BARÇA
INNOVATION HUB

MUSCLE INJURY GUIDE:

Prevention of and Return to Play from Muscle Injuries

Editors:
Ricard Pruna
Thor Einar Andersen
Ben Clarsen
Alan McCall

Senior Editorial Assistant:
Steffan Griffin

Editorial Assistant:
Johann Windt

FIFA MEDICAL CENTRE OF EXCELLENCE

SCIENCE & MEDICINE IN FOOTBALL

Oslo Sports Trauma RESEARCH CENTER

SECTION LEADERS

Clare Ardern
Roald Bahr
Aaron Coutts
Maurizio Fanchini
Phil Glasgow
Tero Jarvinen
Lasse Lempainen
Andrea Mosler
James O'Brien
Tania Pizzari
Nicol van Dyk
Markus Waldén
Arnlaug Wangensteen

INTERNATIONAL CONTRIBUTORS

Abd-elbasset Abaidia
Khatija Badhur
Natalia Bittencourt
Mario Bizzini
Ida Bo Steenhal
Martin Buchheit
Phil Coles
Aaron Coutts
Michael Davison
Gregory Dupont
Caroline Finch
Brady Green
Martin Hägglund
Shona Halson
Joar Harøy
Per Hölmich
Franco Impellizzeri
Gino Kerkhoffs
Ozgur Kilic
Justin Lee
Matilda Lundblad
Nicolas Mayer
Robert McCunn
Tim Meyer
Haiko Pas
Noel Pollock
Janne Sarimo
Anthony Schache
Andreas Serner
Karin Silbernagel
Adam Weir
Jonas Werner
Nick van der Horst
Anne D van der Made

FC BARCELONA CONTRIBUTORS

Juanjo Brau
Xavi Linde
Antonia Lizárraga
Sandra Mecho
Edu Pons
Jordi Puigdellivol
Xavi Valle
Xavi Yanguas

EXERCISE-BASED MUSCLE INJURY PREVENTION (EBMIP) GROUP (see section 1.4.4a)

Andrea Azzalin
Andreas Beck
Andrea Belli
Martin Buchheit
Gregory Dupont
Maurizio Fanchini
Duccio Ferrari Bravo
Shad Forsythe
Marcello Iaia
Yann-Benjamin Kugel
Imanol Martin
Samuele Melotto
Jordan Milsom
Darcy Norman
Edu Pons
Stefano Rapetti
Bernardo Requena
Roberto Sassi
Andreas Schlumberger
Tony Strudwick
Agostino Tibaudi

DESIGNER AND PUBLISHER

FCB Marketing
Department

BARÇA
INNOVATION HUB

Muscle Injury Guide:
Prevention of and Return to Play from Muscle Injuries

Editors:
Ricard Pruna
Thor Einar Andersen
Ben Clarsen
Alan McCall

Senior Editorial Assistant:
Steffan Griffin

Editorial Assistant:
Johann Windt

Summary

E. Editor's biographies

0. Introduction to the Guide

1. General Principles of Preventing Muscle Injury

2. General Principles of Return to Play from Muscle Injury

3. RTP from Specific Muscle Injury

2

General principles of Return to Play from Muscle Injury

2.1.1

RETURN TO PLAY FROM MUSCLE INJURY: AN INTRODUCTION

The previous section on preventing muscle injury in football has outlined various strategies and tools that can be adopted to minimise the risk of players incurring a muscle injury. While in an ideal world we would be able to prevent all muscle injuries from occurring this is unfortunately, impossible. As outlined in our 'Injury Landscape' article (1.2.1.) a professional football team can expect around 16 muscle injuries in a season.

— With Ricard Pruna, Alan McCall and Thor Einar Andersen

As such we need to be optimally prepared to deal with muscle injuries when they come. Following a muscle injury (or any injury for that matter) there are 2 main objectives (and at the same time challenges); 1) to return the player to match-play as soon as possible and 2) to avoid re-injury. There is a fine balance to this, which is complex depending on the context of each individual player, injury and circumstance (figure 1).

<
Figure 1 Objectives (and challenge) of returning a player from injury.

In football, the decision to progress or delay a players' return to play following muscle injury, could be the difference between having a player back two matches earlier (increasing the chance to win 6 points) versus keeping the player out an extra two weeks, lowering his/her injury risk, but maybe gaining fewer points from those two matches.[1] Essentially, it comes down to a decision on an agreed 'level of risk' (for re-injury) that the team is willing to accept i.e. a shared decision of medical, performance practitioners, the coach and the player him/herself.

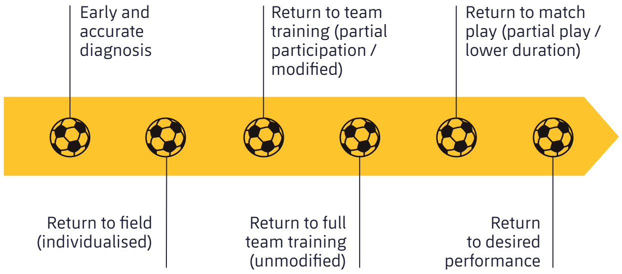
The purpose of this chapter on 'General Principles of Return to Play from Muscle Injury', as with the previous prevention section, is to bring together the best of research knowledge and demonstrate how we combine this with our practical experience and knowledge. Providing you with general principle to follow during the return to play process.

2.1.2

RETURN TO PLAY IN FOOTBALL: A DYNAMIC MODEL

There is a paradigm shift occurring in the way we think about return to play. Instead of return to play being the highly anticipated event occurring at the end of a rehabilitation program, we now consider that return to play starts the moment the injury occurs and continues beyond the point where the player is returning to unrestricted match play (Figure 1). This type of progression is individual and malleable, allowing for faster and slower individual progressions throughout the return to play plan.

— With Clare Ardern and Ricard Pruna



<
Figure 1
Football return to play continuum (adapted from Ardern et al.[1])

The concept of return to play as a continuum was introduced in the Bern 2016 consensus on return to sport,[1] and is something familiar to FC Barcelona clinicians and practitioners, who have been practicing in this framework for the past decade. The purpose of this section is to outline 6 guiding principles for return to football after muscle injury and highlight 4 key considerations for the decision-making team.

GUIDING PRINCIPLE 1

Making an accurate diagnosis is the cornerstone of effective injury management and return to play planning. 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.[2] 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.

THE BARÇA WAY

Working backwards from an anticipated return to desired performance date – which is usually a specific game – helps motivate the player and facilitates effective communication with the manager and performance team. Progress towards the goal is continuously assessed using the milestones in the return to play continuum. In this way we can see whether the player is on track, behind, or ahead of schedule.

GUIDING PRINCIPLE 2

Return to play plans must be tailored to the individual player, who has an individual injury and an individual return to play continuum. An individualised plan is responsive to the needs of the player to appropriately consider factors that might influence prognosis, and those that could influence the risk for reinjury at any stage through the return to play. A one-size-fits-all approach is insufficient in professional football, given the multifactorial nature of return to play, and the need to address specific individual factors based on the player's needs.

GUIDING PRINCIPLE 3

Appropriate loading throughout the return to play continuum is important to stimulate satellite cells to promote muscle tissue healing, and (in later stages of the return to play plan) to ensure the player is adequately prepared for the demands of return to performance. Structuring the return to play plan so that the player spends as much time as possible doing football-specific, pitch-based training (with appropriate modification, according to impairments and functional limitations) provides two important benefits. First, it facilitates appropriate and specific loading (when combined with a well-structured impairment-focused (e.g. strength, flexibility.) management plan). Second, maintaining contact with the team provides the injured player considerable psychosocial and motivation support.

GUIDING PRINCIPLE 4

Use regular assessment and feedback to reinforce and guide collaborative goal setting. Repeat testing and monitoring can help the player see progress, and this is often especially helpful for players with injuries that have extended time loss. Continual assessment of players' performance, in particular football-specific actions such as repeated sprints and external running loads as well as how they are coping with these through internal load markers (e.g. perceived exertion, fatigue, soreness) and psychological readiness and confidence, may help you and the player monitor the progressive restoration of strength, ability to perform football actions and psychological readiness. The information gathered from regular testing can, in turn, guide goal setting about when it is safe to resume restricted training, unrestricted training and unrestricted match play.

GUIDING PRINCIPLE 5

How you communicate with the injured player is important. Focus on using language that emphasises that return to play is a progression that begins at the time of injury. Return to play is not something that automatically happens once rehabilitation is completed. Use positive language that focuses on what the player can do – whether that is modified individual field-based training, modified team training, or performing as desired in the competitive environment. Focusing on the performance aspect in each phase of the return to play continuum is vital to helping the player maintain the sense of being an athlete,[3] irrespective of whether he or she has achieved the goal performance, or not.

GUIDING PRINCIPLE 6

Keeping the player cognitively engaged in football, even when off the pitch, to maintain the high-level cognitive function required for football is essential. The unpredictable nature of football requires high-level cognitive function for reaction time, decision-making, shifting attention, pattern recognition and anticipation.[4] Keeping the football brain active helps the player stay engaged in rehabilitation. Mental fatigue can impact on performance,[5] and training cognitive function should be part of a standard football conditioning program.[5] Therefore, it is also appropriate to include relevant cognitive challenges throughout the return to play continuum. Strategies to consider include choosing typical football movement patterns or skills where decisions have to be made randomly and focusing on attention and temporo-spatial control.

<
Figure 2
Football-specific d high cognitive demands while performing rapid changes of direction, passing and shooting. The player responds to light signals indicating running direction and whether he/she should pass or shoot. This challenges both the players' spatial awareness and reaction times. In a muscle injury with 6-week prognosis, we would typically introduce this drill following the second week.

FOUR KEY CONSIDERATIONS FOR EFFECTIVE RETURN TO PLAY PLANNING

1. Many factors influence the return to play.1 Physical and mental readiness to return to play are both important aspects, and do not always go hand-in-hand.
2. Use a group of sport-specific functional tests and player-reported outcomes to monitor progression and to judge when the player is physically and mentally ready to return to play.1
3. Support the player to be confident about returning to play by keeping him or her involved with the team throughout the return to play plan, by regularly monitoring progress,[6] and by emphasising football-specific elements throughout.
4. Return to play planning is about managing risk.7, 8 Careful planning and regular monitoring will help the decision-making team appropriately consider risk and implement effective risk minimisation strategies for timely return to play.

2.1.3

ESTIMATING RETURN TO PLAY TIME

When a footballer sustains a muscle injury, their first question is invariably: "how long will this take to recover?" Answering this is not easy,[1-5] but in elite-level football it is vital to make an educated guess. As previously discussed, the RTP continuum begins with the anticipated date of return to optimal performance in mind and works backwards, defining the milestones necessary to achieve that goal. This approach motivates the player, allows the manager to plan effectively, and facilitates good communication and realistic expectations from all involved.

— With Ricard Pruna and Ben Clarsen

Recent research has shown that, when used in isolation, both MRI and clinical assessment findings are poor predictors of RTP time.[1-5] That is because even when the same type of injury occurs, myriad individual and contextual factors influence how quickly each player will recover, and how much risk the player and team are willing to take. Nevertheless, it is our experience that when experienced practitioners consider a range of important factors together, it is possible to estimate RTP time surprisingly accurately.

THE FC BARCELONA APPROACH

The foundation for any RTP estimate is an accurate diagnosis. However, it is also essential to consider player-specific (intrinsic) factors, football-specific (extrinsic) factors and other risk tolerance modifiers. We highlight that practitioners should continuously re-evaluate the initial RTP estimation throughout the rehabilitation process, depending on how quickly the player progresses along the milestones defined in the RTP continuum. Key indicators of whether the player is on-target to meet the anticipated RTP date include regaining baseline strength and flexibility measures, completing high-intensity training sessions comparable to (or even greater than) their anticipated match demands, and demonstrating an appropriate level of football-specific cognitive skills and psychological readiness.

THE STARTING POINT: LOCATION AND EXTENT OF TISSUE DAMAGE

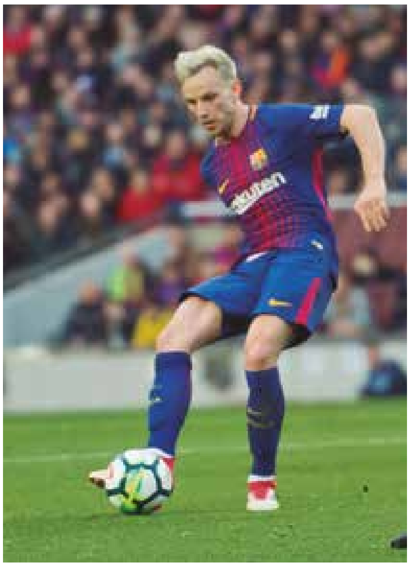
Knowing the exact injury location is arguably the most important factor in predicting RTP time. This is why, at FC Barcelona, clinical assessments are performed and high-quality MRI images are taken as soon as possible after muscle injuries occur. Knowing whether any tendon or bony tissue is involved is vital, as injuries involving these tissues generally heal more slowly and might need referral to a surgeon. In addition, it is necessary to identify injuries to muscle regions that are highly stressed during football, as these need to be managed more conservatively than injuries located in less-stressed regions.

Although the patient history often provides vital information towards making an accurate diagnosis, the initial amount of pain and functional impairment can be misleading when estimating RTP time. Knowing where the injury is located and which tissues are affected provides much more information. For example, hamstring strains located in the middle third of the muscle belly are often severely painful and cause a large haematoma, yet most players return to desired performance within one month – some as quickly as 3 weeks. In contrast, partial ruptures of the proximal hamstrings tendons often initially appear to be minor injuries; they are less painful and their onset is less dramatic. However, these injuries generally take far longer to recover – often up to 10 weeks. The expected return to play times for specific injury locations in the hamstrings, adductors, quadriceps and calf muscles can be found later in this guide.

PLAYER-SPECIFIC FACTORS

Every football player has unique anatomy that will affect his or her recovery from a muscle injury. For example, due to differences in free tendon length, a biceps femoris injury located 5cm from the ischial tuberosity might involve mostly tendon tissue in one player, and muscle tissue in another. Careful examination of each MRI image is therefore necessary.

Variations between players' connective tissue quality may also affect an injury's recovery time. Although this may be determined by genetic factors that we are currently unable to identify with certainty. A history of frequent muscle injury can be a good indication of poor connective tissue quality. More conservative RTP plans should therefore be made for frequently injured players.



FOOTBALL-SPECIFIC FACTORS

Each player's unique role on the pitch needs to be considered when estimating the RTP time. For example, wide defenders and wingers perform more high-speed running than other players so hamstring injury rehabilitation may take longer for players in those positions. Similarly, central midfielders frequently perform rapid direction changes, which places high demands on their adductor muscles. Key positional demands and their consequences for muscle injury rehabilitation are summarised in Table 1.

Additionally, each player has a unique playing style that may also affect his or her RTP plan. For example, some players have an aggressive style, chasing every ball and pressing opponents throughout the whole game. Others are more tactical and therefore more economical with their energy expenditure.

Finally, muscle injuries located in players' dominant and non-dominant legs may have markedly different recovery time, and even different management plans. For example, partial ruptures of the proximal rectus femoris direct tendon are possible to treat conservatively if they are in the non-dominant leg, but the same injury in the dominant leg is a clear case for surgery.

