grade I and II central tendon RF injuries has been reported to average 27.7 and 46.3 days on average respectively [60]. Given the infrequency with which degloving RF injuries are encountered there is limited literature on return to play. It is more common for the myofibrils that attach to the central tendon to fail while the central tendon itself remains intact [26]. This results in increased stress on the intramuscular tendon and it has been hypothesized the indirect and indirect heads may begin to act independently of one another, resulting in shearing forces, possibly explaining longer rehabilitation times observed with higher grade injuries [26]. For intramuscular degloving injuries, the average return to play has been reported to range from 28–58 days, averaging 38.7 days [59].

In Balius et al. series athletes were treated with 2 weeks of absolute rest and local application of ice, compression and NSAIDs. Following this period, the athletes were gradually advanced over four stages of increasing intensity with the qualification that the athlete must be pain free before progressing [60]. Kassarjian et al. recommended a short period of initial rest ranging from 1 to 5 days to allow for inflammation and pain to improve. Formal physical therapy is then initiated initially starting with careful mobilization and isometric contractions, advancing to isotonic contractions. Once able to complete these exercises without pain, eccentric exercises are initiated starting with manual resistance, progressing to more complex exercises with differing forms of resistance. Once pain free with eccentric resistance training, running may begin, gradually advancing back to sport specific drills [61]. Even once the athlete is able to return to play, some suggest limiting repetitive kicking and rapid deceleration running drills for 4 weeks due to potential for reinjury [61]. Of note, platelet rich plasma may accelerate scarring in myotendinous injuries but there is insufficient data to support routine use [61].

Distal Quadriceps Tendinopathy

A 42-year-old male presents with 3 month history of progressively worsening left anterior knee pain. He was recently instructed by his primary care physician to increase his physical activity. In order to do so, he has been jogging and playing pickup basketball that is a change from his previously sedentary lifestyle. He is a smoker and is overweight. The patient has tried a variety of over the counter treatments without improvement in symptoms. He localizes pain over the anterior knee along the quadriceps tendon but there is no palpable defect. He has slight weakness and discomfort with knee extension. He is able to bear weight and walk without discomfort, but when navigating stairs or jogging his pain returns.

Clinical Presentation

Distal quadriceps tendinopathy occurs less frequently than patellar tendinopathy, which is seen 4–5 times more frequently [70, 75]. Patients with quadriceps tendinopathy will complain of insidious onset of pain along the insertion of the quadriceps tendon at the insertion on the superior pole of the patella. Occasionally patients will provide history of recent increase in activities that may exacerbate such as jumping, running or kicking [70]. Running, especially hills, have been associated with quadriceps overuse injuries [4]. Quadriceps tendinopathy may also be observed in nonathletes, often associated with obesity [71]. Symptoms may range from mild pain after intense activity without functional impairment to pain during daily activity and inability to participate at any level of sport [75].

On physical exam, tenderness along the superior pole of the patella and the distal quadriceps tendon will be noted. In severe cases the patient's gait may be antalgic. Patients may note pain at end range flexion of the knee. Discomfort and potentially weakness with knee extension may be noted [70]. The presence of a palpable gap, swelling or effusion or other abnormalities should alert the clinician to presence of other potential etiologies. Weakness in context of comorbidities such as stroke or other ipsilateral limb injuries such as an occult fracture may complicate the diagnosis of quadriceps tendinopathy and additional, confirmatory imaging may be warranted [16].

Differential diagnosis for the patient with distal quadriceps tendinopathy includes patellofemoral pain syndrome, patellar tendinopathy, partial tears of the quadriceps or patellar tendons, and suprapatellar or infrapatellar bursitis [4]. Although rare, patellar stress fractures along the superior pole may masquerade as insertional quadriceps tendinopathy.

Imaging

Radiographs

Changes on radiographs would not be expected for most patients with uncomplicated quadriceps tendinopathy. Obtaining radiographs is helpful in constructing a differential diagnosis and evaluation of other causes of anterior knee pain. In long standing cases of quadriceps tendinopathy, radiographs may reveal calcific changes along the superior pole of the patella from osteophyte formation or occasionally intra-tendinous calcifications [70, 71].

