BARÇA INNOVATION HUB

MUSCLE INJURY GUIDE:

Prevention of and Return to Play from Muscle Injuries

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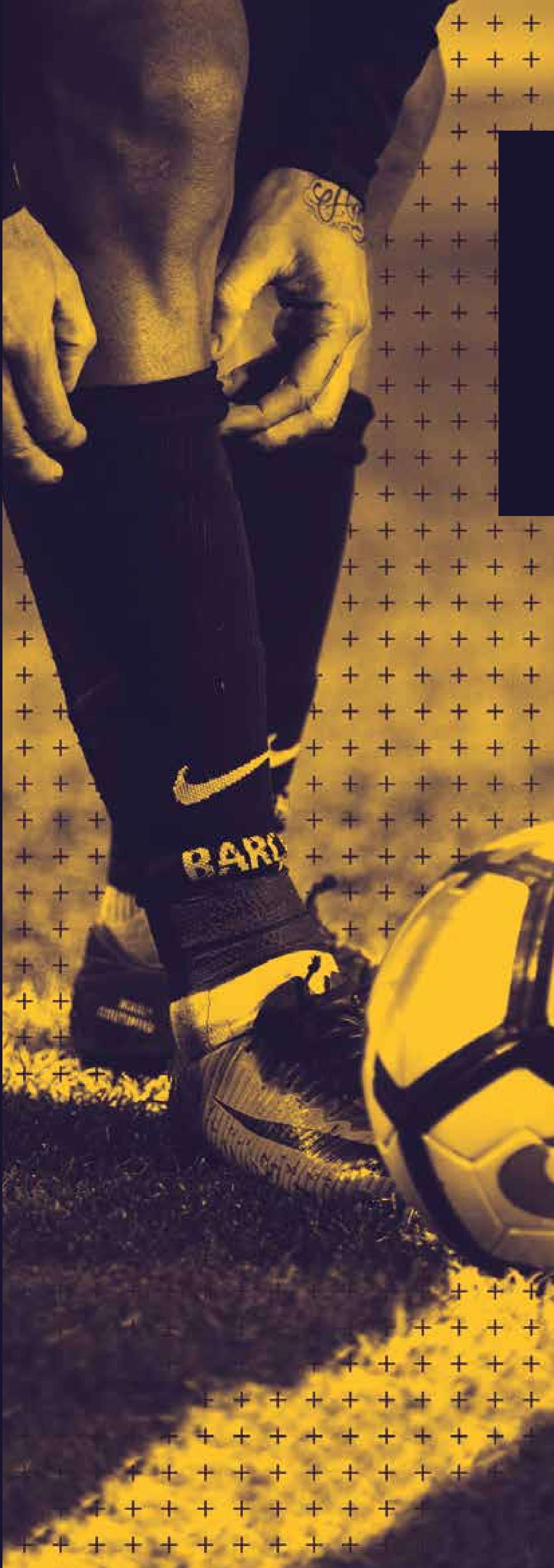

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Summary

3

RTP from Specific Muscle Injury

3.1

RETURN TO PLAY FOLLOWING HAMSTRING MUSCLE INJURY

In this section, we build upon the general principles described earlier in the guide, with specific reference to hamstring muscle injuries.
— With Thor Einar Andersen, Arnlaug Wangensteen, Nicol van Dyk and Ricard Pruna

MAKING AN ACCURATE DIAGNOSIS

Making an accurate diagnosis is the cornerstone of effective injury management and return to play planning. An accurate diagnosis facilitates an estimation of prognosis, and in turn, shared decision-making regarding injury management. Imaging may be used judiciously at this step, but you must be clear about what (if anything) imaging will do to change the return to play plan. At FC Barcelona, we work backwards from the anticipated time to return to full match-play. Understanding biology will help when estimating injury prognosis and planning a strategy for appropriate loading through the return to play continuum.

PATIENT HISTORY

The patient history provides valuable information about the injury event and a preliminary impression of the injury severity. As with other muscle groups, some of the most pertinent elements to focus on include the nature of pain, the mechanism of injury and the functional impact of the injury.[1–3]

Asking about the time to pain free walking (when not seeing the player at the time of injury), pain at the time of injury (using VAS or NRS) and self-predicted time to RTP may give valuable information of the injury extent and has shown associations with time to RTP in some studies.[4]

Although the evidence regarding the actual hamstring injury mechanism is limited, the injury mechanism may provide an insight into the likely muscle affected. In football players, the majority of hamstring injuries occur during high-speed running when the player is running at maximal or close to maximal speed,[5–7] and the injury is thought to occur during eccentric muscle contractions when the hamstring muscles are lengthening while producing forces.[8,9] The biceps femoris long head is the most frequently injured muscle [6,10–12] and commonly located to the musculotendinous junction.[6,10] Other injury situations during movements leading to extensive lengthening of the hamstrings, such as slow-speed stretching type,[7] kicking, high kicking, glide tackling, twisting and cuttings,[7,13] may typically involve the semimembranosus.[6,7] Whether there was a sudden onset with sharp/severe pain and whether the player was forced to stop immediately, can aid in confirming the diagnosis and might give some indications about severity. Common acute injury situations with a mechanism of extreme hip flexion with the knee extended (e.g. sagittal split or falling forwards with the upper body while the leg is fixated to the ground) combined with an audible 'pop' indicate a possible total rupture of the proximal tendon (-s), and further radiological investigations are warranted.[14,15]

Previous hamstring injury, low back pain problems or other injuries, as well as recent loading history may aid the diagnosis. More gradual onset of posterior thigh pain where the player reports characteristic deep, localized pain in the region of the ischial tuberosity that often worsens during or after running, lunging and sitting, suggest a proximal hamstring tendinopathy.[15]

PHYSICAL EXAMINATION

As with other muscle injuries, the physical examination should include observation of gait pattern and function, inspection of the injured area, palpation of the hamstring muscle complex, flexibility and ROM testing of the hip and knee joints, isometric pain provocation tests and muscle strength testing.[1,3,16–18] Pain and deficits compared to the uninjured leg with the different tests are usually registered,[16] and a pain rating scale (NSR or VAS) can be used to quantify the player's subjective pain[16,19] during testing. Pain during palpation at the insertion(s) of the proximal tendons around the ischial tuberosity, as well as excessive pain with provocation tests, large ecchymosis (bruising) of the skin, severe loss of function and ROM restrictions should raise the suspicion of a more severe injury (total rupture).[3,14] In addition, if palpating and applying pressure just distal to the ischial tuberosity, while the player flex the knee, and the clinician is not able to palpate the tendon having normal tension, is a strong indication of an avulsion injury.

Gait and function should be assessed fully around the time of injury, by observing whether the player has pain and/or display an antalgic movement pattern. It is also useful to register pain with progressive trunk flexion with knees extended towards the level of maximal flexion, as this will stress the hamstrings. Hamstring function can also be assessed with two-legs and single leg squats, and two-leg and single leg supine bridges, using different degrees of knee flexion to assess different portions of the muscles and tendons[16,18]. Palpation

may assist to identify the location of the injury and whether there is a presence of palpable defects.[3] The hamstring muscles should be palpated along their entire course, from origin to insertion and bruising, pain, swelling, and tissue defects (discontinuity or 'gap') should be noted, using the ipsilateral leg as a reference point.[3,18,21] In our experience, the muscles and tendons should be palpated both in a relaxed and contracted state. Palpation during contraction makes the anatomical orientation easier and is more likely to provide a specific location of the injury. To measure deficits in ROM and muscle strength, objective assessments using goniometers or inclinometers and hand-held dynamometer are commonly used.[16–18,20,22,23] Hamstring flexibility of the injured leg is usually reduced compared to the uninjured leg after injury,[3,16–18,24] and commonly examined in conjunction with other assessments to establish a diagnosis. The active and passive straight leg raise tests and active and passive knee extension tests are most commonly referred to in the literature following hamstring injuries.[16–18,20,22,25–27] These flexibility tests show moderate to good reliability among healthy participants,[26] and the active and passive knee extension tests show good intertester reliability in athletes with acute hamstring injuries.[27] Pain with isometric contraction and hamstring muscle strength deficits at various angles of knee- and hip flexion compared to the uninjured leg is commonly present initially after injury.[3,16,18,28] Just recently, a meta-analysis reported that lower isometric strength was found post injury, but did not persist beyond 7 days.[28] However, there are few studies that have reported strength deficits throughout the RTP process, as the focus in the literature mainly has been directed towards isokinetic and eccentric strength deficits at or (long time) after RTP.[28]

Additionally, acute posterior thigh pain may be hip-related or have other non-musculoskeletal causes.[3,29] Clinicians should consider whether a potential pain source of the player's presentation may be lumbar spine related, or due to peripheral neurogenic pain, and additional tests (for example slump tests) needed to rule sensitive structures [3,15,30,31] must be considered, especially if the player has an atypical presentation.

The diagnostic accuracy of specific hamstring tests presented are poorly investigated[32] and the prognostic value of these assessments are also inconclusive and conflicting,[4] thus more evidence is needed to identify which clinical tests are most valuable to provide a prognosis for RTP. Of interest, daily physical measures have recently been shown to be useful to inform the progression of the rehabilitation;[18,20] repeated physical examinations after the initial examination and throughout the RTP continuum should be considered.

IMAGING

In cases where the clinical appearance and severity is unclear, imaging is used to confirm the diagnosis and to provide information about the radiological severity and the location of the injury, as well as to guide further treatment.[33] Complete ruptures of the tendon insertions at the ischial tuberosity (with or without avulsion fractures) have a worse prognosis and in footballers, surgery is often indicated [29,33] (see later in this chapter for more information on surgery for hamstring injuries).

Ultrasonography and MRI are commonly used in assisting the clinical diagnosis of acute hamstring injury. Ultrasonography is described as an excellent modality that is also useful in the evaluation of hamstring injuries and has the advantage of increased accessibility and decreased cost.[2] The drawback with this imaging measurement, is that it is highly operator dependent [2] and has failed to show any association with RTP prospectively.[34] MRI has recently been suggested as the preferred imaging technique over ultrasonography, based on its greater sensitivity for minor injuries.[2] At FC Barcelona we always use MRI as the preferred mode of imaging. Clinical examinations (i.e. hamstring flexibility and strength) seems to be less useful in discriminating the presence of intramuscular tendon involvement,[35] and for this purpose MRI is the preferred diagnostic tool

ESTIMATING RTP TIME

LOCATION AND EXTENT OF TISSUE DAMAGE

Estimating how long a player will take to RTP following a hamstring injury is challenging. Recent research has highlighted a poor correlation between RTP times and a range of MRI measures.[36–38] Similarly, there is conflicting evidence on the predictive value MRI-based injury classification systems.[10–12,36–42] We therefore urge practitioners not to rely on MRI results alone, or muscle injury classification systems only, when estimating RTP after hamstring injury.

At FC Barcelona, we use MRI results as a starting point for the RTP estimate, which may then be adjusted due to player-specific factors, football-specific factors, and risk tolerance modifiers (as described previously in this guide). Generally, injuries located more proximally, and those that involve a large amount of tendon tissue, are expected to take longer to RTP.

Table 1 shows the expected RTP times for various hamstring muscle injury locations and severities, based on FC Barcelona clinical experience and injury data collected over 10 seasons. These have not yet been validated in scientific studies and are based on our club only. Note also that these data are only intended as a starting point; player-specific factors, football-specific factors and risk tolerance modifiers should also be considered when estimating RTP time.

Table 1
Estimated RTP times for hamstring muscle injuries based on FC Barcelona data and clinical experience. Note that these are initial estimations only, that do not consider player-specific factors, football-specific factors, or risk tolerance modifiers
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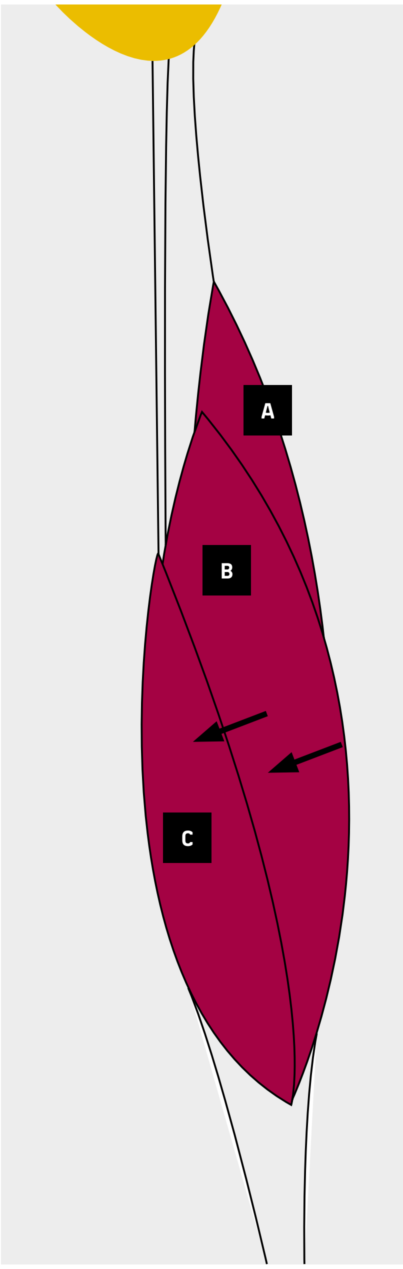
INJURED TISSUES	CONNECTIVE TISSUE INVOLVEMENT	ESTIMATED RTP TIME
Hamstrings free tendon avulsion	Bone	Surgery, 4 months
Hamstrings free tendon transverse tear	Connective tissue gap, wavy tendon	Surgery, 4-5 months
Hamstrings free tendon longitudinal split	Connective tissue affected without gap, wavy tendon	10 weeks
Hamstrings free tendon tear + biceps femoris proximal MTJ injury	No connective tissue gap, wavy tendon	7 weeks
	Connective tissue gap, wavy tendon	8-10 weeks
Hamstrings free tendon stretching	Peritenon halo (tendon fiber microdamage)	4 weeks
Biceps femoris proximal MTJ injury	Peritenon halo	4 weeks
	Little connective tissue involvement	3-4 weeks
	Connective tissue gap, wavy tendon	7 weeks
Biceps femoris – Deep zip (distal myofascial)	Little connective tissue involvement	3-4 weeks
Biceps femoris superficial zip (distal MTJ)	Connective tissue involvement	4-5 weeks
Biceps femoris mixed zip		4-5 weeks
Biceps femoris distal tendon avulsion	Bone injury	Surgery, 4 months
Semitendinosus proximal MTJ injury	Little connective tissue involvement	3 weeks
Semitendinosus raphe MTJ	Little connective tissue involvement	3 weeks
Semitendinosus distal MTJ	Little connective tissue involvement	2 weeks
	Connective tissue gap, wavy tendon	Surgery, 4 months
Semimembranosus proximal tendon avulsion	Bone injury	Surgery, 4 months
Semimembranosus proximal tendon rupture	Partial rupture	5 weeks
	Complete rupture	6 weeks
Semimembranosus proximal MTJ, section A*	Little connective tissue involvement	3 weeks
Semimembranosus proximal MTJ, section B*	Little connective tissue involvement	4 weeks
	Connective tissue gap, wavy tendon	6 weeks
Semimembranosus proximal MTJ, section C*	Little connective tissue involvement	5 weeks
Semimembranosus DISTAL MTJ	Little connective tissue involvement	3 weeks
	Connective tissue gap, wavy tendon	6 weeks

* See figure 1 for illustration of semimembranosus sections A, B and C



PLAYER-SPECIFIC FACTORS

Practitioners should consider some intrinsic factors. With young players the ischial apophysis must be recognized as a potential injury location in proximal injuries.[43] Each player's specific hamstring anatomy may also be important to consider. For example, the length of the free tendon of the biceps femoris may vary from individual to individual, and an injury 5 cm from the ischial tuberosity may affect mostly tendon tissue in one player, but mostly the muscle-tendinous tissue in another player. However, providing an accurate estimate for RTP based on the location of the injury seem to be challenging and the evidence here is conflicting.[10,38,39,42,44]

FOOTBALL-SPECIFIC FACTORS

As the hamstring muscles are highly stressed during long sprints more than 30 meters, wing midfielders, full backs and other players who commonly have to undertake maximal sprints for longer distances during match play, may need longer RTP times and specific drills following injury. In particular this is related to the ability of performing repeated sprints.

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Figure 1
llustration of the semimembranosus sections A, B and C (refer to table 1). Adapted based on Woodley J and Mercer SR. Hamstring muscles: Architecture and Innervation. Cells Tissue Organs, 2005;179:125-141.

HAMSTRING MUSCLE TESTING

Specific and functional testing plays an important role throughout the entire RTP process. During the initial physical examination, testing provides immediate information on which activities the player can perform with and without pain, which may help practitioners develop a clinical impression of injury severity and prognosis. Later, the test can act as important milestones and / or criteria as the player progresses along the RTP continuum and help to guide the final decision to clear the player for unrestricted match participation.

While at FC Barcelona we acknowledge that hamstring muscle testing such as those mentioned below can be of useful, however, we do not actually perform any of the isolated/non-functional tests of muscle strength or flexibility as markers throughout the RTP process for hamstring muscle strain. In our experience, through mobilisation of the injured area as soon as possible following injury and exposure to field-based activities from early on (pain permitting) e.g. on-field football specific exercises, that the strength and flexibility does not suffer and therefore any initial losses are negligible and do not impact on the RTP process.

STRENGTH TESTING

Assessment of muscle strength is one component of the clinical examination, management, screening, and prevention of hamstring muscle injury. Isokinetic strength dynamometry measurement remains a common strength assessment in elite sports teams.[45] However, this is expensive, time consuming and not specific to movements in the field. Strength can be effectively assessed using a hand-held dynamometer (HHD).[46,47] Following injury, these tests can be compared with the uninjured leg at specific time points throughout the RTP process [18,20] and provide valuable information to the RTP decision making process. Traditional strength tests include but are not limited to; isokinetic strength, mid-range and outer-range strength and the Nordic hamstring strength.

POSTERIOR THIGH FLEXIBILITY

There are numerous ways to measure hamstring flexibility, commonly used both for screening, diagnosis and throughout the RTP process, as mentioned above. The most common are the straight leg raises[16] and active and passive knee extension tests,[27] with various degrees of hip flexion, and the Askling H-test.[48]

EXERCISE PRESCRIPTION FOR HAMSTRING INJURIES

The high incidence of hamstring re-injuries remains enigmatic and an insufficient RTP process are mentioned as one of the main reasons for this.[49,50] MRI abnormalities are common at RTP,[51–53] with many athletes that have met clinical clearance returning to play demonstrating incomplete healing of the injured muscle, and therefore may still be in an injury-susceptible state. Re-injuries commonly occur early after RTP,[11,13,54] but an increased susceptibility seems to be present for several months after the index injury.[49,55] Thus, a good and effective RTP process following a hamstring injury is important not only for a quick RTP, but also for reducing the risk of re-injuries. However, there is still lack of consensus about the management and the optimal exercise prescriptions following acute hamstring injuries.[56–58] There are several randomised controlled trials (RCT) investigating the effect of different interventions and exercise protocols after hamstring injuries.[56] Of particular interest, two larger RCT's have been published on the effect of different rehabilitation programs following acute hamstring injuries in male football players.[57,58]

Askling et al.[57] reported that a protocol emphasizing hamstring exercises performed at longer muscle length (L-protocol), was significantly more effective than a conventional exercise protocol with less emphasis on lengthening exercises (C-protocol). Time to RTP was significantly shorter for the players in the L-protocol with 28 days (1SD±15, range 8–58 days), compared to the C-protocol with 51 days (1SD±21, range 12–94 days). Irrespective of the protocol used, stretching-type injury of the hamstrings took significantly longer time to return than sprinting-type (L-protocol: mean 43 vs 23 days and C-protocol: mean 74 vs 41 days, respectively). The L-protocol was significantly more effective than the C-protocol in both injury types. Only one reinjury was registered in the C-protocol group. It therefore seems reasonable to include lengthening/eccentric exercises in a rehabilitation program aimed to return football players effectively, but safely back to play after an acute hamstring injury, although, the optimal volume and intensity of eccentric training after acute hamstring injuries and re-injuries is yet not clear.

