



The management of proximal rectus femoris avulsion injuries

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- Injuries to the quadriceps muscle group are commonly seen in sporting activities that involve repetitive kicking and high-speed sprinting, including football (soccer), rugby and athletics.
- The proximal rectus femoris is prone to avulsion injuries as rapid eccentric muscle contraction leads to asynchronous muscle activation and different force vectors through the straight and reflected heads.
- Risk factors for injury include previous rectus femoris muscle or hamstring injury, reduced flexibility of the quadriceps complex, injury to the dominant leg, and dry field playing conditions.
- Magnetic resonance imaging (MRI) is the preferred imaging modality as it enables the site of injury to be accurately located, concurrent injuries to be identified, preoperative grading of the injury, and aids surgical planning.
- Non-operative management is associated with highly variable periods of convalescence, poor return to preinjury level of function and high risk of injury recurrence.
- Operative treatment of proximal rectus femoris avulsion injuries with surgical repair or surgical tenodesis enables return to preinjury level of sporting activity and high functional outcomes.
- Surgical tenodesis of proximal rectus femoris avulsion injuries may offer an avenue for further reducing recurrence rates compared to direct suture anchor repair of these injuries.

Keywords: avulsion injuries; proximal rectus femoris; quadriceps injuries

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Introduction

Injuries to the quadriceps complex most commonly occur in sporting activities that involve repetitive kicking and high-speed sprinting.^{1,2} In professional football (soccer) and rugby, quadriceps injuries lead to more missed games per year than any other muscle injury, including hip adductor, hamstrings and gastrocnemius injuries.^{2,3} The most commonly injured muscle of the quadriceps complex is the rectus femoris.^{3,4} Injuries to this muscle range in severity from low-grade muscular strains to high-grade complete avulsion injuries (Fig. 1).^{3,4} Suboptimal management of these injuries is associated with prolonged periods of convalescence, poor return to preinjury level of sporting function and high risk of injury recurrence.^{1,5} However, understanding the optimal management of rectus femoris injuries is challenging, as existing reports on non-operative and operative management of these injuries have combined proximal and distal muscle injuries, pooled outcomes for low- and high-grade injuries, mixed varying preoperative imaging modalities, and undertaken operative intervention with heterogeneity in the surgical techniques and postoperative rehabilitation protocols.^{4,6-11} Furthermore, most studies are retrospective case series with limited data on functional outcomes and complications reported at short-term follow-up only.^{7,12,13}

This review aims to provide an evidence-based approach for the optimal management of proximal rectus femoris avulsion injuries. The article provides an insight into the unique anatomical relationship of the two proximal heads that predisposes to avulsion injuries, discusses the clinical features of an avulsion-type injury, and identifies intrinsic and extrinsic risk factors for these injuries. This review also revisits the various imaging modalities for diagnosing proximal

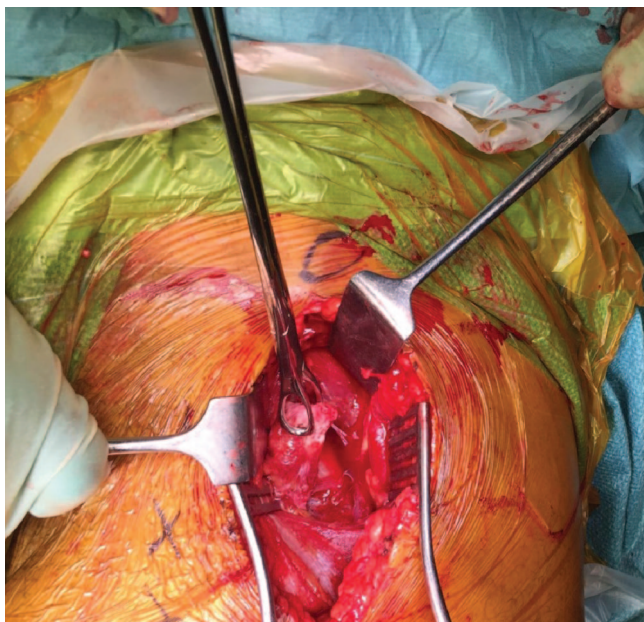


Fig. 1 Intra-operative photograph showing the avulsed proximal rectus femoris tendon.

rectus femoris avulsion injuries, explores current grading systems for stratifying injury severity, and discusses the indications and outcomes with non-operative and operative treatment for these injuries. An improved understanding of the management of these injuries may facilitate early diagnosis and referral for appropriate treatment, aid decision making for non-operative and operative treatment, and provide prognostic information to patients about time for return to sporting activity and injury recurrence.