Ultrasound

Normally the distal quadriceps tendon appears as multiple hyperechoic laminae with thin hypoechoic bands separating the layers. Due to the oblique insertion onto the patella, if the knee is in full extension the distal most insertion is not well visualized due to anisotropy. This is illustrated in Fig. 10.4. The insertion is better visualized with slight flexion of the knee [76]. Structural changes expected within the quadriceps tendon when investigated under ultrasound include thickening of the quadriceps tendon and hypoechoic areas. There may be variable presence of signal on power Doppler [74]. Additionally, in longer standing cases, calcifications may be noted [74]. Musculoskeletal ultrasound has grade 3 evidence for use in diagnosis of distal quadriceps tendinosis and other investigations often do not provide additional information [18, 58].

Visnes et al. prospectively followed a cohort of young elite athletes with serial exam and ultrasound. Those that were asymptomatic but noted to have hypoechoic changes or presence of neovascularization on ultrasound at baseline were more likely to develop symptoms over time. Ultimately, 16% of these initially asymptom-

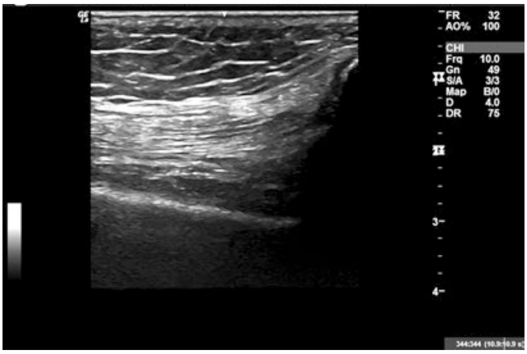

Fig. 10.4 Ultrasound – long-axis quadriceps tendon and insertion onto the superior pole of the patella. Note the anisotropy, seen as an anechoic streak, where the quadriceps tendon meets the patella. The insertion is better visualized with the knee in slight flexion

atic athletes with ultrasound changes went on to develop symptoms either of quadriceps or patellar tendinopathy [72]. Male athletes that developed symptoms were noted to have larger mean baseline quadriceps tendon thickness compared to athletes that remained asymptomatic [72]. For patients undergoing ultrasound of the knee for other reasons, if changes within the quadriceps tendon are noted, the provider should consider counseling the patient on potential development of symptoms as well as next steps in treatment.

MRI

The normal appearance of the quadriceps tendon is low signal fibers with intermediate signal fat interdigitating as seen in Fig. 10.5. The normal multilaminar structure should not be confused with partial tearing on MRI. Superficial fibers of the quadriceps tendon extend over the patella, as the prepatellar quadriceps continuation, blending with the patellar tendon as it inserts onto the tibial tubercle. Of note, the quadriceps fat pad lies deep to the quadriceps tendons insertion and anterior to the suprapatellar recess [56].

Tendinosis of the quadriceps tendon will appear as a thickened tendon with increased signal within the fibers [56]. This is well illustrated in Fig. 10.6. MRI is not typically required for diagnosis of quadriceps tendinopathy especially in cases where extension strength is maintained, and should be reserved for refractory cases or those with other abnormal features or where concomitant pathology is suspected [70].

