Physical Therapy in Sport 33 (2018) 62–69

Contents lists available at ScienceDirect

Physical Therapy in Sport

journal homepage: www.elsevier.com/ptsp

Case Studies

Successful conservative treatment for a subtotal proximal avulsion of the rectus femoris in an elite soccer player

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ARTICLE INFO

Article history:
Received 2 April 2018
Received in revised form
10 July 2018
Accepted 10 July 2018

1. Introduction

Quadriceps muscle strains are a common injury type in soccer. Ekstrand, Hägglund, and Walden (2011) observed that quadriceps muscle strains were the second most frequent muscle injury in elite soccer, just below hamstring injuries, causing more missed games than hamstring and groin muscle injuries, and showing relatively high (17%) re-injury rates.

Quadriceps muscle strains frequently involve the rectus femoris (RF). The direct head of the RF originates from the anterior-inferior iliac spine, proximal to the hip joint, whereas the reflected head originates from the anterior acetabular ridge and anterior hip joint capsule. The proximal tendons extend distally in a central aponeurosis where muscle fibers are pennated in a oblique angle. With its direct head originating proximal to the hip joint, the RF is the only biarticular muscle in the quadriceps femoris group, and so its concentric action combines hip flexion and knee extension. Muscles that act across 2 major joints are thought to be more susceptible to strain injury (Armfield, Kim, Towers, Bradley, & Robertson, 2006). Also, histologic studies (Johnson, Polgar, Weightman, & Appleton, 1973) have shown that the RF has a high percentage of type II fibers, enabling forceful and rapid activities in a similar fashion or other commonly strained muscles such as the medial head of the gastrocnemious and the hamstrings. In agreement with Hasselman, Best, Hughes, Martinez, and Garrett (1995) anatomical, biomechanical and histologic factors predispose the RF to strain injuries and ultimately failure in sports that involve kicking and sprinting, like soccer. In these actions, the rectus femoris acts as part of the lower limb anterior kinetic chain controlling the backswing of the thigh -hip extension- and leg -knee flexion- and providing power for its subsequent forward action in combined hip flexion - knee extension (Mendiguchia, Alentorn-Geli, Idoate, & et al, 2013).

While RF muscle injuries are common in sports, ruptures of the RF proximal tendons are uncommon injuries (Feeley et al., 2008). RF proximal tendons injuries range from small partial tears to complete avulsions at their osseus origin. Indirect head is most often and first injured, while secondary involvement of the direct head occurs less frequently (Ouellette, Thomas, Nelson, & Torriani, 2006). RF proximal tendon injuries have only been reported in small case series and case reports (Appendix 1). Thus, treatment indications for this injury in high-level athletes are not well established, as successful results with both operative and nonoperative approaches have been described. Irmola, Heikkilä, Orava, and Sarimo (2007) reported 5 cases of RF proximal avulsion treated surgically in 4 professional soccer players and 1 hurdler. In spite of 2 of 5 patients having postoperative lateral femoral cutaneous nerve palsy, the results were rated good in all cases, with patients able to return to their pre-injury level of activity 5–10 months after surgery, maintaining it at 20 months average follow-up. Vaquerizo, Casas, Seijas, Ares, and Cugat (2012) performed

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https://doi.org/10.1016/j.ptsp.2018.07.004
1466-853X/

surgery on 6 partial and 4 complete RF proximal ruptures in professional soccer players, achieving a return to play (RTP) in 3–6 months (average 3.8) to prior level with no re-injuries at 30 months average follow-up, while Ueblacker, Müller-Wohlfahrt, Hinterwimmer, Imhoff, and Feucht (2015) reported 4 cases of professional soccer players that underwent suture anchor repair of complete proximal rectus femoris avulsions with significant tendon retraction, resulting in a time to RTP of 111 days average (range 100–134), and time to RTC of 140 days average (range 114–166), all players still competing at their prior level without re-injury at 35 months average follow-up. Recently, Sonnery-Cottet et al. (2017) described a RTP to previous level in 15.8 ± 2.6 weeks with no recurrences in 5 cases of professional soccer players operated with an original surgical technique consisting of excision of the injured RF proximal tendon followed by a muscle-to-muscle suturing of the remnant belly. On the other hand, Hsu, Fischer, and Wright (2005) first reported a gradual rehabilitation program in a NFL kicker that resulted in a full RTC at approximately 12 weeks after avulsion of the direct head of the RF with approximately 1 cm of distal retraction and intact reflected tendon, concluding that rapid recovery from this injury is possible without surgical intervention. In addition, Gamradt et al. (2009) reported a 1997–2006 survey of 11 cases of RF proximal avulsion in NFL players of various positions treated conservatively, describing in detail only 2 of them which featured conservation of the reflected tendon and retractions of 2 and 1 cm respectively. All players achieved NFL RTP and, excluding a player who returned to play at 7 months, the average time was 55 days (range 21–84), although recurrent symptoms were noted in 2 (18%) players. The authors concluded that RF proximal avulsions can be treated non-operatively with a high degree of predictability for return to full unrestricted participation in professional American Football. Considering these studies, it can be concluded that the conservative treatment can be successfully applied in cases of high-level athletes presenting some remnant of any of the two tendons and a minor RF retraction of less than 2 cm. In cases presenting a complete avulsion of both tendons and bigger muscle retraction no successful conservative treatment has been described so far, and surgical treatment probably should be applied with good outcome expectations. Times to RTC range broadly between 3 and 6 months. In the present case report we describe the conservative treatment and outcome of a RF proximal tendon incomplete avulsion with contained muscle retraction in a top-level soccer player.