Clinically relevant anatomy

The unique anatomy of the rectus femoris helps to facilitate its action as an antagonistic muscle to the hamstring muscles at the hip and the knee joints.^{1,6} The rectus femoris is fusiform in shape and arises from two proximal tendon heads, the superficial direct head that originates from the anterior inferior iliac spine, and the deep reflective head that originates from the acetabular ridge.⁵ The two heads merge at the proximal conjoined tendon. However, the straight head remains superficial and blends with the overlying fascia, whereas the indirect head forms the deep muscle fibres and continues as a musculotendinous junction into the muscle belly.^{1,5,7,12} The muscle fibres of the direct head therefore form a unipennate structure, while the muscle fibres of the indirect head originate from both the medial and lateral borders of the tendon, producing a bipennate structure.^{1,12} The distal end of the muscle joins the vastus medialis, vastus lateralis, and vastus intermedius

to form the quadriceps tendon, which inserts into the patella tendon and tibial tuberosity.¹²

Several unique anatomical features of the rectus femoris predispose this muscle to proximal avulsion injuries.⁵ The muscle consists predominantly of type II muscle fibres, which produce forceful, explosive movements with rapid changes in muscle length and velocity during contraction.¹³ The rectus femoris is also the only biarticular muscle of the quadriceps complex, crossing two major joints to generate hip flexion and knee extension.¹² Movements such as kicking, are associated with rapid eccentric muscle contraction that lead to asynchronous muscle activation and different force vectors through the straight and reflected heads.^{5,12,13} The lengthy, narrow, proximal aponeurosis leads to poor dissipation of these forces from the muscle belly to the tendon at this interface, producing high pull out forces at the proximal sites of muscle origin.⁶ These anatomical and biomechanical factors increase the susceptibility of the rectus femoris to proximal avulsion injuries, and predispose the muscle to reinjury after non-operative treatment, requiring a need for operative repair at the injury site.^{12,13}

Clinical features

Patients with acute proximal rectus femoris avulsion injuries most commonly present with sudden onset, severe anterior thigh pain. This may be accompanied by an overlying swelling and ecchymoses, with reduced range of motion in the ipsilateral hip joint.^{8,14} The mechanism of injury is often consistent with sudden, forceful contraction of the quadriceps muscle, such as an abrupt sprint or kicking motion, or a fall with hyperextension of the hip joint.^{12,13} Patients may describe an audible 'pop' at the time of injury. Clinical evaluation may reveal significant thigh swelling, focal tenderness over the anterior inferior iliac spine, generalized anterior thigh tenderness and an antalgic or stiff-legged gait.^{8,15,16} A palpable gap may be felt in the proximal aspect of the anterior thigh, although this may not always be pronounced. In some patients, a sizeable mass in the anterior thigh may be seen with muscle retraction, representing the reflected head of the rectus femoris.^{3,8} Active muscle examination may reveal reduced power with knee extension and hip flexion in the injured limb. Careful clinical examination for additional muscular injuries and neurological compromise is important for early identification and diagnosis of any concurrent injuries.^{12,13} Clinicians should maintain a high index of suspicion and low index for early imaging and appropriate referral in patients with these clinical features. Delays in referral for appropriate treatment are associated with poor functional recovery and increased risk of complications.⁹