POSITION	KEY DEMANDS	CONSEQUENCES FOR MUSCLE INJURY
Goalkeepers, central defenders	Long kicks and jumps	High stress on rectus femoris
Full backs, wingers	High speed running, rapid acceleration and deceleration	High stress on hamstrings
Central midfielders	Frequent direction changes	High stress on soleus
Strikers, attacking midfielders	High speed running, acceleration and deceleration and direction changes	High stress hamstrings and adductors

<
Table 1
Key positional demands and their potential consequences on muscle injury rehabilitation

RISK TOLERANCE MODIFIERS

Whenever a player returns to football after a muscle injury, there is always a risk that the injury will recur. Generally, the sooner the player returns, the higher the re-injury risk. However, it is impossible to know the exact risk in each situation. Therefore, every RTP decision is a "judgment call", ideally made by the player, the medical team, and the coaching and performance team together.[6] The decision is based on a range of factors, such as:

- Whether the injured tissues are likely to have healed sufficiently to tolerate the loads of competitive football
- Whether the milestones along the RTP continuum have been achieved
- If the player feels psychologically ready to return

Importantly, the RTP decision is also highly dependent on the level of re-injury risk that the player and others (e.g. medical and performance team, team manager) are willing to take. Will they accept a re-injury higher risk and return to play early, or reduce the risk by returning more slowly? This is influenced by a wide range of contextual factors called risk tolerance modifiers.[7] These include factors directly related to football, such as the importance of the upcoming games, the importance of the player, and the availability of replacement players, as well as others such as financial factors (e.g. the player is currently negotiating a new contract) or psychological factors (e.g. pressure from self, family, agents etc).

A number of risk tolerance modifiers, in particular those that are directly football-related, can be identified as soon as the injury occurs. These should be considered when estimating RTP time.

PUTTING IT ALL TOGETHER

As illustrated in Table 2, making the RTP estimate for a specific muscle injury involves adjusting the normally expected RTP time upwards or downwards, based on player-specific factors, football-specific factors, and risk-tolerance modifiers.

This process requires medical knowledge, football knowledge and experience, and should be considered an art just as much as a science. We highlight that throughout this section we have used the term estimation, rather than prediction. None of us owns a crystal ball. However, using a guiding framework can help even inexperienced practitioners make more accurate and consistent RTP estimations.

	PLAYER 1	PLAYER 2
Injury location and severity	Biceps femoris tear involving the intramuscular tendon rupture, located in the middle third of the thigh	Biceps femoris tear involving the intramuscular tendon rupture, located in the middle third of the thigh
"Normal" RTP time for this injury	4 weeks	4 weeks
Player-specific factors	1st injury in this location (no change to initial RTP estimate)	3rd injury in this location (Indicates poorer quality connective tissue: +1 week)
Football-specific factors	Central midfielder, tactical playing style (no change)	Wing back, aggressive playing style (High sprint demands: +1 week)
Risk-tolerance modifiers	Key player in the team. Injury occurred in February, 3 weeks before Champions League semi-final (Higher risk acceptable: -1 week)	Player not normally in starting 11. Injury occurred in October (Lower risk strategy: +1 week)
Estimated RTP time	3 weeks	7 weeks

<
Table 2
Example of how the same injury can lead to markedly different RTP time estimates

2.2.1

MAKING AN ACCURATE DIAGNOSIS

When an injury occurs during training or match play, the essential questions to answer as clinician on-field are: where is the localisation of the muscle injury, what type is the injury and, can the player continue to play? In most cases, the player should be taken off the field for further assessments and acute injury management according to the PRICE principle (protection, rest, ice, compression, elevation).
— With Thor Einar Andersen, Arnlaug Wangensteen, Justin Lee, Noel Pollock, Xavier Valle

The first step off-field is a comprehensive clinical examination including detailed patient injury history taking and careful physical assessments. In cases where the clinical appearance and severity is unclear and determining the optimal treatment can be difficult, supplementary radiological imaging can provide important additional information to confirm the radiological severity of the injury and guide further treatment. Making an accurate diagnosis is essential to ensure that injured players receive appropriate treatment and correct information regarding their prognosis.[1] This chapter will discuss the initial and subsequent clinical and possible radiological assessments to enable the clinician to confirm an accurate diagnosis.

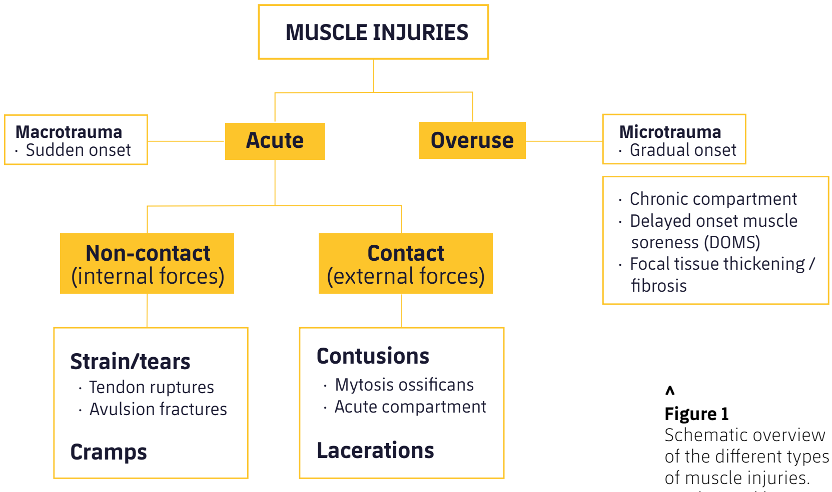


Figure 1
Schematic overview of the different types of muscle injuries. Tendon and bone injuries (avulsion fractures) are included as sub-classifications of muscle strain injuries, as they may appear to be muscle injuries with similar mechanisms and often similar clinical presentation. (Reprinted with permission from Wangensteen 2018[2]).

ON-FIELD MANAGEMENT

Working on-field as a clinician, with the pressure of limited time and the requirement to act quickly when an acute injury happens, the purpose of the initial assessment is to answer some important questions: Is there a muscle injury and where and what type is the injury? And can the player continue to play or not?

Typical signs of an acute muscle injury to identify include, an acute onset of pain where the player is able to recall the inciting event, pain or discomfort with isometric contraction, stretching, and palpation of the injured muscle. In many cases the range of motion (ROM) is restricted. In the section below, we present a guide on how to establish a tentative diagnosis.

Signs that the player may be able to continue to play include, for example, muscle cramps that resolve quickly with no residual symptoms, or mild contusion injuries with no loss of function and minimal pain. However, we encourage the practitioner to err on the side of caution. If in doubt, take them out.

The acute management should be initiated as soon as possible. Despite little evidence basis for the early management of acute muscle (strain) injuries[3], the PRICE principle is traditionally considered the cornerstone for treating acute soft tissue injuries.[4,5] POLICE (protection, optimal loading, ice, compression, elevation) is suggested as an alternative acronym, where optimal loading means replacing rest with a balanced and incremental RTP program where early →

activity encourages early recovery.[6] It is important to initially differentiate between contact and non-contact injuries. In contusion injuries, such as quadriceps contusions, the injured muscle is recommended to be stretched towards maximum during compression in order to minimise hematoma formation (by increasing the counterpressure),[7–9] whereas muscle strain injuries should not be elongated towards outer ranges during the initial management to avoid additional strain and damage.

Later in this section, we describe specific clinical examination tests for the most common muscle injury locations in football – the hamstrings, adductor, quadriceps and calf muscles. The initial clinical examination should be performed as soon as the player leaves the field and with daily follow-up examinations until the correct diagnosis is established. In the following section, we outline a systematic approach to the clinical examination of muscle injuries.

PATIENT HISTORY

A thorough injury history forms the foundation of diagnosis. In fact, in many cases it is possible to accurately diagnose the injury based only on the injury history. The most important questions regarding the injury situation and mechanism, symptoms, previous injury history and workload are shown in Table 1. More detailed information specific to each muscle injury location can be found later in this section.

OFF-FIELD EXAMINATIONS

Clinical examination, including patient history taking and physical assessments, is the cornerstone in the diagnosis of any muscle injury and should be the first step before any further investigations are performed.[10–12] The primary aim of the clinical examination is to determine the type, location and extent of the injury and whether imaging and/or other investigations are needed. In addition, clinical examinations form the basis for further RTP decisions, and are valuable as the foundation for re-testing and comparison when considering information to be provided for the RTP decision-making process. The clinical examination may provide a rough estimate of the severity and time needed to RTP, although further evaluation and observation is likely to increase the accuracy of this estimation. Clinical assessment, in conjunction with imaging, can also identify the rare cases when early surgery is required.

<
Table 1
General patient history questions for muscle injuries

Injury situation	When did the injury occur? During game or training? (timing) First, middle or last part? (register minutes of the game) Season: beginning, middle, end, out of season How did the injury occur? Injury mechanism Contact or non-contact? (i.e. contusion or strain?) Exact movement; high speed running – acceleration/deceleration (typically hamstring); kicking (typically adductor and rectus femoris), stretching; changing directions/cutting; jumps/take offs/landings; towards excessive outer ranges (NB total ruptures!) Forced to stop immediately? Weightbearing impossible or restricted? (might indicate severity) Able to continue? Able to continue with restrictions? 'Popping' feeling and/or sound at time of injury? (might indicate severity and suspicion of total rupture)
Pain	Location (where does the player report pain) Onset: acute or gradual? Severity (a visual analogue scale or a numeric rating scale of 0-10 can be helpful): • at the time of injury onset • today (at time of examination) • at rest Time to pain free walking? Function: • pain with walking? • pain with ascending/descending stairs? • specific activity provoking pain? Other aggravating factors?
Previous injury history	Is this a re-injury? Any feeling of tiredness/discomfort/pain last 7 days before injury onset? Previous injury of same type (location) and side? Previous injury of same type (location), other side? Other muscle injury? (specify) Other injuries and/or complaints • low back pain • fractures • other
Workload	Previous last training and games played (last week/month) Intensity/workload last week/month
Other questions	Initial treatment received Factors that might influence general recovery – e.g. poor sleep, nutrition, recent long-haul flights

Gait and function	Walking: - antalgic gait pattern? - need for crutches? Jogging: - able to jog? Other functional movements (observe ability to and quality, register pain): - two leg squat - one-leg squat - trunk flexion (hamstrings) - calf raises (gastrocnemius) - jumping, kicking and change of directions (minor injuries)
Inspection	Visible ecchymosis (bleeding / hematoma) Swelling? Visible disruption? 'Bulk' / 'gap'?
Palpation	Tenderness / pain provocation with palpation is useful for identifying the specific region/muscle injured, as well as the presence or absence of a palpable defect in the musculotendinous junction. Importantly, detection of any discontinuity or 'gap' at the proximal or distal tendinous insertion should lead to suspicion of a total rupture and should be further investigated and confirmed or disproved by MRI. Location and length of pain Palpable disruption/discontinuity of muscle/tendon Insertional pain
Active and passive range of motion (ROM) testing	ROM is assessed as the presence of pain, the intensity of pain (VAS or NRS) and/or objective in grades with goniometer/inclinometer (°). Active ROM: the player is asked to perform an active ROM exercise without assistant and the restriction of ROM compared to unaffected side is registered. The tests depend on the muscle suspected to be injured but are always instructed to be performed first with a slow motion, thereby with increased speed if appropriate. Passive ROM: is used to elicit muscle stiffness/ assess muscle length. By applying excessive stress/overpressure at the end range, the test might reproduce the player's symptoms.
Isometric pain provocation	The affected muscle or muscle group is tested isometrically at different ranges, commonly by the clinician applying resistance that the player is asked to withstand. Often, a 'brake' test is performed at the end of the test (f.ex after 3 seconds) to assess the eccentric component. The amount of force required to provoke pain can be quantified using a HHD.
Muscle strength/ muscle capacity	Muscle strength of the affected muscles or muscle group is tested either manually or objectively by HHD to detect any weakness / deficit compared to the unaffected side.
Neural tension tests	The mobility of pain-sensitive neuromeningeal structures might be assessed by relevant neural tension tests related to the specific muscles or muscle groups tested. Straight leg raises (SLR) and slump tests are for example used after hamstrings injuries, as involvement of the sciatic nerve is a potential source of pain in the posterior thigh.
Other	Clinical examination of the joints above and below the injury may provide information about contributing factors for the muscle injury.

PHYSICAL EXAMINATION

The physical examination should start with careful inspection and an assessment of function, followed by palpation, active and passive ROM testing, isometric pain provocation and muscle strength testing. Finally, additional tests (such as neural sensitive structures, pulse etc.) can be performed (Table 2). We recommend starting with the uninjured side, as this provides the player with a reference as to what feels 'normal', before examining the injured side. Normally, pain experienced during the different tests is recorded, where pain indicates a positive test and no pain indicates a negative test. Visual analogue scales (VAS) or numeric pain rating scales (NRS)[13,14] are commonly used in order to quantify the player's pain. Objective measurements, for example using goniometers and HHD's, might be useful in order to quantify side-to-side differences or deficits, and to track progression during the RTP process. In section 3, specific physical tests and objective measurements for each of the specific muscle injury locations are elaborated and discussed.

<
Table 2
Overview of general physical examination tests for muscle injuries used to establish a diagnosis. for muscle

IMAGING AND OTHER SUPPLEMENTAL INVESTIGATIONS

Imaging investigations assist in confirming the initial clinical diagnosis and may help guide the RTP estimation. Magnetic Resonance Imaging (MRI) and ultrasonography are normally the recommended modalities to assess muscle injury, although X-ray and CT are occasionally indicated.[15,16]

MRI

MRI using fluid-sensitive techniques (fat-suppressed spin-echo T2 weighted) is ideally suited since it allows the detection of oedema and fibre disruption (tear) at the site of the damage in the first hours after the injury and to provide an objective assessment of the intramuscular and extra-muscular tendon of the muscle. MRI provides a complete assessment of the whole muscle-tendon-bone unit.[15]

At FC Barcelona, MRI is initially used to identify the location and extent of tissue damage. In addition, MRI is used at specific time points during the RTP process to ensure there is no increased oedema or connective tissue gap (see Section 3 – Return to Play from Specific Muscle Injury)

ULTRASONOGRAPHY

Ultrasonography of acute muscle injury may be an alternative, or an adjunct to MRI.[15,16] Muscle oedema is not as reliably delineated on ultrasonography as it is on MRI and assessment of a retracted tendon within a complex haematoma may also be challenging. However, ultrasonography is a higher spatial resolution technique than MRI, and is quicker and cheaper to perform.[15] Most importantly, ultrasonography allows dynamic assessment of the muscle injury. Ultrasonography can also be used in follow up to assess haematoma resorption and the early detection of calcification.[16]

X-RAY AND CT

X-ray of the affected limb is indicated in two situations:

1. When bony avulsion of the tendon attachment is suspected. This is particularly relevant to the adolescent athlete where one might suspect an apophyseal avulsion injury.[17,18] A cortical avulsion may not be visible on MRI as the fragment is often low signal within a retracted low-signal tendon.
2. Full-delineation of myositis ossificans. CT scans may confirm a diagnosis of myositis ossificans following direct muscle trauma.[15] The CT demonstrates classic "egg-shell" appearance of the calcification.