2. Methods

2.1. Participant

Informed consent for the present case report was obtained from the subject, who at the moment of injury was a professional elite-level soccer player (28 yr, 1.76 m, 73 kg) male, midfielder and playing in Spanish First Division (La Liga). This player had been playing professional soccer since he was 17 years old, and the season before this injury had been elected La Liga Best Midfielder and included in the UEFA Champions League Squad of the Season, winning the UEFA Champions League with his team. In the previous two seasons, the player played on 51 and 53 games each, corresponding with 86% and 85% of his team's games respectively.

2.2. Clinical presentation

In the 25th minute of an international game during the 2014/15 season, the player experienced an acute onset of pain at his anterior left groin while performing a long pass with the outside of the left foot to a teammate and fell down on the ground. Unaware of the possibility of a serious injury, having never previously experienced one, the player got up from the ground and started to sprint to defend an opposition player in possession of the ball. At deceleration, a very painful pop in the left groin was felt. The subsequent functional disability led the player to leave the game.

Clinical examination revealed swelling and intense pain at the anterior inferior iliac spine level at palpation or any activation of the RF, with severe disability for walking. No tissue gap at the proximal RF in the groove floor between the tensor fascial lata and sartorius, which would reflect a RF retraction, was noted.

2.3. Injury imaging and diagnosis

A non-contrast magnetic resonance imaging (MRI) was obtained on a 1.5 T scanner using standard T1-weighted, T2-weighted, fat-suppressed proton density weighted and STIR sequences (Fig. 1). On MRI, hematoma may be observed in case of RF proximal tendons tears, which when complete on both tendons will provoke much more tendinous retraction than one tendon rupture alone because of the remaining attachment of the the other tendon. In this case, the findings were deemed as a severe avulsion of the proximal left RF tendons, complete in the posterior reflected portion at the acetabular rim, and subtotal in the anterior straight portion at the anterior inferior iliac spine, where a thin anterior section of the tendon of approximately 2 mm thickness remained intact. This remaining bridge of tendon tissue prevented much retraction of the RF belly to occur, and thus the bone-tendon gap was restricted to 11 mm.

2.4. Case management and outcome

2.4.1. Treatment and follow-up

Therapeutic management and rehabilitation goals were organized in criteria-based phases, as follows:

Phase 1. Immediate Phase. Goals: Protection, initial healing process stimulation, inhibition of catabolism. After 5 days of acute measures consisting in rest, walking restriction with crutches and compression garment, a Platelet-Rich Plasma PRP (PRGF-endoret ®) injection protocol was started, with the extraction of 36 ml of blood, centrifugation on four 12 ml tubes at 580 g for 8 min at room temperature, separation of 2 ml of "buffy coat" PRP remaining above the red series on each tube while avoiding picking up the leukocytes, activation of the total 8 ml with 400 mg of calcium chloride, and finally application by ultrasound-guided injection at the bone-tendon rupture gap site.

This protocol was repeated on day 16 with a second and final injection. These PRP injections, although not a completely proven therapy (Moraes, 2014), with no available studies concerning its application in this specific kind of injury, were employed as a concentrated source of several different growth factors and other cytokines that can potentially stimulate healing of soft tissue. In between, a daily therapeutic work was scheduled, consisting in physiotherapy including comfortable motion therapy and RF relaxation techniques; hyperbaric chamber exposure with pure oxygen administration at 1.3 atm (ATA) for 60 min/day (Oyaizu et al., 2018) preceded by heat exposure for 30 min on a turkish bath at 38 °C; and nutritional intervention including reduction of calories to requirements consistent with the lower physical activity, interstitial glucose level monitoring (Abbott Freestyle Libre System, Abbott Laboratories, Illinois, USA) with subsequent carbohydrates intake management, high protein daily intake maintenance (1-1,5 g/kgBW per day), and timed protein intake (20 g Whey protein right after the rehabilitation sessions). These strategies were aimed to decrease catabolism and increase the input of nutrients and oxygen to the lower limbs right after getting vasodilation to promote biological healing.