Conversely, Mendiguchia et al.[58] showed that male football players who underwent an individualized, multifactorial, criteria-based algorithm with a performance- and primary risk factor-oriented training program from the early stages of the process, markedly decreased the risk of re-injury compared to a general protocol where long length strength training exercises were prioritized, although the time to RTP was longer.

Independent of exercises applied, a multifactorial approach including a comprehensive evaluation of health status, participation risk as well as factors involved in the decision modification is suggested to provide clinicians with an evidence-based rationale for RTP decision making.[59,60] Importantly, these factors should be considered along the course of the RTP continuum.[61]

Still, specific data regarding hamstring strength recovery, self-reported pain/insecurity during ballistic flexibility movements (Askling H-test [48]), active and passive ROM tests and relevant sports specific tests to use in the decision of RTP are sparse. There are yet no valid definitions or objective criteria for RTP,[62] nor criteria for progressing throughout the different stages.[63] Just recently, a Delphi procedure[64] with experts within the field of hamstring management selected by 28 FIFA Medical Centres of Excellence, concluded that the RTP decision should always be a multidisciplinary decision, and for RTP readiness assessment of the player after a hamstring injury, emphasis should be placed on pain relief, flexibility assessment, psychological readiness, and functional performance. Further, that MRI findings should not be used alone for RTP-readiness assessments. However, this Delphi study also revealed the different opinions and discrepancies among the experts within the field.

The management guidelines for hamstring injuries presented here are based predominantly on basic science, therapeutic principles from previous studies on hamstring injuries and clinical expertise.

The journey from early rehabilitation to team training will often be highly individual. To design a RTP program following a hamstring muscle injury based strictly on muscle injury healing phases[65] is likely not appropriate for all athletes. The athlete's signs and symptoms, the combination of clinical expertise and evidence-based knowledge should guide decision-making process for exercise progression. Potential complications should be carefully monitored at all times.

EXERCISES TO OPTIMISE TISSUE HEALING AND RESTORE PERFORMANCE

A carefully-planned, progressive loading program is essential to optimise the quality healing of the tissues and to prevent injury recurrences. The program should include fundamental therapeutic exercises (sometimes referred to as mechanotherapy[66]) and strategies to restore football-specific function. As previously discussed, maintaining football-specific cognitive skills is vital throughout the entire RTP process. Importantly, these three areas are non-hierarchical; there should be gradual progression in all areas and milestones should be determined for each area as the player progresses through the RTP continuum.[61]

Regarding pain during exercises, it is generally recommended that all exercises should be performed close to pain free limit, since loading healing tissue beyond its elastic limit might result in further exacerbations, signalled by the presence of pain with this loading.[67] If the exercise or movement elicits pain from the injured area, the exercise should therefore immediately be adjusted or terminated. Uncontrolled movements of the pelvis could adversely affect load on the hamstrings during high stress events such as sprinting, thus patients are continuously instructed to perform the exercises with adequate control and stabilization of the hip and trunk.[68,69]

Physical assessments and specific criteria for progression throughout the RTP process is usually recommended in order to assist with the clinical reasoning of how to progress or adapt the treatment session of the player on a specific day.[18,20,58] Additionally, clinical reasoning should be performed continuously by the clinician to optimise the loading and the progression for each session and the individual player. Monitoring of the athlete's response through daily measurements (reported pain, palpation, muscle strength, and flexibility) may assist in determining the response to the loading, and whether the athlete is ready for progression or not. In addition to muscle strength measurements, isometric contractions at different muscle lengths may be performed as pain provocation tests throughout the RTP process to help guide exercise and load progression. In the clinical reasoning process, the clinician will also consider factors related to the presumed injury mechanism, player-specific hamstring demands, and presumed individual risk factors such as trunk stability and lumbo-pelvic control.[68,70,71] For players with an injury involving the proximal tendon (-s) (free or intramuscular) or more longstanding problems (proximal hamstring tendinopathy), our experience is that exercises towards outer ranges should be prescribed with caution, in particular exercises involving excessive hip flexion. The RTP continuum can be divided into several phases, but with an overlap of exercises between the phases.

ACUTE STAGE

At FCB a five-stage approach to the management of muscle injuries is used (see RTP principles section). Stepwise progression of loading will facilitate effective tissue healing while restoring functional capacity. Focus during the acute phase of management is to limit the extent of the initial injury and to provide a strong foundation upon which to build the rehabilitation process.

Reduction of pain and inhibition are key goals during this phase. Application of the principles of the POLICE[72], acronym should be initiated as soon as possible following injury. Key interventions include compression and ice. This can be achieved through the use of compressive bandage (see quadriceps section 3.2. figure 1A); where the injury is at lower-third of thigh, it is recommended to include the knee joint in this compression. Modalities combining cooling and compression (see section 3.2. figure 1B) or use of graduated segmental compression (e.g. Normatec, see section 3.2. figure 1C) can further facilitate reduction of pain and swelling in the affected area. Players are allowed to walk as able although it may be necessary to use crutches following severe injuries.

TARGETED TREATMENT

Targeted interventions at this initial stage following injury (e.g. the day/s following muscle injury) that help to reduce pain and enhance movement quality include 'physio-table' based methods such as manual therapy and passive mobilisation of the affected area. Passive modalities should not be seen as standalone interventions but rather as an auxiliary to enhance the mechanotransducive effect of high quality tissue loading. Passive interventions are used primarily to reduce pain and enhance movement so that the active strategies more effectively target the injured tissue.

During the subacute phase, active mobilisation will facilitate both movement capability and improve tissue healing. Exercises performed during this phase should be carried out with good form and compensatory strategies avoided. Examples of interventions during this phase include dynamic mobility, and gentle active tension stretching towards outer pain-free ranges are recommended to be initiated, in addition to active lengthening exercises[6] (Figure 2).

In addition, to maintain the muscle function of the lower limb, the player should also focus on exercises for the hip, gluteus and calf.[58] It is also advised that general upper quadrant and aerobic conditioning is maintained; this can be achieved through the use of elliptical trainers, stationary cycles, aqua jogging and AlterG Treadmill, before progressing walking on a treadmill is initiated when tolerated.

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Figure 2:
Active tension stretching towards extension

FOCUSED MUSCLE ACTIVATION

Low level exercises that provide adequate loading during the early phase of healing are recommended. Functional exercises aimed at retaining and even improving movement patterns are also utilized. Typically, active movements in mid and inner ranges (of knee- and hip flexion) could be performed without resistance or external loading (such as for example prone or seated knee flexion). Focused muscle activation can be useful in the early stages, as the use of manual resistance can help ensure mechanical stimulus is provided to the affected area, while the intensity can be modulated in line with symptoms to ensure vulnerable structures are not overloaded. Examples of isometric to easy concentric exercises with manual resistance are shown in figures 3 and 4. Specific hamstring exercises, such as supine bridges with two legs or one leg if tolerated (Figure 5A-B), and more functional exercises such as one leg squats with attention to pelvic and leg posture may also be performed.

During this phase, it is suggested that exercises are carried out 'little and often' and that movements are biased towards lengthening contractions as soon as possible. Movements during the early strengthening phase should be carried out in a slow and controlled manner. It is recommended that 2-3 sets of 4-6 repetitions of sub-maximal contractions (60-70% MVC) are carried out twice daily. As rehabilitation progresses the intensity of contraction should be increased and the frequency reduced to align with conventional strength training parameters.

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Figure 3:
Isometric exercises

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Figure 4:
Concentric exercises against manual resistance

RESTORING GYM-BASED ACTIVITIES

Once able to effectively recruit the muscle through range it is important to combine table based activation with more conventional gym based training. In this phase, the main aim is to regain full muscle function, which means regaining full voluntary control over the injured muscle throughout a full range of motion. This is achieved through pain-free hamstring strengthening exercises (with controlled progression to longer hamstring lengths), appropriate control of trunk and pelvis, and with progressive movement speed and increased load on the hamstrings.

The exercises should be performed with controlled increase in the load of the particular exercises to ensure continuously increasing tissue capacity and monitored to ensure the exercises are executed appropriately and adaptation is performed as required.

Hamstrings specific strengthening exercises that are increasingly challenging together with a gradual running progression are introduced in this phase. Typically, this includes progression to higher loaded and/or single leg exercises, and exercises towards greater muscle lengths, i.e. eccentric exercises. A variety of exercises could be included, and the exercise selection may be influenced by individual preferences and considerations, such as for example the location of the injury. Several studies using surface EMG and / or fMRI suggest that the hamstring muscle activation patterns are heterogeneous and diverge between different exercises.[73–80] Eccentric knee flexor conditioning, such as the Nordic hamstring exercise reduces the risk of hamstring strain injury when compliance is adequate,[81–83] and the benefits of this type of training are likely to be at least partly mediated by increases in biceps femoris long head fascicle length and improvements in eccentric knee flexor strength.[73] Selecting exercises with a proven benefit on these variables should therefore be included in any effective injury and reinjury prevention protocols. In addition, the Nordic hamstring exercise seems to improve sprint performance and the peak eccentric hamstring strength and capacity.[81]

Typically, relatively higher levels of biceps femoris long head and semimembranosus activity have been observed during hip extension-oriented movements, whereas preferential semitendinosus and biceps femoris short head activation have been reported during knee flexion-oriented movements.[73] Preferably, both hip- and knee dominant exercises should be included in the RTP program.[58] Examples of different bridge exercises commonly used in FCB and other hamstring strengthening exercises are shown in figures 6 to 8.

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Figure 5A:
Two leg bridge

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Figure 5B:
One-leg bridges

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Figure 6:
Bridges and one-leg bridges with increased ranges and various surfaces

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Figure 7:
Bridges combined with knee extensions (eccentric phase) (and knee flexion curls (concentric phase)

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Figure 8:
One leg bridge (can be progressed with plyometric component)

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Figure 9:
Seated leg curls with focus on the eccentric phase

In addition, the player should continue with active stretching exercises (and active dynamic mobility) (see figure 10) and also include coordination- and proprioception exercises.

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Figure 10:
Various active stretching and dynamic mobility exercises

Restoration of normal gym-based training is important. Players routinely complete a range of lower limb strengthening exercises that combine eccentric, concentric and isometric muscle actions. Once there is pain-free recruitment of the hamstrings through range, it is important to normalise gym training as soon as possible while maintaining an additional eccentric stimulus to facilitate adaptations in muscle architecture and prevent recurrence. Exercises that provide the necessary strength and architectural stimulus should be included and maintained beyond return to sport. These might include general hamstrings, quadriceps and glute exercises, such as squats, deadlifts and hip thrusts (See figure 7 in quadriceps specific section 3.2.).

RUNNING PROGRESSION

As early as tolerated, the player should begin a running progression program, addressing volume, intensity, and running mechanics. An important aspect of the resumption of running is to ensure that the loading during running is progressively and carefully increased. Asking the athlete to rate their perceived effort during running may be a good way to ensure that similar loads are maintained within sessions, and to enable careful increases in loading (running speed) when the athlete has safely achieved a given speed.[18] The running could preferably be performed outside on the field. In addition, specific drills and/or football-specific drills with low-speed tasks can be initiated. At FC Barcelona, running in the early stages is commenced on dry sand (figure 11) and progressed to linear running on the field (e.g. figure 12). Manipulation of distance, velocity and volume is then used to train specific subcomponents of running fitness and muscle function.

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Figure 11:
Running circuits in dry sand (starting easy)

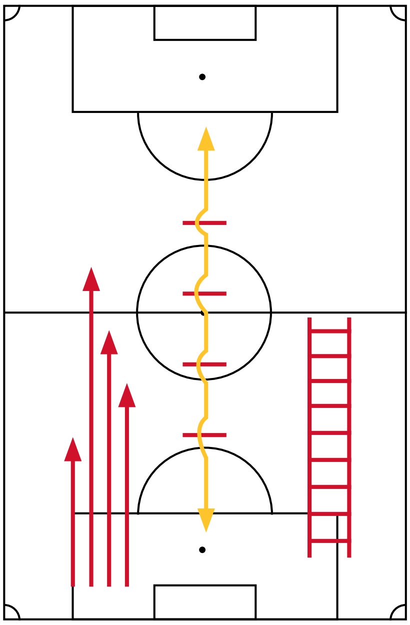

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Figure 12:
Examples of early running in the field

BASIC ON-FIELD TRAINING: RESTORING RUNNING, KICKING AND CHANGE OF DIRECTION

The primary goal during the RTP process is to ensure the player can return safely to activities that yield a high re-injury risk, such as sprinting and kicking. A strong focus on monitored progression of these activities during RTP is therefore essential.

The running is progressed by adding changes in direction and velocity through football-specific drills and tests, including both linear, turns, accelerations and decelerations. Finally, sprints at various distances within specific football situations and stimulations are added. Also a focus on running and sprinting technique, as well as a controlled progression of total running load towards the expected running and sprinting exposure in training and matches for the individual player is emphasised.

Multi-directional running through the execution of simple football skills can be included. Football circuits and training drills can be introduced and progressed in terms of complexity and decision-making before returning to field sessions with the squad. Pain free running up to maximal speed including change of directions, performed under fatigue, is paramount. Similarly, passing and kicking require controlled progression, as emphasized earlier (see quad section 3.2. for more information on passing/kicking progressions).

The exercises are increased with controlled load and strengthening exercises may include more specific modifications for the individual player and activation routine before training is introduced.

COMPLEX FIELD WORKOUT: RESTORING FOOTBALL-SPECIFIC FITNESS, SKILLS AND COGNITION

As outlined in the general RTP section, on-field return to play requires the introduction of progressive complex football-specific tasks such as dribbling, passing and receiving a ball, snake runs and training drills. The use of football specific circuits and manipulation of constraints such as the speed of movement, difficulty of the skill, competition and decision-making become increasingly important during the RTP process. Tasks that place greater stress on the hamstrings should be identified and progressed as the player is able i.e. coping with the demands. Particular attention should be given to managing the number of accelerations, decelerations and changes of direction as these activities are particularly important not only for re-injury risk but also for performance.

At FC Barcelona, particular emphasis is placed upon incorporating the ball during every session (or at least as many as is possible). Practical strategies to progress unanticipated movements include variation of the speed and timing of signals for players. Similarly, introduction of competition and opponents can effectively progress unanticipated, open-skill aspects of the game. Advanced skills and cognitive challenges are introduced and the focus moves from being injury (hamstrings) specific in the early stages to activity (football and position) specific as RTP progresses.

Exercises and activation routine before training is advised to continue, in addition to resumption of partial training with the team. Program which exercises to do with the team, and which to do with medical and performance staff, as well as analysing the locomotor loads (e.g. from GPS) and internal loads of the player in addition to psychological readiness (refer back to section 2.3.2 for specific guidelines for this final transition) when deciding on returning to full training and match-play.

RETURN TO PLAY EXAMPLE FROM FC BARCELONA

— With Xavi Yanguas, Juanjo Brau, Xavi Linde, Ricard Pruna

Figure 13:
An overview of RTP from a hamstring muscle injury at FC Barcelona
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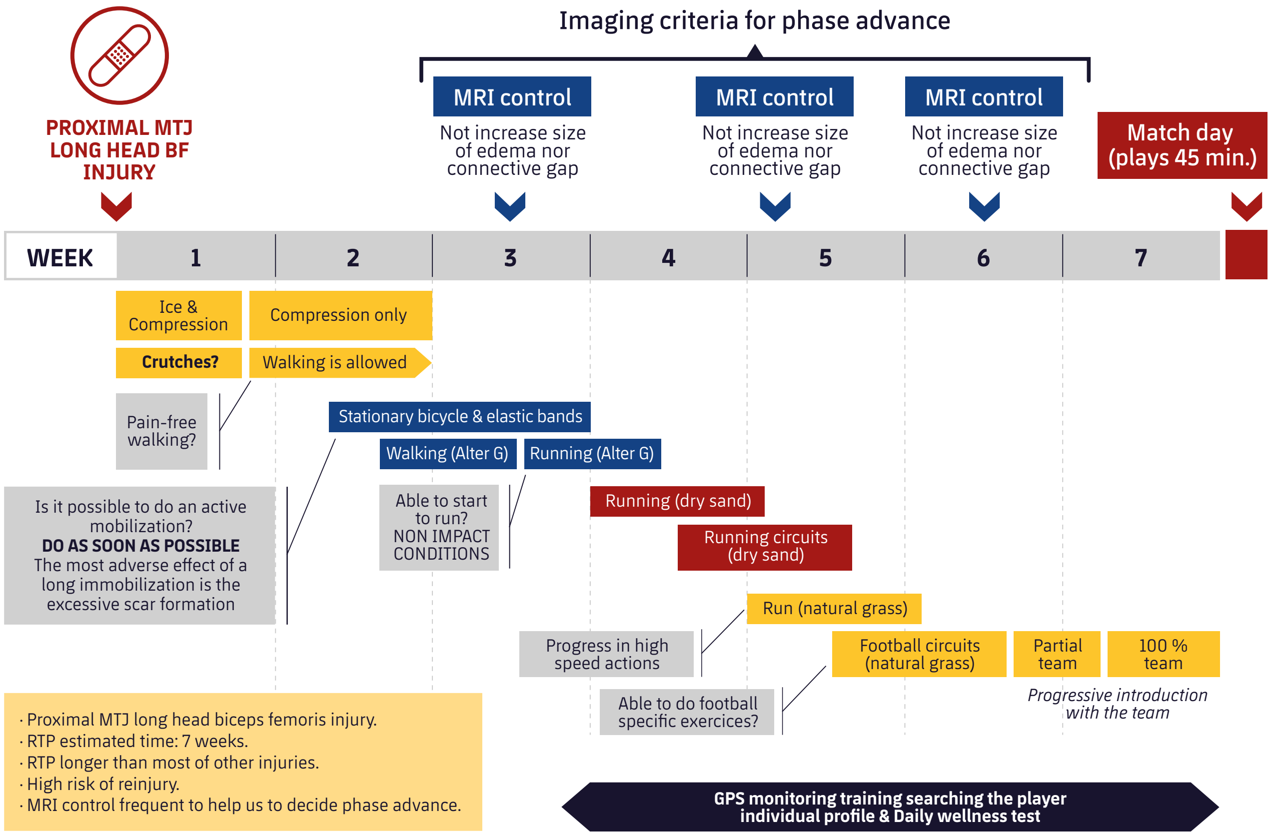

THE BARÇA WAY:

Following an accurate diagnosis of the hamstring muscle injury, we work back from the estimated RTP date. For example in the case in figure 10, we estimate the RTP at week 17. We subsequently work backwards from this to determine the key milestones and exercise progressions to achieve this date. Bearing in mind, that the RTP framework is flexible in order to either accelerate or slow down the progression depending on how the player responding to the RTP program.

Compared to other muscle injury cases that we will show you in this specific muscle injury section (e.g. quadriceps, adductor, calf), this injury requires a greater integration of multiple phases and focuses simultaneously. i.e. several and varied stimuli in the way of strength, accelerations, decelerations, high-speeds.

SURGICAL TREATMENT OF HAMSTRING INJURIES

Most hamstring injuries do not require surgery. However, in some cases surgery should be performed immediately after the injury occurs. Surgery may also be necessary if conservative treatment fails to achieve a satisfactory result – for example if the player has chronic symptoms or recurrent injuries.

— With Lasse Lempainen, Sakari Orava and Janne Sarimo

INDICATIONS FOR EARLY SURGERY

Early hamstring surgery is indicated following avulsion of two or three of the proximal tendons from the ischial tuberosity (Figure 14 A-B, Figure 14 C).[82-86] When only one of the tendons is avulsed, conservative management may be an option. However, in the elite football player, surgery is often recommended – irrespective of which tendon is involved (Figure 15 A-B).[87,88] For proximal tendon avulsion repairs, suture anchors are typically used to reinsert the ruptured tendons back to the bone.

