Review

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The challenge of thigh tendon reinjuries: an expert opinion

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Abstract: This review critically examines the issue of thigh tendon reinjury in athletes, drawing on recent advancements and diverse perspectives in sports medicine. The findings underscore the paramount importance of an early and accurate diagnosis, which significantly influences treatment efficacy and rehabilitation outcomes. We explore the intricacies of tendon anatomy and the mechanisms underlying injuries, highlighting how these factors interplay with athlete-specific risk profiles to affect reinjury rates. A major finding from the review is the necessity for individualized rehabilitation approaches that integrate both traditional methods and emerging technologies. These technologies show promise in enhancing monitoring and facilitating precise adjustments to rehabilitation protocols, thus improving recovery trajectories. Additionally, the review identifies a common shortfall in current practices – premature to play (RTP) – which often results from inadequate adherence to tailored rehabilitation strategies or underestimation of the injury's severity. Such premature RTP significantly heightens the risk of further injury. Through this synthesis of contemporary research and expert opinion, the review advocates for a multidisciplinary approach in managing thigh tendon injuries, emphasizing the need for ongoing research to refine RTP criteria and optimize rehabilitation techniques. The ultimate goal is to support athletes in achieving safer and more effective recoveries, thereby reducing the likelihood of tendon reinjury.

Keywords: muscle injuries; reinjuries; muscle tendon; injury prevention; rehabilitation; sports medicine

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Introduction

The classic structure of muscle–tendon–bone units comprises a muscle anchored at two points: the origin and the insertion, bridged by a tendon or aponeurosis that merges at a musculotendinous junction (MTJ), and an enthesis where this tendon or aponeurosis attaches to the bone [1]. While the MTJ has traditionally been identified as the primary site of muscle injury, recent clinical and radiological evidence increasingly points to the muscle belly as a frequent injury site [2]. His view is supported by advanced imaging techniques and meticulous anatomical studies that show free tendons often extend into the muscle belly, leading to injuries at intramuscular myotendinous or myoaponeurotic junctions [3]. These intramuscular tendons, also referred to as central tendons, serve as central struts anchoring the muscle fibers and play a pivotal role in muscle function and injury mechanics. It is important to note that studies in small animals, often using crush/contusion models, may not be directly applicable to human strain-type injuries, as suggested by recent human-focused research [4].

Substantial central tendons in thigh muscles, such as the biceps femoris (BF) and rectus femoris (RF), are particularly prone to strain. The approach to treatment, prognosis, and rehabilitation duration varies significantly depending on the precise injury location and the anatomical structures involved [5, 6]. While ultrasound scanning offers a quicker, more dynamic method for diagnosis, magnetic resonance imaging (MRI) remains the standard for assessing muscle injuries in professional athletes due to its detailed imaging capabilities, which are crucial for diagnosing the extent of injuries that range from minor strains to potentially career-ending tendon ruptures [3, 7].

The British Athletics Muscle Injury Classification (BAMIC) system provides a comprehensive framework for the classification and grading of muscle injuries. It categorizes injuries based on their anatomical location as “a” (myofascial), “b” (musculotendinous/musculotendinous junction), or “c” (intratendinous) and grades them from 0 to 4 according to MRI markers of injury severity. This system has proven its interobserver reliability [8]. Similarly, the 2020 update to the ISMuLT (Italian Society of Muscles, Ligaments and Tendons) classification of muscle injuries refined the categorization of injuries into myofascial (MF), muscle tissue/MTJ (MT), and tendon (T) injuries, further emphasizing the significance of accurately identifying and recording reinjuries [9, 10]. The introduction of a recording system for the primary injury (R0) and subsequent reinjuries (R1–R3) in the updated ISMuLT classification highlights the critical role of this information in guiding recovery and prognostication [11]. However, it is crucial to note that some prognostic data within the ISMuLT paper are derived from expert opinions rather than direct study results.