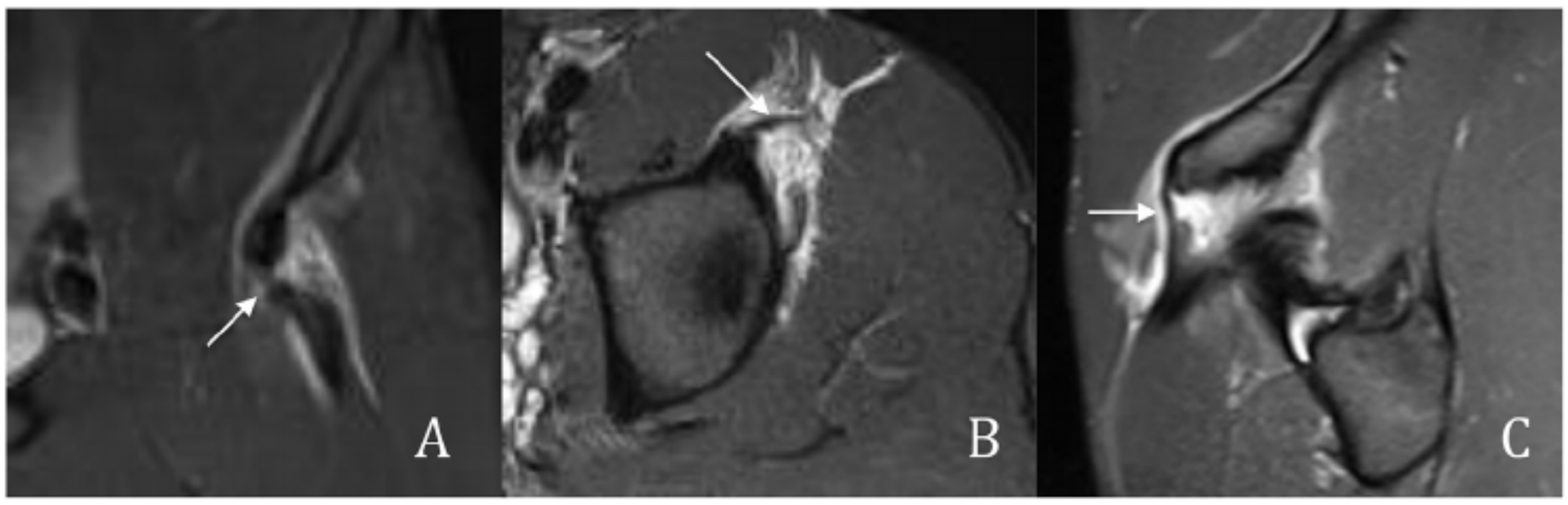

Fig. 1. Initial MRI. Coronal (A), Axial (B) and sagittal (C) views showing complete reflected portion rupture and subtotal straight portion tear with a thin tendon anterior remain of approximately 2 mm thickness (white arrows).

Phase 2. Day 17. Biological Stimulation Phase. Goals: connective tissue proliferation enhancement, RF length restitution, RF neuromuscular reactivation, and initial physical conditioning.

Physiotherapy was continued, adding draining massage and biological stimulation modalities for promoting fibroblasts proliferation as low-level laser (Szymanska et al., 2013), and produce local heating (McGorm et al., 2018) as therapeutical US and diathermy. Hyperbaric chamber and nutritional protocol was also continued.

RF amplitude work with mobilizations, stretching, rolling and muscle relaxation techniques was progressively applied to achieve a gradual increase in RF muscle length, and the RF muscular reactivation was initiated with progressive isometric work. Reconditioning in gym was also started, with upper body and uninvolved limb soccer-functional multi-exercise low-resistance physical work. The exercises employed here and along the whole process of rehabilitation were multiple, variable, functional, multi-planar, and with different types of resistance (elastic, weights, inertial and calisthenics), and the composition of sessions and dosages were variable each day according to periodization, fatigue and load control.

Phase 3: Low-energy rehabilitation. Day 35. Criteria: formed scar in MRI as specified by a specialized radiologist (see Fig. 2), no pain, and normalized RF length in modified Thomas test (Harvey, 1998), considering normal hip flexion 0° and knee flexion 80°. Goals: RF functional maximal strength, low-energy neuromuscular control and low-energy soccer function including specific exercises to counteract the mechanisms of injury on kicking and sprinting. The physiotherapy program was continued as previously, adding more energetic tendon fibrolysis, gliding and mobility techniques. Reconditioning work focused on RF maximal strength, low-energy neuromuscular control and low-energy function attempting to control the more demanding and injury-prone activities for this muscle, namely the eccentric-lengthening actions of the swing-limb loading phase of kicking and the late stance phase of sprinting, through the use of specific rehabilitation drills in the form of a multiplicity of functional exercises combining different types of resistances, movements, directions and planes with the aim of inducing comprehensive functional muscle adaptations to soccer demands. Also, and so setting a block periodization preparation training system (Issurin, 2010) during the rehabilitation period, a first whole-body physical training accumulation-type mesocycle, aimed mainly at aerobic endurance, muscle strength, and general movement techniques was instituted, including also sessions of cycling exercise on hot conditions with the aim of increasing the metabolical load and promoting heat acclimation to improve exercise performance (Lorenzo, Halliwill, Sawka, & Minson, 2010). Finally, initial strength values from the contralateral limb for posterior reference were obtained by using a isokinetic pulley linear system (Dynasystems BlackBox, Granada, Spain) with a functional kick cocking exercise for the RF in eccentric mode at 15 cm/s velocity.

Phase 4: High-energy rehabilitation. Day 75. Criteria: matured scar in MRI (see Fig. 2), >85% of uninvolved side isokinetic RF peak force as a conventional standard of symmetrical maximal strength, >85% of uninvolved side RF cross-sectional area (CSA) in MRI as a measure of muscle volume changes (Yamauchi et al., 2017), and low-energy tasks accomplished with ease. Physiotherapy was continued as previous phase, now suppressing the bio-stimulation modalities and hyperbaric treatment. Reconditioning work shifted to RF rapid strength and power, high-energy neuromuscular control and high-energy functional rehabilitation for soccer including work to specifically counteract the injury mechanism in eccentric hip extension-knee flexion. Also, a concurrent, transmutation-type physical training mesocycle aimed to develop combined aerobic-anaerobic endurance, specific muscle endurance, and specific motion technique was performed. Physical external load was controlled in this phase via telemetric time-motion tracking (GPSports, Canberra, Australia) comprising global positioning system (GPS) and inertial data (Athletic Data Inovations, Sydney, Australia), this system having previously been demonstrated to be reliable in measuring variables of distance and speed (Johnston et al., 2014). Internal workload was measured using session rating of perceived exertion (RPE) in a 10-point modified-Borg scale (Impellizzeri et al., 2004). As time-motion tracking and RPE scoring in trainings as well as optical time-motion register in games before the injury were available for the player, several individual values for volume and high-intensity work were used as a physical load reference for training periodization and relative load control for each rehabilitation session. Particularly of interest was the measurement of the mechanical load absorbed by the player's musculoskeletal system, and so the Force Load parameter as the summation of accelerometer force events was used to represent the mechanical load volume of the sessions, and the distance run at speed over 14 km/h (arbitrary level) together with the number of high-intensity (>3 m/s2 arbitrary level) accelerations and decelerations performed in the session were used as representatives of the high-intensity mechanical load. This control allowed for the implementation of progressive and periodized reconditioning training sessions (see Appendix 3).