Intrinsic and extrinsic risk factors

Intrinsic risk factors for increased susceptibility to rectus femoris injury include previous ipsilateral hamstring or quadriceps muscle injury.⁵ Altered gait patterns such as reduced stride length after previous hamstring injuries may protect the quadriceps and hamstring during the gait cycle but increase vulnerability to injury on rapid forced exertion of these muscles.¹⁰ J. Orchard reviewed outcomes in 183 quadriceps muscle injuries in Australian football players and found height below 1.82 cm was associated with increased risk of quadriceps muscle injury (relative risk: 1.48; 95% CI: 1.09 to 2.02).¹⁰ Fousekis et al reviewed outcomes in 100 professional soccer players and reported a trend for increased risk of muscle injury in shorter players (OR: 0.08; 95% CI: 0.00 to 1.35) and heavier players (OR: 10.70; 95% CI: 0.73 to 156.37) compared to taller and thinner subjects.¹⁷ The authors also reported a trend towards flexibility asymmetries in those players who sustained quadriceps injuries. Witvrouw et al prospectively followed 146 male professional soccer players with no history of lower limb muscle injury over two years, and reported patients with preseason quadriceps tightness had increased risk of quadriceps injury during competitive play.¹¹ Furthermore, leg dominance had also been proposed as a risk factor, with 60% of rectus femoris injuries occurring within the dominant leg, compared to only 33% in the non-dominant leg. In the remaining 7% of patients, leg dominance was unknown, or injuries occurred bilaterally. In the aforementioned study by J. Orchard, quadriceps muscle strains were also more common in the dominant kicking leg (relative risk: 2.13; 95% CI: 1.59 to 28.6), whereas hamstring and calf injuries were almost equally distributed.¹⁰ The study also found the primary extrinsic risk factor for proximal quadriceps injury to be low rainfall at the match venue in the previous seven days, described as a 'dry playing field'.¹⁰ Woods et al reviewed outcomes in 1200 English soccer players and reported increased quadriceps muscle strains with a dry field during preseason for two consecutive seasons.⁴

Preoperative imaging

Plain pelvic or hip radiographs are often the first line of imaging and may reveal avulsion fractures from the anterior inferior iliac spine (Fig. 2). In some patients with delayed presentations, chronic injuries and surgical repair of the avulsed proximal rectus femoris tendon, additional calcification may be seen around the proximal suture anchor repair site.^{3,18} Further imaging in patients with proximal rectus femoris avulsion injuries is often undertaken using ultrasound scan or magnetic resonance imaging (MRI). Ultrasound scan offers a rapid, widely available and relatively inexpensive imaging modality for assessing

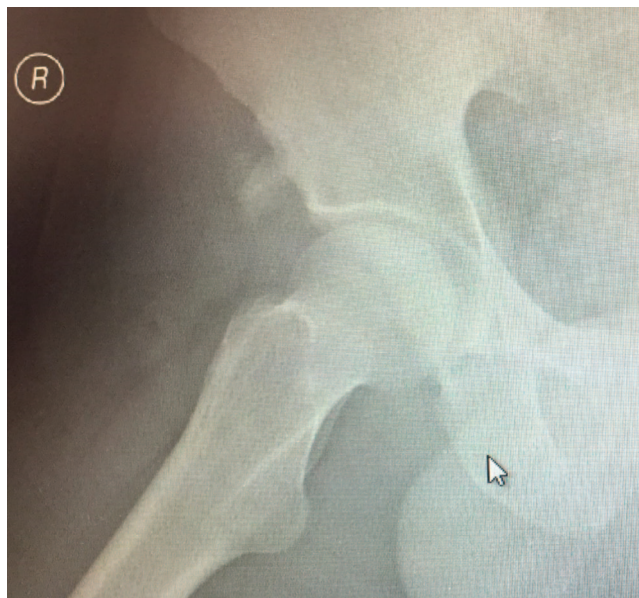


Fig. 2 Plain radiograph showing proximal rectus femoris avulsion injury from the anterior inferior iliac spine.

acute proximal rectus femoris injuries and monitoring follow-up after treatment.⁹ Injuries to the central tendon cord of the proximal rectus femoris identified on ultrasound scan have been associated with poor prognostic outcomes.³ However, ultrasound scan is heavily user-dependent and has limited sensitivity and specificity for identifying proximal rectus femoris injuries compared to MRI.¹⁹

Characteristic findings with T2-weighted MRI scans include proximal retraction of the avulsed rectus femoris stump, with increased signal intensity representing fluid within the surrounding fascial and perifascial compartments.⁵ Interstitial haemorrhage and oedema are distinctively displayed as a feathery appearance of the muscle.^{1,20} Kassarjian et al described MRI findings in eight patients with degloving injuries to the rectus femoris, by which the deeper bipennate component of the indirect head was dissociated from its superficial unipennate component.²⁰ On MRI, this dissociation caused proximal retraction of the inner myotendinous complex, creating an image similar to a finger withdrawing from a glove.²¹ In contrast, myotendinous injury to the indirect component centred along the long, indirect intra-muscular tendon, results in a typical MRI appearance of focal oedema with fluid centred at the myotendinous junction. Hughes et al described this finding as a bull's-eye lesion on MRI.⁷ Overall, MRI is the preferred imaging modality as it enables the site of injury to be accurately located, identifies concurrent injuries, allows for preoperative grading of the injury, and aids surgical planning based on the severity of injury and degree of muscle retraction.¹⁸ MRI of the contralateral uninjured

limb may also help guide operative intervention by displaying the patient's preinjury muscular architecture for comparison.