Apophyseal avulsions of the ischial tuberosity occur occasionally in adolescent players.[89] Surgical repair is traditionally recommended if the avulsed fragment is displaced by more than 1.5 to 2 cm. However, these cases are unusual.

Although surgery is rarely necessary for distal hamstring injuries, in some cases it is necessary. Indications include avulsion of the biceps femoris (BF) or semitendinosus (ST) tendons from the bony insertion, as well as complete ruptures of the distal myotendinous junction (Figure 16 A-B, Figure 17 A-B).[90] Complete ruptures of the BF or ST with retraction should be repaired anatomically as soon as possible after injury. Sometimes, the proximal end of the ST retracts so severely that it cannot be repaired anatomically and the ST is sutured to the semimembranosus (SM) muscle. It is important to note that the consequence of an acute distal ST avulsion is not similar to when the ST tendon is harvested for graft purposes.[90]

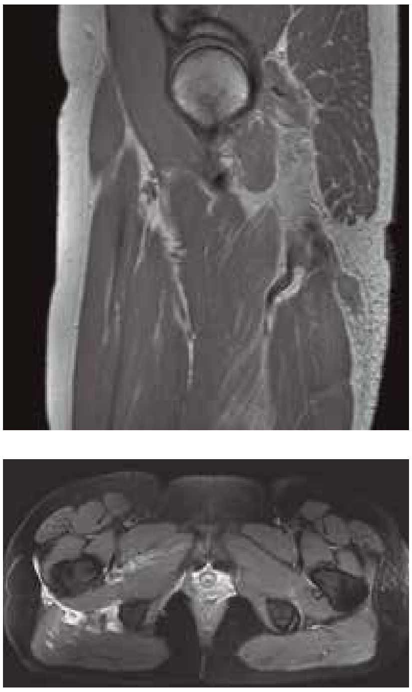

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Figure 14 A-B:
Complete 3-tendon proximal hamstring rupture with a clear retraction on the right side (axial and sagittal images).

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Figure 14C:
Perioperative photo of two tendon proximal hamstring avulsion: BF + ST.

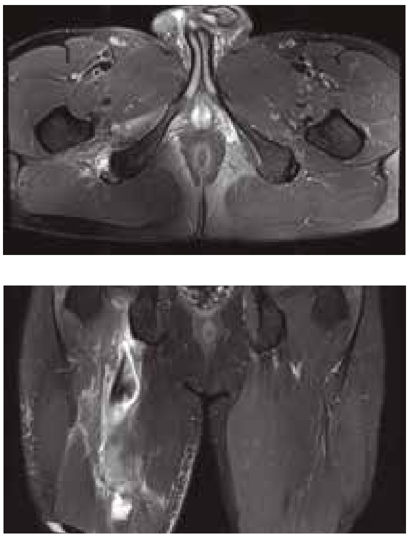

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Figure 15 A-B:
Isolated complete proximal SM tendon rupture with a clear retraction from the ischial tuberosity on the right side (axial and coronal images).

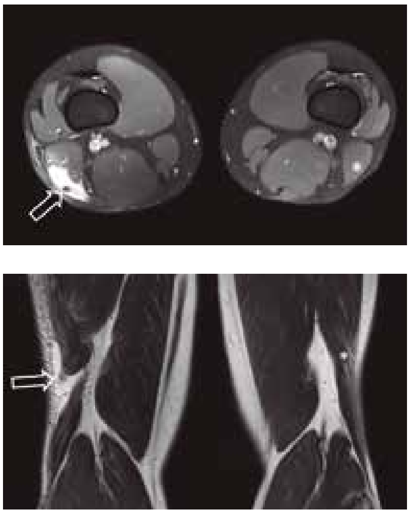

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Figure 16 A-B:
Distal rupture of the long head of the BF at the myotendinous junction. A coronal image (B) shows the retracted BF muscle (axial and coronal images).

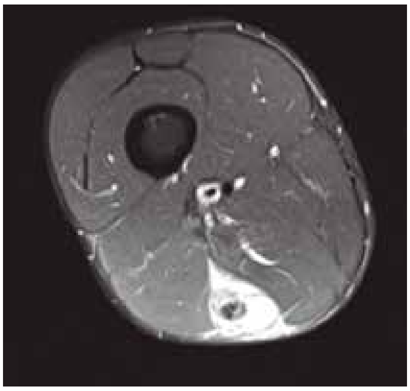

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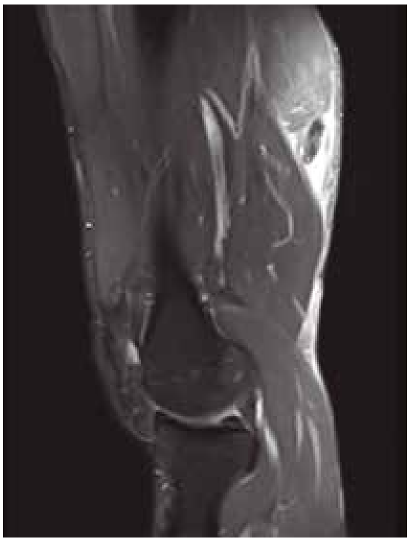
Figure 17 A-B:
Distal rupture of the ST at the myotendinous junction. A sagittal image (B) shows loose and retracted ST muscle belly (axial and sagittal images).



PROGNOSIS FOLLOWING EARLY SURGICAL REPAIR

Following surgical repair of proximal and distal hamstring tendon avulsions, players can normally begin running and performing controlled drills with a ball (i.e. "return to field") after 10-12 weeks, and most have returned to optimal performance after 3 to 5 months.[84,85,87,88,90] However, in some cases rehabilitation may take up to 6-7 months. Persistent symptoms or performance reductions following avulsion repair are rare. The expected return-to-play timeline is similar following surgical repair of complete ruptures at the myotendinous junction, and restoration of full function is also the most likely outcome.

INDICATIONS FOR DELAYED SURGERY

Some hamstring injuries become recurrent or lead to chronic symptoms, despite high-quality conservative treatment. In these cases, surgery may be beneficial. Although the research evidence is limited, potential causes of a poor conservative outcome include incomplete healing of partial avulsions, injuries to the central intramuscular tendon, increased compartmental pressure, excessive scarring, sciatic nerve entrapment, and heterotopic ossification.

INCOMPLETE HEALING OF AVULSION SITE

In proximal non-retracted partial avulsions that remain symptomatic, the MRI may show fluid between the ischial tuberosity and tendon head(s) (Figure 18 A-B). This is a sign of incomplete healing. Surgical treatment involves debdridement of the ischial tuberosity and reinsertion of the detached tendon(s) to the bone. In these cases, surgery is often beneficial and the player can often return to optimal performance after approximately 4-5 months.[88]

Figure 18 A-B:
Chronic incomplete proximal hamstring rupture at the left side. MRI shows fluid between the ischial tuberosity and the tendon heads (axial and coronal images).
v

CENTRAL TENDON INVOLVEMENT

It has also been suggested that hamstring injuries involving the central tendon may have a greater tendency to become chronic and recurrent, and have a higher risk of poor healing with conservative treatment.[91] When a partial and complete rupture of the central tendon occurs, they are typically located 5-20 cm from the proximal tendon origin (Figure 19 A-B, Figure 19 C).[92] If a hamstring injury involving a central tendon rupture remains symptomatic after conservative treatment or becomes recurrent, surgery should be considered. The continuity of the central tendon is restored by suturing, and the attachment of the muscle to the tendon is reinforced. Suture anchors may be used if the tear is located close to the ischial tuberosity.

The optimal treatment strategy of central tendon injuries is not established. According to a recent paper, operative treatment of recurrent central tendon ruptures seems to lead to a good overall outcome in high level athletes, and return to optimal performance was achieved at 3- 4 months from the surgery with no adverse events during follow-up.[92] However, future studies are required to find out whether these injuries should be operated acutely if tendon heads are clearly separated from each other in MRI. The role of (repeated) MRI may be important for confirming the correct diagnosis and evaluating the extent of the injury.[92,93]

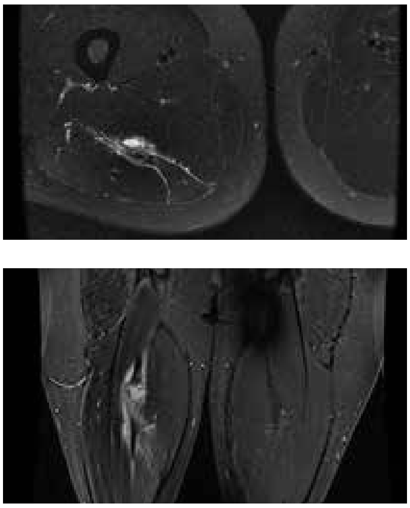


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Figure 19 A-B:
Recurrent central tendon rupture of the SM at the right side (axial and coronal images).

Figure 19 C:
Perioperative photo of the SM central tendon rupture.
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HETEROTOPIC OSSIFICATIONS

Heterotopic ossifications can develop after proximal hamstring injuries, resulting in significant chronic disability (Figure 20 A-D).[94] These cases can be effectively treated by surgical excision of the ossified masses and concomitant debridement with suture fixation of the proximal hamstring tendons to the ischium. Return to preinjury activities is expected in the majority of these cases approximately after 6 months from the operation.

OTHER CAUSES

Surgical treatment should also be considered in chronic and/ or recurrent hamstring injuries with symptoms of pain and tightness of the posterior thigh. These symptoms can be a result of so called post traumatic hamstring syndrome or compartment syndrome.[95-97] The surgical procedure may include excision of adhesions, fasciotomies, sciatic nerve liberation and elongation of the scarred tendons. After surgery, most of the athletes are able to return to the same level of sporting activity as before the onset of the symptoms. This takes normally a mean of 5 months (range, 2-12 months).

CONCLUSION

Even though surgery is rarely necessary for hamstring muscle injuries, it remains an important treatment option for the most severe cases. In fact, its role may even increase in the future.[98,99] In our experience, hamstring injury severity is often underestimated, and clear surgical cases – such as when the proximal tendon is retracted distally from the anatomical footprint – are often missed. This has serious consequences for the recovery time and functional outcomes, which are of upmost importance to the professional footballer.

When choosing a treatment, practitioners should remember that hamstring injuries can be career ending. Surgical treatment should always be considered when athletes sustain complete proximal or distal tendon avulsions. Finally, it is important to note that surgery is technically easier if performed soon after the injury has occurred.

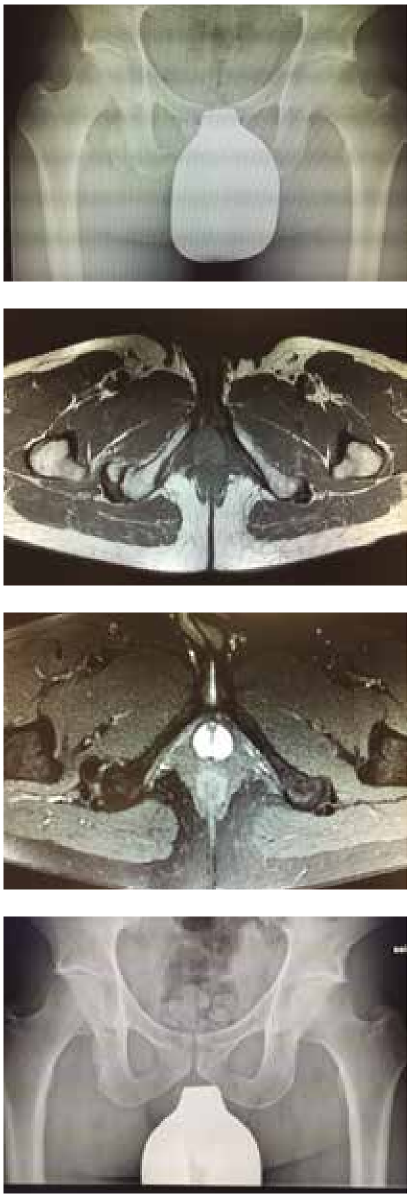

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Figure 20 A-D: Heterotopic ossification next to the right ischial tuberosity causing sciatic nerve impingement. A; x-ray before operation. B and C; mri axial view. D; x-ray taken after operation.

3.2

RETURN TO PLAY FOLLOWING QUADRICEPS MUSCLE INJURY

In this section, we build upon the general principles described earlier in the guide, with specific reference to quadriceps muscle injuries.
— With Phil Glasgow, Mario Bizzini and Andreas Serner

MAKING AN ACCURATE DIAGNOSIS

Making an accurate diagnosis is the cornerstone of effective injury management and return to play planning. An accurate diagnosis facilitates an estimation of prognosis, and in turn, shared decision-making regarding injury management. Imaging may be used judiciously at this step, but you must be clear about what (if anything) imaging will do to change the return to play plan. At FC Barcelona, we work backwards from the anticipated time to return to full match-play. Understanding biology will help when estimating injury prognosis and planning a strategy for appropriate loading through the return to play continuum.

PATIENT HISTORY

A detailed patient history provides key information for the clinician, and can assist in differentiating between different muscle injury types. In particular, the history should provide a detailed insight into the severity, location and nature of pain, the mechanism of injury, and the functional impact of the injury.

The of injury may prove to be a diagnostic aid, as it can provide insight into the likely muscle affected, and the potential prognosis. The more common 'indirect 'injury,[1,2] which usually occurs during sprinting and kicking,[3,4] is typically indicative of a muscle strain to the rectus femoris[3,5], whilst 'direct' injuries are typically associated with a traumatic contusion injury, usually affecting the vastus lateralis muscle[6] It has been shown that direct injuries on average take less than half the time to recover compared to indirect injuries.[2] For proximal "indirect" injuries, a distal iliopsoas injury may give similar clinical findings as a proximal rectus femoris injury.[7] The mechanism of injury may therefore in some cases be helpful in differentiating between injury locations, as rectus femoris primarily occur during kicking and sprinting, and not change of direction, which is a common injury mechanism for acute iliacus and psoas injuries.[4] Practitioners should however be cautious when interpreting injury mechanism information and should never make a diagnosis based on the mechanism alone.

Practitioners should also consider a wide range of differential diagnoses in an athlete with anterior thigh pain, including herniae and neural pathology.

PHYSICAL EXAMINATION

Similar to other muscle injury locations, the clinical examination of quadriceps injuries comprises mainly of muscle palpation, stretch and resistance tests, and functional assessment.[6-8] A detailed patient history should help guide the physical examination, allow differentiation between direct and indirect injury types, and be followed by a tailored physical examination.

Muscle palpation should be performed globally across all compartments of the thigh, and muscle firmness ratings (examiner-rated score between -5 to +5) and thigh circumference (measured at supra-patellar border, as well as 10cm and 20cm proximally), noted in cases where 'direct' injuries are suspected. During inspection and palpation, the presence and location of bruising, swelling, soreness and solid masses should also be identified.[6]

When testing the strength and range-of-motion of the quadriceps, especially if 'indirect' injury is suspected, it is important to remember that the rectus femoris is a bi-articular muscle, in contrast to the other quadriceps muscles. The position of the hip will therefore likely influence test focus.

Strength can be measured subjectively by the clinician, or objectively using tools such as handheld dynamometers, which can be useful in providing an indication of strength at different ranges-of-motion.[9] Quadriceps strength is most commonly tested isometrically in a sitting position (inner-mid range), but can also be measured in supine, which may be more relevant in the assessment of rectus femoris strength.

Range of motion of the quadriceps can also be measured in different ways. To isolate knee flexion range of motion as much as possible, the hip should be in a flexed position. This can be done in supine or a sitting position.[10] This measure may however likely often be irrelevant as a measure of quadriceps flexibility, as the hamstring and calf muscle bulk (or knee joint) can be the limiting factor at end range. A similar ceiling effect may also be present in a prone position with the hip in neutral,[11] however, this knee flexion test may still provide good quantification of quadriceps flexibility e.g. following a quadriceps contusion, and can be assessed using either a goniometer or digital inclinometer to indicate progression of flexibility and pain. The prone position may also be used to get an impression of rectus femoris flexibility by assessing the point of hip flexion movement during the knee flexion movement (Ely's test).[12]

To measure rectus femoris flexibility across both the hip and knee, the modified Thomas test position is most commonly used. Using goniometer to assess knee flexion ROM with the hip in neutral, the test shows moderate reproducibility,[13] whereas a combined hip extension and knee flexion measure using digital inclinometers has shown excellent reproducibility with a standard measurement error of less than 2% (Serner et al, unpublished). The modified Thomas test will also enable the clinician to assess the neural sensitive structures of the anterior thigh, such as the femoral nerve.

The clinician should consider that functional ranges of motion during activities, such as kicking and sprinting occur as part of the wider kinetic chain with the motion of the lower limb being closely linked to the trunk and lumbo-pelvic motion.[14] Recently, a whole-body test focusing on hip range of motion has been described for footballers with groin pain.[15] The hip extension component of this test may have relevance when considering the demands on quadriceps flexibility in the context of its relationship to other segments through a more sport specific range of motion. An additional knee flexion may also be added to the test for a higher focus on rectus femoris flexibility.

IMAGING

Clinical examination tests, including specific palpation of the rectus femoris, resistance and stretch tests with different degrees of hip and knee flexion (e.g. the modified Thomas test) are often sufficient to diagnose injury location, However, in athletes with pain in the proximal part of the thigh, these test are generally poor at accurately localizing injuries in the rectus femoris , as injuries in different hip flexor muscles, such as the iliacus and psoas major, may also cause positive tests in the same areas.[7]

As such, imaging can play a prominent role in determining the precise diagnosis. MRI is usually the imaging modality of choice, as it enables the clinician to accurately localise the injury, and determine whether there is any tendinous involvement. In adolescent athletes, proximal rectus femoris injuries may include an avulsion fracture of the AIIS, and plain radiographs should therefore be considered with presence of proximal insertion pain in this patient group.[16,17]

Imaging 'direct' injuries may be helpful in determining both the location and extent of the injury, as some injuries can have considerable muscle damage and fluid collection.[18] Myositis ossificans develops in about 1 out of 10 injuries, and the risk appear to increase with higher extent of injury.[19] Therefore, imaging may assist in initial treatment decisions, such as potential aspiration of the fluid collection. Myositis ossificans may be detected clinically a few weeks after the initial injury as a more firm mass at the initial injury site, and plain radiographs can be used to confirm the suspicion, which may cause more persistent pain.[20,21]

ESTIMATING RTP TIME

LOCATION AND EXTENT OF TISSUE DAMAGE

In regard to 'direct' muscle injuries, muscle firmness rating and difference in knee flexion ROM appears to have a high association with duration of return to sport[6]. Active knee flexion range of motion at 12-24 hours after injury has also been used to classify severity of contusions into mild, moderate and severe, as >90°, 45-90°, and <45° of knee flexion, respectively, with an associated increase rehabilitation time.[19]

In regard to 'indirect' muscle injuries, the time frame for RTP varies greatly, and is considered to be related to initial injury extent. Imaging details show that proximal injuries often include injury to the tendon itself, "Tp" injuries, and these injuries will predominantly affect the indirect tendon either as avulsion injuries or tendon disruption along its intramuscular course.[4,22,23] This may explain why proximal rectus femoris have been associated with a longer rehabilitation duration than distal injuries.[24]

Whilst there is a current perception that disruption of the intramuscular tendon is associated with a longer RTP duration,[25] the studies on which this perception is based upon, does not describe this factor in detail.[5,24] There is currently evidence that a higher extent of injury appears to be related to longer rehabilitation time, however, the large variations within the different classification categories, prevents clear RTP predictions.[3,5,24] The Munich muscle injury classification, using MRI for categorisation, has been used to provide an overview of the duration of RTP timeline in elite football players. Functional muscle-related neuromuscular disorders and minor structural partial tears can be expected to have similar duration of about 1-3 weeks, whereas moderate partial tears show longer duration of about 4-7 weeks, and subtotal/complete muscle injuries taking around 8-12 weeks.[26] Using the more detailed FCB classification, based on clinical experience and injury data over 10 seasons, we present our predictions on RTP duration in table 1. These form the basis of our rehabilitation strategy and planning, however, it should be noted that variations between individuals can be expected. Additionally, these have not yet been fully validated in the scientific literature.