Phase 5: Return to play (RTP, meaning participation in normal team training, with regular soccer playing drills). Day 101. Criteria: symmetrical RF maximal eccentric strength on isokinetic functional RF testing corresponding to 480 N on both limbs; symmetrical RF CSA in MRI, subjective video-analysis of kicking and sprinting actions judged satisfactory by the head and strength&conditioning coaches; high-energy task telemetry similar to maximal training and normal games data for the player as previously recorded before

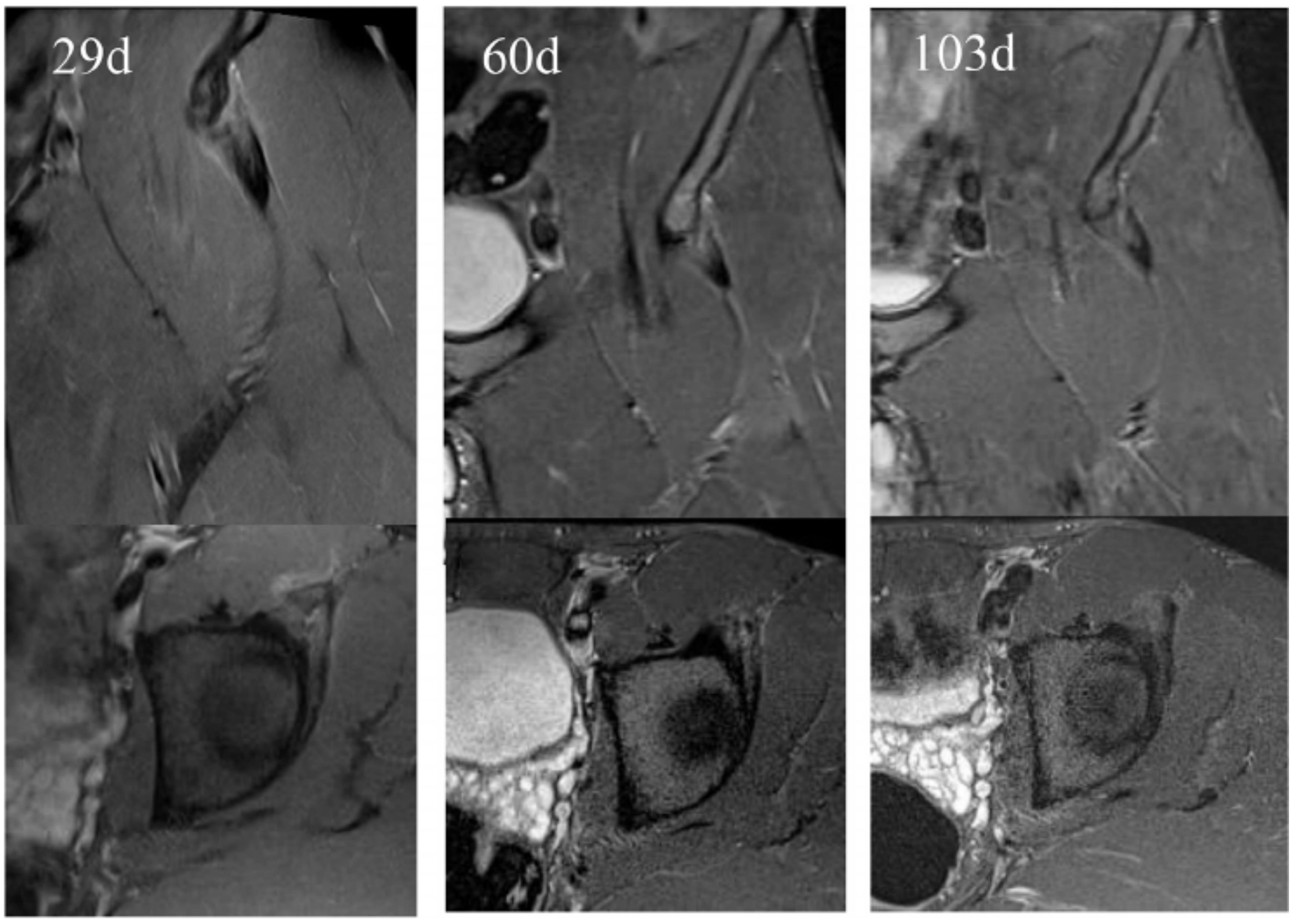

Fig. 2. MRI follow-up. Coronal and Axial comparative views showing evolution of image signal corresponding to day 29, day 60 and day 103.

the injury, corresponding to maximal sprint speed 31 km/h, peak acceleration 4.5 m/s2, and peak deceleration −4.9 m/s2; and shot speed similar to previous records corresponding to 104 km/h (Adidas Micoach Smart Ball, Düsseldorf, Germany). In this phase, a realization-type mesocycle, designed as a pre-competitive training phase and focused mainly on game modeling, and obtaining maximal power, speed and recovery prior to the forthcoming competition was performed including full-energy soccer drills.