Addressing the challenge of reinjury, which can extend recovery periods, decrease performance, and even end careers, is crucial. The duration of rehabilitation and the risk of recurrence are significantly influenced by the injury’s location within the tendon or muscle. Recent research highlights that injuries extending into the tendon, such as in the hamstring, are associated with higher rates of reinjury and longer durations before returning to play [12–14]. This becomes particularly significant in elite sports, where precise and timely rehabilitation is crucial for a sustainable return to play (RTP) [9, 15]. The extended recovery time and higher recurrence rate present significant clinical challenges, especially for elite athletes [15–17]. A thorough understanding of the injury mechanism, anatomy, and available treatment options is crucial for medical professionals to optimize the RTP process [18, 19]. Moreover, if for purely muscular injuries the literature provides some evidence of RTP frameworks [20–22], for the injuries described in this narrative review, there is a complete absence of published studies on clear return-to-play criteria and rehabilitation progression models, making everything even more challenging.

This review investigates the complex issue of reinjury in thigh tendons among athletes, emphasizing the physical, psychological, and career ramifications of recurrent tendon injuries. Understanding the underlying mechanisms, risk factors, and effective prevention and management strategies is essential for athletes, coaches, healthcare professionals, and stakeholders in sports medicine.

Microscopical changes

The healing processes of muscles and tendons significantly differ, with muscle injuries that usually heal facilitated by a satellite cell response and early scaffold formation that supports muscle regeneration and swift functional restoration [23, 24]. However, many studies have shown that muscle injuries can lead to significant complications, such as morphology and functional changes, during the recovery period, and this is an important aspect to consider when planning an RTP [25–27].

Tendon healing, in contrast, is a complex and prolonged process, beginning with an inflammatory response within the first 24 h that leads to extracellular matrix deposition, predominantly comprising type III collagen initially [28]. This matrix transitions into type I collagen from around 6 to 8 weeks postinjury, a crucial phase for restoring the tendon’s tensile strength [29]. During the early stages of healing (first to third weeks), the scar tissue remains relatively soft, and premature or excessive loading at this stage can predispose the tendon to chronic conditions or increase the risk of reinjury. Mechanotransduction, involving the mechanical stimulation of cells, plays a pivotal role in tendon remodeling, enhancing collagen matrix deposition and the mechanical strength of the tissue through structured rehabilitation and controlled loading [29]. In the context of reinjury, particularly during the central tendon’s healing phase, nonoperative treatments may yield suboptimal outcomes if the delicate balance of loading and rest is not maintained [13].

Addressing the differential strain between central and free tendons, it is essential to understand that while both types share structural similarities in their collagen makeup, their mechanical and functional properties differ markedly. The collagen–proteoglycan matrix within the central tendon displays a less organized, wave-like pattern, indicative of its transitional nature between muscle and bone. In contrast, free tendons, which do not have muscle fibers inserted into them, exhibit a more structured arrangement and are capable of sustaining higher strain levels (6 % strain in free tendons vs. 2 % in central tendons) due to their ability to store and release energy efficiently through interfascicular gliding [30, 31].

This distinction is critical for rehabilitation strategies, as the pathology of central tendons, often resulting from acute strains, significantly differs from the degenerative overuse injuries typically seen in free tendons. Such differences necessitate tailored rehabilitation protocols that recognize the central tendon's higher vascularity and the substantial stress it endures at the MTJ, especially under high-energy injury mechanisms [32]. Furthermore, the unique histological organization of the central tendon, combined with its surrounding muscular framework, suggests why injuries here may present with less severity but have higher recurrence rates and extended recovery periods compared to free tendon injuries [3].

These insights underscore the importance of customizing rehabilitation efforts to address the specific biomechanical and physiological challenges associated with different tendon types, particularly emphasizing the need for controlled plyometric exercises and sprinting during the recovery phase [33, 34].

Thigh muscle

The muscles of the thigh are organized into three compartments, delineated by intermuscular septa positioned between the posterior aspect of the femur and the fascia lata. Within the anterior compartment of the thigh reside the sartorius muscle and the four prominent quadriceps femoris muscles: the rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM), and vastus intermedius (VI) [35]. These muscles are indispensable for activities such as knee extension, running, jumping, and kicking. Moving to the posterior compartment, three substantial muscles collectively known as the hamstrings are located: the biceps femoris (BF), semitendinosus (ST), and semimembranosus (SM). These muscles play crucial roles in knee flexion and hip extension, essential for activities like sprinting and sudden changes in speed. Lastly, the medial compartment harbors six muscles: gracilis, pectineus, adductor longus, adductor brevis, adductor magnus, and obturator externus. Their primary function revolves around the thigh adduction at the hip joint. Tendon injuries in the thigh arise from either acute trauma, such as sudden changes in direction, explosive movements, or chronic overuse, as seen in long-distance runners. These injuries' prevention and treatment hinge on understanding the demands placed on these muscle groups.