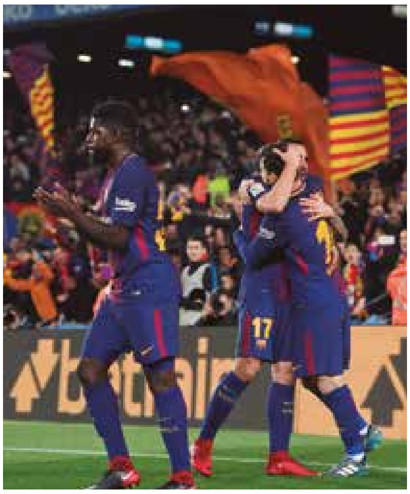
MUSCLE INJURY GRADING AND CLASSIFICATION SYSTEMS

Following the initial examinations, clinicians commonly assign a grade or classify the muscle injury based on the clinical and/or radiological signs and symptoms. An injury 'classification' refers specifically to describing or categorising an injury (for example by its location, injury mechanism or underlying pathology), whereas a 'grade' provides an indication for clinical and/or radiological severity of the injury.[19] Using a grading or classification may ease the communication between clinicians. Although there has been several clinical and radiological grading- and classification systems purposed for muscle injuries, there are currently no uniform approach or consensus to the categorisation and grading of muscle injuries.[19,20] An overview of some of the most common grading- and classification systems purposed are discussed below and summarized in Tables 3 to 7. Radiological systems have historically categorised muscle injuries with simple grading systems based on the severity/extent of the injury ranging from 0-3 representing minor, moderate and complete injuries,[19,21–23] and these have been widely used among clinicians and researchers.[24] The four grade modified Peetrons classification is based on an ultrasound ordinal severity grading system,[22] first described for MRI findings after hamstring injuries among European professional football players in a →

larger study from the UEFA Elite Club Injury Study.[23] It has also been applied for other muscle groups[25] (see Table 3). Radiological grading using modified Peetrons have shown correlations with lay-off time after acute hamstring injuries[23,26,27] and quadriceps injuries.[26] However, this grading system has been criticised for being too simplistic, without considering the anatomical location and specific tissue involvement.[19,28] Thus, the diagnostic accuracy and prognostic value of these grading systems are questionable[19] and the prognostic value of MRI has recently been reported as limited.[29,30]

New MRI classification systems including both the extent (severity grading) as well as the anatomical site/location of the injury has been proposed.[28,31] For example, Chan et al.[31] described a comprehensive system to classify acute muscle injuries based on the severity of imaging assessments using MRI or ultrasound and the exact anatomical site (including the proximal or distal tendon, proximal or distal musculo-tendinous junction and muscular injuries). The British Athletics Muscle Injury Classification[28] grades muscle injuries from 0-4, based on MRI parameters of the extent of injury and classifies the injuries according to their anatomical site within the muscle (Table 5). In total, the classification constitutes 11 grading categories combining the severity grading and the anatomical site classification. There is evidence in hamstring and soleus muscle injuries that those injuries which involve the tendon are associated with longer time to RTP[32–36] which would be expected by an understanding of tendon healing and adaptation to load. The British Athletics Muscle Injury Classification has been assessed for reliability in two radiological studies[37,38] and shown associations with RTP in one retrospective clinical review,[33] but further work is required to investigate its prognostic significance and relevance among football players. The Munich consensus statement classification system[39] was developed for muscle injuries in 2012, differentiating between functional muscle disorders and structural muscle injury (Table 4). It has shown a positive prognostic validity among professional football players in a correlation study.[40] However, the differentiation between 'functional' and 'structural' has been criticized.[28,41]

A strength with using more detailed classification systems including grading and severity, is that they force a more accurate description of the injury with a more diagnostic precision and defined tissue involvement, which may aid clinicians when communicating with other professionals, athletes or coaches. However, more comprehensive classification systems may compromise on the ability to provide an accurate prognosis. One of the problems is that there are large individual variations in time RTP within each of the categories,[42] and the evidence here is scarce. The most important may be that clinicians specify which classification or grading system they are using to avoid misinterpretation and/or miscommunication in clinical practice and research.



GRADE	CLINICAL EXAMINATION		ULTRASONOGRAPHY	MRI
	O'Donoghue (1962)[43]	**Järvinen (2005)[10]**	**Peetrons (2002)[22]**	**Modified Peetrons Ekstrand et al. (2012)[23]**
0			Lack of any ultrasonic lesion	Negative MRI without any visible pathology
I	No appreciable tissue tearing, no loss of function or strength, only a low-grade inflammatory response	Mild (first-degree): strain/ contusion represents a tear of only a few muscle fibers with minor swelling and discomfort accompanied by no or only minimal loss of strength and restriction of the movements	Minimal elongations with less than 5% of muscle involved. These lesions can be quite long in the muscle axis being usually very small on cross-sectional diameter (from 2 mm to 1 cm maximum)	Oedema but no architectural distortion
II	Tissue damage, strength, only a low-grade inflammatory response	Moderate (second-degree): strain/contusion with greater damage of the muscle with a clear loss in function (ability to contract)	Partial muscle uptures; lesions involving from 5 to 50% of the muscle volume or cross-sectionaldiameter. The patient often experiences a "snap" followed by a sudden onset of localized pain. Hypo-and/or anechoic gap within the muscle fibers	Architectural disruption indicating partial muscle tear
III	Complete tear of musculotendinous unit, complete loss of function	Severe (third-degree) strain/contusion: tear extending across the entire cross section of the muscle, resulting in a virtually complete loss of muscle function is termed.	Muscle tears with complete retraction.	Total muscle or tendon rupture.

<
Table 3
Overview of simple clinical and radiological grading systems for muscle injuries

MUNICH CONSENSUS STATEMENT: CLASSIFICATION OF ACUTE MUSCLE DISORDERS AND INJURIES

INDIRECT MUSCLE DISORDER/INJURY:		DIRECT MUSCLE INJURY:
FUNCTIONAL MUSCLE DISORDER		
Type 1	**Overexertion-related muscle disorder**	Contusion
	Type 1A: Fatigue-induced muscle disorder	
	Type 1B: Delayed-onset muscle soreness (DOMS)	
Type 2	**Neuromuscular muscle disorder**	
	Type 2A: Spine-related neuromuscular Muscle disorder	
	Type 2B: Muscle-related neuromuscular Muscle disorder	
STRUCTURAL MUSCLE INJURY		Laceration
Type 3	**Partial muscle tear**	
	Type 3A: Minor partial muscle tear	
	Type 3B: Moderate partial muscle tear	
Type 4	(Sub)total tear Subtotal or complete muscle tear	
	Tendinous avulsion	

<
Table 4
The Munich consensus statement classification of acute muscle disorders and injuries[39]

BRITISH ATHLETICS MUSCLE INJURY CLASSIFICATION

GRADING	ANATOMICAL SITE	COMBINED CLASSIFICATION
Grade 0: Negative MRI	**a**. Myofascial	**0a**: MRI normal
	b. Musculotendinous	**0b**: MRI normal or patchy HSC throughout one or more muscles.
Grade 1: “Small injuries (tears) to the muscle”	**c**. Intratendinous	**1a**: HSC evident at the fascial border <10% extension into muscle belly. HSC of CC length <5 cm.
		1b: HSC <10% of CSA of muscle the MTJ. HSC of CC length <5 cm (may note fibre disruption of <1 cm).
Grade 2: “Moderate injuries (tear) to the muscle”		**2a**: HSC evident at fascial border with extension into the muscle. HSC CSA of between 10%-50% at maximal site. HSC of CC length >5 and <15 cm. Architectural fibre disruption usually noted <5 cm.
		2b: HSC evident at the MTJ. HSC CSA of between 10%-50% at maximal site. HSC of CC length >5 and <15 cm. Architectural fibre disruption usually noted <5 cm.
Grade 3: “Extensive tears to the muscle”		**2c**: HSC extends into the tendon with longitudinal length of tendon involvement <5 cm. CSA of tendon involvement <50% of maximal tendon CSA. No loss of tension or discontinuity within the tendon.
Grade 4: “Complete tears to either the muscle or tendon”		**3a**: HSC evident at fascial border with extension into the muscle. HSC CSA of >50% at maximal site. HSC of CC length of >15 cm. Architectural fibre disruption usually noted >5 cm
		3b: HSC CSA >50% at maximal site. HSC of CC length >15 cm. Architectural fibre disruption usually noted >5 cm
		3c: HSC extends into the tendon. Longitudinal length of tendon involvement >5 cm. CSA of tendon involvement >50% of maximal tendon CSA. May be loss of tendon tension, although no discontinuity is evident
		4: Complete discontinuity of the muscle with retraction
		4c: Complete discontinuity of the tendon with retraction

<
Table 5
The British Athletics Muscle Injury Classification[28]

GRADE	ACTIVE KNEE FLEXION (°)	GAIT PATTERN	TYPICAL PRESENTATION
MILD (Grade I)	**<90°**	**Normal**	May or may not remember incident Can usually continue activity Sore after cooling down or next morning Minimal pain w/resisted knee straightening Might be tender with palpation Full prone ROM +/- Effusion +/- Increased thigh circumference
Moderate (Grade II)	**45-90°**	Antalgic (slight limp)	Usually remembers incident, but can continue activity, although may stiffen up with rest (half-time or full-time) Mild/moderate swelling Pain w/palpation Pain w/resisted knee straightening Limited ROM +/- Effusion +/- Increased thigh circumference
Severe (Grade III)	>45°	Severe limp	Usually remembers incident. Assisted ambulation, difficulty with full weight-bearing Severe pain Immediate swelling/bleeding Pain with static contraction +/- Bulge in the muscle +/- Increased thigh circumference

<
Table 6
Classification of Quadriceps contusion. Adapted from Jackson & Feagin (1973), in Kary et al. (2010)[7] and Brukner & Kahn (2017)[12]

THE FC BARCELONA MUSCLE INJURY CLASSIFICATION – A PROPOSAL

The FC Barcelona muscle injury classification proposal[44] is an evidence-informed and expert consensus-based classification system for muscle injuries developed by experts from three institutions (FC Barcelona Medical Department, Aspetar, and Duke Sports Science Institute); it is based on a four-letter initialism system: MLG-R, respectively referring to the mechanism of injury (M), location of injury (L), grading of severity (G), and number of muscle re-injuries (R) (see Table 7).

MECHANISM OF INJURY (M)	LOCATIONS OF INJURY (L)	GRADING OF SEVERITY (G)	NO. OF MUSCLE RE-INJURIES (R)
Hamstring direct injuries T (direct)	P Injury located in the proximal third of the muscle belly M Injury located in the middle third of the muscle belly D Injury located in the distal third of the muscle belly	0–3	0: 1st episode 1: 1st reinjury 2: 2nd reinjury...
Hamstring indirect injuries I (indirect) plus sub-index s for stretching type, or sub-index p for sprinting type	P Injury located in the proximal third of the muscle belly. The second letter is a sub-index p or d to describe the injury relation with the proximal or distal MTJ, respectively M Injury located in the middle third of the muscle belly, plus the corresponding sub-index D Injury located in the distal third of the muscle belly, plus the corresponding sub-index	0–3	0: 1st episode 1: 1st reinjury 2: 2nd reinjury...
Negative MRI injuries (location is pain related) N plus sub-index s for indirect injuries stretching type, or sub-index p for sprinting type	N p Proximal third injury N m Middle third injury N d Distal third injury	0–3	0: 1st episode 1: 1st reinjury 2: 2nd reinjury...

Grading of injury severity

0: When codifying indirect injuries with clinical suspicion but negative MRI, a grade 0 injury is codified. In these cases, the second letter describes the pain locations in the muscle belly

1: Hyperintense muscle fiber edema without intramuscular hemorrhage or architectural distortion (fiber architecture and pennation angle preserved). Edema pattern: interstitial hyperintensity with feathery distribution on FSPD or T2 FSE? STIR images

2: Hyperintense muscle fiber and/or peritendon edema with minor muscle fiber architectural distortion (fiber blurring and/or pennation angle distortion) ± minor intermuscular hemorrhage, but no quantifiable gap between fibers. Edema pattern, same as for grade 1

3: Any quantifiable gap between fibers in craniocaudal or axial planes. Hyperintense focal defect with partial retraction of muscle fibers ± intermuscular hemorrhage. The gap between fibers at the injury's maximal area in an axial plane of the affected muscle belly should be documented. The exact % CSA should be documented as a sub-index to the grade

r: When codifying an intra-tendon injury or an injury affecting the MTJ or intramuscular tendon showing disruption/retraction or loss of tension exist (gap), a superscript (r) should be added to the grade

<
Table 7
Summary of the proposed FC Barcelona muscle classification system[44]

THE BARÇA WAY: CLASSIFYING MUSCLE INJURIES

The FCB muscle injuries proposal has several key points; the starting point was to incorporate the scientific evidence about muscle injuries at this time within the proposal, the classification was built up within this idea, together with the medical experience of the three sports medicine institutions involved in the project. It is also very important that the structure of the proposal is flexible; the proposal has the capability to adapt to future scientific evidence within the muscle injury field and grow with the future knowledge.

The role and function of connective tissue in force generation and transmission is in our opinion a key factor in the signs, symptoms and prognosis of muscle injuries. Thus, it was one of our purposes to create a grading item that could classify injuries based on a quantifiable parameter (exact % CSA) based on the principle that the more connective tissue is damaged, the greater the functional impairment and the worse the prognosis of the injury will be. The history of an injury plays also an important role, it will not be the same to face a first injury episode than a re-injury or a second reinjury, so the chronology of the injury is included in our proposal.

The purpose is to avoid confusing terminology will help to have and easy communication. The classification is still a theoretical model that needs to be tested and see if it shows an adequate grouping of injuries with similar functional impairment, and prognostic value. The goal of the classification is to enhance communication between healthcare and sports-related professionals and facilitate rehabilitation and RTP decision-making.

2.3.1

EXERCISE PRESCRIPTION FOR MUSCLE INJURY

When a player sustains a muscle injury, the chances of it recurring are high. In fact, epidemiological research consistently identifies previous injury as the most powerful risk factor for muscle injuries.[1] Fortunately, the risk of recurrence can be reduced through careful management of the return to play process, including appropriate prescription of therapeutic and football-specific exercises.

— With Phil Glasgow, Thor Einar Andersen and Ben Clarsen

A carefully planned exercise programme is not only essential to optimise the quality of healing tissues, but also to maintain the player's fitness, skills and football cognition so that when they do return to play, they are ready to perform optimally.

This chapter outlines the general principles of exercise prescription for muscle injuries, including strategies to optimise structural adaptations and maintain football-specific fitness, skills and cognition. The chapter is not intended as a recipe; practitioners need to consider each player individually and assess their progress throughout the entire RTP process.

BEGIN WITH THE END IN MIND

In top-level football, the medical and performance team is under constant pressure to return the player to competition safely, in the shortest possible time. To accomplish this, they need to manipulate a range of training variables to ensure that the player is working at the limit of their capacity, while simultaneously allowing sufficient time and restitution for tissue healing. To define the necessary tissue capacity and functional requirements, practitioners need a detailed understanding of the football-specific activities and level to which the player must return. We refer to this as beginning with the end in mind. At FC Barcelona, this involves a close collaboration between the player and medical, coaching and performance analysis specialists.