2.4.2. Outcome

Return to competition (RTC, meaning participation in a regular competition game) was achieved on day 115 after the injury. Criteria included the normalization of training session physical load tracking data to values comparable to pre-injury levels, and meeting the demands of the games both in volume and high-intensity load. Lastly a satisfactory, "no-doubt" subjective confidence response from the player was required.

Some residual and occasional discomfort was felt by the player for several months after the injury, this considered a normal expectation from these injuries fibrous scar tissue remodeling process, and no more training sessions or games were missed due to this injury for the rest of the season.

At one year follow-up, the player was clinically and functionally asymptomatic, on MRI a stable tendon scar signal was verified by an expert radiologist, and time-motion tracking data of physical performance during training sessions and games were comparable with pre-injury values.

The following season 2015/16 (see Fig. 3), the player played 44 games corresponding with 85% of appearances, won the European Champions League with his team and was elected for the FIFA/FIFPro World XI, UEFA Team of the Year, UCL Squad of the Season, La Liga Best Midfielder, and La Liga Ideal XI, making this season his most successful ever as an individual player. In season 2016/17, he underwent chondral surgery on his right knee and was out from competition for 4 weeks. However, he played 41 games, and not only won again the European Champions League with his team, but also La Liga, FIFA Club World Cup and UEFA SuperCup, making this season his most successful ever in collective terms. Individually, he was again selected for the FIFA/FIFPro World XI and UEFA Champions League Squad of the Season.

At three years follow-up, the player was playing normally while maintaining no re-injuries in his left RF, and the percentage of appearances on his team's games was 76%.

3. Discussion

RF proximal tendon injuries have only been reported in small case series and case reports. The conservative approach here described allowed for a complete recovery of this case, and it is composed by multiple interventions. Several biological stimulation measures were taken in the first phase of treatment of this case. While the time to RTP and functional and performance outcomes of the present case can be considered very satisfactory, the intrinsic limitations of a single case report study make it impossible to determine the relative weight of these therapies and strategies on the positive final result.

The muscular training methodology employed in this case for the recovery of the RF function was closely based on the injury mechanism and specific action demands for this muscle in soccer. RF strains have been found mainly in sports requiring repetitive kicking and sprinting actions. In soccer kicks, RF is stretched during backswing due to the combination of hip extension and knee flexion motion (Herzog & Keurs, 1988). This lengthening provides a progressive increment in the passive resistance of the muscular structure that in turn decelerates the thigh and stores elastic energy for the subsequent reversal of direction of the thigh and concentric forward action. Combined with the passive stretching, the RF also shows a high activation in eccentric mode at the end of the backswing phase that contributes to the deceleration of the thigh (Lees, Asai, Andersen, Nunome, & Sterzing, 2010). The combination of stretching and powerful eccentric contraction increases dramatically the RF tension at the end of the backswing and the beginning of the forward swing kick. A similar eccentric force strain pattern has been described for RF during late stance - early swing phase of

Season	Games	%App	Goals	Assists	Team Honours	Individual Honours
2011-12	41	77%	5	7		
2012-13	53	86%	4	9	Spanish SuperCup	
2013-14	51	85%	2	9	UEFA Champions League Spain King's Cup	La Liga Best Midfielder UCL Squad of the Season
2014-15	25	42%	1	5	UEFA SuperCup FIFA Club World Cup	FIFA/FIFPro World XI
2015-16	44	85%	3	4	UEFA Champions League	FIFA/FIFPro World XI UEFA Team of the Year UCL Squad of the Season La Liga Best Midfielder La Liga Ideal XI
2016-17	41	68%	1	5	UEFA Champions League La Liga FIFA Club World Cup UEFA SuperCup	FIFA/FIFPro World XI UCL Squad of the Season
2017-18	43	76%	2	8	UEFA Champions League UEFA SuperCup Spanish SuperCup	To be released on late 2018

Fig. 3. Player's main playing statistics before and after injury on 2014-15 season.

maximal sprinting when RF decelerates the thigh before starting limb forward motion (Mendiguchia et al., 2013). To perform these tasks without rupturing under peak tension, the RF needs enough length and eccentric strength with very good neuromuscular action coordination. These characteristics are deeply affected by the injury, which causes major muscular retraction, atrophy and neuromuscular inhibition. The rehabilitation strategy in this case started in phase 2 by progressively re-gaining the muscle length and starting muscle isometric contraction as an initial step in starting strength work. This was progressively oriented to the eccentric deceleration - motion reversion - concentric acceleration cycle of the RF action, progressing from shortened positions (hip flexion and little knee flexion) with low load and low speed at phase 3, to fully functional actions in lengthened positions (hip extension and high knee flexion) with high load and high speed at the end of phase 4. References for muscle length level and functional eccentric strength should not be based on previous records or the contralateral limb baseline values, as these could be inadequate and related with the very emergence of the injury. On the other hand, achieving in rehabilitation more muscle length than required could lead to impairing of the decelerating and passive elastic energy storing of the muscle in its specific soccer kicking and sprinting functions. We then agreed on increasing the length of RF bilaterally to the conventionally accepted normality of 90 ° of knee flexion on modified Thomas test to be achieved at the beginning of phase 3 and then maintained. In a similar manner, we got bilateral eccentric isokinetic strength values in a functional position of 480 N at the end of phase 4, representing 30% higher than the initial levels recorded on the uninvolved right limb at the beginning of phase 3. To check the adequacy of these arbitrary length and eccentric force muscular level settings, at the end of phase 4 we visually analyzed the video recordings of maximal kicking and sprinting actions of the soccer reconditioning drills, focusing on the comparative trunk, hip and knee joint angles at the end of backswing phase of both limbs until we judged them symmetrical and comparable with the available imagery of this and other top-level players while performing these tasks. Telemetry of maximal running speed and ball velocity at maximal kicking completed the functional picture for RTP clearance. We believe that the restitution of muscle length and eccentric strength to the necessary levels for the specific actions of a given athlete's sports discipline is of paramount importance for performance recovery and re-injury prevention.