Injury classification

There is currently no formal classification system for grading proximal rectus femoris avulsion injuries within the existing literature, although existing muscular grading systems may be adapted to describe the severity and location of this injury. Lempainen et al described four different injury patterns in the proximal rectus femoris that can be used to guide treatment.¹⁸ This anatomical description is based on injury patterns to the two proximal heads of the rectus femoris. The injury patterns described are as follows: normal anatomy; complete two-tendon avulsion; complete rupture of the proximal conjoined tendon; and partial tear of the proximal rectus femoris (direct head). The authors recommended operative intervention in elite athletes for complete two-tendon avulsions and complete rupture of the proximal common tendon. Non-operative treatment was recommended for partial tears. While this description does provide some recommendations for management, the grade of the injury and amount of tendon retraction are not included. These factors are known to influence surgical decision making and postoperative outcomes.²²

The Munich consensus statement defined a comprehensive classification for athletic muscle injuries to improve clarity of communication between healthcare professionals and facilitate further research studies on muscle injuries.²² The Munich classification broadly divides indirect muscle injuries into functional and structural muscle injuries. Functional injuries are further subclassified into over-exertional related muscle disorders (Type 1), and neuromuscular muscle disorders (Type 2). Structural muscle disorders are subclassified into partial muscle tears (Type 3) and total muscle tears (Type 4). However, this classification system has limited applicability to the unique two-head anatomy of the proximal rectus femoris and does not provide treatment recommendations. While some studies on rectus femoris tears do classify these injuries according to the Munich consensus statement, this classification has not been broadly implemented for proximal rectus femoris avulsion injuries.¹

The British athletics muscle injury classification (BAMIC) system can be applied to any muscle injury and has been widely adopted to report on hamstring injuries and adductor injuries.²³ The classification system uses MRI and has high inter- and intra-observer agreeability.^{17,24} The BAMIC classification system initially stratifies muscle injury based on the severity of the injury (grade 0 – normal MRI, grade I – small tears to the muscle, grade II – moderate tears to the muscle, grade III – extensive tears to the

muscle, and grade IV – complete tears to the muscle or tendon). The injury is then further subclassified based on the anatomical site of the injury (type a – myofascial, type b – musculotendinous, and type c – intra-tendinous). This classification is often used on imaging reports, but to our knowledge, this classification system has not been used in any existing studies on proximal rectus femoris avulsion injuries.

Non-operative treatment

Non-operative treatment follows the principles of soft tissue injury management including rest, ice, compression, and protected weight-bearing.¹⁵ Rehabilitation at the early stage includes pain relieving modalities, gentle range of motion, and functional movement training. Gentle strength training is initiated with isometric contractions and light eccentric exercises. Graduated return to resistance strength training, cardiovascular training and running is instituted after achievement of pain-free, full range of hip and knee motion.⁵ Core stability is important to counteract torsional, lateral flexion, and extension forces during sprinting and kicking activities.⁵ Core stability exercises should be included in rehabilitation protocols as they are thought to decrease overload of the rectus femoris and reduce injury recurrence.^{25–27} More recently, platelet-rich plasma injections have gained popularity in the treatment of acute muscle injuries, including proximal rectus femoris tears.^{25,26} Isolated case reports and small case series have reported complete resolution of pain and full recovery in strength following treatment of rectus femoris tears with non-operative management and platelet-rich plasma injections.^{25,26} However, there remains a paucity of any high-quality evidence to support the use of platelet-rich plasma injections for proximal rectus femoris avulsion injuries, and guidelines for optimal doses and injection regimes have not been established.