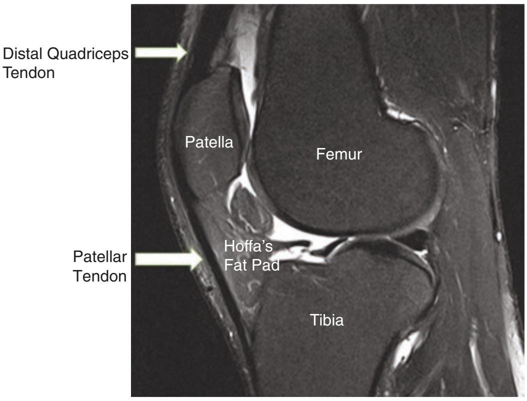

Fig. 10.5 MRI – normal quadriceps tendon

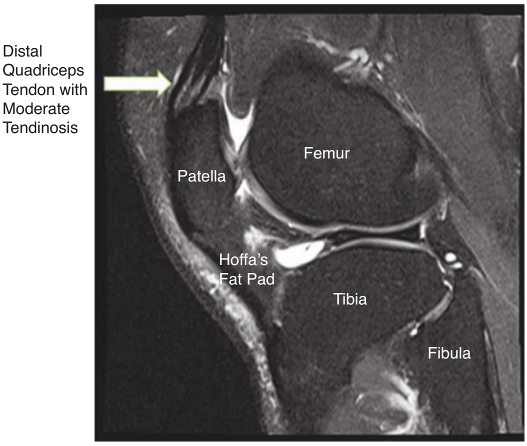

Fig. 10.6 MRI – moderate tendinopathic changes quadriceps tendon

Pappas et al. followed 24 asymptomatic collegiate basketball players with pre and post season knee MRI. A high prevalence of MRI documented changes consistent with quadriceps tendinopathy was noted in preseason scans, observed in 75% of the athletes. In post season scanning, 90% of knees were found to have changes on MRI consistent with quadriceps tendinopathy, but all of these athletes remained asymptomatic [73]. It is unclear, however, if changes observed on MRI may eventually develop symptoms consistent with quadriceps tendinopathy.

Treatment

Nonoperative treatment is the mainstay of treatment in quadriceps tendinopathy and is successful in the majority of cases [70]. Activity modification is often required initially in order to reduce symptoms. Physical therapy regimens should focus on flexibility, strength, and core stability of the quadriceps, hip, and core muscle groups. Flexibility of the hip flexors is of particular importance, as tight iliopsoas muscles may restrict hip extension and force the rectus femoris to become overloaded through increased hip flexion with activities such as kicking and jumping [5]. Eccentric strengthening programs for the extensor mechanism, as well as core, hip and pelvic muscles are focuses of physical therapy for quadriceps tendinopathy.

Some studies suggest that it is also important to focus on proprioceptive input with neuroplastic training regimens, ensuring short and long-term stability and proper biomechanics [25]. With most conservative measures of treating quadriceps tendinopathy, relief of pain is typically a measure of healing and can guide progression to initiate quadriceps, core, and hip strengthening. Proper strengthening and return to controlled movements effectively, begins the process of return to play after these injuries. The chronicity and severity of the condition can also dictate expected timing needed for rehabilitation and treatment prior to return to play. If the tendon injury is associated with a corresponding muscle strain, it is likely to have a more complicated recovery. The use of platelet rich plasma has been used anecdotally given success in other tendinopathies, such as patellar tendinopathy, but studies specifically investigating application of platelet rich plasma in the distal quadriceps tendon are lacking.

Distal Quadriceps Tendon Rupture

A 50-year-old male, with history significant for obesity, type II diabetes mellitus and hypertension presents after a slip and fall at his home while navigating wet steps on his front stoop. He is unable to bear weight and there is a palpable gap along his distal quadriceps tendon. He is unable to complete a straight leg raise.

Clinical Presentation

Quadriceps tendon ruptures are relatively uncommon, but devastating injuries, with an overall incidence is 1.37/100,000 per year [5]. Complete ruptures occur over four times more frequently in males than females [5]. These injuries primarily affect middle aged adults with a mean age of 50.5 in males and 51.7 in females [5]. Among all ruptures, the vast majority occur unilaterally but there are case series and case reports describing simultaneous, bilateral quadriceps tendon ruptures [12–14]. Once the tendon fails, the zone of injury may propagate resulting in disruption of the retinacula and even nearby vascular structures leading to hematoma formation that may require surgical evacuation depending on severity and risk of damage to surrounding structures [15]. As quadriceps tendon ruptures typically affect middle-aged individuals, only a small number of cases reports describe this pathology in younger athletes [8].

The most common injury mechanism in quadriceps tendon ruptures is that of a suddenly contracted quadriceps muscle on a flexed knee with a planted foot, which leads to an eccentric contraction. This type of injury is most commonly seen in the nondominant leg, particularly with simple falls, falls downstairs, and sporting injuries with the lower extremity in this position [3]. The most common mechanism of injury is eccentric overload of the extensor mechanism as patients attempt to prevent falling with the foot planted and the knee partially flexed [8]. The rectus femoris is the only quadriceps muscle that traverses two joints and is at increased risk of tendon rupture. Additionally, there have been reports of quadriceps tendon tears due to direct blows sustained during contact sports [7].