STRUCTURED, BUT FLEXIBLE

The RTP process is a dynamic continuum during which the nature and difficulty of exercises are progressed in response to tissue healing and the functional abilities of the player. Every player is unique, and no two injuries are exactly the same. As such, the RTP process should be individualised. The multi-dimensional nature of return to play means that the therapists, strength and conditioning and technical staff must organize several concurrent phases with different goals and milestones.

FACTORS INFLUENCING LOADING PROGRESSION

The most common way of measuring progress in the RTP process is the player's perception of pain.[2] The amount of discomfort tolerated during training should be guided by the rationale for the specific exercise. For example, when the primary goal of the exercise is tissue loading, some discomfort may be acceptable. In contrast, when the focus is to restore movement quality, exercises should be pain-free.

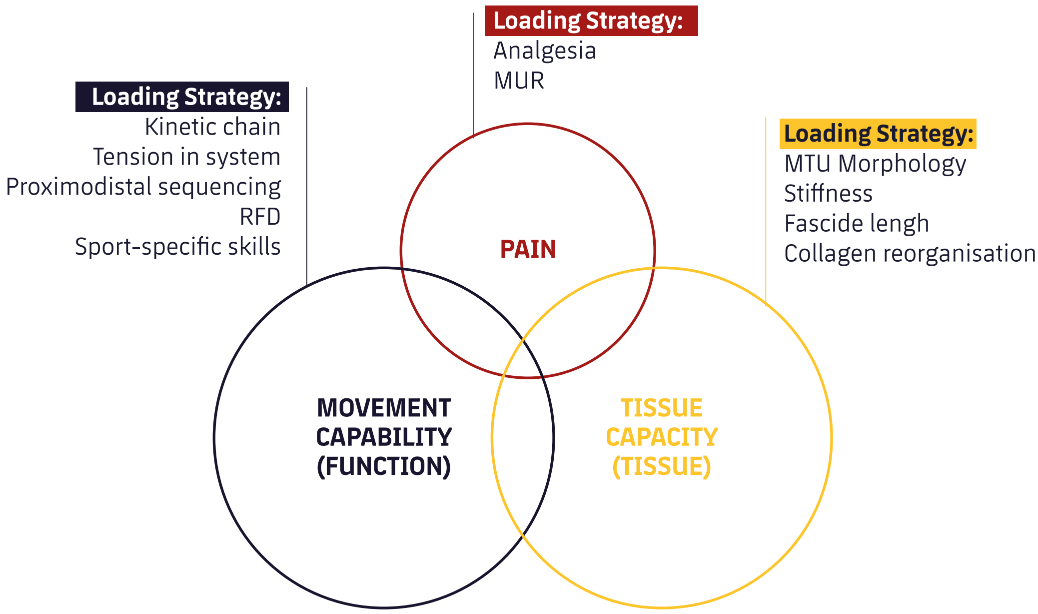
Other tests of muscle function (e.g. Askling's H-test and Isokinetic testing) can also help inform RTP readiness. However, it is important to recognise that no single test can determine the player's ability to progress. Instead, practitioners should use a battery of tests assessing different aspects of function. Execution of sport specific skills with good technique also helps guide progression. Clinical testing for specific muscle groups is discussed in the relevant sections. It is necessary to communicate closely with the player throughout return to play process to ensure the programme aligns with their functional ability, psychological readiness and specific performance demands.

TARGET SPECIFIC ADAPTATIONS

When designing an exercise programme, practitioners should ask a number of simple questions (Figure 1):

- What is happening at a tissue level?
- What outcomes are you trying to achieve with your exercise prescription?
- What is the specific adaptation associated with different exercise or football activity types?
- Is the goal of the exercise to reduce symptoms, stimulate tissue adaptation (tissue capacity) or enhance function (movement capability)?

Once the desired outcome of an exercise or football activity is clear, it is possible to plan progressions to maximise adaptation. For example, where the goal of loading is increased fascicle length, the intervention may be eccentric loading and progression will include addition of load, increased speed and range of motion. In contrast, where the desired outcome is to increase rate of force development, the exercise (or football activity) may be a jump squat and progressions involve a move from high load power (80% 1RM load) to low load power (30% 1RM load).



<
Figure 1
What Are the Goals of Loading? MUR = Motor Unit Recruitment, RFD= Rate of Force Development

TARGET SPECIFIC ADAPTATIONS

The RTP process commences almost immediately following injury with attention given to graduated loading of the injured tissue to facilitate healing. While the main focus of management during the early stages of the RTP process will be directed towards resolving the clinical signs and symptoms, targeted loading of the tissue should also be included. Early loading is an effective stimulus for regeneration and has been shown to result in better outcomes in terms of capillary ingrowth, less fat infiltration, fibre regeneration, more parallel orientation of fibres, less intramuscular connective tissue, improved biomechanical strength and less atrophy.[3]

RESTORING MUSCLE STRUCTURE

Muscle tissue is highly sensitive and adaptable to mechanical loading. Following injury, muscle undergoes a number of changes in structure and function both as a direct consequence of tissue insult and as an indirect consequence of reduced loading and recruitment. These changes include, reduced fascicle length and physiological cross-sectional area (PSCA) as well as alterations in neuromuscular activation.[4-7] The RTP process should therefore focus on restoring muscle structure (especially fascicle length and cross-sectional area).

STRENGTH TRAINING

Adequate strength is essential for safe and effective return to football. During the return to play process, strength training should concentrate on the restoration of injury-related deficits. Lieber[8] has suggested that during the first two weeks of strength training in uninjured, untrained individuals, only 20% of strength increases may be attributed to structural changes. This implies that initial strength gains are primarily due to neuromuscular adaptations. Given that following injury neuromuscular capacity can be significantly diminished, it is reasonable to suggest that it may be more effective during the early stages of return to play to carry out strengthening exercises 'little and often' in order to avoid neural system fatigue and facilitate both structural and neuromuscular adaptations.

EARLY IN THE RTP PROCESS: MOVEMENT IS KEY

Simple isotonic training may be necessary to facilitate motor recruitment in the early stages of the RTP process. The recruitment of muscles throughout range during functional movements often help to restore pain free range of motion and normalise pain. While there is some evidence that isometric contractions may reduce pain in tendinopathy, more dynamic movements tend to be more effective in muscle injury management. Some principles for early strengthening of muscle following injury are summarised below.

As soon as the player can effectively recruit the muscle without significant pain or inhibition, it is important to incorporate eccentric (lengthening) contractions. Eccentric contractions have consistently been shown to result in greater morphological and neuromuscular adaptations than both isometric and concentric training.[9,4,5]

ECCENTRIC EXERCISE IN RTP PROCESS: WHEN AND HOW?

Eccentric exercise has become the mainstay of the muscle injury return to play process. Traditionally, clinicians often delay the introduction of eccentric training until late stage rehabilitation due to perceived risks associated with increased muscle tension and associated muscle soreness. This is also reflected in most RCTs, where eccentric training is often not included until halfway through the RTP process. However, two protocols have included eccentric training from day 5 onwards, and both reported favorable outcomes in terms of RTP time and recurrence rates.[10-12] Importantly, neither study reported adverse effects with the early inclusion on eccentric training.

Although protection of the injured muscle is paramount, low-level, controlled eccentric exercises have the potential to further reduce pain inhibition and facilitate tissue adaptation without causing any further damage. Practitioners must take care to ensure that the player can tolerate the resistance, complexity and range of motion. They should seek to identify ways to stimulate the muscle under lengthening conditions while providing appropriate support and safety. Examples of early stage eccentric training are included in the relevant muscle specific sections and football specific exercises below.

Eccentric training should be maintained throughout the entire RTP process and should target movement-specific adaptations for the affected muscle. For example, for hamstring training should include both knee-flexion dominant and hip-extension dominant movements. Similarly, for quadriceps injury, eccentric exercises should focus on both hip flexion and knee extension. Examples are included in the muscle specific sections.

RESTORING FOOTBALL-SPECIFIC FITNESS, SKILLS AND COGNITION

Muscle injuries have a range of consequences on a player's football performance that need to be addressed throughout the RTP process. Therefore, you have to think wider than just the injured muscle.

At the injury site, the injured muscle and its agonists will lose strength, power, and endurance capacity. The extent to which each of these attributes is affected should be identified using specific testing, for example isokinetic and jumping tests. Thereafter, exercise prescription should specifically address the identified deficits.

Muscle injury results in both structural and neuromuscular deficits. During football sporting activities, muscle is constantly 'tuned' to enable an individual to maintain position, move voluntarily and react to perturbations.[13] Neuromuscular control (NMC) is the product of the complex integration of afferent proprioceptive input, central nervous system (CNS) processing and neuromuscular activation. While great attention has been given to the role of NMC in ligament rehabilitation, it has often been overlooked in muscles.

There is evidence that prolonged deficits in NMC following muscle injury may have a role to play in recurrence. Reduced activation of previously injured biceps femoris long head at longer muscle lengths may be related to shorter fascicles, eccentric weakness and reduced ability to protect the muscle at longer lengths.[14,15] Reduction in the ability of the muscle produce, transfer or modulate load will likely result in an increased risk of reinjury. The RTP process should therefore seek to improve the central nervous system's ability to fine tune muscle coordination and improve the football skill execution; this is discussed below.

It is important when designing strength training programmes that the content reflects how the muscle functions during football. Careful manipulation of training load, volume and frequency can achieve football-specific performance benefits such as increased muscular endurance, running speed or jump height, as well as protection from recurrence.

Muscle injuries also have consequences on the player's general conditioning, including their cardiovascular fitness and their general load tolerance. A comprehensive RTP programme must therefore include general conditioning strategies that replicate the player's normal football demands as much as possible, both in terms of the metabolic pathways involved, and the stresses on musculoskeletal system.

An intelligently designed return to play programme that has the correct combination of contraction type (concentric, eccentric, isometric, plyometric), exercise choice (e.g. free weights vs. machine weights and football activities), load, number of sets, repetitions, speed of contraction and frequency of training can significantly enhance the benefits of training. Principles for progression of strengthening during the mid to late stage of the RTP process include: Max Strength > Longer Muscle Lengths > Rate of Force Development Training > Move from Moderate to High Speed with and without ball and on and off field. Hence, the nature of training used should minimise stress on the injured tissues while simultaneously exercising muscle groups involved in football. This is essential towards the end of the RTP process to adapt to the high demands of match play. The footballer must have trained enough and specific to return to football and performance safely[16]

It is widely accepted that the ability to move part or parts of the body through a wide range of purposeful movements during a sporting event can have a significant influence on football performance and the potential for (re)injury. It is also recognized that that functional ranges of motion during activities such as kicking and long passes exceed those normally measured during clinical assessment.[17] The role of flexibility in the site of muscle injury has been the source of debate for many years with conflicting findings for all major muscle groups.

Tests of multi-segmental whole body mobility[18] and dynamic flexibility[17] have shown strong correlations with injury presentation and may be more useful measures (and interventions) of flexibility during the RTP process. It is suggested that mobility training during the RTP process reflects the range and direction of the movements carried out during the football activities. Rather than a reductionist approach that views flexibility in isolation, clinicians should consider whether a muscle group has adequate flexibility combined with increased strength at longer lengths for safe and effective function.

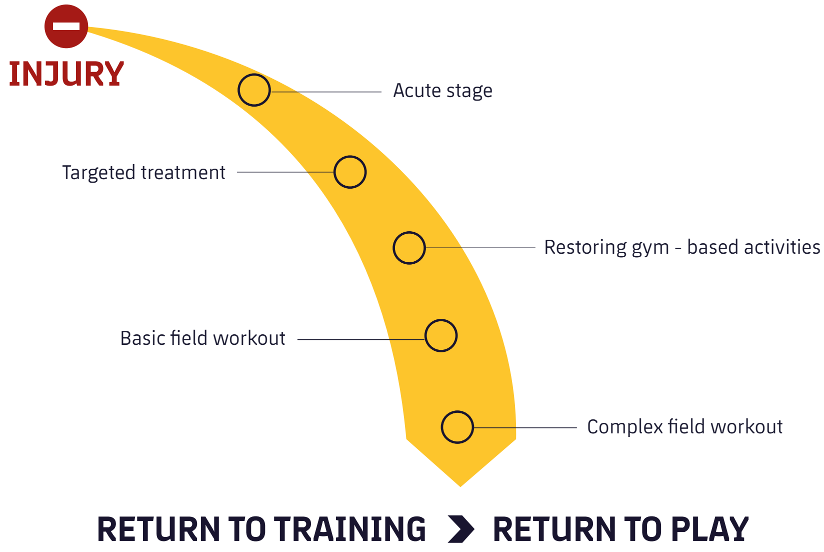
MAINTAINING FOOTBALL COGNITION

As the RTP process develops, the complexity of the task should be increased to involve multiple segments through multiple planes of movement. Early examples of this include football -specific tasks such as dribbling, passing and receiving a ball, snake runs and basic training drills. Particular attention should be given to facilitating effective loading of tissues through functional patterns as well as release and attenuation of force; for example, deceleration and change of direction.

Introduction of unanticipated movements is essential for effective restoration of function. The ability to respond to a dynamic and variable environment is often a key driver in the perpetuation of symptoms. Gradual introduction of physical perturbations facilitates reactive neuromuscular adaptations as well as sudden responses to verbal or visual commands. At all times the quality of the movement is monitored and where maladaptive patterns are adopted, exercises and football activities should be regressed to ensure correct form.

Reintroduction of sport-specific skills, competition and other environmental constraints should focus on widening the movement repertoire of the athlete and allow sufficient time for skill acquisition and consolidation through practice. It is important to incorporate cognitive challenges and decision making into the rehabilitation programme.

At FC Barcelona, every effort is made to return the injured player to modified training participation on the pitch and with the team as early as possible to preserve football technical and tactical skills and cognition abilities. As much as possible should be done with a ball as soon as possible and drills should reflect the demands of the player, such as team tactics, position and role in the team. Data derived from Global Positioning Satellite (GPS) systems during training drills and match play is used to tailor the on-field RTP process individually in close collaboration between medical staff, performance analysts and coaching staff. Specific examples are discussed in the next section.



<
Figure 2
The FC Barcelona 'Return to Play Process'

THE BARÇA WAY:

The above schematic (figure 2) provides an overview of the Return to Play process in FC Barcelona in regards to managing and rehabilitating the injured player. The various components are not step by step i.e. you do not need to complete one before moving to the next; this process is dynamic and components can overlap as the player progresses through the RTP process.

The key point is to get the player moving as soon as is safely possible.

1. The acute stage following the injury can last anywhere from approximately 1 to 3 days. At this very early stage, the focus is on ice and compression.

2. Table treatment is the time to stimulate the muscle and promote healing and gain mobility – e.g. passive and active muscle stretching, isometric and eccentric types of contractions.

3. As soon as possible, it is time to get the player moving in the gym. This component can be (and usually is) a combination of table treatment and gym based exercises, from basic through to more advanced functional exercises (as the progression of the injured player allows). The key is to progress continuously from passive workouts to active workouts.

4. Basic field work – In this component of the RTP process, we start to introduce field based sessions, with varying surfaces. It is important to maintain the gym work here, but to reduce the table treatment. Basic football skills are reintroduced and trained and position specific movements are included.

5. Complex field work – In this part of the RTP process, the basic work in the field is phased out in favour of more advanced skills and movements with decision-making tasks at higher intensities and more challenging. Gym work is still maintained here, in particular as a pre field session activation.