Non-operative treatment of proximal rectus femoris avulsion injuries is associated with highly-variable periods of convalescence, with studies reporting return to preinjury level of sporting function at six weeks to one year after injury.¹⁵ The associated loss of muscle strength and functional decline with non-operative management is associated with poor return to baseline activity and decreased functional performance.^{15,18,28,29} Non-operative management is associated with residual scarring and tethering of the avulsed tendon stump to adjacent soft tissues, with injury recurrence in 18% of cases.³⁰ In professional athletes, proximal rectus femoris avulsion injuries are career-threatening injuries, and there is very limited evidence to support non-operative management of high-grade injuries in these patients. Gamradt et al reviewed outcomes in 11 professional American football players with proximal

rectus femoris avulsion injuries undergoing non-operative management and reported mean time for return to play was 69.2 days, with a range of 21 days to 208 days.³⁰ Two of the 11 patients had recurrent injuries after return to sporting activity. Hsu et al described two cases of proximal rectus femoris avulsions in American football players managed non-operatively, and reported return to competitive play in 6 to 12 weeks after injury.¹⁶ However, this study did not record any measurement of quadriceps strength or functional outcomes, and recurrence was assessed for only a limited time after return to sporting activity. Straw et al reported on a soccer player with a chronic rupture of the rectus femoris, and found that the patient could not kick or sprint even after 12 months of non-operative treatment.²⁸ Esser et al presented a case of a collegiate-level football goalkeeper who suffered a complete proximal rectus femoris avulsion after taking a goal kick.⁹ The patient was able to return to sporting activity after five months of rehabilitation. Park et al described a severe proximal rectus femoris musculotendinous injury in a recreational athlete.¹⁵ The athlete was able to return to kicking activities at three to four months; however, he did not return to baseline function until one year post injury. Non-operative treatment of proximal rectus femoris avulsion injuries may also lead to calcification of the avulsed tendon stump, which may cause secondary hip impingement and reduced functional performance.^{31,32} In patients refractory to non-operative treatment, operative intervention may be required to excise the calcified tissue.

Non-operative management of proximal avulsion injuries should be reserved for patients with low functional demands. Patients should be informed that non-operative management of these high-grade injuries has a highly variable time frame for convalescence, poor return to pre-injury level of functional performance, and high risk of recurrence with return to sporting activity.^{9,15,18,33,34}

Operative treatment

Operative treatment of proximal rectus femoris avulsion injuries is often reserved for patients with moderate to high functional demands or patients with persistent pain and functional compromise refractory to non-operative treatment.^{26,30} Both primary surgical repair of the avulsed tendon and excision of the proximal tendon remnant with muscular suture tenodesis have been described as operative techniques for reducing the risk of recurrence compared to non-operative management for these high-grade injuries.³⁵

Operative repair with suture anchors to reattach the avulsed proximal rectus femoris tendon aims to restore the preinjury anatomical architecture and native muscle tension to facilitate postoperative rehabilitation and return to sporting function. Lempainen et al reviewed outcomes

in 19 professional soccer players undergoing suture anchor repair of proximal rectus femoris avulsion injuries, and reported outcomes as good (full return to preinjury level of sports without any symptoms) in 17 cases and moderate (return to preinjury level of sports with some residual symptoms) in two cases at mean 2.8 years (range: one to 11 years) follow-up.¹⁸ Two patients with chronic injuries developed permanent loss of sensation due to iatrogenic injury to the lateral femoral cutaneous nerve. Ueblacker et al reviewed outcomes in four professional soccer players undergoing surgical repair of acute and chronic proximal rectus femoris injuries.³⁶ The study reported that none of the study patients had any subjective complaints, restrictions in their ability to play, or pain at 35 ± 6 months follow-up.³⁶ Repeat MRI scans at follow-up revealed that all anatomically inserted tendons remained intact. García et al reviewed outcomes in 10 professional soccer players from the Spanish football league undergoing surgical repair of proximal rectus femoris injuries, and the reported mean time for return to sporting function was 3.8 ± 0.8 months.³⁷ However, this study involved patients with both proximal avulsion injuries and intra-tendinous tears, and also included three patients with recurrent injuries following previously unsuccessful surgical repair. Irmola et al followed four professional soccer players and one national-level hurdler undergoing surgical repair of complete proximal rectus femoris avulsion injuries.³⁸ The study found that the median time for return to sporting activity was nine months (range: five to 10 months). In this study, time from injury to surgical intervention was 18 to 102 days, which may have adversely affected postoperative rehabilitation time. Delays in operative treatment may lead to additional calcified deposits and scar tissue around the avulsed stump, which can irritate surrounding soft tissue structures, increase the risk of iatrogenic nerve injury during surgical dissection, and further delay return to sporting function.³⁵ Similarly, in older patients with rectus femoris avulsion injuries, the avulsed tendinous segment may contain periosteum and is more likely to form bone.^{31,32}