Hamstrings

Hamstring injuries, prevalent in sports demanding dynamic movements like acceleration and deceleration, pose a significant challenge due to their complexity and the risk of recurrence [36]. From an anatomical standpoint, the SM muscle is situated beneath the ST muscle. Its attachment points include the superolateral impression on the ischial tuberosity above and primarily the groove and adjacent bone on the medial and posterior surfaces of the medial tibial condyle below. The ST muscle lies medially to the BF and originates alongside the long head of the BF muscle from the inferomedial aspect of the upper area of the ischial tuberosity. With a spindle-shaped muscle belly, it terminates in the lower half of the thigh, forming a long cord-like tendon. This tendon, positioned atop the semimembranosus muscle, descends toward the knee. Curving around the medial condyle of the tibia, it inserts into the medial surface of the tibia just posterior to the tendons of the gracilis and sartorius muscles, forming part of the pes anserinus. It is noteworthy that anatomical variations are frequent, occasionally resulting in the ST having a distinct insertion site.

Central tendons within the hamstrings play a pivotal role in these injuries, extending considerable lengths within the muscle belly and influencing both acute and chronic injury patterns [37]. The hamstrings contain a substantial central tendon, which extends considerable lengths within the muscle belly, influencing both acute and chronic injury patterns. These central tendon tears, typically located 10–20 cm distal from the origin, are difficult to diagnose as they can appear similar to simple muscle strains [38]. The BF's central tendon, shared with the ST tendon medially, exhibits significant variations; some are completely enveloped by muscle tissue while others lie adjacent to it [39]. The tendon spans a considerable length in both the proximal and distal portions of the muscle belly, affecting injury dynamics and recovery process [38].

Hamstring injuries most commonly occur in athletes during high-speed running or overstretching of the posterior thigh [40, 41]. In football, the injury mechanisms vary greatly involving different closed and open kinetic chain sprint- and stretch-related movements [42–44]. However, rapid movements with high eccentric demands of the hamstrings seem to be the key element in these injuries. The most severe proximal hamstring injuries happen following rapid hip flexion with concurrent knee extension [45]. The severity of hamstring injuries varies, ranging from muscle strains to avulsions of 1 or 2–3 tendinous insertions on the ischial tuberosity. The proximal MTJ of the long head of the BF (PMTJ) is also frequently injured, as attributed to its long, narrow aponeurosis, which leads to poor dissipation of force from the muscle belly to the tendon at this interface [46–48]. While many hamstring injuries can be managed conservatively [49], complete ruptures of the proximal hamstring complex often require surgical intervention to restore function and prevent chronic issues or recurrence [50, 51] (Figure 1).

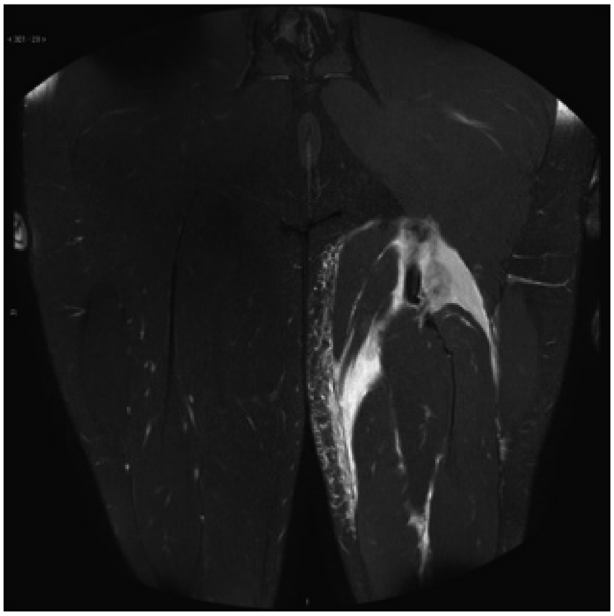

Figure 1: MRI coronal proton density fat-saturated image of complete proximal hamstring tendon disinsertion with retraction in a professional rugby athlete.