Table 1:
Estimated RTP times for quadriceps muscle injuries based on location and tissues involved
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INJURED TISSUES	CONNECTIVE TISSUE INVOLVEMENT/ IMAGING FINDINGS	ESTIMATED RTP TIME
Direct tendon avulsion	large connective tissue affected and gap and wavy tendon	Surgery 4-5 months
Direct tendon transversal tear	Connective tissue Findings: tendon gap, wavy tendon	Non-surgical? Surgery 4-5 months
Direct tendon longitudinal tear	Connective tissue Imaging findings: no tendon gap, wavy tendon	8-12 weeks
Indirect tendon avulsion	large connective tissue affected and gap and wavy tendon	Surgery 3-4 months
Indirect tendon tear	Connective tissue Findings: tendon gap, wavy tendon	6 weeks
Indirect tendon stretching	Peritendon Findings: halo appearance	2 weeks
Conjoined tendon transverse tear	Connective tissue Findings: tendon gap, wavy tendon	First try conservative 10 weeks, if re-injury surgery 4 months
Conjoined tendon longitudinal tear	Connective tissue Findings: no tendon gap, wavy tendon	8-10 weeks
Direct tendon MTJ with tendon disruption.	Connective tissue	5- 7 weeks
Anterior myofascial	Little connective tissue affected	2- 3 weeks
Indirect tendon intramuscular MTJ	Connective tissue	3 weeks
Indirect tendon MTJ with intramuscular tendon disruption.	Connective tissue Findings: tendon gap, wavy tendon	6 weeks
Degloving		7- 8 weeks
Distal tendon MTJ	Connective tissue	2 weeks
Distal tendon MTJ with tendon disruption	Large connective tissue affected, gap, wavy tendon	7 weeks

PLAYER-SPECIFIC FACTORS

At FC Barcelona, over 10 seasons of consistent injury registration throughout the club, we have seen that younger players, in particular academy players have a higher frequency of rectus femoris injury and therefore this is a pertinent consideration for us when planning the RTP process and timeline for players.

Furthermore, unlike other lower extremity muscle lesions, leg dominance appears to play a role in quadriceps injury with the dominant (kicking) leg involved in approximately 2/3 of cases.[1,27] This is an interesting finding and suggests we may need to consider within the time to RTP estimation if the injury is to the dominant leg.

Finally, whether or not the player has had a previous muscle injury in the quadriceps (or any of the muscle groups) and how many, are key aspects we account for when planning RTP.

FOOTBALL-SPECIFIC FACTORS

In our experience at FCB, players in playing positions with high emphasis on shooting and goalkeepers may require a longer RTP to ensure they are able to perform to at least (or ideally) better level than at pre-injury.

Additionally, the time of the season may be appropriate to consider. Two studies have reported an increased risk of quadriceps injury rates during pre-season compared to in-season incidence. In a study of 91 English League football clubs,[28] it is reported that quadriceps injuries were the most common pre-season muscle injury with and incidence of 29% (Groin 12%; Hamstring 11%). The UEFA injury study[27] also showed a 40% increase in the rate of quadriceps injuries during pre-season. This is in contrast to other lower limb muscle injuries, which tend to increase as the season progresses. The reason for this pre-season increase is not clear, but a number of authors have suggested that it may be due to an increase in the volume of kicking during training. Further studies are required to confirm whether this is indeed the case.

QUADRICEPS MUSCLE TESTING

Functional testing plays an important role throughout the entire RTP process. During the initial physical examination, testing provides immediate information on which activities the player can perform with and without pain. This helps practitioners develop a clinical impression of injury severity and prognosis. Later, functional tests act as important milestones as the player progresses along the RTP continuum, and help guide the final decision to clear the player for unrestricted match participation.

Assessment can begin by examining isolated muscle contractions, then progress to more dynamic lower limb actions such as walking, running, jumping, and kicking (Figure 1). Finally, if symptoms allow, high-demand actions should be tested, such as maximal sprinting, changing direction and accelerating from stationary positions.[2] Practitioners should not only assess the player's pain, but also their ability to perform high quality movements repeatedly, as well as their ability to generate fast movement.

Strength and range of motion can be measured using the test described above under physical examination. Additionally, detailed strength information can be provided using more advanced (and expensive) isokinetic dynamometry, which is frequently used to measure open chain function of the quadriceps. However, isokinetic dynamometry is considered non-functional, time consuming, expensive and specificity to on-field tasks are questionable. As such at FC Barcelona we do not use isokinetic testing to guide the RTP process.

Other measures of quadriceps strength and functional capacity include closed chain multi-segment actions, such as squatting, leg press, and jump performance. While not isolated to the quadriceps, these exercises place high demand on the anterior thigh and provide a good indication of the function of the quadriceps during more functional activities. Various jump tests can be used, from more static jumps, such as the counter-movement and drop jumps, to triple & six-meter timed hops.

Several "functional tests" have been described in the literature[29]. The T-test, pro shuttle and long shuttle drills can be used to evaluate the athlete's performance in tasks requiring quick starts, dynamic direction changes, and movement efficiency.[29,30] Endurance tests, such as the yo-yo intermittent recovery tests, may also have a role in determining functional capacity. Additionally, sprint test over different distances, as well as hard decelerations should be considered.

Additional specific tests that are pertinent to quadriceps function include speed dribbling, short-to-long passing, and shooting, all of which have been proposed in the literature,[31] but have never been fully scientifically validated.

QUADRICEPS MUSCLE TESTING

Although this muscle injury guide primarily deals with acute muscle strains, a brief mention on the management of quadriceps contusions is pertinent considering these are not uncommon in footballers.

INTRA- VERSUS INTERMUSCULAR HAEMATOMA

Any type of external impact can cause a bleeding within a muscle, usually within the muscle fascia, with a consequent increase in intramuscular pressure. Where bleeding is contained within the fascial sheath, localized swelling remains for longer than 48 hours after trauma, and is associated with pain, tenderness and reduced knee ROM. Quadriceps muscle activation is also usually significantly reduced. An intramuscular haematoma, depending on its severity, may take several days or weeks to fully recover/heal.

Bleeding can also occur between muscles, and in this case the blood spreads in the surrounding structures, so that the local pressure does not raise. An intermuscular haematoma will usually result in bruising and swelling distal from the trauma location within 24-48 hours. Quadriceps muscle activation usually recovers within few days, and the overall healing is significantly quicker than in cases with intramuscular haematoma.

The first 24 hours following a contusion are most important in the treatment of quadriceps contusions, where the POLICE protocol,[32] should be initiated as soon as possible, e.g. meaning tight compression around the thigh should applied as soon as possible, and include the knee joint if injury is at lower-third of thigh. Usually the athlete can fully weight bear, but following severe contusions crutches may be necessary initially.

The use of ice, but foremost compression, should be maintained in the first 2 days in the case of severe contusions. Massage, electrotherapy and stretching should be avoided. Immobilising the knee in 120° of knee flexion for the first 24 hours after trauma may also be beneficial,[33] and ROM should be increased gradually with only minimal discomfort.

Continuously repeated examinations can be helpful to distinguish between intermuscular and intramuscular bleeding, with persistent/increased swelling and poor function suggesting an intramuscular haematoma.[34]

EXERCISE PRESCRIPTION FOR QUADRICEPS MUSCLE INJURIES

Rehabilitation of quadriceps injuries requires both structure and flexibility based upon both the best available evidence and relevant individual factors (e.g. player history, physical characteristics). While there are a number of studies investigating the management of other lower limb muscle injuries, there is a distinct lack of clinical studies related to quadriceps injuries. There are no randomised studies on treatment of quadriceps muscle injuries. The management guidelines for quadriceps injuries presented here are based predominantly on basic science, therapeutic principles extrapolated from studies on other muscle groups and clinical expertise.

The journey from early rehabilitation to team training will often be highly individual. To design a Return to play (RTP) programme following a quadriceps muscle injury based strictly on muscle injury healing phases[35] is likely not appropriate for all athletes. The athlete's signs and symptoms, the combination of clinical expertise and evidence-based knowledge should guide decision-making process for exercise progression. Potential complications should be carefully monitored at all times. It is also important to differentiate between contusions and strains of the quadriceps (as outlined earlier in this section) in order to determine which RTP strategies to adopt.

EXERCISES TO OPTIMISE TISSUE HEALING AND RESTORE PERFORMANCE

At FCB a five-stage approach to the management of muscle injuries is used (see RTP principles section). Stepwise progression of loading will facilitate effective tissue healing while restoring functional capacity. Focus during the acute phase of management (i.e. initial day/s) is to limit the extent of the initial injury and to provide a strong foundation upon which to build the rehabilitation process.

Reduction of pain and inhibition are key goals during this phase. Application of the principles of the POLICE,[32] acronym should be initiated as soon as possible following injury just as they are for contusions. Again, the key interventions include combining cooling and compression (e.g. Game Ready, Figure 1B) or use of graduated segmental compression (e.g. Normatec, Figure 1C) can further facilitate reduction of pain and swelling in the affected area. Players are allowed to walk as able although it may be necessary to use crutches following severe injuries.

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Figure 1A:
Compressive Bandage for Quadriceps Strain

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Figure 1B:
Game Ready

^
Figure 1C:
Normatec

It is important to commence controlled active movements as early as possible. A primary goal during this phase of management is to facilitate quadriceps activation. Several strategies may be used to enhance movement quality, reduce pain and facilitate healing of the injured tissue. Pain, muscle activation and ability to walk pain free are useful benchmarks for progression. It is important that the goals of the particular rehab session and the individual exercises used relate to the adaptation required (see Figure 1. in section 2.3.1.).

TARGETED TREATMENT

Interventions that help to reduce pain and enhance movement quality include table-based methods such as manual therapy and passive mobilisation. Due to the risks associated with the development of myositis ossificans in the quadriceps, it is advised that manual therapy (especially massage) is not applied directly to the injured area during the early stages and that any treatments focus on enhancing mobility of the surrounding structures. Passive modalities should not be seen as standalone interventions but rather as an auxiliary. Passive interventions are used primarily to reduce pain and enhance movement so that the active strategies more effectively target the injured tissue, thus enhancing the mechanotransductive effect.

During the subacute phase, active mobilisation will facilitate both movement capability and improve tissue healing. Exercises performed during this phase should be carried out with good form and compensatory strategies avoided. Examples of interventions during this phase include dynamic mobility, active tension stretching (Figure 2). Focus should be placed on appropriate muscle activation throughout range whilst maintaining good trunk and whole body positioning. It is also advised that general upper quadrant and aerobic conditioning is maintained; this can be achieved through the use of elliptical trainers, stationary cycles, aqua jogging or an AlterG Treadmill.

FOCUSED MUSCLE ACTIVATION

Focused muscle activation can be useful in the early stages. While it is almost impossible to completely isolate each individual quadriceps muscle, knee extension exercises with the hip in a flexed position will tend to have a higher focus on the vastii muscles, whereas knee extension exercises with the hip in extension will have a higher focus on the rectus femoris. The use of manual resistance can help ensure mechanical stimulus is provided to the affected area, while the intensity can be modulated in line with symptoms to ensure vulnerable structures are not overloaded. Isotonic contractions through range at this stage are useful to enhance recruitment and provide a mechanical stimulus. It is suggested that the quadriceps are challenged at a number of different hip and knee positions. Multi-planar movements such as lower limb PNF patterns can be particularly useful as they can reflect kicking positions (See Figure 3 for examples). During this phase, it is suggested that exercises are carried out 'little and often' and that movements are biased towards lengthening contractions as soon as possible

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Figure 2:
Dynamic mobility and active tension stretching

Movements during the early strengthening phase should be carried out in a slow and controlled manner. It is recommended that 2-3 sets of 4-6 repetitions of sub-maximal contractions (60-70% MVC) are carried out twice daily. As rehabilitation progresses the intensity of contraction should be increased and the frequency reduced to align with conventional strength training parameters. It is also advised that pain during strengthening is kept to a minimum and that any symptoms improve within a given session. Where there is persistent inhibition of the quadriceps, the use of electrical muscle stimulation may be beneficial (even in terms of strength gains), as it has been documented after ACL reconstruction.[36]

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Figure 3:
Focused Muscle Activation

RESTORING GYM-BASED ACTIVITIES

Once able to effectively recruit the muscle through range it is important to combine table based activation with more conventional gym based training. Simple exercises such as a seated leg extension (figure. 4) can be useful for a focus on the vastii muscles, whereas a standing hip flexion and knee extension using a cable pulley (or elastic) would be an appropriate exercise for a focus on the rectus femoris (figure 5). These "isolated" exercises can be continued and progressed throughout the rehabilitation period to ensure ongoing improvements in tissue capacity.

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Figure 4:
Seated leg extension

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Figure 5:
Cable kicking

Reverse Nordics (figure 6) are a simple and effective way of introducing eccentric training, these can be progressed by altering trunk position and increasing hip extension to increase the lever arm. Eccentrically biased contractions that involved varying degrees of hip extension and knee flexion are recommended. Bulgarian split squats, Cable reverse lunges and Russian Belt exercises are useful exercises that load different parts of the quadriceps and can be biased towards eccentric action by adding assistance during the concentric phase.

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Figure 6:
Reverse Nordics

Restoration of normal gym-based training is important. Players routinely complete a range of lower limb strengthening exercises that combine eccentric, concentric and isometric muscle actions. Once there is pain free recruitment of the quadriceps through range, it is important to normalise gym training as soon as possible, while maintaining an additional eccentric stimulus to facilitate adaptations in muscle architecture and prevent recurrence. Exercises that provide the necessary strength and architectural stimulus should be included and maintained beyond return to sport. These might include general quadriceps and glute exercises, such as squats, deadlifts and hip thrusts (Figure 7).

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Figure 7:
Gym based
strengthening exercises
(squat and hip thrusts).

Abdominal and trunk strengthening will also be important, especially dynamic trunk rotation, to facilitate integration of dynamic rotational movements, such as kicking (e.g. Cable pulley woodchopper, Trunk rotation landmine. Strength training during rehabilitation should consider sequential progressions from slow speeds and higher loads through to low load and high speed and finally to plyometric activities that reflect on-field demands.

BASIC ON-FIELD TRAINING: RESTORING RUNNING, KICKING AND CHANGE OF DIRECTION

A primary goal during rehabilitation is to ensure the athlete can return safely to high injury risk activities, such as sprinting and kicking. A strong focus on monitored progression of these activities during rehabilitation is therefore essential. This may include a focus on running and sprinting technique, as well as a controlled progression of total running load towards the expected running and sprinting exposure in training and matches for the player. In the early stages running is commenced on dry sand and progressed to linear running on the field. Manipulation of distance, velocity and volume is then used to train specific subcomponents of running fitness and muscle function.

Players should be progressively exposed to acceleration, deceleration and change of direction to enhance the force absorption capabilities of the quadriceps.[37] Attention should be given to challenging players in a wide range of positions and activities in order to build greater resilience.[38,39] Multi-directional running through the execution of simple football skills can be included in football circuits. Familiar training drills can be introduced and progressed in terms of complexity and decision making (see below) before returning to field sessions with the squad.

At FC Barcelona, particular emphasis is placed upon incorporating the ball during rehabilitation. Given that quadriceps injuries are more common in the dominant leg, it may be appropriate for quadriceps injuries to delay introduction of the ball due to the potential risk associated with kicking. The ball should be introduced to sessions in a systematic and gradual manner. Different types of kick have been shown to involve different levels of quadriceps activation,[40] meaning that side-foot kicking will place less stress on the quadriceps than an instep or toe kick. Specific drills that introduce different types of kick and progress the volume and intensity should be considered.

A number of authors have described "interval kicking programs" for football players that outline appropriate progressions of kicking type, volume and intensity following ACL injuries.[41,42] However, as muscle injuries, have a considerably shorter duration, the kicking progression will be much faster than these recommendations. The type of kick (side-foot, instep), intensity of kick (passing, shooting) and the challenge associated with kicking (open play, free-kick, goal kick) should be introduced gradually and relative volume and intensity progressed. Examples of kicking progressions include moving from two touch passing drills to one touch drills. Kicking a dead ball (corner kicks, goal kicks, free kicks and penalties) require greater accuracy and often involve higher forces thereby placing greater stress on the quadriceps muscles. Goalkeepers will require specific focus on position-specific skill with greater attention given to goal kicks and punt kicks. Other core skills, such as jumping, diving and shuffling movement, will be of greater importance for goalkeepers. Position-specific match averages of kicking from a professional football league have also been published to help guide session construction.[43] Key considerations for the progression of kicking are summarised in Table 2.

An important consideration, for kicking and sprinting, is that both iliopsoas and rectus femoris muscles generate hip flexion forces.[44] Musculoskeletal modelling studies have shown how a reduction in the strength/activation of the iliopsoas muscle may result in rectus femoris compensation to generate more hip flexion force.[45] This highlights the importance of multi-segmental exercises, involving both the lower limb and the trunk. Focus on synergistic activation of these muscles, as well as other key muscles involved in sprinting and kicking can be initiated early and progressed independently of the progression of the isolated exercises for the injured muscle.

Specific exercises for the iliopsoas muscle include standing hip flexion with a cable/ elastic[46] (figure 8) or eccentric hip flexion using manual resistance.

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Figure 8:
Hip flexion with resistance (cable pulley or elastics)

Furthermore, the adductor longus is also highly involved in hip flexion during kicking;[47] a higher adductor strength may therefore assist in reducing the load on the rectus femoris during kicking. This can also be done with a simple cable/ elastic exercise,[48] or without equipment using the Copenhagen Adductor exercise (figure 9).[49,50]

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Figure 9:
Copenhagen Adductor exercise

KICKING SKILL	PROGRESSION
Passing	**Kick Type:** Side-foot Instep kicking **Distance:** Short Long **Velocity:** Low High **Ball Control:** Receive ball and pass, no constraints 2-touch passing 1-touch passing Passing to stationary target Passing to moving target (player) **Advanced passing drills:** Running onto ball Hurdles, cones Vary how ball is fed to player: different directions, on ground, in the air. Decision making
Indirect tendon stretching	**Kick Type:** Side-foot Instep kicking **Distance:** Short Long **Velocity:** Low High **Ball Delivery:** Feed ball from different positions Increase speed on ball Aerial balls – increase distance and provide target **Volley following execution of football skills:** Dribbling Skills circuit Opponent
Shooting	**Kick Type:** Side-foot Instep kicking Knuckle ball Toe shot Chipped ball **Distance:** Short Long **Velocity:** Low High **Ball Position:** Moving ball Stationary Ball **Scenario:** Free-kick +/- wall Corner Penalty Goal kicks (if applicable) **Challenge:** Open goal Fixed target Goalkeeper

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Table 2:
Kicking
Progressions

COMPLEX FIELD WORKOUT: RESTORING FOOTBALL-SPECIFIC FITNESS, SKILLS AND COGNITION

As outlined in the general RTP section, on-field Return to Play requires the introduction and progression of complex football-specific tasks such as dribbling, passing and receiving a ball, snake runs and training drills. The use of football specific circuits and manipulation of constraints, such as the speed of movement, difficulty of the skill, competition and decision-making become increasingly important during the rehabilitation process. Tasks that place greater stress on the quadriceps should be identified and progressed as able. Particular attention should be given to managing the number of accelerations, decelerations and changes of direction as these activities place significant stress on the quadriceps.[37]

It is also important to prepare the player for return to contact situations. Block tackles in particular have the potential to place significant load through the quadriceps and can be introduced during the final stage of rehab in a controlled manner by kicking a partially deflated ball that is blocked by the therapist. These can be progressed through the use of harder balls, kicking pads or other objects (e.g. Swiss Ball). Tackling technique and return to open squad sessions should be progressively introduced to include unpredictable challenges associated with the game.