The main limitation of direct surgical repair is the highly variable risk of injury recurrence after returning to sporting activity. The reported range of injury recurrence following surgical repair of the avulsed tendon ranges from 15% to 60% within one-year follow-up.^{5,9,15,16,18,23,26,28,34–36,38,39} This has been attributed to surgical repair of the avulsed proximal tendon causing the fibrocartilage layer at the enthesis to be replaced by fibrous tissue.^{18,25} This inhibits regeneration of fibrocartilage at the bone–tendon interface, delays healing at this interface for up to two years after surgery, and increases the risk of further avulsion injuries at this site.^{18,27} Another plausible explanation is that surgical repair restores native tension in the rectus femoris, but the pull out forces during muscle exertion are

concentrated at the suture anchor repair sites.⁴⁰ In order to create a more tension-free construct with a more uniform stress distribution across the repair site and reduce risk of reinjury at the operative site, some surgeons have advocated for muscular tenodesis. This procedure involves resection of the avulsed tendon and any associated calcified deposits, with multiple interrupted sutures to attach the muscle belly in a side-to-side fashion without tension to the surrounding muscle (vastus lateralis), sartorius fascia, and rectus bed. Sonnery-Cottet et al followed four patients with recurrent injuries, and one patient with a primary injury of the proximal rectus femoris, undergoing surgical excision of the proximal tendon remnant with muscle-to-muscle suture repair.³⁴ The authors found that all patients returned to their preinjury level of function at 15.8 ± 2.6 weeks, with no injury recurrence at three months follow-up. Additionally, all patients had Marx activity scores of 16 and Lower Extremity Functional Scale scores of 80 at three months follow-up. Wittstein et al reported five cases of chronic tears of the reflected head of the rectus femoris treated with excision of the reflected head and tenodesis.³⁵ All patients reported a significant decrease in pain after surgery and were able to return to collegiate-level athletics. Further higher-quality studies are required to assess quadriceps strength, range of motion, functional outcome scores and complications in patients with primary rectus femoris avulsion injuries undergoing surgical repair versus primary tenodesis.

Conclusion

Injuries to the quadriceps muscle group are commonly seen in sporting activities that involve repetitive kicking and high-speed sprinting, including football (soccer), rugby and athletics. The proximal rectus femoris is prone to avulsion injuries as rapid eccentric muscle contraction leads to asynchronous muscle activation and different force vectors through the straight and reflected heads. Risk factors for injury include previous rectus femoris muscle or hamstring injury, reduced flexibility of the quadriceps complex, injury to the dominant leg, and dry field playing conditions. MRI is the preferred imaging modality as it enables the site of injury to be accurately located, concurrent injuries to be identified, preoperative grading of the injury, and also aids surgical planning. Non-operative management is associated with highly variable periods of convalescence, poor return to preinjury level of function and high risk of injury recurrence. Operative treatment of proximal rectus femoris avulsion injuries with surgical repair or surgical tenodesis enables return to preinjury level of sporting activity and high functional outcomes. Surgical tenodesis of proximal rectus femoris avulsion injuries may offer an avenue for further reducing recurrence rates without compromising time for return to

sporting activity or functional outcomes compared with direct suture anchor repair of these injuries.

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ICMJE CONFLICT OF INTEREST STATEMENT

FSH reports board membership of the *Bone and Joint Journal* and *The Annals of the Royal College of Surgeons*; consultancy for Smith & Nephew, Corin, MatOrtho and Stryker; payment for lectures including service on speakers' bureaus for Smith & Nephew and Stryker; royalties paid by Smith & Nephew, MatOrtho, Corin and Stryker, all outside the submitted work.