The rehabilitation process continuum was organized with a training periodization model (Reiman & Lorenz, 2011) and divided into phases, marked by the introduction of new therapies and training works according not to the theoretical and conventional healing times but to the biological and biomechanical evolution of the injury as measured with clinical and diagnostic imaging data and functional criteria. This criteria-based strategy allows for a better adaptation of the rehabilitation work to the individual injury healing status, thus saving recovery time while keeping the risk of re-injury relatively low. The functional status was thoroughly controlled during the whole rehabilitation process through the use of functional evaluation and time-motion tracking of physical work during rehabilitation sessions. This continuous workload tracking allowed not only determination of the introduction of each phase, but also to design the load profile of the rehabilitation microcycles and to control the adequate periodization of the rehabilitation sessions in a progressive and physiological manner and in comparison with the pre-injury training load values. Objective physical data such as the maximal shot speed and maximal sprint speed also helped to determine the moment of RTC in adequate levels of performance. The maintenance of continuous objective performance measurements after RTC, including not only the analysis of time-motion tracking data for the player's training sessions and games, but also the individual and team's results and achievements over the next seasons, allows the evaluation of the outcomes of the medical management of the case in a more precise manner, in contrast with studies reporting just "*good*" or "*RTP at the same level*" results. The verification of high levels of physical performance and sporting success immediately post RTC and in the following seasons, suggests that it is possible to utilize the time of a prolonged injury to develop the physical condition of the player in order for him to perform better directly after the injury, and as an enhanced basis for higher sporting career achievements.

In conclusion, this case report shows that it is possible to treat an incomplete high-grade RF proximal tendon rupture conservatively with excellent results in terms of time to RTC and subsequent sports performance. The main characteristics of the presented conservative approach include the application of a staged functional and clinic criteria-based rehabilitation program, the use of healing bio-stimulation techniques on the early phases, a muscular training methodology based on the function of the muscle and on the injury mechanism, and the continuous and long-term objective measurement of physical load and performance as a reference for rehabilitation loads management and performance outcomes evaluation.

Conflicts of interest

None declared.

Ethical approval

Informed consent has been provided by the participant according to Declaration of Helsinki (2013). Also consent from Real Madrid CF was obtained to use of the data relative to medical records.

Funding

None declared.

Appendix 1. Evidence regarding operative/conservative management of RF proximal tendons injuries

Author	Case	Treatment	RTP time	Follow-up
Irmola et al. (2007)	4 professional soccer players and 1 hurdler	Surgery	5–10 months	Activity maintained at 20 months average
Vaquerizo et al. (2012)	6 partial and 4 complete ruptures in professional soccer players	Surgery	3–6 months (average 3.8)	No re-injuries at 30 months average
Ueblacker et al. (2015)	4 professional football players complete avulsions with significant tendon retraction	Surgery: suture anchor repair	RTP 111 days average (range 100–134), RTC 140 days average (range 114–166)	All players still competing at their prior level without re-injury at 35 months average
Sonnery-Cottet et al. (2017)	5 cases of professional football players	Surgery: excision of the tendons and muscle-to-muscle suturing	15.8 ± 2.6 weeks	No recurrences
Hsu et al. (2005)	1 NFL kicker avulsion of the direct head with approximately 1 cm of distal retraction	Gradual rehabilitation program	Approximately 12 weeks	
Gamradt et al. (2009)	11 NFL players of various positions, describing in detail 2 of them which featured conservation of the reflected tendon and retractions of 2 and 1 cm respectively	Conservative	55 days (range 21–84), excluding a player who returned to play at 7 months	Recurrent symptoms were noted in 2 (18%) players

Appendix 2. Rehabilitation program

Phase	Day	Criteria	Treatment	Training
1 Inmediate	3		• PRP injection 8 ml × 2 day 16 • Physiotherapy motion therapy and RF relaxation. • Hyperbaric oxygen 1.3 ATA 60 min/day preceded by heat exposure 30 min on a turk bath at 38 °C • Nutritional intervention	
2 Biological stimulation	17	• PRP protocol finished	• Physiotherapy APP + laser, US, diathermy • RF amplitude • Isometrics	Upper body and uninvolved limb basic physical work
3 Low-energy rehabilitation	35	• Formed scar in MRI • No pain • Normalized RF length in Thomas test	• Physiotherapy APP + tendon fibrolysis and mobilization	• RF functional maximal strength exercises • RF low-energy neuromuscular control exercises • RF low-energy function in soccer (kicking, sprinting) exercises • Whole-body physical training aerobic endurance and strength endurance
4 High-energy rehabilitation	65	• Matured scar in MRI • >85% of uninvolved RF maximal strength on isokinetic functional RF testing • >85% of uninvolved side RF cross-sectional area (CSA) in MRI • Low-energy tasks accomplished	• Physiotherapy APP except biological stimulation modalities and hyperbaric oxygen	• RF functional rapid strength and power exercises • RF high-energy neuromuscular control exercises • RF high-energy function in soccer (kicking, sprinting) exercises • Whole-body physical training anaerobic endurance and maximal strength