6. As the player has sufficiently progressed through this RTP process, he/she is ready to return to training, starting partial training with the team (maintaining additional work with the physical coaches). With appropriate management of loads, the players demands will be increased until he/she is ready to join 100% with the team.

2.3.2

RESTORING PLAYERS' SPECIFIC FITNESS AND PERFORMANCE CAPACITY IN RELATION TO MATCH PHYSICAL AND TECHNICAL DEMANDS

Restoring the players' specific fitness and performance capacity before joining the team for collective training sessions and competitions is essential
— With Martin Buchheit and Nicolas Mayer

In the lead up to returning to unrestricted football training and play, the players generally train individually with a physical/rehabilitation coach who ensures that the player's locomotor (i.e. running/movement) and technical loads are progressively built in relation to match demands (figure 1), while respecting indices of load tolerance, well-being (i.e. how the player is coping with those loads) and psychological readiness. Importantly, since these individual RTP sessions should prepare the players to train/play with the team within a few days, it is of utmost importance for the ball to be integrated as much as possible, and that specific movement coordination and muscle actions, decision-making, mental fatigue and overall self-confidence are considered continuously.

To illustrate our approach, we provide example of sequential RTP load progressions, i.e., designed for two common muscle injuries (hamstrings and rectus femoris) for two different playing positions in the field (wide defender, WD full back - FB and central midfielder (playing as a '6'), CM) (figure 2). The re-conditioning of both muscle groups requires the targeting of different locomotor patterns (with reference to the selective activation of those muscles in relation to specific running phases[1]); playing positions are also associated with distinct locomotor and technical demands (figure 1), which all need to be taken into account when designing the RTP program. While we acknowledge that there exist large differences in locomotor and technical demands within the same positions due to variations in players' physical profiles, style of play and match context, we have chosen to use the average demands of those 2 playing positions as a starting point to illustrate our methodology. In real-life scenarios, we recommend the systematic use of each player's unique locomotor and technical profile based on historical club data (i.e. from match analysis data) and personal observations (style of play and technical demands).

MATCH DEMANDS

The physical activity performed during matches should be considered as target for the conditioning programming. Assuming that the building up of minutes of play during matches may be progressive as well following an injury (i.e., playing 25-35 min as a sub for the first match post injury), the demands of 1 full half (45 min) to 60 minutes could be considered as the initial pre-competition target. To assess those specific physical demands, we recommend assessing the injured player's locomotor load with respect two distinct types of demands; high-speed running (HSR, which essentially put constrains on the hamstring muscles) and high-intensity actions (HIA) which encompasses all acceleration, deceleration and changes of direction activities and put major constrains on the quadriceps, adductors and the gluts) (figure 1). In the example given, we use mechanical work (MW) as the metric to measure HIA. It is important to note that this metric currently has preliminary validity and reliability only and needs to be tested further in scientific investigations.

However, we use this to illustrate the importance of the distinction between HSR and HIA in relation to individualising the RTP program according to the muscle injury location and player demands.

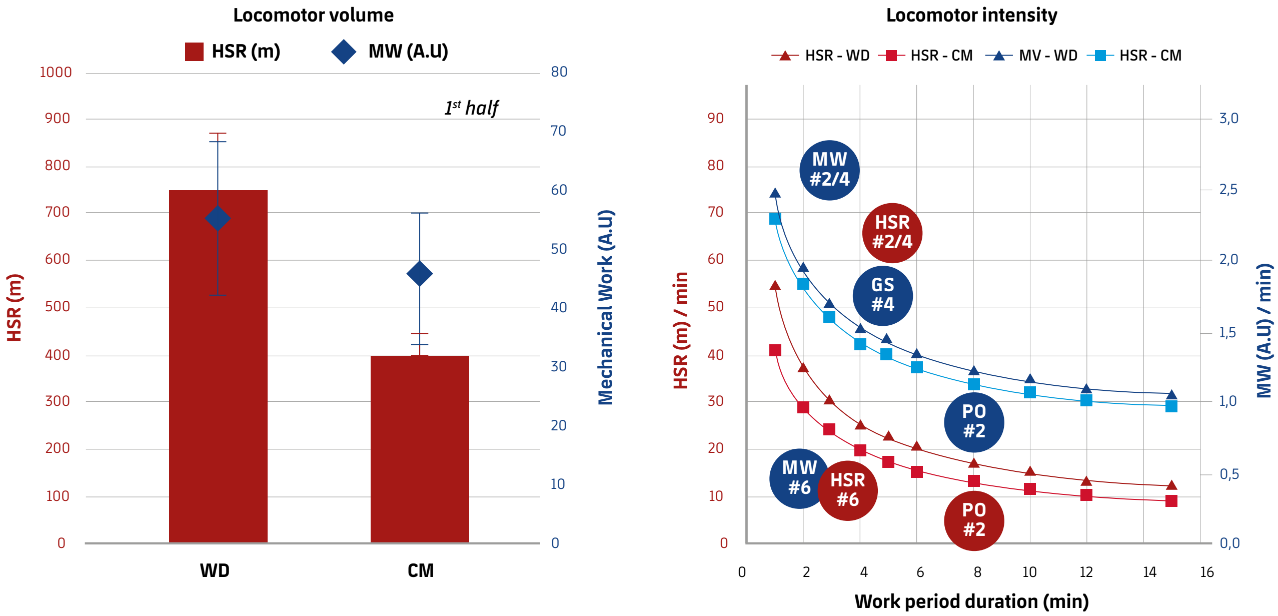
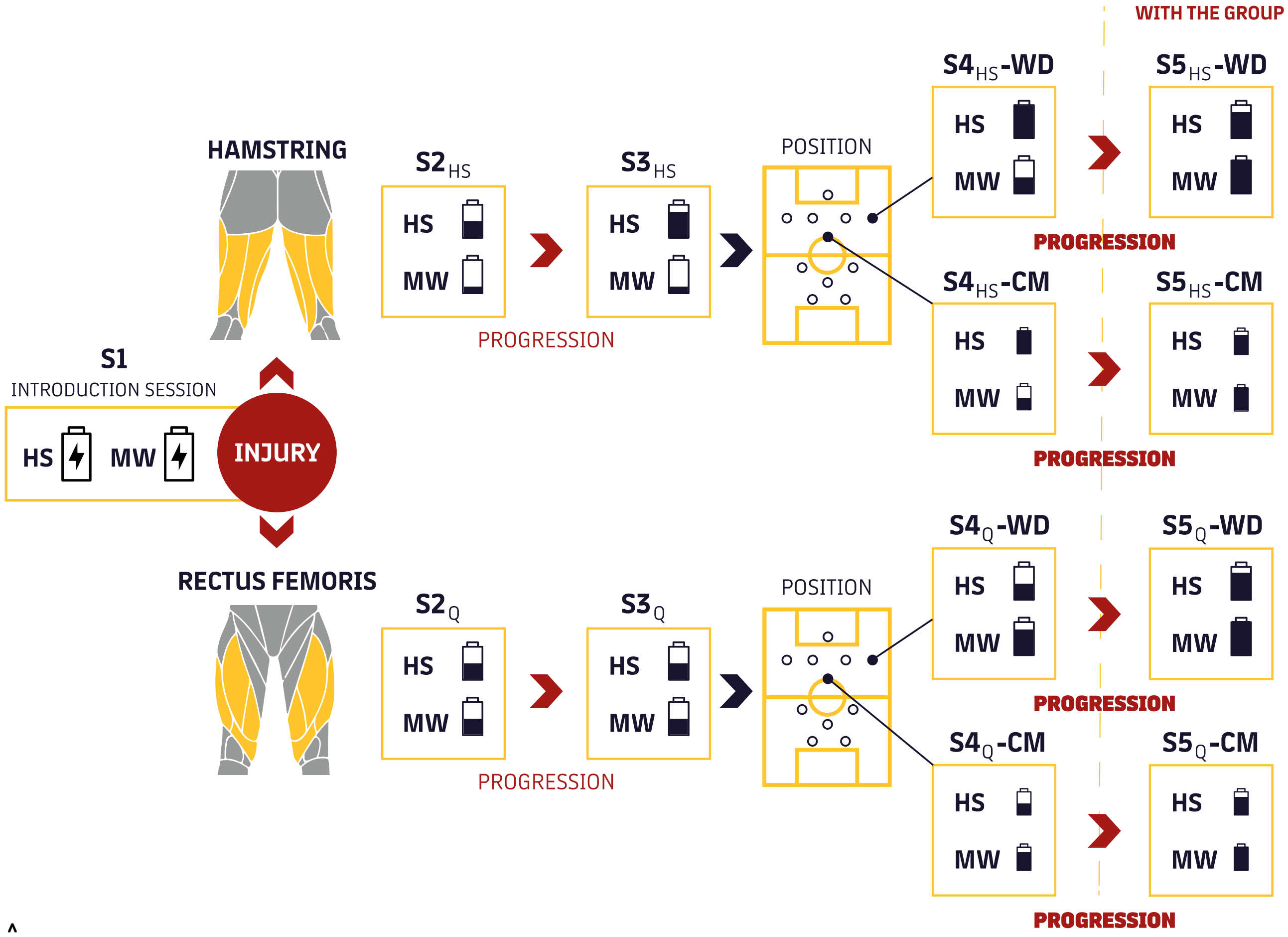


Figure 1
Summary of the worst case-scenarios for locomotor volume demands (± standard deviation, SD) during League 1 and Champions League matches (1st half) for a wide defender (WD) and a midfielder (playing as a '6', CM), in terms of volume (left panel) and intensity (right panel) of high-speed running (HSR) and HIA expressed as mechanical work (MW). Volume refers to the greatest running distances covered during halves (± SD). Intensity is expressed, over exercise periods from 1 to 15 min, as 1) peak distance ran > 19.8 km/h per min, which is used as a proxy of HSR intensity and 2) peak MW per min (adapted from[2]). For example, over block periods of 4 min, CM can cover a maximum of 20 m of HSR / min. Similarly, WD can cover up to 55 m of HSR over 1 min-periods. For figure clarity, SD (~25%) are not provided for peak intensities. Adapted from Lacome et al.[3] The blue and red circles refer to the different specific training drills within S4 sessions, as indicated in Table 1 (HSR) and 2 (WM) with orange and blue backgrounds, respectively. #2/4 refers to the types of high-intensity training sequences with both a high neuromuscular strain and a metabolic component (mainly oxidative energy, Types #2; oxidative and anaerobic energy contribution, Type #4). #6 refers to Type #6 drills involving a high neuromuscular strain (but a low metabolic component), referring to quality high-speed and mechanical work training (long rests in between reps). The HSR and mechanical work intensity of 4v4 game simulations (with goal keeper, GS) and 6v6, 8v8 and 10v10 possession games (PO, without goal keeper) in which player participate at the end of the RTP process (S5, Table 1 and 2) is also shown. HSR intensity is not mentioned for such GSs, since the size of the pitch prevents player to reach such high speeds.

MUSCLE INJURED, LOAD PROGRESSION AND INTEGRATION OF POSITION-BASED PHYSICAL AND TECHNICAL MATCH DEMANDS

It is essential to build the cognitive and technical aspects alongside the locomotor demands. The sessions detailed in Figure 2 and table 1 are designed to target, alongside the integration of player- and position-specific technical tasks i) neuromuscular components in an isolated manner ("quality" sessions, such as Type #6 [4], see Table 1 legend) as well as ii) metabolic conditioning that often also integrates important neuromuscular demands (such as Types #2 or #4[4] see table 1 legend). Neuromuscular training refers to acceleration, deceleration, change of direction (i.e. measured MW as a proxy of HIA), speed and strength training which primarily relies on the performance of the neuromuscular system. Metabolic conditioning refers to the contribution and development of the aerobic and/or anaerobic energy systems.[4] It is important to consider that the progressions in load should be subtle to avoid excessive spikes.[5] We believe that the progressions should also be aimed at building up locomotor loads with alternations in session main objectives (cf tactical periodization paradigm, allowing the physiological quality targeted a given day to recover the following day[6]). This should avoid creating excessive muscle soreness / residual fatigue from one day to the other, and helps players to train every day, which in turn may accelerate their full return to train/competition. Figure 2 illustrates how the locomotor contents of the sessions, in terms of HSR and MW may be modulated in response to 1) the muscle injured and 2) the position-specific locomotor demands. Table 1 and 2 provide the details of the sessions both in terms of locomotor load and technical orientations. For example, after a typical introductory session (S1) the focus/building up of HSR vs. MW differs in relation to muscle injury [with a greater emphasis on progressively building HSR after hamstring (HS) injury (S2HS) vs. building MW after a quadriceps injury (S2Q)]. After some progressions in terms of HSR and MW, the locomotor targets are further adapted based on the player's playing position. Following those final individual sessions (S1-S4), when it comes to transitioning with the team, we request players to participate in some (but not all) team training sequences, and to perform some extra/individualized conditioning work. When taking part to in some of the game situations, we have them playing as jokers (or floaters, being systematically with the team in possession of the ball) for a few days, which has been shown to decrease their locomotor demands by 30% compared with the other players.[2] This offers a relatively safe (less contacts, no defensive role and no shots) and progressive loading for RTP players, while allowing them to be exposed to the most specific types of locomotor (especially decelerations and turns), technical and cognitive demands. This last phase of the RTP process is crucial since it allows players to regain their confidence and in turn, their full match-performance capacity. Finally, before their participation with the team as jokers/floaters, RTP players need sometimes to be exposed to specific warm-up sequences. They should also perform some individual conditioning work post session (in relation to the injury and individual game demands) (table 1 and 2).



^
Figure 2
Example of four sequential RTP load progressions in terms of the volume of locomotor demands, i.e., high-speed running (HSR) and mechanical work (MW). The sessions are designed for two very common muscle injuries (i.e., hamstrings, see details in Table 1 and rectus femoris, see details in Table 2) for two different playing positions in the field (wide defender, WD and central midfielder, MD). The size of the battery represents the actual/absolute volume of match demands (one half), while the coloured part within each battery represents the relative portion of one-half demands that is completed during the given session. Note that the total number of sessions required within each phase is obviously injury and context-dependent.