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REFERENCES

- Morgan C, Konopinski M, Dunn A, Milsom J.** Rehabilitation of rectus femoris injuries in kicking athletes. *SPSR* 2018;1:1–11. https://sportperfsci.com/wp-content/uploads/2018/06/SPSR35_Morgans-al_180615_final.pdf (date last accessed 13 July 2020).
- Ekstrand J, Häggglund M, Waldén M.** Epidemiology of muscle injuries in professional football (soccer). *Am J Sports Med* 2011;39:1226–1232.
- Pollock N, Patel A, Chakraverty J, Suokas A, James SLJ, Chakraverty R.** Time to return to full training is delayed and recurrence rate is higher in intratendinous ('c') acute hamstring injury in elite track and field athletes: clinical application of the British Athletics Muscle Injury Classification. *Br J Sports Med* 2016;50:305–310.
- Woods C, Hawkins R, Hulse M, Hodson A.** The Football Association Medical Research Programme: an audit of injuries in professional football—analysis of preseason injuries. *Br J Sports Med* 2002;36:436–441.
- Mendiguchia J, Alentorn-Geli E, Idoate F, Myer GD.** Rectus femoris muscle injuries in football: a clinically relevant review of mechanisms of injury, risk factors and preventive strategies. *Br J Sports Med* 2013;47:359–366.