Early surgical treatment is recommended for acute complete hamstring avulsions [52, 53] and in certain cases of incomplete hamstring tears, especially in athletes. However, some hamstring injuries may become chronic and recur [54], possibly due to the involvement of the central tendon and an initial misdiagnosed injury that leads to an RTP process faster than what the injury needs [28, 55]. High recurrence rates of hamstring muscle injuries (16–34 %) further complicate treatment [36]. Incomplete proximal hamstring ruptures, often involving one or two tendons, present a significant challenge to surgeons [56, 57].

Studies have shown that injuries involving the central tendon, especially within the BF, are more likely to recur and require longer recovery times compared to other hamstring injuries. A study confirmed that most hamstring muscle injuries occurred at the MTJ of the central tendon, exhibiting a feather-like pattern of edema on MRI [58]. Comin et al. [13] noted that the appearance of the central tendon in these injuries is variable. Occasionally, the tendon maintains its structural integrity despite the disruption of surrounding muscle fibers, whereas in other instances, this integrity appears to be lost, and the tendon assumes an irregular or wavy contour or is frankly disrupted. They reviewed 62 hamstring injuries among elite Australian Rules footballers. Of the 62 injuries, 45 (72 %) involved the BF, and of these 45, 12 (27 %) had central tendon disruption with the subgroup with no proximal tendon involvement (n=12, mean: 13.0, range 6–26). The authors retrospectively analyzed injury databases from 6 Australian Rules football teams and one professional rugby league team. Of the 62 hamstring muscle injuries included in the study, 12 involved the central tendon. All these injuries were to the BF muscle, with none involving any other hamstring muscle. The authors reported that central tendon injuries were significantly more likely to recur than other injuries. Additionally, the mean recovery time following central tendon disruption was more than three times (72 days; interquartile range [IQR]: 42–109) that of other BF muscle injuries (21 days; IQR: 9–28), as well as 3 times that of the median combined recovery time of injuries to all hamstring muscles (21 days; IQR: 14–42).

Recent research indicates that recovery outcomes can vary significantly based on the athlete's sport and the specifics of the injury, with some studies showing no clear differences in recovery times between injuries with or without tendon involvement, suggesting that other factors such as injury severity and treatment efficacy may also play crucial roles. Pollock et al. [59] reviewed 65 hamstring injuries in 44 elite track and field athletes. The results showed that injuries that extended into the tendon ("c" injuries) had a longer time to return to full training and were more likely to recur compared to other grades of injuries. There was a significant difference within classifications 1a–3c for time to return to full training. Separate linear regression analysis of grade and site demonstrated that grade 3 severity ($p<0.001$) and intratendinous (c) site ($p=0.008$) were associated with an increase in the time to return to full training. Grade 3c injuries (n=7) had a mean return time of 84 days (SD 49.4, range 40–128) compared with grade 2b injuries (n=17) with a return time of 21 days (SD 10.2, range 12–49) and 2c injuries (n=8) of 27 days (SD 49.4, range 40–128). No significant differences were found between grades 1 and 2 ($t=-1.138$, $p=0.263$) or between classifications (a) and (b) ($t=-0.240$, $p=0.812$). There was also a significant difference within classifications 1a–3c concerning injury recurrence. Separate binary logistic analysis of grade and site suggested that grade was not associated with recurrence ($p=0.133$–0.968), but that intratendineous injuries (c) were associated with a higher risk of recurrence ($p=0.002$). This significantly increased repeat injury rate was 63 % in 2c injuries and 57 % in 3c injuries. In comparison, the repeat injury rate in 2b injuries was only 6 % ($p<0.001$), and there were no recurrences in any myofascial (a) injury class.

Vermeulen et al. [60] in 41 athletes with central tendons showed that in more than 50 % of cases, the RTP was obtained before healing on MRI and 18 of 34 (44 % overall) partial-thickness tendon discontinuities became continuous, and 6 out of 7 (15 % overall) complete thickness tendon discontinuities became partial-thickness tendon discontinuities. However, the reinjury rate was 20 %, lower than that reported by Pollock et al. (33 %) [59].