S1: Introduction session

- Low-intensity running related to sensations (6-8')
- Hip mobility + Running drills
- Agility closed-drills
- Functional work (without the ball)
- Type #1: 2x 4-min set: 6x 20s (slalom run 45° 80m) /20s (jog) (TD > 14.4 km/h ≈ 1000m, MaxV < 16 km/h).
- Cool down (3-5')

S2$_{HS}$:

- Monitoring (1): 4-min run at 12 km/h
- HIP mobility + Running drills
- Agility **closed**-skills (quality)
- Functional work with the ball (preparation)
- Technical Work with a Metabolic component
- Type #1: 1 x 3-min set: 15s (slalom run 65m) /15s (jog) (> 19.8 km/h ≈ 250m, MaxV < 22 km/h)
- Cool down (3-5')

S3$_{HS}$:

- Hip mobility + Running drills
- Agility **closed** to **open**-skills + Technical work
- Monitoring (2): 4 straight-line high-speed runs(box-to-box), 70m in 13s, 30-s passive recovery (> 19.8 km/h ≈ 200m)
- Technical Work Metabolic component + Neuromuscular constraints
- Type #2: 1 x 6min 40s set: 10s (50 m) /20s (passive) + 5s (28 m) /15s (passive) (> 19.8 km/h ≈ 250m, MaxV < 24 km/h)
- Cool down (3-5')

S4$_{HS}$-WD:

- Mobility + Technical work (short pass/volley)
- Running drills + Technical work (control/pass)
- Agility (<10m) + decision (quality)
- Type #6: Speed progression: 1x 10m, 1x 15m, 1x 20m (MaxV > 25km/h, rest between reps: 45s)
- Technical work: being orientated (3/4), dribbling and crossing
- I. Type #2: 1 x 4-min set: 10s (slalom 55 m) /20s (passive) (>19.8km/h ≈ 400m) *
- II. Type #2: Specific WD: 1 x 4-min set: 10s (technical demand: dribbling, passing, crossing) / 20s (passive) (>19.8km/h ≈ 300m)

S4$_{HS}$-CM:

- Mobility + Technical work (short pass/volley)
- Running drills + Technical work (control/pass)
- Agility (<10m) + decision (quality)
- Type #6: Speed progression: 1x 10m, 1x 15m, 1x 20m (MaxV > 25km/h, rest between reps: 45s)
- Technical work: taking information, controlling and COD with the ball, passing (5 to 20m)
- I. Type #2: 1x 4-min set: 10s (COD = 2x 25m)/ 20s (passive) + 5s (constraints)/25s (passive) (>19.8km/h ≈ 200m)
- II. Type #2: Specific CM: 1x 4-min set: 10s (with technical demand: turning, dribbling, passing) / 20s (passive) (>19.8km/h ≈ 150m)

S5hs-WD and S5hs-CM: in addition to taking part into possession games (without goal keeper) and game situations (with goal keepers) with the team as jokers/floaters initially, we recommend players to do some extra Type #6 high-speed runs aiming at reaching close-to-max velocities (with the volume adjusted with respect to distance of the following match). S4HS-WD drills with an orange background refer to the drills shown in Figure 1, right panel.

<
Table 1
Example of session details of the hamstring injury sequential RTP load progressions.

Distance to run are provided for a player with an average locomotor profile (i.e., maximal aerobic speed 17.5 km/h, velocity reached at the end of the 30-15 Intermittent Fitness test (VIFT[7]) of 20 km/h and maximal spring speed of 32 km/h[8]). Note that the physiological objectives of each locomotor sequence (in terms of metabolism involved and neuromuscular load) is shown while using one of the 6 high-intensity training Types as suggested by Buchheit & Laursen.[4] Type #1, aerobic metabolic, with large demands placed on the oxygen (O2) transport and utilization systems (cardiopulmonary system and oxidative muscle fibers); Type #2, metabolic as type #1 but with a greater degree of neuromuscular strain; Type #3, metabolic as type #1 with a large anaerobic glycolytic energy contribution but limited neuromuscular strain; Type #4, metabolic as type #3 but a high neuromuscular strain; Type #5, a session with limited aerobic response but with a large anaerobic glycolytic energy contribution and high neuromuscular strain; and Type #6 (not considered as HIIT) involving a high neuromuscular strain only, referring typically to quality high-speed and mechanical work training (long rests in between reps). Extended from figure 1 in Buchheit & Laursen.[4] Red font: emphasis on HSR running. Blue font: emphasis on MW. Green font: monitoring drills (see below). Text highlighted in orange refers to the HSR drills shown in figure 1 (right panel); Text highlighted in blue refers to the MW drills shown in figure 1 (right panel). Note: Slalom runs with 45° angles are often used (e.g., S1, S2HS) to decrease the actual neuromuscular load: turning at 45° requires to decrease running speed (less HSR) and doesn't requires to apply strong lateral forces (less MW), which in overall make the neuromuscular demands of these runs very low.[1]

See Table 1 for legends. Note: for the S2Q session, 10s/10s is preferred to other HIIT formats for the fact that it requires a greater number of accelerations than with longer intervals, which may help building up this capacity in a controlled and safe manner.

<
Table 2
Example of session details of the quadriceps injury sequential RTP load progressions.

S1: Introduction session

- Low-intensity running related to sensations (6-8')
- Hip mobility + Running drills
- Agility closed-drills
- Functional work (without the ball)
- Type #1: 2x 4-min set: 6x 20s (slalom run 45° 80m) /20s (jog) (TD > 14.4 km/h ≈ 1000m, MaxV < 16 km/h).
- Cool down (3-5')

$S2_Q$:

- Monitoring (1): 4-min run at 12 km/h
- Hip mobility + Running drills
- Agility **closed**-drills (quality)
- Type #6: Mechanical work (45-90°): 6x 5+5m 45° CODx1 / 6x 5+5m 90° CODx1 (r: 45s between reps)
- Functional work with the ball (sensations)
- Type #1: 1 x 4-min set: 10s (slalom 45m) /10s (passive) (> 19.8 km/h ≈ 250m, MaxV < 22 km/h)
- Cool down (3-5')

$S3_Q$:

- Hip mobility + Running drills
- Agility **closed** to **open**-skills + Technical work
- Type #6: Mechanical work (45-90°): 2x 5+5+5m 45° CODx1 / 2x5+5+5m 90° CODx2 (r: 45s between repetitions)
- Technical work with Metabolic component
- Type #6: Mechanical work (130-180°): 4x5+5m 130° CODx1 / 4x5+5m 180° CODx1 (r: 45s between reps)
- Technical work with Metabolic component
- Cool down (3-5')

$S4_Q$-WD:

- Mobility + Technical work (short pass/volley)
- Running drills + Technical work (control/pass)
- Agility (<10m) + decision (quality)
- Monitoring (2): 4 straight-line high-speed runs(box-to-box), 70m in 13s, 30-s passive recovery (> 19.8 km/h ≈ 200m)
- Technical work: spreading, being orientated, controlling + passing backwards, inside, forwards
- I. Type #6, Mechanical work: 5+10m CODx1 + Finishing on small-goal, 2x 45°, 90°, 130°, 180° (r: 45s between reps)
- II. Type #2/4: Specific WD Mechanical work: 2x 3min 30s-set: 6 x ≈10s (specific) /≈25s (walk)

$S4_Q$-CM:

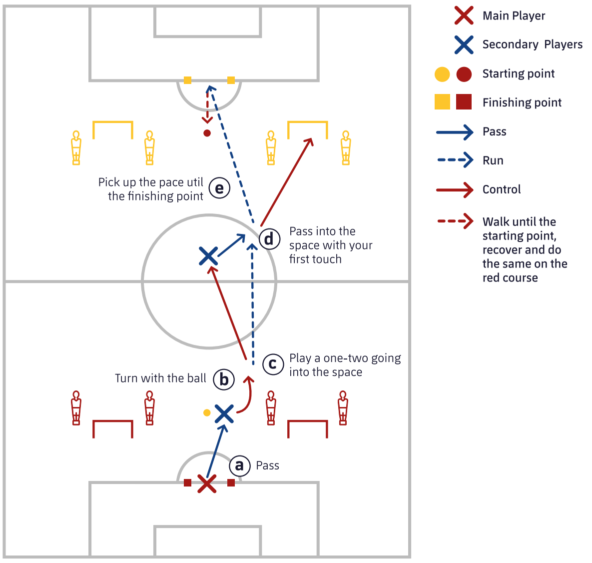
- Mobility + Technical work (short pass/volley)
- Running drills + Technical work (control/pass)
- Agility (<10m) + decision (quality)
- Monitoring (2): 4 straight-line high-speed runs(box-to-box), 70m in 13s, 30-s passive recovery (> 19.8 km/h ≈ 200m)
- Technical work: COD with the ball, being orientated, repeating short passes, playing between 2 lines and behind the defensive line
- I. Type #6, Mechanical work: 5+5+5m CODx2 + Finishing on small-goal, 2x 45°, 90°, 130°, 180° (r: 45s between reps)
- II. Type #2/4: Specific CM Mechanical work: 2x 2min 55s set: 5 x ≈10s (specific) /≈25s (walk)

S5Q-WD and S5Q-CM: in addition to taking part into possession games (without goal keeper) and game situations (with goal keepers) with the team as jokers/floaters initially, we recommend players to perform some additional acceleration/speed work with specific movement patterns of high quality (Type #6) including some kicking exercises (long balls and shoots). S4Q-WD drills with a blue background refer to the drills shown in Figure 1, right panel.

Figure 3
Schematic illustration of each of the Type #2 sequence described in Table 1 for session S4HS-WD, S4HS-CM, S4Q-WD and S4Q-CM.
v

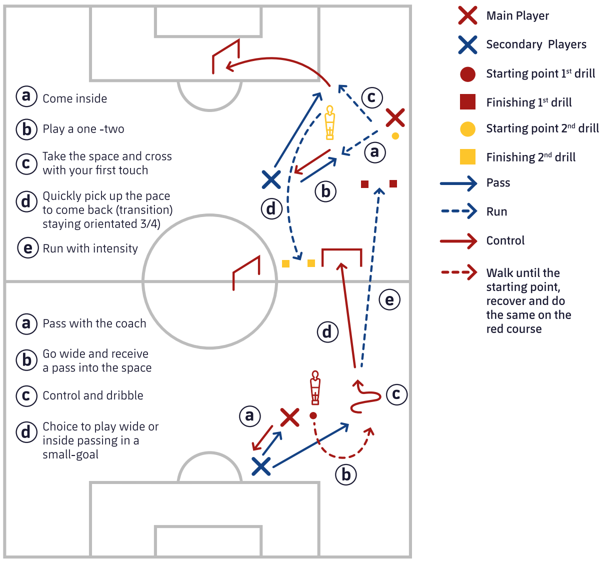
S4 HS - CM

Type #2 - 10s / 20s x8



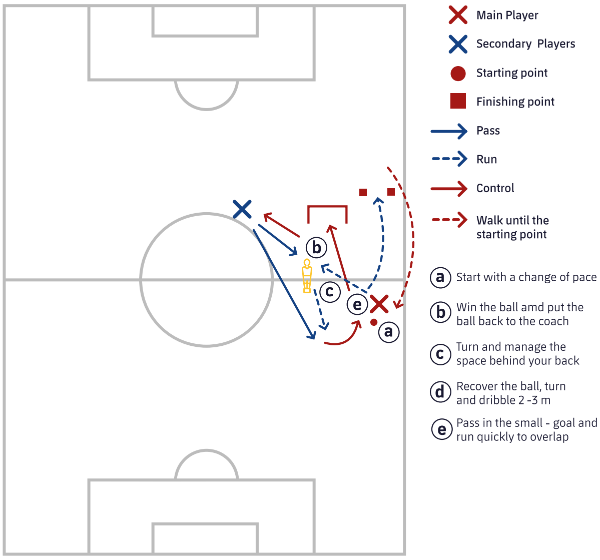
S4 HS - WD

Type #2 - 10s / 20s x8



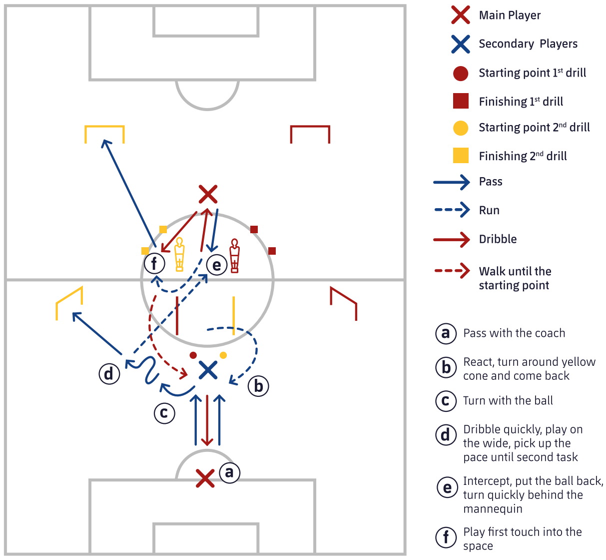
S4 Q - WD

Type #2/4 - ~ 10s / ~ 25s x6 - 2 sets



S4 Q - CM

Type #2/4 - ~ 10s / ~ 25s x5 - 2 sets



MONITORING THE RTP PROCESS IN THE FIELD

The monitoring of the responses to these types of RTP sessions is performed using both objective and subjective measurements. More specifically, toward the end of the sequence progression, as a part of one of the specific session, we conduct a standardized running test[9] (4-min run at 12 km/h where HR response is monitored in relation to historical data and used as a proxy of cardiovascular fitness, followed by 4 x 60m straight-line high-speed runs where both stride balance and running efficiency are examined via accelerometer data[10]) (See Table 1, e.g., green fonts, session S2HS and S3HS or S2Q and S4Q). Daily wellness assessment and medical screening are conducted daily to guide/adjust the loading of each session.

KEY MESSAGES IN RESTORING PLAYER'S SPECIFIC FITNESS AND PERFORMANCE CAPACITY DURING RTP

1. Consider the muscle injury type as a guide for RTP progression, e.g. Hamstring muscle requires more progressive loading of HSR, whereas Quadriceps muscle likely requires greater focus on HIA progressions and loading
2. Individualise further, the target physical loads (in terms of both volume and intensity, Figure 1 right panel) and technical demands based on the players' position on the field (using individual data if possible and knowledge of his playing style).
3. Facilitate players transition from individual to team work while adjusting the initial team sessions (individual warm-up, extra conditioning post session, and more importantly playing as joker during game-based sequences).
4. Monitor internal load to determine how the player is coping with these demanding final sessions before returning to competitions
5. Consider the players' psychological readiness to a) re-join the team and b) return to full match-play

2.4.1

REGENERATIVE AND BIOLOGICAL TREATMENTS FOR MUSCLE INJURY

Despite the substantial regenerative potential that skeletal muscle possesses in the form of its own stem cells, injured skeletal muscle still heals, like most of our tissues, by a repair process, not by complete regeneration. Thus, the healing will result in the formation of non-functional scar tissue.[40] The outcome of this repair process is that the ruptured skeletal muscle fibers remain terminally separated by the scar tissue that has formed at the site of the injury, i.e. inside the injured skeletal muscle.[40]

— With Tero AH Järvinen, Haiko Pas and Jordi Puigdellivol

Few tissues, such as bone, can heal by a regenerative response, i.e. the healing tissue produced is identical by structure and function to the tissue that existed at the site pre-injury. Therefore, intensive research efforts have been aimed at finding ways to stimulate skeletal muscle regeneration and converting the skeletal muscle repair process to the regenerative one.[40]

Regenerative medicine is an exciting field of translational research in tissue engineering and molecular biology that deals with the "process of replacing, engineering or regenerating human cells, tissues or organs to restore or establish their normal function to pre-injury level". Regenerative medicine holds the great promise of engineering damaged tissues and organs by using stem cells or stimulating the body's own repair mechanisms to functionally heal (regenerate) injured tissues or organs, better and faster than the body's own healing response.[40]

As some regenerative medicine products are in clinical use and are being offered to football players, we will review the scientific evidence supporting their use in injured athletes as well as provide evidence-based recommendations for their usage.

ACTOVEGIN

BACKGROUND

Actovegin® is a deproteinized hemodialysate of ultra-filtered (<6 kDa) calf serum from animals under 8 months of age. It has been used widely to treat sport injuries, especially acute skeletal muscle ruptures. In addition, Actovegin® has been claimed to have oxygen-enhancing capacity, i.e. to improve the athletic performance.