Movement characteristics (and associated quadriceps muscle activity) differ significantly during anticipated and unanticipated movements, such as landing and side-stepping.[51,52] Importance should therefore be given to incorporate unanticipated movements into rehabilitation. Practical strategies to progress unanticipated movements include variation of the speed and timing of signals for players. Similarly, introduction of competition and opponents can effectively progress unanticipated, open-skill aspects of the game. Advanced skills and cognitive challenges are introduced and the focus moves from being injury (quadriceps) specific in the early stages to activity (football and position) specific as rehabilitation progresses.

RETURN TO PLAY EXAMPLE FROM FC BARCELONA

— With Xavi Yanguas, Juanjo Brau, Xavi Linde, Ricard Pruna

Figure 10:
Specific example from FC Barcelona of the Return to Play process from quadriceps injury
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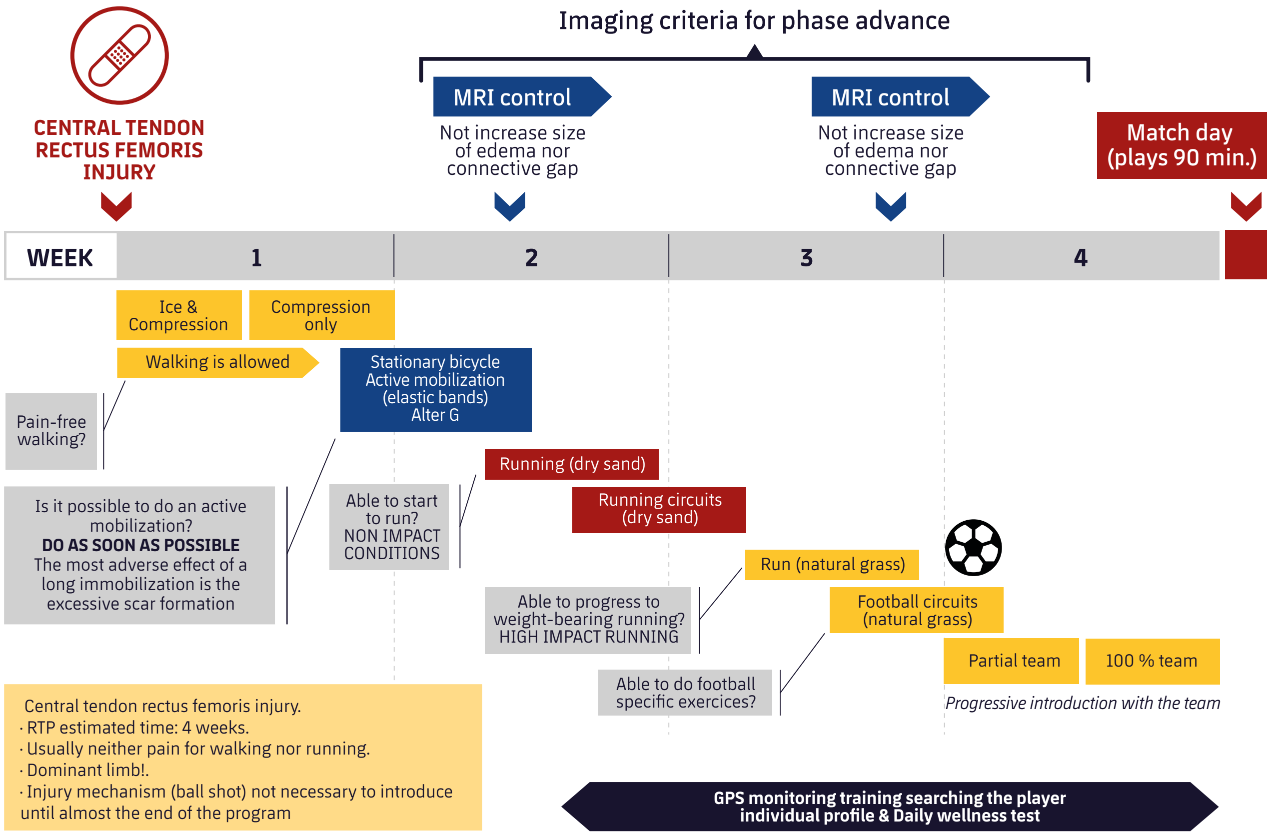

THE BARÇA WAY:

The central tendon rectus femoris injury above is, in our experience, potentially one of the more serious muscle injuries in a footballer. This is especially so, if the injury is located in the dominant leg.

The introduction of the ball is brought in at the later stages of rehabilitation for this injury due to the potential re-injury risk with kicking. It is not necessary to bring it in earlier as this is a skill that the player will not forget how to do in a relatively short period of time.

Our approach to a graduated program with the ball is to progress from initial easy passes of the ball with the inside part of the foot. This is done by the player with the physiotherapist or fitness coach and later introduced with the team, importantly, avoiding hard shots at goal. This is progressed until shots are allowed in a controlled environment and eventually fully with the team.

As with all of our RTP process for muscle injury (and indeed injury in general), the framework is flexible, allowing for a faster or slower progression according to the coping and adaptation of the player.

SURGERY FOR RECTUS FEMORIS MUSCLE INJURIES

Rectus femoris muscle injuries are common in sports. Most of these injuries are strains or direct contusions which are treated by conservative means with good results.[37] There are, however, also more severe rectus femoris injuries which can result in impaired athletic performance and long rehabilitation times. In these severe rectus femoris injuries the decision of optimal treatment method is not always so evident.

— With Lasse Lempainen, Sakari Orava and Janne Sarimo

PROXIMAL RUPTURES

Proximal rectus femoris (PRF) ruptures are relatively rare injuries among top-level athletes. PRF injuries can be complete avulsions or partial tears, and some of partial injuries seem have a tendency to progress to recurrent injuries.

In the literature the exact location of the injury is often inadequately presented which makes it difficult to compare different studies. The tear may be an avulsion of the tendon from bone or a rupture involving the proximal tendinous part. These different injuries may vary in their natural course.

Overall it seems that most of the injuries in the proximal insertional area are primarily suitable for conservative treatment and the outcome is mainly good even in complete avulsions with some retraction.[22] However, sometimes the healing does not progress as expected and return to play is delayed. This can occur in both complete and partial tears.

Operative treatment of complete PRF rupture has typically a good prognosis in professional soccer players. After suture anchor fixation of PRF rupture or resection of the proximal tendon the athletes seem to return to the same level of competition with high probability.[53-57]

Given the mainly good functional outcome and low complication rate, the authors advocate surgical treatment in proximal rectus femoris avulsions in professional soccer players if conservative treatment does not yield in good results within a few months or if there is significant retraction of both tendon heads in a proximal avulsion. The full return to play can be even achieved after 3 to 4 months from the operation.[57]

MID-SUBSTANCE RECTUS FEMORIS RUPTURES

The clinical entity considering mid-substance rectus femoris muscle ruptures is mainly lacking in the literature. Only few case reports of rectus femoris mid-substance rupture repair has been previously published.[58-60] These more serious mid-substance ruptures may cause significant functional loss in hip flexion and in knee extension strength, poor coordination as well as cramping pain and may require surgical intervention for proper healing. This has previously been shown also in these earlier mentioned case reports.

Based on authors' own experience, operative treatment for complete mid-substance rectus femoris rupture with clear cap between ruptured muscle ends is often beneficial for competitive athletes (Figure 11 A-D).[61] Usually these athletes were able to return to their former level of sport after an average of 5 months from the surgery.

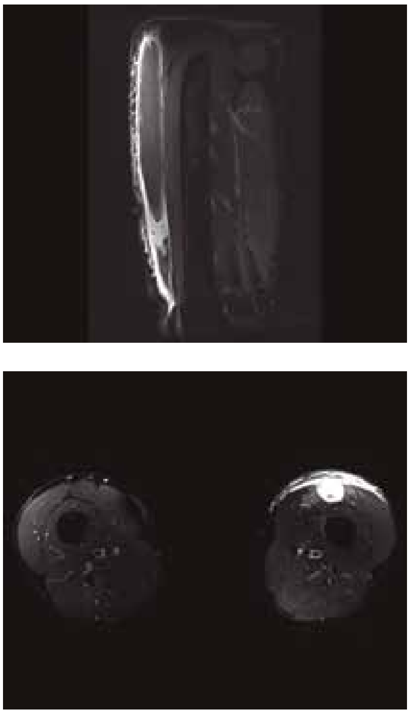

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Figure 11 A-B: Complete mid-substance rectus femoris muscle rupture (sagittal and axial images).

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Figure 11 C-D:
Perioperative photos of complete rectus femoris rupture with clear gap between ruptured ends.

CENTRAL TENDON RUPTURES

Like in hamstring injuries rectus femoris injuries involving the central tendon seem to have a tendency to become chronic injuries. If central tendon is totally ruptured operative treatment may be the best option in top level athletes especially in recurrent injuries (Figure 12 A-B).

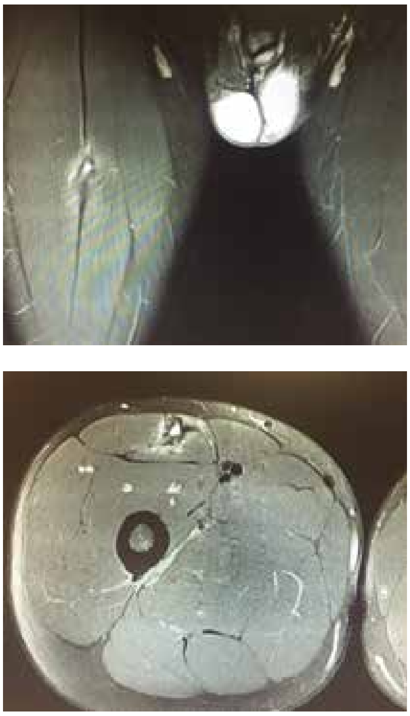

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Figure 12 A-B:
Recurrent central tendon rupture of the rectus femoris at the right side (coronal and axial images).

QUADRICEPS TENDON RUPTURES

Complete and also severe partial quadriceps tendon ruptures should be operated acutely after injury (Figure 13).[62]

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Figure 13
Partial quadriceps tendon rupture (sagittal image).

CONCLUSION

There are many different types of tears that can occur in the rectus femoris muscle and the quadriceps muscle group. The indications for surgery are somewhat obscure but chronic pain and disability that lasts for more than a few months after a complete or partial tear is definitely one of them. Surgery might also be considered in complete proximal avulsions with significant retraction or complete tears in which there is a significant gap between the tendon ends in the muscular part.

3.3

RETURN TO PLAY FOLLOWING GROIN MUSCLE INJURY

In this section, we build upon the general principles described earlier in the guide, with reference to acute groin muscle injuries, specifically, injuries to the adductor, hip flexor and abdominal muscle groups.
— With Andrea Mosler, Andreas Serner, Joar Harøy, Jonas Werner and Adam Weir

MAKING AN ACCURATE DIAGNOSIS

Making an accurate diagnosis is the cornerstone of effective injury management and return to play planning. An accurate diagnosis facilitates an estimation of prognosis, and in turn, shared decision-making regarding injury management. Imaging may be used judiciously at this step, but you must be clear about what (if anything) imaging will do to change the return to play plan. At FC Barcelona, we work backwards from the anticipated time to return to full match-play. Understanding biology will help when estimating injury prognosis and planning a strategy for appropriate loading through the return to play continuum.

PATIENT HISTORY

As with other muscle injuries, the patient's history, with insight into pain, mechanism of action, and functional impact will provide a great insight into the likely pathology. A complete history should fully investigate the onset, location, and severity of pain, and aim to differentiate between chronic, and acute groin injuries. With adductor injuries in particular, kicking is the most frequent groin injury situation in football, and the adductor longus the most commonly injured muscle with this mechanism of injury.[1] The adductor longus reaches its highest muscle activity and maximal rate of stretch in the swing phase of kicking, potentially exposing the muscle to injury risk.[2] Ball impact may also influence muscle load and injury risk, but this has not yet been investigated. Change of direction is also a frequent injury situation for acute groin injuries, but the specific contributing factors are currently unknown. Hip flexor injuries seem to have a somewhat different injury situation pattern. Rectus femoris injuries occur primarily during kicking and sprinting, while the iliopsoas muscles are mostly injured during change of direction.[1] Little is known about the common mechanisms of injury for abdominal muscles in football players.

PHYSICAL EXAMINATION

The clinical examination of athletes with sudden onset groin pain should primarily aim to determine if it is a muscle injury, and distinguish specifically which muscles are injured. Since the groin region encompasses a large number of different muscles, a thorough clinical examination is essential. As with other muscle injuries, the clinical examination is based on muscle palpation, stretch, and resistance tests. These elements can help differentiate between the various muscle groups in the groin region.

Studies have shown that clinical examination on its own can distinguish adductor muscle injury from other groin muscle injuries such as hip flexor, and abdominal injuries.[1,3] Appropriate consent should be obtained, and the patient potentially offered a chaperone for medicolegal reasons prior to clinical examination due to the need to palpate the sensitive inguinal and pubic regions. Palpation should include: along the adductor muscles, along the hip flexors, the inguinal region, as well as the pubic symphysis. Substantial bruising may also indicate a more extensive muscle injury. The 0° Squeeze test (long lever) has the highest specificity and positive predictive value for diagnosing an adductor injury, and palpation has the highest sensitivity and negative predictive value.[3]

On initial examination, groin injuries that fall under the 'hip flexor' category may be difficult to differentiate, providing a considerable risk of misdiagnosis.[1] The clinical examination tests for the hip flexors muscles are generally poor, and cannot accurately determine the specific muscle injury location.[3]

About 10% of patients with acute groin injuries will complain of some form of abdominal-related groin pain, though not necessarily abdominal muscle injury.[1] Palpation of the distal rectus abdominis, the inguinal ring, and inguinal canal is useful to differentiate abdominal muscle injury from other sources of acute abdominal-related groin pain. Additionally, stretch and resistance testing may cause pain in the abdominal muscle region.[3]

Consideration should also be given to other differential diagnoses, including spinal/neural pathology, herniae, and hip-joint pathology, and examinations tailored accordingly if any of these pathologies are suspected.

IMAGING

Ultrasound (US) and magnetic resonance imaging (MRI) may assist in the clinical diagnosis, both in relation to injury location, and extent of injury. It should also be noted that approximately 20% of acute groin injuries will present with negative findings on imaging (i.e. grade 0).[1,3] A lack of pain on muscle palpation is the best finding to predict a negative MRI.[3] While MRI is still considered the gold standard for muscle injuries, and MRI assessment of acute groin injuries has shown high intra- and inter-rater reproducibility,[4] it appears that the location of injuries may be determined with a similar accuracy through US examination.[1]

Most acute groin muscle injuries are indirect, and direct injuries are rare. Approximately two thirds of acute adductor muscle injuries involve a single muscle from the adductor group, while multiple adductor muscles are injured simultaneously in the remaining cases. The adductor longus is the most frequently injured muscle, both in isolation, and in combination with other adductor muscle injuries.[5] The adductor longus is injured in about 9 out of 10 athletes with an adductor muscle injury.[1,5] Isolated injuries of the other adductor muscles are far less frequent (about 10% of adductor injuries). Such injuries will usually be located in the pectineus, adductor brevis, or obturator externus muscles.[5] Due to the deeper location of these muscles, the diagnosis of the specific muscle involved in the injury may be difficult using only clinical examination, and imaging may be needed to provide greater certainty. Although these injuries are often considered to have a shorter rehabilitation time, good quality evidence on prognosis is lacking.

Imaging is rarely able to locate abdominal muscle injuries, but when found, the injury will likely be seen in the rectus abdominis in connection with a complete proximal adductor longus avulsion.[5,6] There is currently no evidence regarding the involvement of the oblique abdominal musculature, or transversus abdominis, in relation to acute groin injuries.

ESTIMATING RTP TIME

There is wide variation in RTP times following groin muscle injury[7]. In some cases, players may be able to RTP almost immediately, while other cases can take months. To estimate the RTP time for a specific injury, practitioners need to consider the exact location and extent of the tissue damage as well as player-specific and football-specific factors. As discussed earlier in this guide, various risk tolerance modifiers also influence the RTP estimate.

LOCATION AND EXTENT OF TISSUE DAMAGE

As mentioned above, acute adductor injuries usually occur in a single muscle, most often the adductor longus muscle.[1,7] These adductor longus injuries can mostly be divided into three characteristic locations: (a) The proximal insertion, (b) the MTJ of the proximal tendon, and (c) the MTJ of the distal tendon.[5] Generally, adductor longus injuries are more serious[5] and lead to longer time-loss than do other adductor muscle tears based on FC Barcelona data and experience. Adductor longus muscle injuries with a proximal avulsion, or extensive connective tissue damage and a large gap, result in much longer time loss than do proximal MTJ injuries (Table 1). In rare cases these injuries may also require surgery[5,8]

Other isolated adductor muscle tears are rare,[5] and usually result in a shorter absence from match-play according to FC Barcelona data (often only a few days).

Table 1 shows the expected RTP times for various adductor muscle injury locations and severities, based on FC Barcelona clinical experience and injury data collected over 10 seasons. These have not yet been fully validated in scientific studies. Note also that these data are only intended as a starting point; player-specific factors, football-specific factors and risk tolerance modifiers should also be considered when estimating RTP time.

INJURED TISSUES	CONNECTIVE TISSUE INVOLVEMENT	ESTIMATED RTP TIME
Proximal avulsion	Bone	8- 10 weeks
Proximal MTJ	Large connective tissue affected, gap, wavy tendon	6 weeks
Proximal MTJ	Little connective tissue affected	3 weeks
Proximal MTJ	Peritendon Halo	2 weeks
Distal MTJ	Superficial injury	3 weeks
Distal MTJ	Deep injury	5 weeks

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Table 1
Estimated RTP times for adductor muscle injuries based on location and tissues involved

PLAYER-SPECIFIC FACTORS

Practitioners should consider a range of intrinsic factors when estimating RTP following adductor muscle injury. Recurrence and/or progression to long-standing groin pain are problematic with groin muscle injuries.[9,10] Therefore, players who have sustained re-injuries need longer to recover from the same initial tissue damage.[11] Hence, the RTP process should always be conducted thoroughly and carefully before returning to match-play following groin muscle injury.[12]

FOOTBALL-SPECIFIC FACTORS

As the groin muscles are loaded during rapid direction change, long inside passing, shooting, and in sliding tackles, midfielders and any player who commonly perform these actions, may require longer RTP times.[7] Specifically, football players who perform with particularly rapid movements, repeated high intensity change of direction runs, and long-distance shooting during matches may be more prone to adductor injuries, and these actions should be considered in planning RTP.

GROIN MUSCLE TESTING

As with other muscle groups, muscle testing provides a key role in determining injury severity, and also progress along the RTP continuum. During the initial physical examination, testing provides immediate information on which activities the player can perform with and without pain. This helps practitioners develop a clinical impression of injury severity and prognosis. Functional tests act as important milestones as the player progresses along the RTP continuum, and help to guide the final decision to clear the player for unrestricted match participation.

STRENGTH

Assessment of muscle strength is an essential component of the physical examination and planning RTP following groin muscle injury. Strength can be measured subjectively, but preferably objectively using a HHD. Testing can be performed either unilaterally, or bilaterally as a squeeze test.[13,14,15] Eccentric adduction strength is usually assessed in side lying using a hand held dynamometer.[13,14] Abduction strength testing is also relevant to assess, and enables the calculation of the adduction/abduction strength ratio, which on average is 1.2 for football players.[13,14] The measurement of hip flexion strength has been described using a HHD and an isokinetic dynamometer.[16,17] The intra-tester and inter-tester reliability for the assessment of hip adduction, abduction and flexion strength using a HHD have been reported as good to excellent.[13,15,17,18] The reported error of measurement with these tests means that the interpretation of small changes in strength (i.e. <10%) using a HHD dynamometer should be done with caution.[13,15,17] The various testing positions using HHDs are demonstrated in Figure 1.