Wangensteen et al. [61], in a larger prospective analysis, noted only a small difference in recovery time following central tendon injury compared with other hamstring injuries, suggesting that the BAMIC categorization only accounted for a small variance in recovery time. Recent studies from English Premier League soccer clubs also indicated varying impacts of central tendon involvement on recovery and reinjury rates. Shamji et al. [62] reported significantly longer recovery times following central tendon injury compared to other types, while McAuley et al. [63] found no significant differences in recovery or recurrence between injuries with and without tendon involvement of the same grade. Both of these studies describe recovery times that are more comparable to those reported by van der Made et al. [64, 65] than those described by Pollock et al. [59]. As both studies involve a retrospective review of medical records, the physicians involved in the RTP decision were not blinded to MRI characteristics such as intramuscular tendon disruption. This is where the possibility of the aforementioned "self-fulfilling prophecy" is introduced, which may have caused a delay in RTP in cases with tendon disruption.

Injury to the distal musculotendinous T junction (DMTJ) of the BF is a distinct clinical entity that behaves differently from other hamstring injuries due to its complex, multicomponent anatomy and dual innervation [66]. Injury in this region demonstrates a particularly high rate of recurrence, and often surgery is a valid option [67]. According to Entwisie et al. [66], injuries to the DMTJ of the BF involved the long head component in 51 % of cases, both the long and short head components in 43 % of cases, and the short head component in 7 % of cases in this study. The recurrence rate of injury to the DMTJ of the BF in this series was 54 %, suggesting it is one of the most commonly reinjured muscles. However, this concept seems to be not confirmed by a recent study [68], where injuries with either intramuscular tendon or T-junction involvement were not associated with an increased rate of reinjury/subsequent injury to the same limb (intramuscular tendon involvement - odds ratio=0.96, T-junction involvement - odds ratio=1.03) in a cohort of professional rugby players, showing how this topic is complicated.

Rectus femoris

The RF muscle, spanning the hip and knee joints, endures high mechanical stress, especially during activities like soccer kicks [69], sprinting, and directional changes [70, 71]. This muscle originates from two primary tendons: the direct tendon from the anteroinferior iliac spine, and the indirect tendon from the acetabular margin and hip capsule [72]. Recent anatomical studies have identified a third membranous origin, extending from the indirect tendon to the greater trochanter, intertwining with the gluteus minimus [73]. These structures should be considered in future diagnostic algorithms for RF injuries.

Based on their location, RF injuries are classified as proximal, middle-third, or distal injuries [74–76]. The tendon convergence occurs distal to their origins, forming the conjoint tendon. Here, the direct tendon is positioned anteriorly and superficially, while the indirect tendon is deeper and posterior. Below this juncture, the muscular component starts laterally relative to the indirect tendon, and the muscle fibers from the direct tendon spread over the proximal third of the muscle, forming an aponeurotic expansion that merges with the anterior fascia. The indirect tendon's initial oval shape transforms as it progresses distally, adopting a thinner, comma-like shape before flattening and shifting from a medial to a more central position within the muscle. This transition gives rise to the central tendon, detectable via ultrasound and MRI [77]. In the distal third, this deep tendon becomes almost vertical and lies intramuscularly in the anterior aspect of the distal muscle belly [3].

The distal MTJ appears in the proximal third of the RF. As it extends distally, the connective tissue thickens, evolving into the posterior aponeurosis. The muscle fibers terminate relatively proximal to the patella, leaving a free tendon that integrates with the superficial layer of the quadriceps tendon, while the intermediate and deep layers are formed by the vastus medialis, lateralis, and intermedius, respectively, inserting at the patella's superior border.

Injuries involving the central tendon tend to be more severe than typical muscle strains involving only muscle tissue [13, 28]. Accurate diagnosis and classification of the injury are crucial in determining the appropriate treatment, considering the extent of the muscle belly affected, the injury location, and connective tissue damage [78, 79]. Severe cases, such as complete proximal RF avulsions or mid-substance ruptures, often necessitate surgical intervention, particularly in high-performance athletes [6, 80, 81] (Figure 2).

Hughes et al. [82] described a series of intrasubstance RF injuries originating from the tendon of the indirect head, often resulting in a "bull's eye" appearance on MRI.

Cross et al. [83] examined the clinical and MRI appearance of 25 quadriceps injuries of which 15 were RF injuries. Seven of the 15 RF injuries involved the central tendon. They described a typical MRI appearance showing a feather-like pattern of injury in the coronal T2 view. The clinical importance of this central tendon involvement is shown by the prolonged rehabilitation time in this group (27 days) compared with the remainder of the RF injuries (9 days).