Certain medications have also been implicated in predisposing individuals to quadriceps tendon injuries and rupture including anabolic steroids, statins, fluoroquinolones and prolonged use of local or systemic corticosteroids [7, 13]. Systemic diseases may lend an individual to quadriceps tendon injury including autoimmune disorders such as rheumatoid arthritis and systemic lupus erythematosus, diabetes, systemic endocrine dysfunction, gout, and obesity [7, 9].

Spontaneous ruptures, also termed nontraumatic ruptures, may occur in patients with underlying tendinopathy who present in the absence of trauma with tendon tears in areas of hypovascularity. This zone of hypovascularity is located 1–2 cm from the superior pole of the patella [11]. This is in contrast to traumatic ruptures that most frequently occur at the tendon osseous junction [24]. Case reports of bilateral spontaneous ruptures also exist although uncommon [9, 14, 16]. Bilateral injuries have been associated with obesity and have also been observed in patients in renal failure requiring hemodialysis [14, 16].

For quadriceps tendon rupture, physical exam will reveal pain localized over the superior pole of the patella in the distal thigh. The pain is often described as an immediate, intense tearing sensation at the time of rupture, while relief may be achieved by placing the extremity in knee extension [7, 8]. A diagnostic triad has been described that includes pain, inability to actively extend the knee and the presence of a suprapatellar gap [8]. If the physical exam is limited due to pain, consideration should be given to aspiration and injection with intra-articular anesthetic so the extensor mechanism can be more thoroughly assessed, although this may not be practical in all clinical settings [8]. The presence of a suprapatellar gap may be masked by the presence of a large hemarthrosis, and is a potential source of missed diagnosis [8]. The clinical picture can also be obscured if the medial and lateral patellar retinaculum remain intact. In this scenario, patients maintain some ability to extend the knee despite complete rupture of the tendon. Knee extension will be weaker compared to the contralateral side and an extensor lag may be present [8]. Similarly, the ability to bear weight on the extremity should not completely rule out quadriceps tendon rupture, as an intact retinaculum may allow for engagement of the extensor mechanism in the stance phase. Thorough and complete assessment of the hip and knee should also be completed. Associated pain and disability from quadriceps tendon rupture may distract the patient and clinician from associated injuries such as anterior cruciate ligament tears [10].

Imaging

Radiographs

Radiographs are commonly obtained as the initial diagnostic study for knee trauma including quadriceps tendon ruptures. Anteroposterior and lateral radiographs alone may reveal findings strongly suggestive of quadriceps tendon rupture including loss of quadriceps tendon shadow, suprapatellar mass, and suprapatellar calcific densities [17]. The loss of quadriceps tendon shadow has been noted to be present in 100% of cases [17]. Suprapatellar calcific densities may originate from avulsion of the patella or from calcification within the quadriceps tendon itself [17]. Additional findings may include joint effusion. A low-lying appearance of the patella termed patella baja is commonly noted (Fig. 10.7) [22, 57].

Ultrasound

Normal tendons are linear with fibrillary appearance and intermediate echogenicity. Rupture of the quadriceps tendon will reveal a loss of the normal echo texture and discontinuity of the fibers as well as hypoechoic to anechoic hematoma formation [8, 57]. Ultrasonography offers the advantage of contralateral comparison of the unaffected extremity. Dynamic evaluation during flexion and extension may also be undertaken to add additional diagnostic information and clarity to partial versus full thickness tears [57]. With contraction of the quadriceps or with distraction of the patella, the suprapatellar gap will be accentuated in full thickness tears [8].

Fig. 10.7 Lateral knee radiograph demonstrating patella baja as seen quadriceps tendon rupture

Foley, et al., noted 100% sensitivity and specificity in diagnosis of quadriceps tendon high grade partial and complete tears under ultrasound retrospectively when compared with surgical correlation as the reference standard. For original nonretrospective ultrasounds, 96% of complete quadriceps tendon ruptures were correctly diagnosed [57]. Musculoskeletal ultrasound has grade 3 evidence for use in diagnosis of distal quadriceps tears and other investigations often do not provide additional information [18, 58].