TEST	DESCRIPTION
SQUEEZE 0°[15] 	Player lies supine with 0˚ hip flexion and legs abducted to the length of the tester's forearm. The HHD is placed 5 cm superior to the medial malleoli. Player squeezes their ankles together, against the HHD and examiner's hand, with maximal force, without lifting the legs or pelvis. The presence of pain in the hip/groin is recorded using an 11-point numeric rating scale (NRS) (0-10), and location recorded.
SQUEEZE 45°[13] 	Player lies supine with 45˚ hip flexion and feet flat on the table Examiner places hand with HHD between the knees. Player presses knees together, against the HHD and examiner's hand, with maximal force, without lifting the legs or pelvis. The presence of pain in the hip/groin is recorded using an 11-point numeric rating scale (NRS) (0-10), and location recorded.
ECCENTRIC HIP ADDUCTION[13] 	Player lies on the side of the tested leg, knee straight and foot beyond the end of bed. Hip and knee of the non-tested leg is in 90° flexion with knee resting on a firm surface to maintain neutral pelvic rotation. Player holds on to the side of the bed with one hand for stabilisation. Examiner lifts the tested leg into full adduction with the HHD placed 5cm proximal to the most prominent part of the medial malleolus. The player exerts a 3 s isometric maximum voluntary contraction against the HHD and a 2 sec break is then performed by the examiner pushing the leg slowly towards the bed, ensuring not to touch the bed. Standardised instruction is: "go ahead-push-push-push-push-push", a total of 5secs. Player instructed to push as hard as possible within their comfort zone and maintain the effort while the break is performed. Any pain experienced by the player during testing is recorded using an 11-point NRS (0-10), with location also recorded.
ECCENTRIC HIP ABDUCTION[13] 	Player lies on the side of the non-tested leg, hip and knee in 90° flexion and holds on to the side of the examination bed with one hand for stabilisation. Examiner lifts tested leg into abduction until level with body, knee straight and the HHD placed 8cm proximal of the most prominent part of the lateral malleolus. The player exerts a 3sec isometric maximum voluntary contraction against the HHD and a 2sec break is then performed by the examiner pushing the leg slowly towards the bed, ensuring not to touch the bed. Standardised instruction is: "go ahead-push-push-push-push-push", a total of 5secs. Player is instructed to push as hard as possible within their comfort zone and maintain the effort while the break is performed. Any pain experienced by the player during testing is recorded using an 11-point NRS (0-10), with location also recorded.
ISOMETRIC HIP FLEXION AT 90°[17] 	Player is in the sitting position, with the hip in 90° flexion, and holds onto the sides of the examination bed with both hands for stabilisation. The HHD is placed 5 cm proximal to the proximal edge of the patella. The examiner applies resistance directly downwards while the player exerts a maximal effort against the HHD and the examiner. Standardised instruction is "go ahead-push, push-push-push and relax" (lasting 5secs).

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Figure 1
Groin muscle tests using hand-held dynamometry

Other strength tests that may also be considered in the physical examination and RTP planning process include outer-range eccentric hip adduction, oblique sit-up, and isometric hip flexion at 0°.

These strength tests may provide an insight into isolated muscle function, but should then be progressed to more functional, dynamic and sports-specific tasks including (but not limited to) hopping, jogging, kicking, and multi-directional high-speed running.

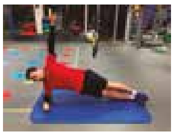
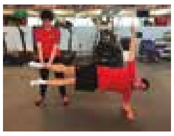
TEST	DESCRIPTION
SIDE PLANK[19] 	Players are instructed to lift their hips off the bed (or floor) by supporting their weight through their feet and forearm The head, trunk and legs to be placed in line with each other Players are then instructed to hold this position for as long as possible. Standardized encouragement is given at 30-second intervals throughout the test. The time is recorded from the start of the test until the player's hips touches the bed (or floor), at which point the test ends.
LONG LEVER POSTERIOR TILT PLANK[20] 	Lie face-down with fists on the floor, feet shoulder width apart, and spine and pelvis in a neutral position. Elbows are spaced 6 inches apart at nose level. The gluteal muscles are contracted as strongly as possible while attempting to draw the pubic bone toward the belly button and the tailbone toward the feet (posterior pelvic tilt). Lift the body up on the forearms and toes, keeping the body as straight as possible. Time that the player is able to maintain this position is recorded.
COPENHAGEN ADDUCTION[21] 	Players are in the side-lying position with their lower forearm supporting their body on the ground, and other arm placed along the body. The upper leg is held higher than the head, either on a bed, or at the height of the hip of a partner The player lifts their lower leg and body in a 3-sec concentric hip adduction movement until the body reaches a straight line, and the feet touch each other. This is followed by a 3-s eccentric adduction where the body is lowered halfway to the ground and the foot of the lower leg lowered until it just touches the ground, without pushing on the ground Repeat until fatigue, or loss of ability to maintain a straight body position Number of repetitions recorded for the test.

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Figure 2
Groin muscle tests using hand-held dynamometry

ENDURANCE

Muscle endurance is a key consideration when it comes to returning players to sport after groin muscle injury and the following tests could be relevant to consider (Figure 2).

RANGE OF MOTION

Deficits in the range of motion of certain movements have been found in athletes with current groin pain.[22,23] The reliability and measurement error of assessing hip range of motion (ROM) requires consideration when determining which measurement method to use.[24] Therefore, when ROM measures are used for the monitoring of injury, it is recommended to use as few testers as possible, use a goniometer or inclinometer, take the average of two tests, and apply consistent methods, particularly specifying the criteria for the end of range. Measurements relevant for groin muscle assessment include: bent knee fall out,[13] passive adductor test, and passive hip extension in the modified Thomas test position, with and without knee flexion.[3]

FUNCTIONAL TESTS

The validity of functional tests of specific relevance to groin muscle injuries has not yet been established. However, the following tests have shown reliability and could be relevant to include in the examination and management of acute groin injury:

- Single leg squat evaluated with the front plane projection angle (FPPA);
- Star Excursion Balance Test;
- Single leg hop for distance: anterior/medial/lateral;
- Triple hop;
- Change of direction tests (t-test, Illinois Agility test) .

As with muscle injuries to the quadriceps, and especially pertinent to RTP for the football player, kicking capacity should be assessed and considered during the RTP continuum. Passing and drills progression[25] and "interval kicking programs"[26] for football players have been described in detail, and position-specific match averages of kicking from a professional football league have also been published, enabling functional parameters to be set.[27] However, as muscle injuries have a considerably shorter duration, the kicking progression will be much faster than these recommendations. The type of kick (side-foot, instep), intensity of kick (passing, shooting) and the challenge associated with kicking (open play, free-kick, goal kick) should be introduced gradually and relative volume and intensity progressed.

EXERCISE PRESCRIPTION FOR GROIN MUSCLE INJURIES

Most groin muscle injuries make a complete and rapid recovery, yet some can progress to develop long-standing symptoms. Therefore, the focus of acute groin muscle injury RTP is to ensure complete recovery, prevent recurrence, and avoid long-standing groin pain.

An effective way to prevent inappropriate loading during the RTP process is to use clinical milestones to guide progression of specific adductor loading exercises, fitness training, and graded return to football participation.

EXERCISES TO OPTIMISE TISSUE HEALING AND RESTORE PERFORMANCE

As with all muscle injuries, reduction of pain, swelling and inhibition are key goals for the acute phase of groin muscle injury. Application of the principles of the POLICE[28] acronym should be initiated as soon as possible following injury. During the acute phase, it is also important to activate the affected muscle early to optimise the stimulus for regeneration through the process of mechanotransduction.[29] Initially, this primarily involves active or manual assisted ROM and light resistance exercises performed on the treatment table. Passive treatment modalities provide little value and are not normally needed beyond the initial acute phase of the RTP process. In contrast, exercises where load can be isolated as much as possible to the injured muscle may provide optimal structural adaptation. Additionally, isolated exercises can provide an impression of the load capacity of the injured muscle, and subsequently determine progression of exercises.

TARGETED TREATMENT

Isometric activation of the adductor, hip flexor or abdominal muscle may be commenced very early in the RTP process with the exercise progressed in range, resistance and/or speed as the muscle recovers. This exercise minimises the stability requirements of the body, thereby better isolating muscle action, and provides easily monitored load progression throughout rehabilitation.

Stretching, both active and passive, may be appropriate if the player has considerable hip range of motion deficits or asymmetries. In particular, restricted hip extension may have importance in groin muscle injury management. However, practitioners should consider that passive stretching of the injured groin muscle is often not beneficial, and may even aggravate pain.

Prior to initiating resistance exercises, simple dynamic flexibility exercises are recommended. Leg swings can include hip adduction and abduction in the frontal plane, hip flexion and extension in the sagittal plane, and combined diagonal swings. These movements will safely improve range of motion from an early stage in the RTP process and increase the player's confidence in movement. Speed and range of motion should be progressed according to the player's symptoms and confidence.

Increasing the capacity of the groin muscles to tolerate rapid loading at a lengthened state is a key element to include in the RTP process. Ensuring that loading occurs through full range is therefore important. Improving the ability of the muscle-tendon-unit to tolerate load at a lengthened state may be achieved with eccentric training, which can often be incorporated early in the RTP process, depending on player symptoms. There are many exercises for the groin muscles that incorporate an eccentric contraction, however, few are able to induce an eccentric overload, which is likely to increase the required adaptation. Manual resistance exercises (e.g. figure 3) are therefore a good option for table treatment before progressing to more gym based exercises (figures 4 and 5). Other options for early eccentric training are also pictured below, and these exercises can be gradually progressed by increasing range, speed and adding resistance. Should the player have a fear of early movement, simple ball squeezes between the knees may be used to activate the adductors very early in the RTP plan, and will provide a foundation for further progression. However, it is recommended to progress these exercises to train with the muscle at length as early as possible.

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Figure 3
Supine eccentric hip adduction against manual resistance

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Figure 4
Concentric and eccentric adduction against the resistance of an elastic band or cable pulley

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Figure 5
Hip extension with isometric adduction using a fit ball

RESTORING GYM-BASED ACTIVITIES

During the transition to more advanced gym-based exercises, the strategies discussed above can still be relevant. However, ideally there should be a gradual phasing out of the low intensity exercises, in favour of more intense strength and functional exercises, eventually progressing to field-based activities.

In addition to specifically strengthening the injured muscle, a strong focus is recommended on optimising the function of the synergist muscles involved in the injury movement(s). Groin muscle injuries are reported to occur mainly during kicking and change of direction actions,[1] which are categorised as open and closed chain movements respectively. Therefore, when progressing through the RTP process, and in particular when transitioning into the gym and advancing resistance exercises, a focus on both posterior and anterior kinetic chain muscle groups should be included in the rehabilitation of groin muscle injuries.

Some examples of more advanced exercises that may be used to optimise synergistic muscle function, and restore function of the injured muscle are shown below (figures 6A to 6N).

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Figure 6A. "doggie" exercises and 6B. Hip abduction at 90º flexion.
Figure 6C. Hip extension in 4-point kneeling and figure 6D "superman"
exercise. Figure 6E. Straight and 6F oblique sit-ups with high concentric and eccentric load. Figure 6G side plank and 6H front plank exercises. Figure 6I. Hip flexion and figure 6J bridge exercises. Figure 6K. Abduction side-step with an elastic band and figure 6L abduction on a bosu. Figure 6M. Reverse Nordic exercise. Figure 6N. Copenhagen adduction exercise.

General body strengthening, coordination and neuromuscular retraining are important progressions to include as the player progresses through the gym based return to play phase before entering back into basic field based workouts. Some examples of exercises that could be used to achieve these aims are shown below (Figure 7).

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Figure 7
Functional gym exercises

BASIC ON-FIELD TRAINING: RESTORING RUNNING, KICKING AND CHANGE OF DIRECTION

For returning to full kicking capacity, a general focus should be aimed at the adductor, hip flexor, trunk, and knee extensor muscles. This can be achieved using cable exercises with a focus on each of these muscle groups. Additionally, the tension arc exercise will focus on the anterior chain, with considerable stability requirements depending on the resistance and speed of movement. Other exercises of relevance to include in the gym program are: squats/leg press, hip thrusts, seated and standing calf raises, and unilateral push-off exercises. Exercises focusing on the posterior chain muscles can often be performed with high load and very early following injury, whereas exercises focusing on anterior chain muscles will often be affected by pain from the injured groin muscle, and load should therefore be progressed as symptoms dictate.

A progressive running program should be commenced as soon as symptoms permit. Slow linear running can often be performed very early following acute groin injury, and can be progressed in intensity and volume relatively quickly. Similarly, side-stepping with small steps is often possible early after injury. This can be progressed to larger steps and zig-zag running with increasing speeds, and be followed by faster change of direction drills and reactive agility exercises. See figures 8A to 8C for an example of some of these types of drills.

COMPLEX FIELD WORKOUT: RESTORING FOOTBALL-SPECIFIC FITNESS, SKILLS AND COGNITION

A football can be incorporated with the various exercises outlined above at almost all levels. In this phase it is essential that these exercises are progressed further to prepare the player to return to the team and eventually match-play. A controlled kicking progression program is advised, with a focus on increasing both velocity and volume of kicks, to ensure the player is ready for the kicking demands of training and match play. In general, short passes and technical ball skills can be introduced relatively early in the RTP process, followed by the introduction, and controlled progression, of longer passes and shots. These can occur when the player can demonstrate adequate control, and their pain has resolved. Close monitoring from the medical and performance team is therefore required.

The aim of the final phase of the RTP process is to train the player to return to their required level of play with a minimal risk of re-injury. Therefore, it is important to focus on training and testing all potentially injurious actions, in addition to training the player to cope with his/her usual and worst-case scenario loads of playing football. Many groin muscle injury movements are influenced by the close presence of an opponent causing a rapid decision-making process influencing player movements, resulting in injury risk. Therefore, training reactive/unanticipated actions, in addition to pre-planned actions, are essential in the RTP process, not only from the perspective of minimising re-injury risk but also for ensuring optimal performance (see section 2.3.2 for more detailed information). For timed change of direction and agility drills, tests such as the T-test and the Illinois Agility Test have shown good reliability.

Figure 8A.
Straight running (run out, walk back).

Figure 8B.
Progression of straight line to advancing zig-zag / change of direction runs.

Figure 8C.
Agility drills with potential for reactive situations.

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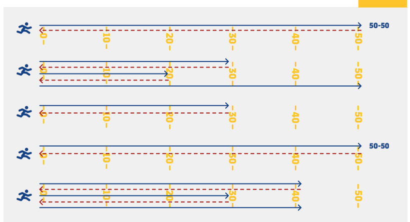

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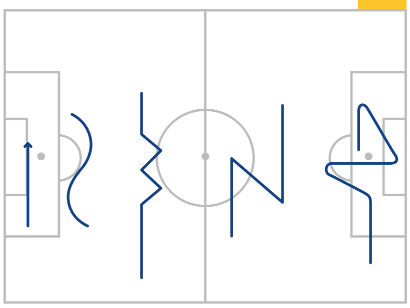

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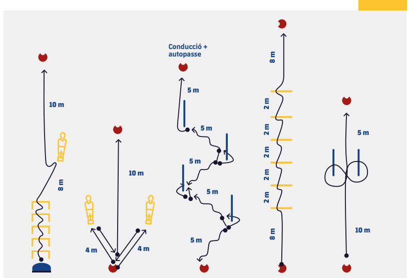

RETURN TO PLAY EXAMPLE FROM FC BARCELONA

— Xavi Yanguas, Juanjo Brau, Xavi Linde, Ricard Pruna

Figure 9:
An overview of RTP from an acute adductor muscle injury at FC Barcelona
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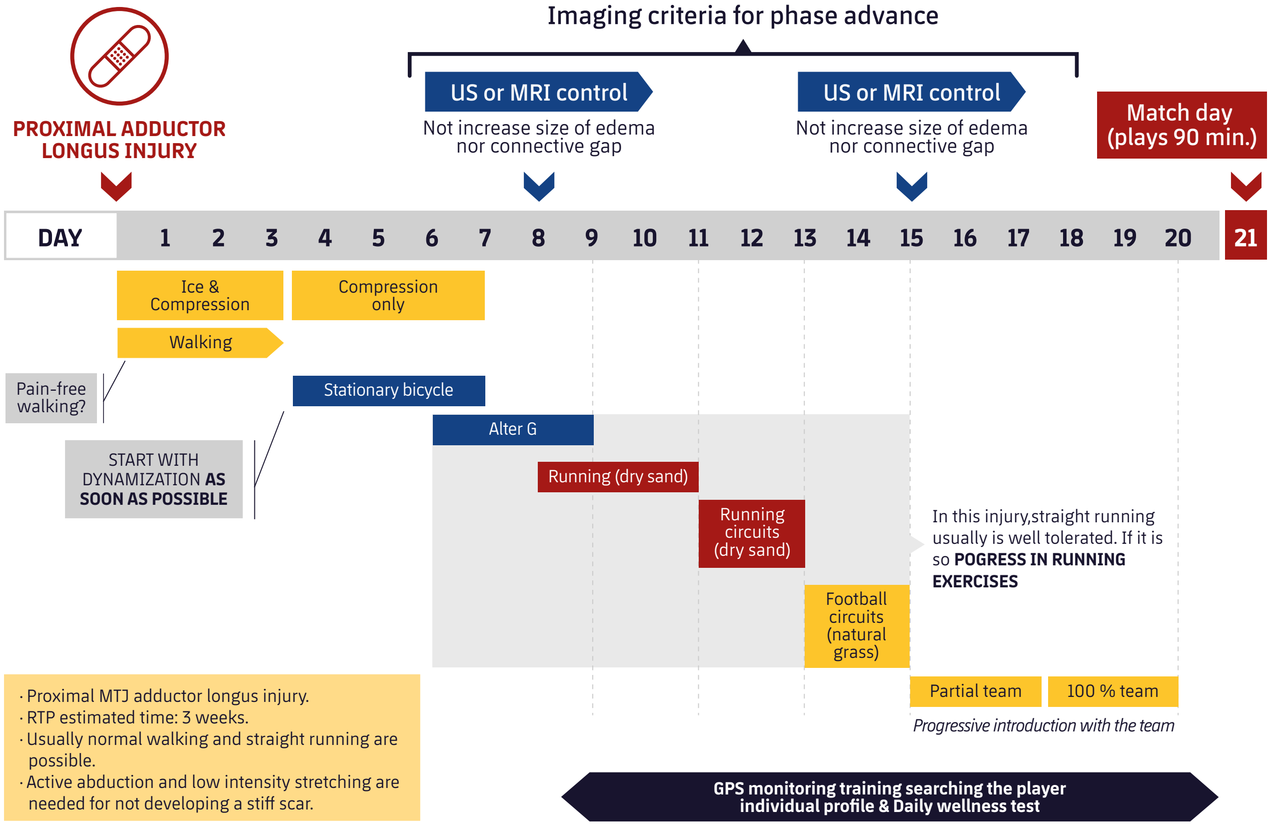

THE BARÇA WAY:

Adductor injuries located proximally in the miotendinosous junction as detailed above in figure 9, are more disabling than those located distally.

In our experience, with this type of injury, straight-line running is usually possible a few days after the injury and only sideways movements should be restricted. We believe that it is important to stretch the structure (pain-permitting) in order to minimise the possible formation of scar tissue. We have seen that adductor injuries where this has not been achieved could increase the risk of ongoing groin pain.

As with all of our specific examples, we estimate the time to RTP and work backwards from the anticipated return date to plan the program, however, it is important to remember that this is flexible and can and will be adjusted according to the progression of each player.

SURGERY FOR ADDUCTOR MUSCLE INJURIES

Acute adductor muscle injuries are most commonly seen in so-called cutting sports with multidirectional movement patterns such as football and ice hockey. Adductor longus is far the most commonly injured muscle among the hip adductors, but also lesions in the adductor brevis and pectineus are seen. Lesions to the other adductors are rare. The injuries can in general be located at the insertions proximally or distally or in the muscle at the musculo-tendinous junction (MTJ).[6]
— With Per Holmich

INDICATIONS FOR SURGERY

Most adductor injuries do not require surgery. However, in some rare cases surgery should be performed within a week or so after the injury occurs. Surgery may also be necessary if conservative treatment fails to achieve a satisfactory result – for example if the player has chronic symptoms or recurrent injuries.