Balius et al. [77] published an ultrasound study of 35 cases of RF injuries involving the central tendon

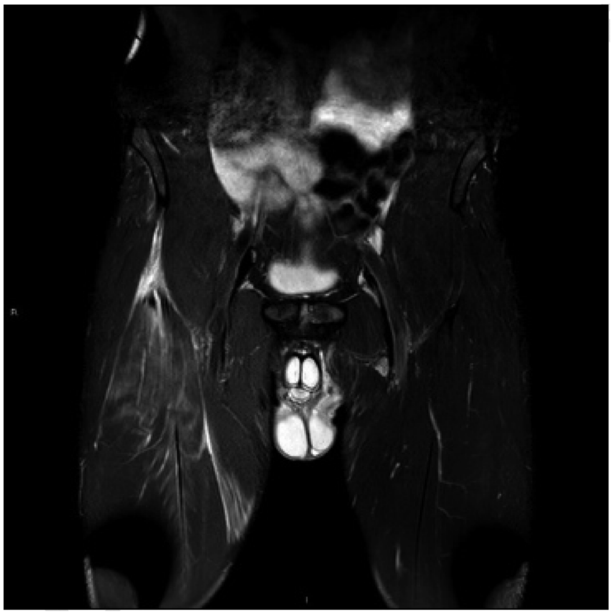

Figure 2: MRI coronal proton density fat-saturated image demonstrating complete rupture of the conjoint tendon in a professional athlete, involving both direct and indirect tendons of the RF with retraction.

(aponeurosis). The injuries involving this tendon had a longer time to RTP than the 13 peripheral RF injuries (15 days) in their cohort. Most of the distal central tendon injuries were grade I (14) or II (20) with only one complete tendon tear. The average RTP for grade I injuries was 28 days and the grade II injuries were 46 days. These injuries were equally distributed between proximal and distal, with the proximal injuries having a longer time to RTP (49 vs. 32 days).

Hughes et al. [82] postulated that the indirect (central tendon) and direct heads of the proximal tendon begin to act independently, creating a shearing phenomenon in contrast to what occurs in the normal rectus femoris. This hypothesis was then used as a potential explanation for the longer rehabilitation associated with acute injuries involving the central tendon [83].

Reinjury: from risk factors to management and prevention strategies

Understanding and addressing the risk factors for reinjury in thigh muscle tendons is paramount for developing effective prevention and management strategies [84]. These risk factors are divided into intrinsic and extrinsic categories, each influencing the likelihood of recurrence significantly [9] (Table 1). Unfortunately, to date, the causal relationship of the risk factors recognized in the literature is still unknown. This could result in further difficulties in addressing the issue of these injuries [85].

Table 1: Risk factors for a thigh muscle tendon reinjury.

Intrinsic	Extrinsic
Older age	MRI findings
Previous injury	Incorrect treatment approach (conservative vs. surgical)
Microscopical tendon healing process	Inappropriate return to play (RTP) time
Muscle strength imbalances	Type of sport, training load, and intensity
Genetic predispositions	Equipment used
Hormonal factors	Environmental conditions
	Lack of communication between medical staff and coaching staff

Intrinsic factors include physiological and biomechanical attributes such as age, previous injury history, and the microscopical process of tendon healing. Older age may decrease tissue elasticity and recovery capacity, while a history of previous injuries often leads to weakened structures or incomplete rehabilitation, increasing the risk of further injury [9] (Figure 3). Additionally, recent literature emphasizes the role of motor control in the recurrence of muscle or tendon injuries, highlighting it as a critical aspect of the risk profile for tendon injuries [86].

Extrinsic factors encompass elements like MRI findings, which are essential for assessing the extent of an injury and guiding treatment strategies. Incorrect treatment modalities and the timing of RTP are particularly critical, with both premature and overly delayed RTP increasing the risk of reinjury [9]. Training load, intensity, and the type of sports activity significantly affect tendon stress; high-speed running, sudden directional changes, and jumping are activities associated with higher risks [9].