MRI

Magnetic resonance imaging (MRI) historically has been the modality of choice and has been reported to have 100% sensitivity, specificity, and positive predictive value in detecting quadriceps tendon rupture [21]. MRI permits analysis of the quadriceps tendon in the setting of extensive edema or hematoma and allows visualization of other pathology within the knee [22]. MRI consistently and accurately detects and localizes quadriceps tendon rupture and can be a valuable tool during preoperative planning [23]. Limitations include increased cost and decreased availability in the emergency setting. Indications for use are often reserved for cases in which the diagnosis may be equivocal on physical examination, radiographs or ultrasound. Concomitant intra-articular injuries are seen in 9.6% of cases, and if strong suspicion for injury beyond the quadriceps tendon tear itself, MRI should be obtained [57].

Ruptures more commonly occur at the tendon-osseous junction and partial tears are more frequent than complete ruptures [24]. MRI findings of complete rupture on sagittal images show fluid signal within a torn and retracted quadriceps tendon without direct fiber insertion into the superior pole of the patella [24]. Such findings can be appreciated as in Fig. 10.8. The patellar tendon may take on a wavy appearance in the setting of patella baja [24]. A large joint effusion, adjacent hematoma, and/or avulsed osseous fragments may also be appreciated as per Fig. 10.9a, b.

Complete ruptures of the quadriceps tendon will appear as fluid signal with a retracted tendon that migrates proximally. Fibers are not visualized inserting onto the patella as complete quadriceps tendon tears occur most frequently at the insertion. The patella itself will retract distally and, as a result of loss of tension, the patellar tendon will appear wavy in appearance (Fig. 10.8). Associated findings include hematoma, effusion and avulsion fragments. In cases of partial tears, the superficial most contribution from the rectus femoris is most frequently disrupted [56].

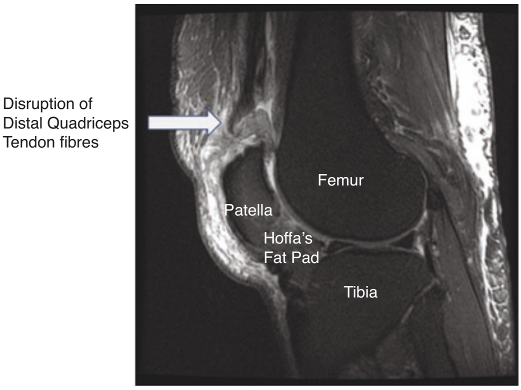

Fig. 10.8 MRI – T2 sagittal – full thickness quadriceps tendon tear

Treatment

Nonoperative

Low-grade distal quadriceps tendon tears may be treated nonoperatively [8, 57]. Treatment protocols are not standardized and vary by provider, but will typically consist of a period of immobilization in full extension followed by protected range-of-motion and gradual strengthening, usually under the guidance of a physiotherapist. Bracing may be discontinued once satisfactory strength and muscle control has been demonstrated, as well as ability to perform single leg raise without discomfort [8]. Although no studies have directly investigated aspiration of traumatic hemarthrosis in the setting of partial quadriceps tendon tears, consideration should be given to aspiration to improve pain and potentially accelerate recovery. This should be completed early in the treatment course before the hematoma has consolidated [8].