The most common location is the MTJ followed by the proximal insertion and very rarely the distal insertion. The MTJ injuries can be located at the proximal tendon MTJ, the intramuscular MTJ and the distal tendon MTJ. The injuries are evenly distributed among these with approximately one third each.[6] Not much has been reported in the literature regarding these injuries and no consensus regarding the treatment exists at present.

TREATMENT – DISTAL INSERTIONAL LESION

The very few reports regarding distal insertional lesions indicate that they were successfully treated with non-operative rehabilitation. Weight bearing as tolerated and gradually increasing load was applied and return to sport reported at 5 months.[30]

TREATMENT – MTJ LESION

The MTJ lesions are in general treated non-surgically with success, and even in the rare cases with involvement of the intramuscular tendon the best treatment is probably also non-surgical rehabilitation.[6]

TREATMENT – PROXIMAL INSERTIONAL LESION

The lesions at the proximal insertion are reported more commonly in the literature and the treatment recommended is both surgical and non-surgical. A case-series including 19 American Football players competing in the National Football League, found that non-surgical treatment of proximal adductor tendon rupture resulted in faster return-to-play than surgical treatment in players.[31] In a case report of a male football player who suffered two acute adductor longus ruptures, one in each leg, 10 months apart, where both injuries were treated non-surgically, both injuries had very different recovery times, especially regarding the hip adductor strength. This indicates that it is in most cases not possible to predict return to sport time and it is advised that measurement of adductor strength is used as part of the decision making.[32]

Other small series have reported successful return to sports after surgical treatment. At present there are no firm recommendations available in the literature on who to operate. Large retraction of the tendon from the bone, avulsion of a bony fragment from the pubis bone, avulsion of the full fibrocartilage of the adductor longus and high level of performance have been suggested as arguments for surgical treatment. However, as mentioned even elite athletes can successfully return to sport without surgery and perhaps even faster. The risks of surgery (such as infection, scar formation) should always be mentioned as a point to take into account when choosing treatment.

One of the reasons non-surgical treatment for adductor lesions often works well is probably that the adductor longus or brevis are not alone. They are part of a large and strong muscle group that is able to take over and replace some of the functions and strength lost until the muscle has recovered.

SURGICAL TECHNIQUE

The surgical technique recommended is in summary as follows: With the patient placed supine an incision in the inguinal crease over the adductor muscle group is made. The incision is usually between 5 and 8 cm long. The fascia is incised and the lesion can be inspected. After debridement the tendon (with or without a bony fragment) as well as the pubis origin is prepared and the tendon is reinserted anatomically with suture anchors. Postoperatively partial weight bearing is allowed and passive range-of-motion exercises are administered for the first 2 weeks. After that increasing load can begin until 4 weeks where full weight bearing usually can start.[33,34]


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RETURN TO PLAY FOLLOWING CALF MUSCLE INJURY

In this section, we build upon the general principles described earlier in the guide, with specific reference to calf muscle injuries.
— With Tania Pizzari, Brady Green, Karin Silbernagel, and Anthony Schache

MAKING AN ACCURATE DIAGNOSIS

Making an accurate diagnosis is the cornerstone of effective injury management and return to play planning. An accurate diagnosis facilitates an estimation of prognosis, and in turn, shared decision-making regarding injury management is planned. Imaging may be used judiciously at this step, but you must be clear about what (if anything) imaging will do to change the return to play plan. At FC Barcelona, we work backwards from the anticipated time to return to full match-play. Understanding biology will help when estimating injury prognosis and planning a strategy for appropriate loading through the return to play continuum

PATIENT HISTORY

The patient history provides valuable information towards making an accurate diagnosis.[1-3] Descriptions of symptoms, such as the pain intensity the extent of loss of function, provide an immediate impression of the injury severity and prognosis.[1] The injury mechanism has previously been used as an indication of which muscle is affected, with gastrocnemius traditionally thought to be strained during high force or high velocity actions.[3] This is because gastrocnemius injuries are thought to typically occur in positions combining knee extension and ankle dorsiflexion, resulting in eccentric overload or attempted reversal of the stretch-shortening cycle.[1-3] However, soleus injuries can also occur in the same positions, along with positions involving knee flexion and ankle dorsiflexion. Therefore, practitioners should be cautious when interpreting injury mechanism information and should never make a diagnosis based on the mechanism alone.

Players with gradual-onset calf pain (i.e. calf injuries without a clear mechanism or inciting event) typically report a sense of tightening and subsequent loss of function that progresses over the course of a match or training session. In some cases, these symptoms may not be apparent for several hours, or even days, and subsequent investigations confirm the presence of an acute muscle injury. In our experience, gradual-onset presentations most often involve soleus. The diagnosis may be aided by other factors including recent loading history, calf muscle and other injury history and player age.[1-4] Practitioners should also consider differential diagnoses when assessing gradual-onset calf pain, such as neurological or medical causes of pain (e.g. thrombophlebitis).[1-3-5]

PHYSICAL EXAMINATION

Physical examination of calf muscle injuries involves palpation, strength testing, applied stretch and a functional testing battery (Figure 1).[1-3] The practitioner should develop an immediate impression of injury severity.[3] Early information from the physical assessment should also direct attention during further testing.[1-5] The location of pain should be established at rest and during the assessment, noting the consistency of pain location or the manner in which it changes.[1] Clinical tests (palpation, strength, stretch) should be performed systematically in both knee extension and knee flexion.[1] Pain reproduction on resisted calf contraction and applied stretch can change with the test position.[1] If there is a greater level of pain and loss of strength with the knee extended compared to with the knee flexed, it typically indicates gastrocnemius involvement.[1-3] When findings are similar in both positions, or worse with the knee flexed, it typically indicates soleus involvement.[1] Note that calf muscle injuries can involve more than one muscle, which often confuses the clinical picture during the physical examination.[1]

During inspection and palpation, the presence and location of bruising, swelling, soreness and solid masses should be identified.[1] In severe injuries, there may be a palpable tissue defect.[1-3] Substantial bruising may indicate a larger muscle injury. However, bruising is naturally more pronounced in gastrocnemius injuries, as gastrocnemius is more superficial.[1-3]

Palpation begins superficially and proximally with the gastrocnemius. Gastrocnemius medialis can be palpated from the posteromedial aspect of the knee and the course of the fibres can be followed inferiorly, eventually combining with the superficial central aponeurosis and termination into the triceps surae musculotendinous junction (MTJ).[1] A similar approach can be used for gastrocnemius lateralis, noting that the orientation of fibres are different to that of the medialis as they course to the triceps surae MTJ.[3] Soleus palpation commences approximately one-third the distance down the tibia, however palpation of the proximal aspects of the soleus is often difficult and cannot reliably differentiate between muscles injured. As palpation continues down the leg, the soleus becomes more accessible in the middle third of the lower leg, particularly from the medial side. It continues further inferiorly than gastrocnemius prior to terminating into the central, medial and lateral aspects of the Achilles tendon.[1]

IMAGING

Magnetic resonance imaging (MRI) is the most useful modality to identify the exact injury location, potential prognostic indicators, and individual anatomical factors.[4-6-10] Ultrasound can be useful for medial gastrocnemius ruptures at the distal muscle-tendon junction. However, ultrasound lacks sensitivity for detecting soleus muscle injury.[10] This may explain why research studies conducted prior to the widespread use of musculoskeletal MRI report lower rates of soleus injuries.

INJURED TISSUES	CONNECTIVE TISSUE INVOLVEMENT	ESTIMATED RTP TIME
Soleus myofascial	Little connective tissue involvement	2-3 weeks
Soleus injury with central intramuscular tendon involvement	Large connective tissue involvement	6 weeks
Soleus injury with lateral intramuscular aponeurosis involvement	Large connective tissue involvement	4 weeks
Soleus injury with medial intramuscular aponeurosis involvement	Large connective tissue involvement	5 weeks
Gastrocnemius myofascial injury	Little connective tissue involvement	2 weeks
Medial gastrocnemius injury including partial rupture of the distal MTJ (tennis leg)	Large connective tissue involvement	7 weeks

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Table 1:
Estimated RTP times for calf muscle injuries based on FC Barcelona data and clinical experience. Note that these are initial estimations only, that do not consider player-specific factors, football-specific factors, or risk tolerance modifiers

ESTIMATING RTP TIME

There is a wide variation in RTP times following calf muscle injury.[11] In some cases, players may be able to return almost immediately. However, it can also take months. To estimate the RTP time for a specific injury, practitioners need to consider the exact location and extent of the tissue damage as well as player-specific and football-specific factors. As discussed earlier in this guide, various risk tolerance modifiers also influence the RTP estimate.

LOCATION AND EXTENT OF TISSUE DAMAGE

Generally, soleus injuries result in greater time loss than do gastrocnemius injuries, especially when there is disruption of the central, medial or lateral intramuscular tendo-aponeurotic portions of the soleus.[4-7-8] Central intramuscular tendon tears are generally considered to be the most serious.[4-6] However, as discussed below, lateral aponeurosis tears can be similarly serious in certain players.

Table 1 shows the expected RTP times for various calf muscle injury locations and severities, based on FC Barcelona clinical experience and injury data collected over 10 seasons. They have not yet been fully validated in scientific studies. Note also that these data are only intended as a starting point; player-specific factors, football-specific factors and risk tolerance modifiers should also be considered when estimating RTP time.

PLAYER-SPECIFIC FACTORS

Practitioners should consider a range of intrinsic factors when estimating RTP following calf muscle injury. In particular, players who have sustained re-injuries, as well as older players (i.e. those over 30 years) need longer to recover from the same initial damage.

Players with a genu varum (bow-legged) anatomy, which is common among footballers,[12-14] often have more developed lateral soleus muscles and a thicker lateral intramuscular aponeurosis. This can often be seen on careful inspection of MRI images. In these players, injuries involving the lateral aponeurosis are comparable to those involving the central intramuscular tendon in players with a normal anatomical alignment (Table 1).

FOOTBALL-SPECIFIC FACTORS

As the calf muscles are highly stressed during rapid direction changes, central midfielders and other players who commonly change directions need longer RTP times following injury. This includes goalkeepers, who also expose their calf muscles to particularly high loads during multi-directional explosive movements.

CALF MUSCLE TESTING

Functional testing plays an important role throughout the entire RTP process. During the initial physical examination, testing provides immediate information on which activities the player can perform with and without pain. This helps practitioners develop a clinical impression of injury severity and prognosis.[1] Later, functional tests act as important milestones as the player progresses along the RTP continuum, and help to guide the final decision to clear the player for unrestricted match participation.

The functional capacity of the calf muscles should be tested using a battery of functional tests with increasing difficulty, until the player's symptoms prevent further testing (Figure 1). Assessment should begin by examining isolated, stationary activities in weight-bearing positions, such as calf raises,[3] then progress to more dynamic lower limb actions such as walking, running, jumping and hopping (Figure 1). Finally, if symptoms allow, high-demand actions should be tested, such as maximal sprinting, changing direction and accelerating from stationary positions.[5] Practitioners should not only assess the player's pain, but also their ability to perform high quality movements repeatedly, as well as their ability to generate fast movement.[1-5]

A carefully-planned, progressive loading programme is essential to optimise the quality of healing tissues and to prevent injury recurrences.[1-2] The programme should include fundamental therapeutic exercises (sometimes referred to as mechanotherapy)[15] and strategies to restore football-specific function. As previously discussed, maintaining football-specific cognitive skills is vital throughout the entire RTP process. Importantly, these three areas are non-hierarchical; there should be gradual progression in all areas and milestones should be determined for each area as the player progresses through the RTP continuum.[16]

Assessment

Starting point → Final testing

Walking	(1) Pain while walking (0-10), (2) Antalgic walking gait.	TESTS OF BASIC FUNCTION & STRENGTH
Single leg calf raise	(1) The number of repetitions performed are >25 or within 10% of other side, (2) Presence of pain (0-10).	
Double leg jumping	(1) Movement quality with repeated performance, (2) Presence of pain (0-10).	TESTS OF CONTRACTILE ENDURANCE
Jogging, slow running	(1) Pain while jogging, slow running (0-10), (2) Antalgic running gait.	
Submaximal hopping on the spot	(1) Movement quality with repeated performance compared to other side, (2) Presence of pain (0-10).	
Maximal forward hopping	(1) Distance compared to other side (within 10%), (2) Presence of pain (0-10)	TESTS OF POWER & FUNCTION
Striding	(1) Striding at incrementally faster speeds (50-90%), (2) Presence of pain (0-10), (3) Antalgic running gait.	
Fast change of direction running and cutting	(1) Performance of multi-directional running and cutting at incrementally faster speeds and sharper angles, (2) Presence of pain (0-10).	
Sprinting	(1) Performance of sprinting at maximum speed (100%) for 20m, (2) Presence of pain (0-10), (3) Antalgic sprinting gait.	

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Figure 1:
Graduated functional testing battery for calf muscle strain injuries.

EXERCISE PRESCRIPTION FOR CALF INJURIES

Traditionally, practitioners have prescribed calf muscle loading exercises in positions of knee extension to target the gastrocnemius, and knee flexion to target the soleus. However, this is a misconception; both the gastrocnemius and the soleus muscles contribute to plantar flexion force generation, irrespective of the knee angle.[17-18] Therefore, practitioners should vary the loading positions based on football-specific functional demands.

EXERCISES TO OPTIMISE TISSUE HEALING AND RESTORE PERFORMANCE

During the early rehabilitation phase, players should perform low-load, non-weight-bearing muscle activation exercises.[1-3] This involves training with no external resistance, or against light resistance (e.g. an elastic band). In this phase, gentle isometric and isotonic contractions can be performed in supine and seated positions.[1] The position of the athlete, the degree of knee flexion, and the position of the foot should be varied.[1] Also, attention should be paid to intrinsic foot musculature and ankle plantarflexors that are functionally interdependent of the calf muscles (flexor digitorum longus, flexor hallucis longus, tibialis posterior, and peroneus longus).[19]

Early exercises can be progressed by adding weight-bearing plantarflexion, such as standing calf raises, and light resistance training.[3] Training position during calf raises will alter the degree of activity in synergistic muscles.[19] For example, flexor digitorum longus (FDL) shows more activity during heel raises in adducted foot positions compared to 'normal' and abducted positions, while tibialis posterior shows consistent contractile activity in all three foot positions.[19] Early muscle activation exercises are progressed to begin regaining strength endurance and hypertrophy of the calf muscles.[3] This involves progressing the time under tension, relative intensity, and overall volume of loading. In practice, exercises targeting gastrocnemius may involve a lower number of repetitions, or time under tension, due to the fatigability of this predominantly fast-twitch muscle.[18]

High load resistance training is introduced following achievement of an acceptable baseline of calf muscle activation and strength-endurance (e.g.. 25 high quality, single leg calf raises).[1] During this stage, resistance exercises are prescribed with a higher relative intensity and a lower number of repetitions than earlier exercises.[3] Isolated calf strengthening exercises utilise machine-based resistance to apply external load to the musculotendinous unit,[20-21] and are performed in knee extension and knee flexion.[1-2] Standing calf raises and seated calf raise machines are commonly used (figures 2A and 2B).[20-22] These are effective for developing the maximal force generating capacity of gastrocnemius and soleus.[20] It is important to note that the seated calf machine still brings about significant positive adaptations in the gastrocnemius, despite traditionally being considered to be preferential to soleus.[21] Regardless, isolated calf strengthening is important because it stimulates structural adaptations in the calf muscles that may be protective against re-injury and that underpin high-level calf function: local muscle activation, hypertrophy, muscle-tendon junction integrity and musculotendinous unit stiffness.[21-23-25] Progression of load during general calf muscle rehabilitation is also needed to begin gradually exposing the tissue to greater stresses throughout the stretch-shortening cycle, including the eccentric phase, which is implicated in muscle injury.[5]

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Figure 2A:
Standing calf raise

Figure 2B:
Seated calf raise

Once the player has regained maximal calf strength (e.g. compared to pre-injury tests and/or the non-injured side), the player should gradually begin performing exercises involving explosive stretch-shortening cycle actions. This induces adaptations to tissue length (fascicle length), type II muscle fibre hypertrophy, maximal strength and contractile velocity more effectively than conventional resistance training alone.[24-26-27] Adaptations from strengthening exercises prepare the entire triceps surae for advanced, power-based plyometric exercises and running-based stresses that are encountered during ongoing field-based rehabilitation.[24-27-28] In addition, retraining of multi-joint, compound movements should always occur in conjunction with training of local calf muscle function.[3] Compound exercises are useful to retrain the abilities of force application and load absorption in positions that mimic function, in order to achieve successful transfer of gym-based rehabilitation to the pitch.[22] Throughout general calf strengthening the isometric capacity ('position-dependent strength') of the musculotendinous unit should also be developed in conjunction with isotonic and dynamic calf training.[23-25] Retraining isometric capacity in various positions[1] is one method to ensure the force-generating capacity has been developed across the spectrum of contractile modes and joint positions,[25] including the joint positions considered to be injurious.[1-2]

General calf rehabilitation also includes stretching and mobility practices.[3] These interventions are one method of ensuring the injured triceps surae regains the compliance[29-30] and length[31-32] required to carry-out the specialised stretch-shortening cycle actions in dynamic functions.[33-35] Stretching prescriptions should include active lengthening of the local tissues while in knee extension and knee flexion, along with global drills that apply a tensile force to the tissues in-series with the calf muscles, such as the hamstrings and plantar fascia.[3]

The rehabilitation programme should include running as early as possible.[3] In the early phases, strategies to minimise ground reaction force may be necessary, such as running on an Alter-G treadmill (figure 3) or in water. Alternatively, elliptical fitness machines can be a low-impact alternative to running in the early phases of rehabilitation. Once the player has achieved pain-free walking and is tolerating eccentric loading, over ground running may be trialled.

^
Figure 3:
Alter-G treadmill

Once running ability has begun to progress, slow jogging prescriptions that are of an excessive volume should be avoided.[36-38] The calf muscles have a high degree of muscle work throughout stance for stability and propulsion even during slow running, and receive less contribution to work from elastic recoil than occurs during faster running, particularly in the case of soleus.[39-42] Furthermore, slower running results in longer ground contact times and peak forefoot loading remains high, which creates large work demands and time under tension for the triceps surae.[37-38] Therefore once running capacity begins to progress it is not necessary to overload the calf muscles with slow running prescriptions,[36] particularly in cases of calf muscle injuries that are hypothesized to be related to the overall running workload performed prior to injury.[1]

Progressive exposure to high-speed running and sprinting is necessary for rehabilitation to progress. Progression of speed (or 'running intensity') should also occur during exercise and football-specific drills retraining change of direction, multi-directional running, accelerations, decelerations and reactive agility.[33-43-45] Running at greater speeds and in different conditions is required to match the load requirements of the sport, and to best prepare for the demands of competition.[36-46] Sprint training is also useful for developing calf force and power attributes, musculotendinous unit stiffness and fascicle lengths.[47-51] The timeline for progressing parameters of both running speed and volume should however consider the characteristics of the calf injury, including clinical indicators of injury severity and structures involved.[4-6-8] Running prescriptions should also take into account the recent and long-term training history of the athlete to ensure the prescribed volumes and intensities of running do not compromise subsequent injury risk, or risk of re-injury.[32-52-53]

Retraining plyometric capacity is a foundation of calf rehabilitation following injury.[5-35] Plyometric exercises develop athletic attributes underpinned by calf function; including starting acceleration, running velocity, change of direction ability and jumping performance. These attributes are correlated positively with a number of attributes of the triceps surae, such as general and high-velocity strength, activation, musculotendinous unit stiffness and neuromuscular coordination.[35-54-57] One key to successful rehabilitation is to restore the capacity of the triceps surae to tolerate repeated, rapid ground contacts and the force profiles, in both application and absorption,[39-58-59] exposed to the lower leg during function.