CLINICAL EVIDENCE

In acute skeletal muscle injuries (or any other injury), only anecdotal evidence exists for Actovegin,[1,2] and there is no experimental or clinical data available to prove its efficacy. The only clinical trial in sports medicine has shown that Actovegin® is not ergogenic (performance-enhancing) and does not influence the functional capacity of skeletal muscle.[3]

RECOMMENDATION

Not recommended

NSAIDS - NON-STEROIDAL ANTI-INFLAMMATORY DRUGS

BACKGROUND

Non-steroidal anti-inflammatory drugs (NSAIDs) are a class of drugs that provide analgesic (pain-killing), antipyretic (fever-reducing) and anti-inflammatory effects. NSAIDs are widely used in athletes to provide pain-relief after injuries. NSAIDs have been extensively studied on injured skeletal muscle. Short-term use of different NSAIDs in the early phase of healing leads to a decrease in the inflammatory cell reaction, with no adverse effects on the healing process or on the tensile strength or on ability of the injured muscle to contract.[4,5] Furthermore, NSAIDs do not delay myofibre regeneration.[6]

CLINICAL EVIDENCE

Three placebo-controlled, randomized trials have assessed the effects of NSAIDs on human skeletal muscle injury and a large number of studies have assessed their efficacy in mild "skeletal muscle injury" i.e. in delayed-onset muscle soreness (DOMS).[7] In less severe type of muscle injury (DOMS), a short-term use of NSAIDs resulted in a transient improvement in the recovery from exercised-induced muscle injury[8,9] More recently, NSAIDs were shown to enhance skeletal muscle regeneration and remodeling in young humans with skeletal muscle injury.[9] However, NSAIDs did not accelerate the recovery from severe hamstring injury.[10]

RECOMMENDATION

Recommended in acute phase as well as in DOMS. Care must be taken with prolonged or frequent use of NSAIDs however, due to their potential gastric (and other) side-effects.

CORTICOSTEROIDS

BACKGROUND

Corticosteroids are a class of steroid hormones that are involved in a wide range of physiological processes, among them the suppression of inflammation. Corticosteroids (either orally or by local injection) have been administered in acute skeletal muscle injuries with the aim of alleviating the inflammatory response in the early phase of healing. Experimental studies have reported delayed elimination of the hematoma and necrotic tissue, retardation of the muscle regeneration process and, ultimately, reduced biomechanical strength of the injured muscle with the use of glucocorticoids in the treatment of muscle injuries.[4-11]

CLINICAL EVIDENCE

No clinical studies addressing the effect of corticosteroids on injured skeletal muscle exist.

RECOMMENDATION

Not recommended (based on vast experimental data showing significant, almost complete, retardation of the healing process).

PRP

BACKGROUND

Platelet-rich plasma (PRP) is a concentrate of platelet-rich plasma protein derived from whole blood by centrifugation that removes red blood cells (and immune cells). PRP has an increased concentration of plasma-derived growth factors and platelets, which in turn, contain a large number of growth factors.[12] In vitro- as well as experimental studies have indicated that PRP could enhance the recovery of different sports injuries, among them, skeletal muscle ruptures.[13]

CLINICAL EVIDENCE

Two placebo-controlled, randomized controlled trials (RCTs) on athletes with acute skeletal muscle injury have shown that PRP has no beneficial effect on any of the recovery parameters (return to play, rate of re-injuries).[14,15] Recent meta-analyses have shown that PRP does not shorten "return to play"-time nor reduce the recurrence rate of the injury.[16,17] Furthermore, it was recently shown in experimental skeletal muscle injury-model that both PRP and early rehabilitation accelerate skeletal muscle regeneration, but they do not have any synergy when both treatments are prescribed together.[18] This may be the explanation why PRP has failed in the RCTs to stimulate skeletal muscle regeneration in athletes with an injury.[18]

RECOMMENDATION

Not recommended

LOSARTAN

BACKGROUND

Losartan, an angiotensin II type I receptor blocker , is one of the most commonly used drugs for hypertension. Some RCTs carried out in the cardiovascular medicine provided "hints" that losartan could also inhibit fibrosis and scar formation, in addition to its blood pressure-lowering function. Furthermore, early experimental studies suggested that Losartan could inhibit growth factor-β1 (TGF-β1)-driven scar formation. As TGF-β1 is the growth factor responsible for fibrosis and scar formation in injured skeletal muscle, there has been interest to use it as inhibitor of scar formation in injured skeletal muscle. Experimental research has indeed indicated that losartan can stimulate skeletal muscle regeneration and inhibit scar formation after injury.[19-21] Despite enthusiasm towards losartan, one needs to note that more recent research has proven that losartan is not an inhibitor of TGF-β1.

CLINICAL EVIDENCE

Losartan has been recently studied on injured human skeletal muscle in RCT.[22] No effect on regenerating skeletal muscle was identified for Losartan after DOMS-type of mild skeletal muscle injury in the RCT.[22] Furthermore, losartan has also been tested in large RCTs as an anti-fibrotic molecule in other human diseases where fibrosis and scar formation take place. Losartan has failed in all these RCTs to inhibit and fibrosis/scar formation.[23-25]

RECOMMENDATION

Not recommended

STEM CELLS (MESENCHYMAL)

BACKGROUND

Stem cells are cells with the ability to differentiate into a multitude of cell types. Among the different populations of stem cells, mesenchymal stem cells (MSCs) have received most interest in sports medicine. MSCs are stem cells that are able to differentiate into cells of one germ line, mesenchyme, i.e. to osteoblasts (bone), chondrocytes (cartilage), tenocytes (tendon), myocytes (skeletal muscle) or adipocytes (fat).[26]

The mode of action of MSCs is considered two-fold: firstly, their differentiating potential would theoretically allow them to replace lost or injured tissue.[26-28] Secondly, MSCs produce a vast number of growth factors that could augment tissue regeneration. In addition, MSCs have an immunoregulatory effect (suppression of chronic, detrimental inflammation) on their environment.[27-28]

CLINICAL EVIDENCE

To our knowledge, stem cells of any kind, have not yet been tested to treat muscle injuries in clinical trials. Some sports medicine organizations, such as The Australian College of Sports and Exercise Physicians, strongly advise against the use of stem cell-therapies, and there is no definitive evidence ruling out a potential increased cancer risk with these cell therapies.

RECOMMENDATION

Not recommended (based on total lack of clinical evidence)

EXTRACORPOREAL SHOCKWAVE THERAPY (ESWT)

BACKGROUND

Extracorporeal shockwave therapy (ESWT) is based on abrupt, high amplitude pulses of mechanical energy, similar to soundwaves, generated by an electromagnetic coil or a spark in water. “Extracorporeal” means that the shockwaves are generated externally to the body and transmitted from a pad through the skin. ‘Shock wave’ therapies are now extensively used in the treatment of musculoskeletal injuries and have been advocated also for skeletal muscle injuries.

CLINICAL EVIDENCE

No clinical studies addressing the effect of ESWT or “shock waves” on injured skeletal muscle exist.

RECOMMENDATION

Not recommended (based on total lack of clinical evidence)

HYPERBARIC OXYGEN THERAPY (HBOT)

BACKGROUND

HBOT is the medical use of oxygen at greater than atmospheric pressure to increase the availability of oxygen to the body. HBOT has been used to treat various conditions such as gas gangrene, chronic wounds, carbon monoxide poisoning. As the supply of oxygen is crucial for the repair of sports injuries, HBOT has been advocated for skeletal muscle rupture. There is indeed preliminary, experimental evidence supporting the use of HBOT to treat skeletal muscle injuries.[29-33]

CLINICAL EVIDENCE

HBOT was shown to improve the recovery from less severe skeletal muscle injury, i.e. delayed-onset muscle soreness (DOMS), in one randomized controlled trial[27], but another two randomized controlled trials found no or very little beneficial effects.[34,35] There are no clinical studies addressing the effects of HBOT on severe skeletal muscle injuries.

RECOMMENDATION

May have a slight benefit in treating DOMS, but no clinical studies on “severe”/”real” skeletal muscle injuries have been published.

THERAPEUTIC ULTRA-SOUND (TUS)

BACKGROUND

TUS is widely used in the treatment of muscle injuries, although the scientific evidence on its effectiveness is somewhat vague. The micro-massage produced by high-frequency TUS waves are proposed to have analgesic properties, and it has been proposed that TUS could somehow enhance the initial stage of muscle regeneration. However, TUS does not seem to have a positive (muscle-healing enhancing) effect on the final outcome of muscle healing in experimental skeletal muscle injury models.[36-38]

CLINICAL EVIDENCE

Randomized controlled trial showed that TUS reduced pain and improved recovery after DOMS.[39] No clinical study are available on TUS on severe skeletal muscle injuries.

RECOMMENDATION

Recommended for DOMS-type of injuries, no evidence available to support the use in severe skeletal muscle injuries.

EARLY REHABILITATION

BACKGROUND

A series of experimental studies have established that early, active mobilization started after a short period immobilization/rest (duration: inflammatory period of healing) is ideal therapy for injured skeletal muscle.[40]

CLINICAL EVIDENCE

A recently published randomized controlled trial showed that early rehabilitation produces significantly faster return to sports than delayed rehabilitation protocol without any significant risk of re-injury.[41]

RECOMMENDATION

Recommended. Athletes should be encouraged to start early, active rehabilitation immediately after the inflammatory period (3 – 5 days). Safe and effective treatment protocols have been developed and scientifically tested (proven to work without increased risk of re-injury) for certain muscle groups such as hamstrings, calf and quadriceps muscles.[41-43]

TAKE HOME MESSAGE

Despite the vast amount of scientific interest and financial resources devoted to the field of regenerative medicine, most of the recent and the promising innovations have failed to live up to their billing in clinical trials. For some of the new, basic research-derived innovations such as stem cells, the jury is still out as they have not progressed from pre-clinical studies to clinical studies, and as such fail to truly address their potential clinical value in the care of injured athletes.

We still rely on rehabilitation protocols started early after the injury in the treatment of the ruptured skeletal muscle. What is both encouraging as well as helpful, is that substantial scientific progress has been made in terms of validating early rehabilitation as the gold standard therapy for injured skeletal muscle. Standardized, "battle-tested" rehabilitation protocols have been introduced to the field recently to provide a framework for safe and efficient rehabilitation.[41-44] By adhering to these protocols, the injured athletes can recover from serious skeletal muscle injuries as fast and effectively as possible.[41-44]

2.4.2

SURGERY FOR MUSCLE INJURIES

When dealing with muscle injuries, the main principles of non-operative treatment should be used as a common guideline. There are, however, more severe muscle injuries in which surgical treatment should be considered. Especially in athletes, but also in other physically active people, if misdiagnosed and/ or improperly treated, a complete or even a partial muscle rupture can cause considerable morbidity and lead to decreased performance.[1,2]

— Lasse Lempainen and Janne Sarimo

The indications for surgery in muscle injuries are not always generally acknowledged. However, there are certain clear indications in which surgical treatment is beneficial even though no evidence-based treatment protocol exists.[3] These indications include the athlete with a complete rupture of a muscle with few or no agonist muscles (e.g. hamstring, pectoralis, adductor), or a large tear where more than half of the muscle is torn. Furthermore, surgical treatment should be considered if an athlete complains of permanent extension pain (e.g. rectus femoris) in a previously injured muscle. In such a case, formation of scar restricting the movement of the injured muscle has to be suspected and surgical deliberation of adhesions should be considered.

In literature, muscle injuries are often categorized as isolated muscle injuries. They could however also be considered as tendinous injuries, as the site of the rupture often involves both the muscle and tendon tissue itself, like in the cases of complete avulsions or central tendon ruptures.[4-6] Early and correct diagnosis, as well as accurate classification of muscle injuries, are the basic elements for proper treatment and recovery from injury.[7] The tendon area involved in the muscle injury has to be taken into account when making a decision of possible surgical intervention and also when deciding the surgical technique itself.[6]

In the later section on 'Specific Muscle Injuries' section of this Guide, we and other experts will provide further information and guidelines related to the surgical indications and management of specific muscle injury types; hamstrings, quadriceps, adductor and calf.


beko
Rakuten

REFERENCES

2.1.1. Return to Play from muscle injury: An introduction

1. McCall A, Lewin C, O'Driscoll G, et a;. Return to Play: the challenge of balancing research and practice. team success in Qatari professional football. Br J Sports Med 2017; 51:702-703.

2.1.2. Return to Play in football: A dynamic model

1. Ardern CL, Glasgow P, Schneiders A, et al. 2016 Consensus statement on return to sport from the First World Congress in Sports Physical Therapy, Bern. Br J Sports Med 2016;50:853-864.
2. Wangensteen A, Almusa E, Boukarroum S, et al. MRI does not add value over and above patient history and clinical examination in predicting time to return to sport after acute hamstring injuries: a prospective cohort of 180 male athletes. Br J Sports Med 2015;49:1579-1587.
3. Brewer BW, van Raalte JL, Linder DE. Athletic identity: Hercules' muscles or Achilles heel? Int J Sport Psychol 1993;24:237-254.
4. Pruna R, Bahdur K. Cognition in football. Journal of Novel Physiotherapies 2016;6:6.
5. Coutts AJ. Fatigue in football: it's not a brainless task! Journal of Sports Sciences 2016;34:1296.
6. Podlog L, Dimmock J, Miller J. A review of return to sport concerns following injury rehabilitation: practitioner strategies for enhancing recovery outcomes. Phys Ther Sport 2011;12:36-42.
7. Creighton DW, Shrier I, Schultz R, et al. Return-to-play in sport: a decision-based model. Clin J Sports Med 2010;20:379-385.
8. Shrier I. Strategic Assessment of Risk and Risk Tolerance (StARRT) framework for return-to-play decision-making. Br J Sports Med 2015;49:1311-1315.