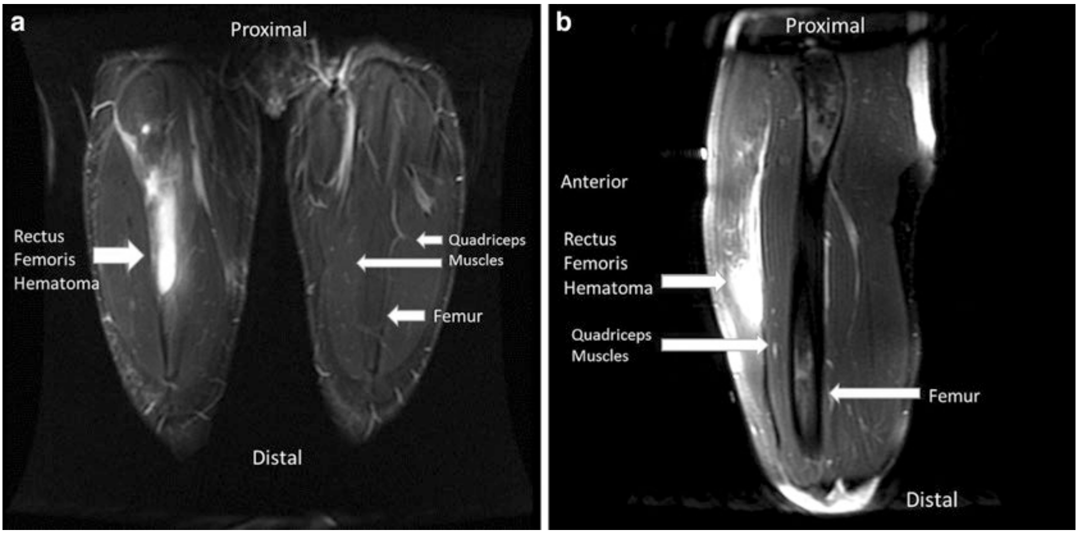

Fig. 10.9 (**a**, **b**) Rectus femoris hematoma.

Operative

Nonsurgical management of acute unilateral distal quadriceps tendon ruptures portend poor clinical results including long-term disability and weakness [27]. Consideration should be given to operative repair of high-grade partial thickness tears as well [57]. Delaying surgery of full thickness tears increases the difficulty of repair and may lead to less than satisfactory outcomes. Proximal tendon retraction away from the superior pole of the patella progresses rapidly over the first 72 hours after injury [7]. After 72 hours, difficulty with tendon-osseous apposition during repair may occur, however a 2008 case report highlighted successful delayed tendon repair at least 8 years after injury [28]. As such, early intervention is recommended, though delayed repair does not guarantee poor results [29, 30]. Many methods for surgical repair have been described, each of which has shown satisfactory results to achieve optimal functional outcome. The current literature, however, does not have randomized, controlled trials directly comparing the many surgical techniques [7].

For standard repairs, patients are placed supine on the operating room table with a bump under the ipsilateral greater trochanter. The use of a sidebar or sandbag can be employed to achieve intraoperative flexion at 30 degrees if desired. Alternatively, strategic use of sterile bumps can be employed. Nearly all techniques utilize a straight, midline longitudinal incision extending from proximal to the tear location to distal to the tibial tubercle. This permits adequate exposure of the underlying extensor mechanism. Full thickness medial and lateral soft tissue flaps are created to uncover the medial and lateral patellar retinaculum. Aspiration of the hematoma in the zone of injury and thorough debridement of fibrous and degenerative tissue are necessary to accurately identify healthy tissue planes and freshen the tendon edge for repair. Less common myotendinous or midsubstance ruptures can be treated with end-to-end primary repair with nonabsorbable sutures. More common tendon-osseous tendon tears may be repaired using a trans-osseous versus suture anchor techniques [30–33].

When performing the trans-osseous repair technique, an Allis or Lahey clamp can be used to tension the tendon distally after identifying and isolating its free edge. Two heavy, nonabsorbable sutures are placed in a locked, continuous fashion (Krakow) through the end of the tendon, leaving four suture limbs free at the distal stump. Next, attention is turned to preparing the patellar bone bed for healing. The superior pole is cleared of soft tissue and to a bleeding surface. The knee is flexed to 30 degrees and three 2-mm parallel drill holes through the patella are created in an anterograde fashion with care not to disrupt the articular surface. A suture passing device is then used to pass the free suture limbs from proximal-to-distal through the bone tunnels. Two limbs are passed through the central hole and a single limb is passed through the medial and lateral holes, respectively. The knee is then brought back into full extension and the suture limbs are tensioned as quadriceps excursion is analyzed. If sufficient tendon-osseous contact is achieved the sutures are tied over a bone bridge. The repair is reinforced with side-to-side repairs of retinacular defects. Suture irritation given the subcutaneous nature of the repair has been reported.