Effective management of reinjury encompasses interventions across all phases of injury – from acute care through to complete recovery, with an acute phase initiated early following the patient's clinical presentation to allow for better tissue adaptation [87]. Rehabilitation programs should address not only tendon healing but also muscle imbalances, flexibility, and overall leg strength through progressive loading exercises [88–90]. Rehabilitation programs should address not only tendon healing but also muscle imbalances, flexibility, and overall leg strength through progressive loading exercises. Physiotherapists typically follow a process that begins with identifying the key performance indicators of the sport [91]. They then determine the physical attributes that correspond to these indicators and allocate time for the development of these capacities. Effective training plans are

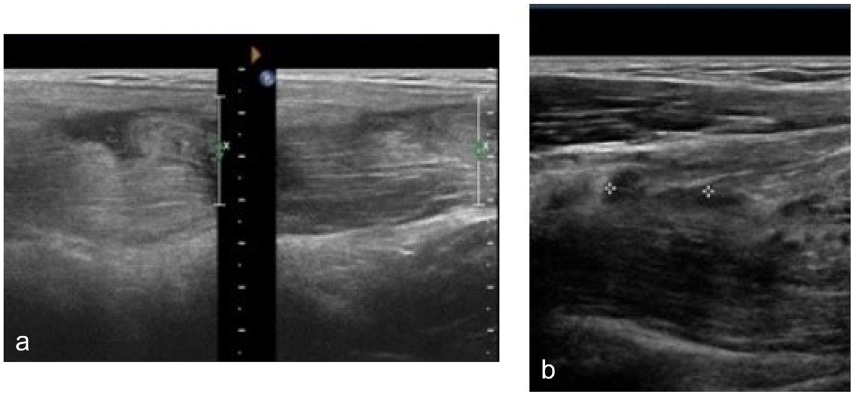

Figure 3: A lesion of the proximal tendon of rectus femoris in a professional football player (ultrasound images): the first episode (a) and the reinjury (b) that occurred 30 days after.

grounded in a theoretical and biological understanding of human movement and adaptation to exercise stimuli [92]. This understanding, combined with knowledge of the optimal sequencing of these stimuli, enables one stimulus and its subsequent adaptation to enhance the next. Therefore, reverse or backward engineering, when effectively integrated with plans for nutrition, conditioning, and technical and tactical training, likely provides athletes with the best chance of achieving their performance goals and reducing the risk of reinjury [93].

For hamstring injuries involving three tendons, surgical intervention is recommended [94]. Two-tendon injuries are also often treated by operative means, especially in athletes with clear tendon retraction. Isolated one-tendon hamstring injuries most often respond well to conservative treatment, but symptomatic cases with clear tendon retraction and loss of tension of the injured structure often require operative treatment among professional athletes [95]. Surgical treatment of hamstring tendon injuries leads to high satisfaction and return to sports rates, acute repair having better outcomes, and lower rate of complications than chronic repair [57].

Sometimes tendon injuries tend to recur, either during the rehabilitation process or after the successful RTP. Recurring tendon injuries can be difficult to treat successfully, and they can jeopardize athletes' careers. If tendon injury recurs despite the appropriate conservative treatment, surgical options should be carefully considered. In situations where conservative management falls short, surgical intervention may be considered, particularly for central tendon reinjuries. Surgical aims include tendon repair and addressing any muscle imbalances or anatomical anomalies. Postoperative rehabilitation is imperative for a successful sports return.

Recent studies in the field of sports medicine have shed light on various aspects of thigh tendon reinjury. Advancements in imaging techniques like MRI and ultrasound have greatly enhanced our understanding of tendon pathology and healing processes (Figure 4). The integration of wearable technology in rehabilitation offers real-time monitoring