Plyometric exercises require sensible progression and integration into the rehabilitation plan. Plyometrics are typically integrated later in the rehabilitation once the athlete has developed satisfactory activation, strength-endurance and maximal calf muscle strength. The frequency, volume and difficulty of plyometric drills are parameters to consider when prescribing these exercises.[24-54] Plyometric prescriptions should also be considered in the context of running-based training that is being completed concurrently. The stresses encountered during the stretch-shortening cycle of plyometric muscle actions acutely affect the capacity of the triceps surae and therefore have the potential to re-injure or exacerbate if not diligently planned.

Bilateral plyometric exercises are generally commenced first (Figure 4) before moving onto unilateral exercises (Figure 5). Initial plyometric drills are also more concentrically-biased, and are usually performed over a more limited range of motion to shield the recovering muscles from attempting to store and release strain energy beyond their current capacity.[3] The relative intensity of plyometric exercises should always be planned for, monitored intra-session and later progressed appropriately. When prescribing plyometric exercises clinicians should take into account the requirement of forces to be absorbed (eccentric phase), summated (amortization phase) and then utilized to generate positive work (concentric phase); along with the relative movement velocity. In practice, variables are not always progressed at the same time due to the high stresses encountered by the triceps surae. There should also be time afforded for restoring plyometric endurance, as the triceps surae will be required to function in this way for extended durations once returning to play; and the calf muscles have been shown to be significantly more likely to be injured in the final minutes of soccer match play.[11]

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Figure 4:
Bilateral jumping

Figure 5:
Unilateral hopping/jumping

RESTORING FOOTBALL-SPECIFIC FITNESS, SKILLS AND COGNITION

Progressive reintroduction to skill-based training is fundamental to player outcomes following calf muscle strain injury. A planned sequence of skill training should be outlined with the flexibility to be altered according to the ongoing clinical presentation. Early in rehabilitation players can safely perform stationary passing drills and then progress to straight line running drills with dribbling and passing of the ball.

Later in rehabilitation, ball drills that include change of direction and a response to an opponent or external cue can be incorporated. Following this, the player can commence controlled, lower level, skill drills with teammates before participating in small-sided games (e.g. 4 against 4 on a small pitch), and other uncontrolled training drills. At end-stage rehabilitation, the player should be participating in full training and have satisfactorily restored complete skill-based and running workloads that are comparative not only to the main training group[60] but most importantly, to what that player is used to doing. Internal load should be monitored alongside external (e.g. GPS) loads and psychological readiness to return (refer back to section 2.3.2.). Remembering also that the local response of the triceps surae should be monitored in conjunction with general quantification of training workloads, utilizing tests of functional capacity (Figure 1).

RETURN TO PLAY EXAMPLE FROM FC BARCELONA

— Xavi Yanguas, Juanjo Brau, Xavi Linde, Ricard Pruna

Figure 6:
An overview of RTP from a calf muscle injury at FC Barcelona
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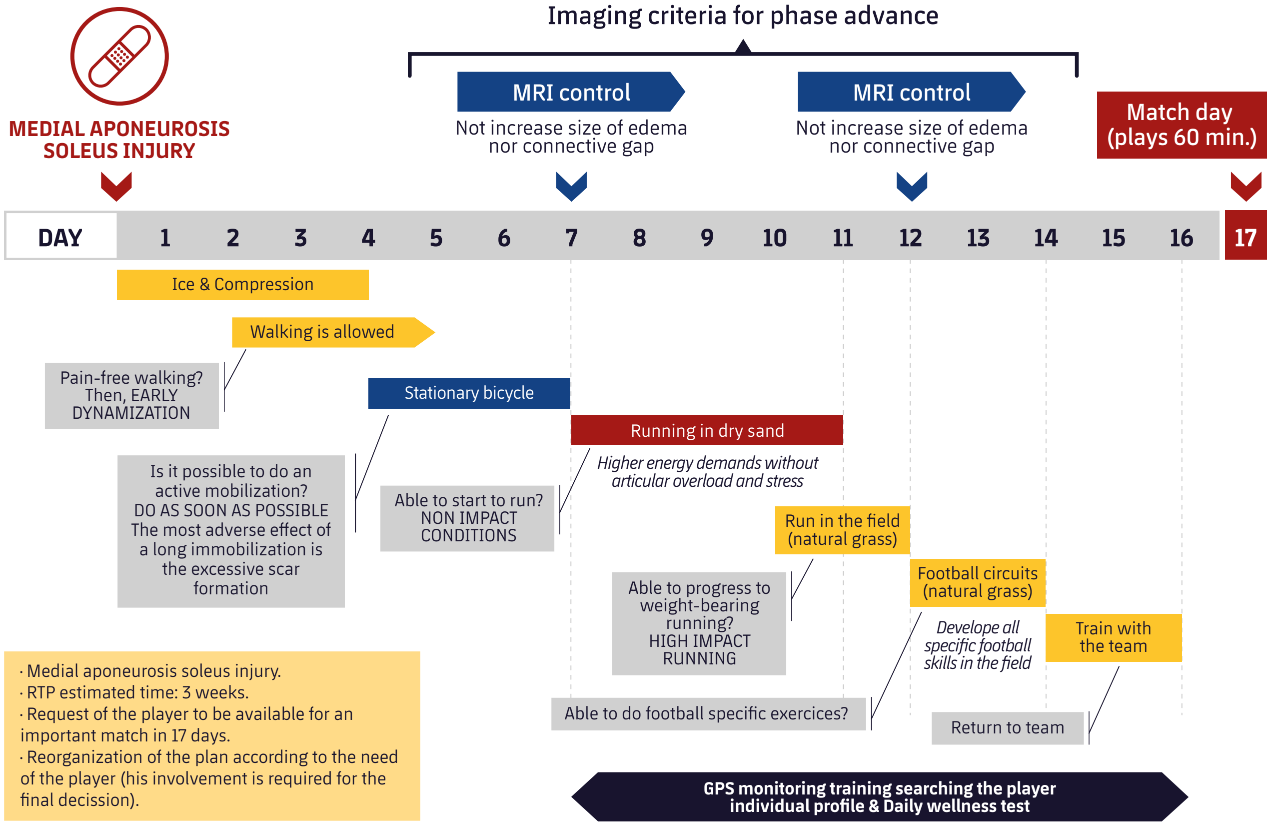

THE BARÇA WAY:

Following an accurate diagnosis of the calf muscle injury, we work back from the estimated RTP date. For example in the case in figure 11, we estimate the RTP at 17 days. We subsequently work backwards from this to determine the key milestones and exercise progressions to achieve this date.

You will notice that, the order of progression is not to finish one step in order to start the next, we gradually overlap the progressions i.e. as one phase is coming to an end, we introduce the next. For example, in the above case, running in dry sand can occur simultaneously to introducing running in the field which in turn can be overlapped with integration of football specific running circuits.

As with all of our case examples (e.g. hamstring, quadriceps and adductor muscles), the framework is flexible, meaning that if a player is progressing faster than estimated, we can advance the exercises also. Likewise, if his/her progression is slow, then we prolong if needed.

SURGERY FOR CALF MUSCLE INJURIES

The ankle muscle complex consists of the medial and lateral head of the gastrocnemius muscle, the soleus muscle, and the plantaris muscle. The gastrocnemius muscle is the most superficial muscle of the calf muscle complex and can be divided into a medial and lateral head. The gastrocnemius especially facilitates rapid locomotion (e.g. juming, running) whereas the soleus is especially designed for strength.[1] The anterior aponeurosis of the gastrocnemius muscle unites with the central intramuscular tendon and the posterior aponeurosis of the soleus to form the Achilles tendon. The general function of the calf muscles is plantar flexion of the ankle.[1,2]

— With Özgür Kilic, Anne D van der Made, Gino MMJ Kerkhoffs

Similar to prognosis of the hamstrings, quadriceps and adductors, the vast majority of calf muscle complex injuries are treated non-operatively using (criteria-based) rehabilitation programs. However, given the high pressure on players and medical staff to return to the pre-injury level as fast and as safe as possible, it is paramount to recognize those injuries that warrant surgical intervention. Failure to do so could potentially result in suboptimal outcome, persistence or worsening of dysfunction and complaints, or recurrent injury. In this chapter, we will go over specific injuries for which early and delayed surgical intervention should be considered, surgical technique, and prognosis.

INDICATIONS FOR EARLY SURGERY

ACHILLES TENDON RUPTURE

While Achilles tendon rupture is commonly known as an injury that plagues middle-aged individuals, younger patients may also be affected, especially those engaging in sports.[3] Since early reports of surgical intervention in the 1920s that made surgical repair increasingly popular, several techniques for surgical repair have been developed. Fifty years later, it became clear that conservative management by means of casting techniques could also yield acceptable results. However, there is no consensus on which treatment is superior and preferable.[3,4] In this guide, we will mainly focus on acute ruptures.

The primary treatment goal is to restore function, yet the possibility of a re-rupture is often mentioned as a rationale to opt for surgery. While earlier research noted differences in re-rupture rate between surgical and conservative treatment in favor of surgical intervention, more recent systematic reviews found lower overall re-injury rates that were not significantly different between both groups.[4,5] This is undoubtedly the result of continuous development of both treatment modalities, for example by the use of newer techniques and/or functional braces that allow for earlier mobilization, which is known to positively affect tendon healing.[4,6]

With respect to function, there is evidence that surgical intervention leads to a quicker return to sports/work and better recovery of function.[3,4] Again, this may also be attributable to a quicker start of rehabilitation rather than the choice of treatment alone. In the elite athlete, these results make a compelling case in favor of surgical intervention. In a 11-year follow-up UEFA Champions League injury study, all total Achilles tendon ruptures were treated surgically.[7]

With regard to surgical technique, there are several options. Surgical repair can be performed open or percutaneous, by means of end-to-end suturing techniques or an augmented repair. An open procedure allows for the best control of tendon length and has the has the advantage that it allows for early tension on the repaired tendon. On the other hand, this approach is more prone to complications such as (minor) wound problems.[3] Percutaneous repair was found to effectively reduce the number of wound complications.[3] However, this may be at the cost of inferior repair strength, and thereby higher risk of re-rupture, when compared to open surgery.[3]

In case of chronic Achilles tendon ruptures, surgical repair involves debridement until viable tendon tissue remains, often followed by a lengthening procedure (e.g. V-Y, rotational flaps, tendon augmentation, tendon transfer) to achieve adequate length for reapproximation.[8] Post-operatively, early mobilization is advised as it results in quicker return to sports/work and improved functional outcome, without increasing the risk of a rerupture.[3,5,6,9] Although there is a lot of variation between studies, the average return to play rate is approximately 80%, at a mean 6 months.[10]

COMPARTMENT SYNDROME

The lower leg is divided into four compartments: anterior, lateral, deep posterior and superficial posterior. A compartment syndrome is caused by increased interstitial pressure within such a compartment and consequently results in compromised tissue perfusion and compression of neurovascular structures.[11,12] Compartment syndrome can be acute or chronic.

Acute compartment syndrome (ACS) is a surgical emergency which can be devastating for the lower leg (e.g. amputation in a worst case scenario) and it is therefore of extreme importance that it is recognized timely.[13] The characteristic presentation of ACS is commonly summarized using 'the 6 P's': pain, pulselessness, pallor, paresthesia, paralysis and poikilothermia. Mainly, it occurs secondary to a trauma such as tibial fracture.[13] ACS following a direct blow or fracture is usually suspected and thus timely recognized. Alternatively, muscle rupture, exercise, non-contact muscle injuries and chronic exertional compartment syndrome (CECS) have been reported to induce ACS.[14-20] It is paramount to recognize these atypical and rare presentations of ACS, as these are easily missed and can have grave consequences.

Chronic exertional compartment syndrome is well-described in athletes.[14 21] In contrary to ACS, CECS-induced pain, muscle tightness and cramps are completely eliminated within minutes after ceasing activity in the majority of the cases.[14] Complaints are typically exercise-related. Next to pain, muscle weakness and dysesthesia distal of the affected compartment due to loss of sensory nerve function may be present.[22] In soccer, players participate in exercise with repetitive loading, which makes them especially at risk for CECS.[22] The measurement of the intra-compartmental pressure (ICP) is the most broadly used test to confirm the diagnosis. High sensitivity (97%) is reported when a intra-compartmental pressure of ≥35 mmHg is considered pathognomic.[22]

Treatment for ACS and CECS is a surgical fasciotomy to decrease intra-compartmental pressure.[11 13 15 23] In case of ACS, therapy consists of dermato-fasciotomy of all four compartments.[22] As for CECS, fasciotomy of only the affected compartment is sufficient.[24] Conservative treatment for CECS (e.g. non-steroidal anti-inflammatory drugs, physiotherapy, podiatry or massage) have been advocated but none of these methods enabled return to play on pre-injury level.[12 15 21 22 25 26] Therefore, especially in athletes, a fasciotomy is the only rational approach.[22] Surgical techniques for fasciotomy vary. In case of ACS, a long single incision made from the head of the fibula to the lateral malleolus is referred to as the single incision technique.[27] The most commonly performed ACS fasciotomy is the double-incision, four-compartment technique incorporating a longitudinal anterolateral and posteromedial incision.[27 28] Several techniques are described for fasciotomy per compartment in case of CECS.[24] As CECS often appears in the anterior compartment, fasciotomy can be performed through a small incision in a half open manner, under regional or general anaesthesia.[22] If timely intervened, surgical treatment of ACS and CECS can be expected to lead to complete recovery with a full return to sports at pre-injury level within three months.[15 16 18 21] Failure to diagnose ACS timely can lead to long-term disability.[16] Post-operative rehabilitation is of utmost importance. In order to prevent the formation of restrictive scar tissue, patients should be encouraged to restart activity as soon as the day after surgery.[22] Low recurrence rates (3-4%) and good results can be obtained with this protocol.[22 24]

Another rare syndrome that could cause CECS-like complaints is popliteal artery entrapment syndrome (PAES). A clinician should consider PAES as part of the differential diagnosis, especially in case of unexplained lower leg pain or when complaints persist after fasciotomy. It is reported that more than 80% of the PAES cases have associated CECS.[29] The most frequently described symptom in patients with PAES is intermittent claudication of the calf with isolated calf cramp during exercise.[29] When concurrent CECS is present, additional symptoms can be paresthesia and swelling.[29] In cases of functional PAES (PAES not caused by anatomical restrictions), surgeons may decide to only perform a fasciotomy for CECS, as this is less invasive.[29] If complaints persist, a second operative procedure to treat PAES can be performed.[29] There are different types of PAES (Anatomical types I to VI and Type F (functional)).[30] Operative treatment differs from type to type. In general, achieving normal anatomy within the popliteal fossa is the treatment goal.[31] Approximately 80% of the patients were able to resume sport at pre-injury level after PAES surgery.[29]

Finally, a rare cause of compartment syndrome or PAES is the presence of accessory muscles, such as an accessory soleus muscle.[32-37] Fasciotomy, tendon release, accessory muscle debulking and excision have been successful treatments for the symptomatic accessory soleus muscle.[35 37]

INDICATIONS FOR DELAYED SURGERY

MUSCULOTENDINOUS AND INTRAMUSCULAR TENDON INJURY

Primary treatment for musculotendinous and intramuscular tendon injuries in the calf muscle complex is conservative involving criteria-based rehabilitation programs. Conservative treatment is initiated according to the RICE (rest, ice, compression and elevation) principle.[2 38]

In our hands, an operation is rarely needed as nonoperative treatment results in good outcome in the majority of the cases.[38-41] Järvinen et al. suggested that "muscle injuries do heal conservatively" could be used as a guiding principle in the treatment of muscle traumas.[38] However, they also acknowledged that surgical intervention might be indicated in some cases. These indications include a large hematoma, high-grade injury (i.e. grade 3 or injuries that involve rupture of more than half of the muscle cross-sectional area), and the aforementioned compartment syndrome.[38 39 42 43]

However, for calf muscle injuries, if no or insufficient progress is made despite prolonged treatment (duration >4-6 months), surgical treatment may be considered.[38 44] There are a few studies outlining the surgical treatment of injuries within the calf muscle complex. Järvinen et al. have advocated the following general principles: removal of hematoma and necrotic tissue, excision of scar tissue and reattachment of the torn muscle if the injury is near the musculotendinous junction (MTJ).[38]

A recent case report demonstrated good clinical results after surgical treatment of injuries near the MTJ.[44] The surgery included reattachment of the muscle fibers using sutures with the foot positioned in plantar flexion.[44] Post-operative treatment included immobilization of the patient for 3 weeks in a long leg cast with the knee flexed 60° and the ankle plantar flexed 20°-30° and an additional 3 weeks in a below knee cast, with the ankle plantar flexed, followed by range of motion and progressive weight bearing exercises after removal of the cast.[44]

ACHILLES TENDINOPATHY

The initial treatment for Achilles tendinopathy is a conservative and multifactorial approach that includes exercise (e.g. eccentric or heavy slow resistance training, identification and correction of etiological factors, and symptomatic therapies.[45 46] While these strategies are effective in the majority of cases, a subset of patients will experience chronic (>3 months) complaints of tendon pain and dysfunction.[45 47] If no or insufficient progress is made despite adequate and prolonged conservative treatment, surgical consultation is warranted.
The 11-year follow-up study UEFA Champions League injury study showed that 38% of the severe (absence >28 days) tendinopathies were treated surgically.[7] Alfredson and Cook recently proposed a treatment algorithm including recommended timeframes, with surgical intervention as a last resort.[45]

Surgical treatment options of refractory Achilles tendinopathy generally aim to remove pathological tissue and stimulate a healing response.[45 48-50] Augmentation or reconstruction may be performed when a large portion of the Achilles tendon is resected.[48]

With regard to prognosis, in the series by Paavola et al. 67% returned to full physical activity after 7 months, and 83% were either asymptomatic or had mild pain during strenuous activities.[50] Similar to Achilles tendon rupture, the post-operative rehabilitation program is likely to be an important determinant for clinical outcome.[45]

TAKE HOME MESSAGE

The calf muscle complex is commonly injured in sports. The majority of injuries can and should be treated conservatively. However, there are several indications for surgical intervention. These include compartment syndrome, Achilles tendon rupture, refractory Achilles tendinopathy and recalcitrant musculotendinous injury.

Achilles tendon rupture in the athlete and compartment syndrome are absolute indications for surgical intervention. Especially in acute compartment syndrome, rapid surgical intervention is necessary in order to prevent devastating irreversible damage.

Musculotendinous injury, intramuscular tendon injury and Achilles tendinopathy are primarily treated conservatively. However, when symptoms and dysfunction persist despite adequate (conservative) therapies, surgery may be indicated.

There is high pressure on athletes and medical staff to return to the pre-injury level as fast and as safe as possible.

Therefore, recognizing injuries that will benefit from surgical intervention in terms of quicker return to play with better function is paramount.

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Combining both current best practice with scientific evidence is considered the gold standard in the creation, implementation and delivery of the football medicine and science program. In the true spirit of FC Barcelona, we are 'mes que un club' (more than a club) and in the creation of this Muscle Injury Guide: 'Prevention of and Return to Play from Muscle Injuries' we have welcomed into our football family, over 60 sports medicine and performance practitioners and applied researchers operating at the highest levels of team-sports and research.

Our aim with this practical recommendations Guide was to bridge the gap between what is done in practice with what the highest quality evidence from scientific research is telling us. We do not intend this Guide to be a 'must follow recipe' but rather to provide some key ingredients that you can adapt and integrate appropriately into your own practice and in your specific circumstances.
By identifying key gaps between current practice and scientific evidence we aim to also provide some key directions for future research for those readers in applied research roles.

We hope you enjoy reading the combined knowledge and experiences of FC Barcelona, Oslo Sports Trauma Research Centre and the many internationally renowned contributors included throughout the Guide.

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