6. Orchard J, Walt S, McIntosh A, Garlick D. Muscle activity during the drop punt kick. *J Sports Sci* 1999;17:837–838.
7. Hughes C IV, Hasselman CT, Best TM, Martinez S, Garrett WE Jr. Incomplete, intrasubstance strain injuries of the rectus femoris muscle. *Am J Sports Med* 1995;23:500–506.
8. Shimba LG, Latorre GC, Pochini AC, Astur DC, Andreoli CV. Surgical treatment of rectus femoris injury in soccer playing athletes: report of two cases. *Rev Bras Ortop* 2017;52:743–747.
9. Esser S, Jantz D, Hurdle MF, Taylor W. Proximal rectus femoris avulsion: ultrasonic diagnosis and nonoperative management. *J Athl Train* 2015;50:778–780.
10. Orchard JW. Intrinsic and extrinsic risk factors for muscle strains in Australian football. *Am J Sports Med* 2001;29:300–303.
11. Witvrouw E, Danneels L, Asselman P, Cambier D. Muscle flexibility as a risk factor for developing muscle injuries in male professional soccer players: a prospective study. *Am J Sports Med* 2003;31:41–46.
12. Hasselman CT, Best TM, Hughes C IV, Martinez S, Garrett WE Jr. An explanation for various rectus femoris strain injuries using previously undescribed muscle architecture. *Am J Sports Med* 1995;23:493–499.
13. Kary JM. Diagnosis and management of quadriceps strains and contusions. *Curr Rev Musculoskelet Med* 2010;3:26–31.
14. Devitt BM, Smith B, Stapf R, O'Donnell JM. Avulsion of the direct head of rectus femoris following arthroscopic subspine impingement resection: a case report. *J Hip Preserv Surg* 2015;3:56–60.
15. Park CK, Zlomislis V, Du J, Huang BK, Chang EY, Chang DG. Nonoperative management of a severe proximal rectus femoris musculotendinous injury in a recreational athlete: a case report. *PM R* 2018;10:1417–1421.
16. Hsu JC, Fischer DA, Wright RW. Proximal rectus femoris avulsions in national football league kickers: a report of 2 cases. *Am J Sports Med* 2005;33:1085–1087.
17. Fousekis K, Tsepis E, Poulmedis P, Athanasopoulos S, Vagenas G. Intrinsic risk factors of non-contact quadriceps and hamstring strains in soccer: a prospective study of 100 professional players. *Br J Sports Med* 2011;45:709–714.
18. Orchard J. The 'northern bias' for injuries in the Australian Football League. *Aust Turfgrass Manag* 2000;23:36–42.
19. Lempainen L, Kosola J, Pruna R, Puigdemol J, Ranne J, Orava S. Operative treatment of proximal rectus femoris injuries in professional soccer players: a series of 19 cases. *Orthop J Sports Med* 2018;6:2325967118798827.
20. Lee JC, Mitchell AWM, Healy JC. Imaging of muscle injury in the elite athlete. *Br J Radiol* 2012;85:1173–1185.
21. Kassarjian A, Rodrigo RM, Santisteban JM. Intramuscular degloving injuries to the rectus femoris: findings at MRI. *AJR Am J Roentgenol* 2014;202:W475–480.
22. Hughes C IV, Hasselman CT, Best TM, Martinez S, Garrett WE Jr. Incomplete, intrasubstance strain injuries of the rectus femoris muscle. *Am J Sports Med* 1995;23:500–506.
23. Straw R, Colclough K, Geutjens G. Surgical repair of a chronic rupture of the rectus femoris muscle at the proximal musculotendinous junction in a soccer player. *Br J Sports Med* 2003;37:182–184.
24. Mueller-Wohlfahrt HW, Haensel L, Mithoefer K, et al. Terminology and classification of muscle injuries in sport: the Munich consensus statement. *Br J Sports Med* 2013;47:342–350.
25. Pollock N, James SLJ, Lee JC, Chakraverty R. British athletics muscle injury classification: a new grading system. *Br J Sports Med* 2014;48:1347–1351.
26. Fyfe JJ, Opar DA, Williams MD, Shield AJ. The role of neuromuscular inhibition in hamstring strain injury recurrence. *J Electromyogr Kinesiol* 2013;23:523–530.
27. Pogliacomi F, Visigalli A, Valenti PG, et al. Rectus femoris myotendinous lesion treated with PRP: a case report. *Acta Biomed* 2019;90:178–183.
28. Matthew Q, Nicholas L, Phillip S, Ramin RT. Treatment of direct head of the rectus femoris injury with PRP therapy in a Division I basketball player. *Int J Sports Ex Med* 2019;5.
29. Kraeutler MJ, Garabekyan T, Mei-Dan O. The use of platelet-rich plasma to augment conservative and surgical treatment of hip and pelvic disorders. *Muscles Ligaments Tendons J* 2016;6:410–419.
30. Taylor C, Yarlagaadda R, Keenan J. Repair of rectus femoris rupture with LARS ligament. *BMJ Case Rep* 2012;2012:bcr0620114359.
31. Gamradt SC, Brophy RH, Barnes R, Warren RF, Thomas Byrd JW, Kelly BT. Nonoperative treatment for proximal avulsion of the rectus femoris in professional American football. *Am J Sports Med* 2009;37:1370–1374.
32. Zini R, Panasci M, Papalia R, Franceschi F, Vasta S, Denaro V. Rectus femoris tendon calcification: arthroscopic excision in 6 top amateur athletes. *Orthop J Sports Med* 2014;2:2325967114561585.
33. Zini R, Panasci M. Post-traumatic ossifications of the rectus femoris: arthroscopic treatment and clinical outcome after 2 years. *Injury* 2018;49:S100–S104.
34. Bottoni CR, D'Alleyrand JCG. Operative treatment of a complete rupture of the origination of the rectus femoris. *Sports Health* 2009;1:478–480.
35. Sonnery-Cottet B, Barbosa NC, Tuteja S, et al. Surgical management of rectus femoris avulsion among professional soccer players. *Orthop J Sports Med* 2017;5:2325967116683940.
36. Wittstein J, Klein S, Garrett WE. Chronic tears of the reflected head of the rectus femoris: results of operative treatment. *Am J Sports Med* 2011;39:1942–1947.
37. Ueblacker P, Müller-Wohlfahrt HW, Hinterwimmer S, Imhoff AB, Feucht MJ. Suture anchor repair of proximal rectus femoris avulsions in elite football players. *Knee Surg Sports Traumatol Arthrosc* 2015;23:2590–2594.
38. García VV, Duhrkop DC, Seijas R, Ares O, Cugat R. Surgical treatment of proximal ruptures of the rectus femoris in professional soccer players. *Arch Orthop Trauma Surg* 2012;132:329–333.
39. Irmola T, Heikkilä JT, Orava S, Sarimo J. Total proximal tendon avulsion of the rectus femoris muscle. *Scand J Med Sci Sports* 2007;17:378–382.
40. Dean CS, Arbeloa-Gutierrez L, Chahla J, Pascual-Garrido C. Proximal rectus femoris avulsion repair. *Arthrosc Tech* 2016;5:e545–e549.
41. Barber FA, Cawley P, Prudich JF. Suture anchor failure strength: an in vivo study. *Arthroscopy* 1993;9:647–652.