Alternative repair techniques with suture anchors for acute repairs or V-Y quadriceps turndown and/or soft tissue augmentation for chronic repairs have also been described in the literature [32, 34–37]. Suture anchors have been reported to provide multiple advantages over traditional methods [34, 35]. Potential advantages include reduced operative time, smaller surgical incisions, easy access to implantation site, better resistance of suture material, minimization of stress along the suture line with range of motion, higher strength of repair, and more consistent load-to-failure characteristics [32, 35, 38]. Bushnell et.al describe their use of two or three 5.0-mm suture anchors to secure the tendon with a modified Mason-Allen technique that limits soft tissue exposure [33]. Prior to skin closure, the knee is taken through a range of motion up to the “stress point” of the repair, defined by the position that excessive force is required for further flexion [34]. This “stress point” is used as a reference point for safe knee range of motion during early rehabilitation [34]. Richards, et.al describe a similar suture anchor technique but secure the tendon with a locking, continuous (Krakow) stitch supplemented with a side-to-side repair of the retinaculum [35]. Other methods of repair include the use of hamstrings autografts, Dacron vascular grafts, polydioxanone (PDS) cord, carbon fiber, and synthetic prosthetic ligaments [34]. Two separate reports in 2008 describe novel techniques using free hamstrings autograft to treat chronically retracted and scarred quadriceps tendon ruptures not amenable to primary repair [36, 37].

Rehabilitation protocols after repair vary by surgeon and continue to be controversial in the literature. Goals of physical therapy include preventing quadriceps weakness and loss of knee motion. In general, most patients are placed in a removable knee immobilizer in full extension after surgery and are allowed to fully bear weight on the limb. Knee immobilizers or hinged knee braces allow the wound to be evaluated 48 hours later, whereas the traditional use of a cast makes wound inspection and management more cumbersome. Some authors have advocated for early range of motion though most surgeons still wait 4–6 weeks prior to permitting knee flexion with physical therapy over fear for the risk of rerupture [40, 41]. Disadvantages of cast immobilization include persistent pain, difficulty regaining motion, decreased patellar mobility, muscle weakness, loss of bone mass, poor cartilage nutrition, and patella baja [41]. Advocates of early motion starting 7 days after surgery cite improved tendon vascularity, earlier organization and remodeling of collagen fibers, and an increase in the number of collagen filaments and breaking strength of the tendon with controlled tension on the tendon [41]. Langenhan, et.al compared restrictive versus early range of motion rehabilitation protocols in 66 patients with a minimum 24 month follow-up [40]. No clinical difference was identified with the use of the IDKC subjective knee form, number of reruptures, or overall complication rate [40]. Patients in the restrictive protocol did return to work on average 10 days later than those in the early range of motion group, but this difference did not reach significance [40].

Several retrospective case series have studied the results of various methods of surgical repair techniques and rehabilitation protocols. Siwek, et.al evaluated outcomes on 36 ruptures and found good to excellent functional results in all patients treated within 72 hours, good results in three patients treated after a 2 weeks delay, and unsatisfactory results in three patients treated greater than 4 weeks after injury [29]. Another study reviewed 53 ruptures with varying surgical techniques and postoperative rehabilitation protocols [40]. No differences were identified among patients treated acutely, but operative delay led to poorer functional outcomes and decreased satisfaction scores [40]. Rasul, et.al immobilized 19 ruptures for 6 weeks after surgery [41]. Excellent results were noted in 17 patients who had early repair with good results in the two patients treated in a delayed fashion [41]. One study showed that 84% of working patients were able to return to their previous occupations [28]. However, more than 50% could no longer participate in their pre-injury recreational activities [28]. Among professional American football players, even with timely surgical repair, the rate of return to play in regular season games was 50% [8]. For those that did return to play, the average number of games after injury was 40.9 games [8].

Conclusion

The quadriceps is a unique complex of individual muscles and tendons that must work together in harmony to allow for a wide assortment of dynamic functions. However, given that the quadriceps is comprised of these separate components, its intrinsic complexity lends itself to potential for injury to yield improper function and subsequent damage with profound impact on mobility. Should injury occur, it is important to determine the mechanism of injury and true etiology of the derangement in order to proceed with the correct treatment plan for the patient. The wide array of dynamic function and injury mechanisms are what lead the multitude of treatment options when it comes to healing the quadriceps muscle group and their tendons.

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