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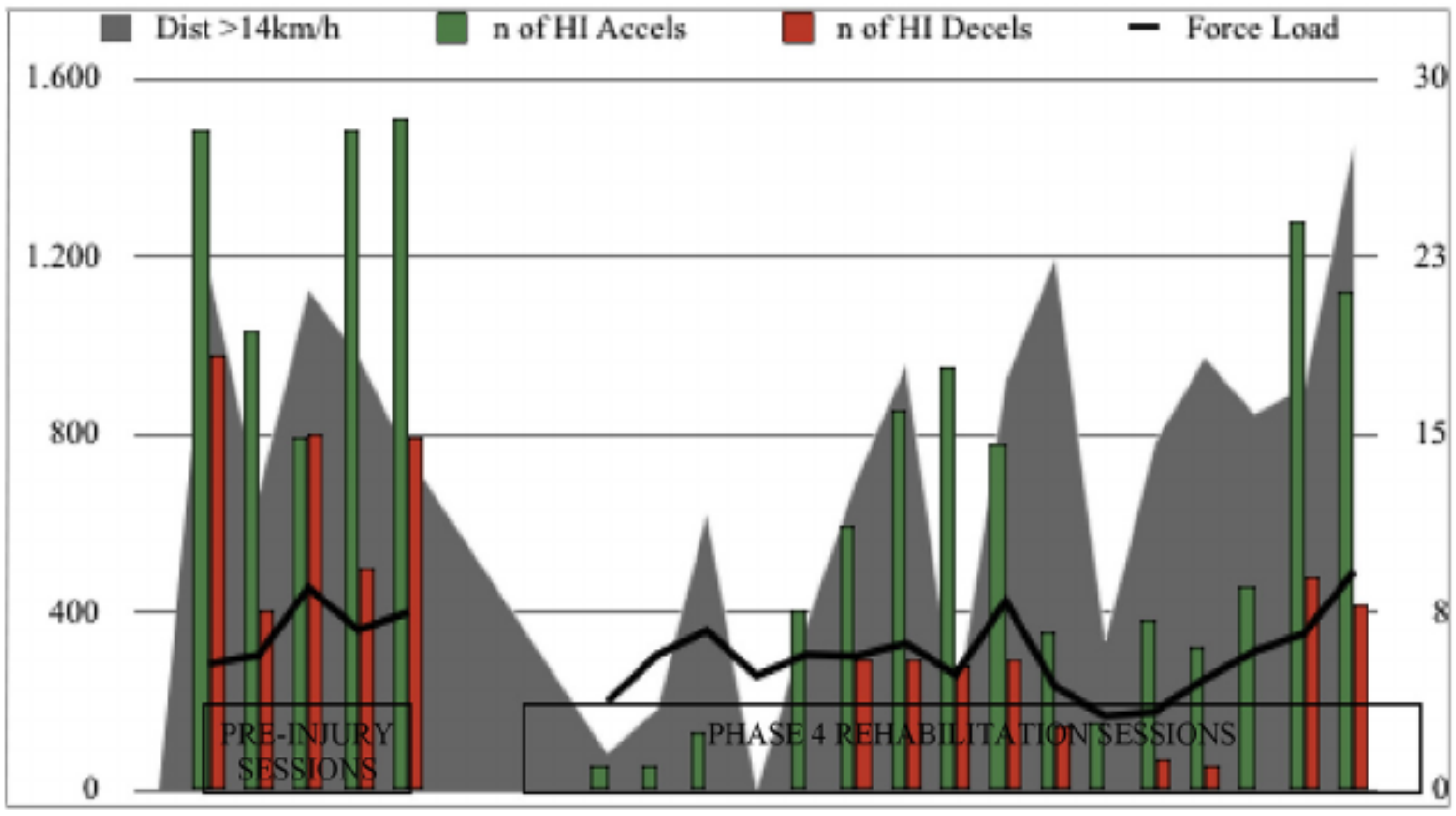
Phase	Day	Criteria	Treatment	Training
5 Return to Play	101	• Symmetrical RF maximal strength on isokinetic functional RF testing • Symmetrical RF cross-sectional area (CSA) in MRI • Subjectively satisfactory video-analysis of kicking and sprinting actions • High-energy telemetry similar to maximal training and normal games before the injury		Speed, power, rapid strength, and full-energy soccer drills. Individual and with team.

Appendix 3. Selected load monitoring data during Phase 4 of rehabilitation. Dist>14 km/h: Meters run at speed over 14 km/h. Force Load: Summation of accelerometer force events in arbitrary units (au). n of HI Accels: Number of high-intensity (>3 m/s2 arbitrary level) accelerations. n of HI Decels: Number of high-intensity (>3 m/s2 arbitrary level) accelerations



References

Armfield, D. R., Kim, D. H., Towers, J. D., Bradley, J. P., & Robertson, D. D. (2006). Sports-related muscle injury in the lower extremity. *Clinics in Sports Medicine, 25*, 803–842.

Ekstrand, J., Hägglund, M., & Walden, M. (2011). Epidemiology of muscle injuries in professional football (soccer). *The American Journal of Sports Medicine, 39*, 1226–1232.

Feeley, B. T., Powell, J. W., Muller, M. S., Barnes, R. P., Warren, R. F., & Kelly, B. T. (2008). Hip injuries and labral tears in the national soccer League. *The American Journal of Sports Medicine, 36*, 2187–2195.

Gamradt, S. C., Brophy, R. H., Barnes, R., Warren, R. F., Byrd, J. W., & Kelly, B. T. (2009). Nonoperative treatment for proximal avulsion of the rectus femoris in professional american football. *The American Journal of Sports Medicine, 37*, 1370–1374.