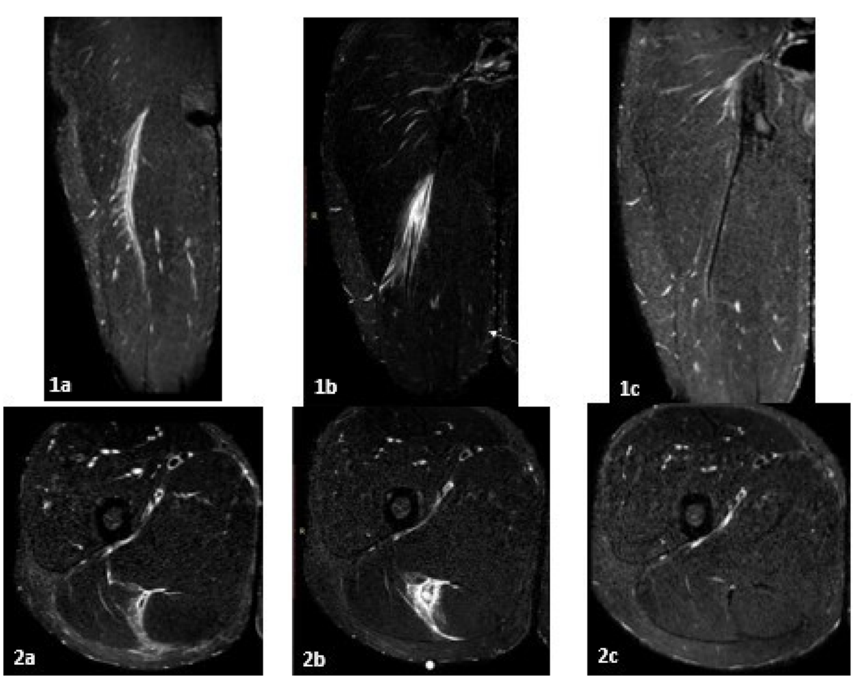

Figure 4: Axial (1a–c) and coronal (2a–c) STIR MR sequences of a 22-year-old professional soccer player. Initially, Figures (1a–2a), taken 3 days postcompetition following the first indirect trauma, display a musculotendinous junction tear of the biceps femoris with the central tendon intact, classified as grade 3b according to BAMIC. After 45 days, subsequent pain during competition onset is captured in Figures 1b–2b, showing a biceps femoris retear with a central tendon lesion, upgraded to grade 3c BAMIC. Figures (1c–2c) later reveal a fibrous scar indicating "regenerated" central tendon, depicting a normal tear-healing process on MRI.

of recovery, ensuring that athletes do not prematurely return to intense activities – a common cause of reinjury.

From a practitioners' perspective, eccentric training, high-intensity running, and sprinting, integrated with a variety of other exercise modes that also carry some level of effectiveness in a multidimensional program, represent the most commonly addressed strategies to reduce the risk of muscle injury [96]. The specific load and regimen should be tailored to the severity of the tendon injury, and it might vary between initial and recurrent injuries [97–99]. Programs should incorporate plyometric and functional training to provide comprehensive benefits and facilitate a more robust recovery [100]. Additionally, the role of nutrition and supplements in tendon health is becoming a focus area [100].

Implementing injury mechanisms for injury prevention, rehabilitation, and return to sport protocols can be crucial in avoiding tendon reinjuries [101]. For example, football players rehabilitating with RF injuries are often able to run, jump, and make rapid changes of direction without problems after 4 weeks, but kicking the ball often leads to reinjuries. The reinjuries often occur in similar situations to the initial injuries. In hamstring injuries, the investigated injury mechanisms (closed and open kinetic chain movements, sprinting- and stretching-related movements, specific biomechanical factors, eccentric muscle action) should be assessed and complemented into everyday rehabilitation [44, 71]. The main goal of rehabilitation should be to strengthen the weaknesses, minimize risk factors, and increase the tendons' capability to tolerate injury-inciting actions. Video analysis of injury mechanisms can reveal individual risk factors, such as poor technique during performance, which should be considered in prevention and rehabilitation to avoid reinjuries [41, 42, 102]. When assessing the appropriate RTP, initial injury mechanisms can be analyzed and implemented into rehabilitation protocols and RTP tests to simulate realistic injury-prone situations. Sport-specific, individual, and mechanism-based prevention and rehabilitation strategies are highly recommended.

Conclusions

In conclusion, this review highlights the importance of a thorough understanding of anatomy and injury mechanisms to effectively manage and prevent thigh tendon reinjuries. It advocates for personalized rehabilitation approaches that incorporate both established practices and innovative technologies, tailored to the individual athlete's needs. However, the field must address the existing knowledge gaps through ongoing, rigorous research to enhance recovery outcomes and reduce the likelihood of reinjury among athletes. This ongoing research will be crucial in refining current treatment modalities and in developing new strategies that can be reliably recommended across sports medicine.

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