Harvey, D. (1998). Assessment of the flexibility of elite athletes using the modified Thomas test. *British Journal of Sports Medicine, 32*, 68–70. https://doi.org/10.1136/bjsm.32.1.68.

Hasselman, C. T., Best, T. M., Hughes, C., Martinez, S., & Garrett, W. E. (1995). An explanation for various rectus femoris strain injuries using previously undescribed muscle architecture. *The American Journal of Sports Medicine, 23*(4), 493–499.

Herzog, W., & Keurs, H. (1988). Force-length relation of in-vivo human rectus femoris muscles. *European Journal of Physiology Pfluegers Archiv, 411*, 642–647.

Hsu, J. C., Fischer, D. A., & Wright, R. W. (2005). Proximal rectus femoris avulsions in national football League kickers. A report of 2 cases. *The American Journal of Sports Medicine, 33*, 1085–1087.

Impellizzeri, F. M., Rampinini, E., Coutts, A. J., et al. (2004). Use of RPE-based training load in soccer. *Medicine & Science in Sports & Exercise, 36*(6), 1042–1047.

Irmola, T., Heikkilä, J. T., Orava, S., & Sarimo, J. (2007). Total proximal tendon avulsion of the rectus femoris muscle. *Scandinavian Journal of Medicine & Science in Sports, 17*, 378–382.

Issurin, V. B. (2010). New horizons for the methodology and physiology of training periodization. *Sports Medicine, 40*(3), 189–206, 0112-1642/10/0003-0189/$49.95/0.

Johnson, M. A., Polgar, J., Weightman, D., & Appleton, D. (1973). Data on the distribution of fibre types in thirty-six human muscles : An autopsy study. *Journal of Neurological Sciences, 18*, 111–119.

Johnston, R. J., Watsford, M. L., Kelly, S. J., et al. (2014). Validity and interunit reliability of 10 Hz and 15 Hz GPS units for assessing athlete movement demands. *The Journal of Strength & Conditioning Research, 28*(6), 1649–1655.

Lees, A., Asai, T., Andersen, B., Nunome, H., & Sterzing, T. (2010). The biomechanics of kicking in soccer: A review. *Journal of Sports Sciences, 28*, 805–817. https://doi.org/10.1080/02640414.2010.481305.

Lorenzo, S., Halliwill, J. R., Sawka, M. N., & Minson, C. T. (2010). Heat acclimation improves exercise performance. *Journal of Applied Physiology, 109*(4), 1140–1147.

McGorm, Roberts L. A., Roberts, L. A., Coombes, J. S., & Peake, J. M. (2018). Turning up the Heat: An evaluation of the evidence for heating to promote exercise recovery, muscle rehabilitation and adaptation. *Sports Medicine, 48*, 1311. https://doi.org/10.1007/s40279-018-0876-6.

Mendiguchia, J., Alentorn-Geli, E., Idoate, F., et al. (2013). Rectus femoris muscle injuries in football: A clinically relevant review of mechanisms of injury, risk factors and preventive strategies. *British Journal of Sports Medicine, 47*, 359–366.

Moraes, V. Y. (April 2014). Platelet-rich therapies for musculoskeletal soft tissue injuries. *Cochrane Database of Systematic Reviews, 29*(4). CD010071. 2014.

Ouellette, H., Thomas, B. J., Nelson, E., & Torriani, M. (2006). MR imaging of rectus femoris origin injuries. *Skeletal Radiology, 35*, 665–672.

Oyaizu, T., Enomoto, M., Yamamoto, N., Tsuji, K., Horie, M., Muneta, T., et al. (2018). Hyperbaric oxygen reduces inflammation, oxygenates injured muscle, and regenerates skeletal muscle via macrophage and satellite cell activation. *Scientific Reports, 8*, 1288. https://doi.org/10.1038/s41598-018-19670-x.

Reiman, M. P., & Lorenz, D. S. (2011). Integration of strength and conditioning principles into a rehabilitation program. *International Journal of Sports Physical Theraphy, 6*(3), 241–253.

Sonnery-Cottet, B., et al. (2017). Surgical management of rectus femoris avulsion among professional soccer players. *Orthopaedic Journal of Sports Medicine, 5*. https://doi.org/10.1177/2325967116683940, 2325967116683940.

Szymanska, J., Goralczyk, K., Klawe, J. J., Lukowicz, M., Michalska, M., et al. (2013). Phototherapy with low-level laser influences the proliferation of endothelial cells and vascular endothelial growth factor and transforming growth factor-beta secretion. *Journal of Physiology & Pharmacology, 64*(3), 387–391.

Ueblacker, P., Müller-Wohlfahrt, H. M., Hinterwimmer, S., Imhoff, A. B., & Feucht, M. J. (2015). Suture anchor repair of proximal rectus femoris avulsions in elite football players. *Knee Surgery, Sports Traumatology, Arthroscopy, 23*, 2590–2594.

Vaquerizo, V., Casas, D., Seijas, R., Ares, O., & Cugat, R. (2012). Surgical treatment of proximal ruptures of the rectus femoris in professional soccer players. *Archives of Orthopaedic and Trauma Surgery, 132*, 329–333.

Yamauchi, K., Yoshiko, A., Suzuki, S., Kato, C., Akima, H., Kato, T., et al. (2017). Muscle atrophy and recovery of individual thigh muscles as measured by magnetic resonance imaging scan during treatment with cast for ankle or foot fracture. *Journal of Orthopaedic Surgery, 25*(3). https://doi.org/10.1177/2309499017739765, 2309499017739765.