2.1.3. Estimating Return to Play time

1. Hamilton B, Wangensteen A, Whiteley R, et al. Cohen's MRI scoring system has limited value in predicting return to play. Knee Surgery, Sports Traumatology, Arthroscopy 2018;26(4):1288-94.
2. Schut L, Wangensteen A, Maaskant J, et al. Can Clinical Evaluation Predict Return to Sport after Acute Hamstring Injuries? A Systematic Review. Sports Med 2017;47(6):1123-44
3. Wangensteen A, Guermazi A, Tol JL, et al. New MRI muscle classification systems and associations with return to sport after acute hamstring injuries: a prospective study. European radiology 2018;19:1-0.
4. Whiteley R, van Dyk N, Wangensteen A, et al. Clinical implications from daily physiotherapy examination of 131 acute hamstring injuries and their association with running speed and rehabilitation progression. Br J Sports Med 2018;52(5):303-10
5. Wangensteen A, Almusa E, Boukarroum S, et al. MRI does not add value over and above patient history and clinical examination in predicting time to return to sport after acute hamstring injuries: a prospective cohort of 180 male athletes. Br J Sports Med 2015;49(24):1579-87
6. Ardern CL, Glasgow P, Schneiders A, et al. 2016 Consensus statement on return to sport from the First World Congress in Sports Physical Therapy, Bern. Br J Sports Med 2016;50(14):853-64
7. Shrier I. Strategic Assessment of Risk and Risk Tolerance (StARRT) framework for return-to-play decision-making. Br J Sports Med 2015;49(20):1311-5

2.2.1. Making an accurate diagnosis

1. Whiting P, Harbord R, de Salis I, et al. Evidence-based diagnosis. J Health Serv Res Policy. 2008;13 Suppl 3:57–63. Doi: 10.1258/jhsrp.2008.008025.
2. Wangensteen A. Acute hamstring injuries - diagnosis and prognosis. Dissertation from the Norwegian School of Sports Sciences. Oslo, Norway; 2018.
3. Orchard JW, Best TM, Mueller-Wohlfahrt H-W, et al. The early management of muscle strains in the elite athlete: best practice in a world with a limited evidence basis. Br J Sports Med. 2008;42:158–159. Doi: 10.1136/bjsm.2008.046722.
4. Glasgow P, Phillips N, Bleakley C. Optimal loading: key variables and mechanisms. Br J Sports Med. 2015;49:278–279.
5. Järvinen TAH, Järvinen TLN, Kääriäinen M, et al. Muscle injuries: optimising recovery. Best Pract Res Clin Rheumatol. 2007;21:317–331. Doi: 10.1016/j.berh.2006.12.004.
6. Bleakley CM, Glasgow P, MacAuley DC. PRICE needs updating, should we call the POLICE? Br J Sports Med. 2012;46:220–221. Doi: 10.1136/bjsports-2011-090297.
7. Kary JM. Diagnosis and management of quadriceps strains and contusions. Curr Rev Musculoskelet Med. 2010;3:26–31. Doi: 10.1007/s12178-010-9064-5.
8. Aronen JG, Garrick JG, Chronister RD, et al. Quadriceps contusions: clinical results of immediate immobilization in 120 degrees of knee flexion. Clin J Sport Med Off J Can Acad Sport Med. 2006;16:383–387. Doi: 10.1097/01.jsm.0000244605.34283.94.
9. Trojian TH. Muscle contusion (thigh). Clin Sports Med. 2013;32:317–324. Doi: 10.1016/j.csm.2012.12.009.
10. Järvinen TAH, Järvinen TLN, Kääriäinen M, et al. Muscle injuries: biology and treatment. Am J Sports Med. 2005;33:745–764. Doi: 10.1177/0363546505274714.
11. Askling C. Type of acute hamstring strain affects flexibility, strength, and time to return to pre-injury level. Br J Sports Med. 2006;40:40–44. Doi: 10.1136/bjsm.2005.018879.
12. Brukner P, Khan KM. Brukner & Khan's Clinical Sports Medicine 5th Edition. vol. Volume 1. 5th ed. Australia: Mc Graw-Hill Education; 2017.
13. Hawker GA, Mian S, Kendzerska T, et al. Measures of adult pain: Visual Analog Scale for Pain (VAS Pain), Numeric Rating Scale for Pain (NRS Pain), McGill Pain Questionnaire (MPQ), Short-Form McGill Pain Questionnaire (SF-MPQ), Chronic Pain Grade Scale (CPGS), Short Form-36 Bodily Pain Scale (SF-36 BPS), and Measure of Intermittent and Constant Osteoarthritis Pain (ICOAP). Arthritis Care Res. 2011;63 Suppl 11:S240-252. Doi: 10.1002/acr.20543.
14. Farrar JT, Young JP, LaMoreaux L, et al. Clinical importance of changes in chronic pain intensity measured on an 11-point numerical pain rating scale. Pain. 2001;94:149–158.
15. Lee JC, Mitchell AWM, Healy JC. Imaging of muscle injury in the elite athlete. Br J Radiol. 2012;85:1173–1185. Doi: 10.1259/bjr/84622172.
16. Lee JC, Healy J. Sonography of lower limb muscle injury. AJR Am J Roentgenol. 2004;182:341–351. Doi: 10.2214/ajr.182.2.1820341.
17. Eberbach H, Hohloch L, Feucht MJ, et al. Operative versus conservative treatment of apophyseal avulsion fractures of the pelvis in the adolescents: a systematical review with meta-analysis of clinical outcome and return to sports. BMC Musculoskelet Disord. 2017;18:162. Doi: 10.1186/s12891-017-1527-z.
18. McKinney BI, Nelson C, Carrion W. Apophyseal avulsion fractures of the hip and pelvis. Orthopedics. 2009;32:42.
19. Hamilton B, Valle X, Rodas G, et al. Classification and grading of muscle injuries: a narrative review. Br J Sports Med. 2015;49:306. Doi: 10.1136/bjsports-2014-093551.
20. Grassi A, Quaglia A, Canata GL, et al. An update on the grading of muscle injuries: a narrative review from clinical to comprehensive systems. Joints. 2016;4:39–46. Doi: 10.11138/jts/2016.4.1.039.
21. Takebayashi S, Takasawa H, Banzai Y, et al. Sonographic findings in muscle strain injury: clinical and MR imaging correlation. J Ultrasound Med Off J Am Inst Ultrasound Med. 1995;14:899–905.
22. Peetrons P. Ultrasound of muscles. Eur Radiol. 2002;12:35–43. Doi: 10.1007/s00330-001-1164-6.
23. Ekstrand J, Healy JC, Waldén M, et al. Hamstring muscle injuries in professional football: the correlation of MRI findings with return to play. Br J Sports Med. 2012;46:112–117. Doi: 10.1136/bjsports-2011-090155.
24. Kerkhoffs GMMJ, Es N, Wieldraaijer T, et al. Diagnosis and prognosis of acute hamstring injuries in athletes. Knee Surg Sports Traumatol Arthrosc. 2012;21:500–509. Doi: 10.1007/s00167-012-2055-x.
25. Hallén A, Ekstrand J. Return to play following muscle injuries in professional footballers. J Sports Sci. 2014;32:1229–1236. Doi: 10.1080/02640414.20_14.905695.
26. Hallén A, Ekstrand J. Return to play following muscle injuries in professional footballers. J Sports Sci. 2014;32:1229–1236. Doi: 10.1080/02640_414.2014.905695.
27. Ekstrand J, Lee JC, Healy JC. MRI findings and return to play in football: a prospective analysis of 255 hamstring injuries in the UEFA Elite Club Injury Study. Br J Sports Med. 2016;50:738–743. Doi: 10.1136/bjsports-2016-095974.
28. Pollock N, James SLJ, Lee JC, et al. British athletics muscle injury classification: a new grading system. Br J Sports Med. 2014;48:1347–1351. Doi: 10.1136/bjsports-2013-093302.
29. Reurink G, Brilman EG, de Vos R-J, et al. Magnetic resonance imaging in acute hamstring injury: can we provide a return to play prognosis? Sports Med Auckl NZ. 2015;45:133–146. Doi: 10.1007/s40279-014-

0243-1.

30. Wangensteen A, Almusa E, Boukarroum S, et al. MRI does not add value over and above patient history and clinical examination in predicting time to return to sport after acute hamstring injuries: a prospective cohort of 180 male athletes. Br J Sports Med. 2015;49:1579–1587. Doi: 10.1136/bjsports-2015-094892.

31. Chan O, Del Buono A, Best TM, et al. Acute muscle strain injuries: a proposed new classification system. Knee Surg Sports Traumatol Arthrosc Off J ESSKA. 2012;20:2356–2362. Doi: 10.1007/s00167-012-2118-z.

32. van der Made AD, Almusa E, Whiteley R, et al. Intramuscular tendon involvement on MRI has limited value for predicting time to return to play following acute hamstring injury. Br J Sports Med. 2017. Doi: 10.1136/bjsports-2017-097659.

33. Pollock N, Patel A, Chakraverty J, et al. Time to return to full training is delayed and recurrence rate is higher in intratendinous ('c') acute hamstring injury in elite track and field athletes: clinical application of the British Athletics Muscle Injury Classification. Br J Sports Med. 2016;50:305–310. Doi: 10.1136/bjsports-2015-094657.

34. Brukner P, Connell D. "Serious thigh muscle strains": beware the intramuscular tendon which plays an important role in difficult hamstring and quadriceps muscle strains. Br J Sports Med. 2016;50:205–208. Doi: 10.1136/bjsports-2015-095136.

35. Comin J, Malliaras P, Baquie P, et al. Return to competitive play after hamstring injuries involving disruption of the central tendon. Am J Sports Med. 2013;41:111–115. Doi: 10.1177/036354_6512463679.

36. Pedret C, Rodas G, Balius R, et al. Return to Play After Soleus Muscle Injuries. Orthop J Sports Med. 2015;3:2325967115_595802. Doi: 10.1177/_2325967115595802.

37. Patel A, Chakraverty J, Pollock N, et al. British athletics muscle injury classification: a reliability study for a new grading system. Clin Radiol. 2015;70:1414–1420. Doi: 10.1016/j.crad.2015.08.009.

38. Wangensteen A, Tol JL, Roemer FW, et al. Intra- and interrater reliability of three different MRI grading and classification systems after acute hamstring injuries. Eur J Radiol. 2017;89:182–190. Doi: 10.1016/j.ejrad.2017.02.010.

39. Mueller-Wohlfahrt H-W, Haensel L, Mithoefer K, et al. Terminology and classification of muscle injuries in sport: The Munich consensus statement. Br J Sports Med. 2012;47:342–350. Doi: 10.1136/bjsports-2012-091448.

40. Ekstrand J, Askling C, Magnusson H, et al. Return to play after thigh muscle injury in elite football players: implementation and validation of the Munich muscle injury classification. Br J Sports Med. 2013. Doi: 10.1136/bjsports-2012-092092.

41. Tol JL, Hamilton B, Best TM. Palpating muscles, massaging the evidence? An editorial relating to "Terminology and classification of muscle injuries in sport: The Munich consensus statement." Br J Sports Med. 2012;47:340–341. Doi: 10.1136/bjsports-2012-091849.

42. Wangensteen A, Guermazi A, Tol JL, et al. New MRI muscle classification systems and associations with return to sport after acute hamstring injuries: a prospective study. Eur Radiol. 2018. Doi: 10.1007/s00330-017-5125-0.

43. O'Donoghue DH. Treatment of injuries to athletes. Philadelphia, US.: WB Saunders; 1962.

44. Valle X, Alentorn-Geli E, Tol JL, et al. Muscle Injuries in Sports: A New Evidence-Informed and Expert Consensus-Based Classification with Clinical Application. Sports Med Auckl NZ. 2017;47:1241–1253. Doi: 10.1007/s40279-016-0647-1.

2.3.1. Exercise prescription for muscle injury

1. Ekstrand J, Hägglund M, Waldén M. Epidemiology of muscle injuries in professional football (soccer). The American journal of sports medicine 2011;39(6):1226-32.

2. Hickey JT, Timmins RG, Maniar N, et al. Criteria for progressing rehabilitation and determining return-to-play clearance following hamstring strain injury: a systematic review. Sports medicine 2016;29:1-3.

3. Järvinen TA, Järvinen TL, Kääriäinen M, et al. Muscle injuries. The American journal of sports medicine 2005;33(5):745-64.

4. Timmins R, Ruddy J, Presland J, et al. Architectural changes of the biceps femoris after concentric or eccentric training. Medicine and science in sports and exercise 2016;48(3):499-508.

5. Timmins RG, Bourne MN, Shield AJ, et al. Short biceps femoris fascicles and eccentric knee flexor weakness increase the risk of hamstring injury in elite football (soccer): a prospective cohort study. Br J Sports Med 2016;50(24):1524-35.

6. Bourne M, Opar,DA, Williams,MD, et al. Muscle activation patterns in the Nordic hamstring exercise: Impact of prior strain injury. Scand J Med Sci Sports 2015 doi: 10.1111/sms.12494.

7. Brockett, CL, Morgan, DL, & Proske, U. Predicting hamstring strain injury in elite athletes. Medicine and Science in Sports and Exercise 2004;36(3):379-387

8. Lieber R. Skeletal Muscle Structure and Function: Implications for Rehabilitation and Sports Medicine, 2nd edn. Lippincott Williams and Wilkins 2002.

9. Brockett CL, Morgan DL, Proske UW. Human hamstring muscles adapt to eccentric exercise by changing optimum length. Medicine & Science in Sports & Exercise 2001;33(5):783-90.

10. Askling CM, Tengvar M, Thorstensson A. Acute hamstring injuries in Swedish elite football: a prospective randomised controlled clinical trial comparing two rehabilitation protocols. Br J Sports Med 2013;47:953-959

11. Askling CM, Tengvar M, Tarassova O, et al. Acute hamstring injuries in Swedish elite sprinters and jumpers: a prospective randomised controlled clinical trial comparing two rehabilitation protocols. Br J Sports Med 2014;48(7):532-9.

12. Mendiguchia J, Martinez-Ruiz E, Edouard P, et al. A multifactorial, criteria-based progressive algorithm for hamstring injury treatment. Medicine & Science in Sports & Exercise 2017;49(7):1482-92.

13. Nigg BM, Wakeling JM. Impact forces and muscle tuning: a new paradigm. Exercise and sport sciences reviews 2001;29(1):37-41.

14. Opar DA, Williams MD, Timmins RG, et al. Knee flexor strength and bicep femoris electromyographical activity is lower in previously strained hamstrings. Journal of Electromyography and Kinesiology 2013;23(3):696-703.

15. Fyfe JJ, Opar DA, Williams MD, et al. The role of neuromuscular inhibition in hamstring strain injury recurrence. Journal of electromyography and kinesiology 2013;23(3):523-30.

16. Blanch P, Gabbett TJ Has the athlete trained enough to return to play safely? The acute:chronic workload ratio permits clinicians to quantify a player's risk of subsequent injury Br J Sports Med 2016;50:471-475

17. Askling CM, Nilsson J, Thorstensson A. A new hamstring test to complement the common clinical examination before return to sport after injury. Knee surgery, sports traumatology, arthroscopy 2010;18(12):1798-803.

18. Tak IJ, Langhout RF, Groters S, et al. A new clinical test for measurement of lower limb specific range of motion in football players: Design, reliability and reference findings in non-injured players and those with long-standing adductor-related groin pain. Physical Therapy in Sport 2017;23:67-74.

2.3.2. Restoring player's specific fitness and performance capacity in relation to match physical demands

1. Hader K, Mendez-Villanueva A, Palazzi D, et al. Metabolic Power Requirement of Change of Direction Speed in Young Soccer Players: Not All Is What It Seems. PLoS One 2016;11(3):e0149839. doi: 10.1371/journal.pone.0149839 [published Online First: 2016/03/02]

2. Lacome M, Simpson BM, Buchheit M. Locomotor and heart rate responses of floaters during small-sided games in elite soccer players: effect of pitch size and goal keepers. Int J Sports Physiol Perform 2017:Sep 27:1-13. doi: 10.1123/ijspp.2017-0340. [Epub ahead of print].

3. Lacome M, Simpson BM, Cholley Y, et al. Small Sided Games in elite soccer: Does one size fits all? Int J Sports Physiol Perform 2017:Jul 17:1-24. doi: 10.1123/ijspp.2017-0214. [Epub ahead of print].

4. Buchheit M, Laursen PB. High-intensity interval training, solutions to the programming puzzle: Part I: cardiopulmonary emphasis. Sports Med 2013;43(5):313-38.

5. Gabbett TJ. The training-injury prevention paradox: should athletes be training smarter and harder? Br J Sports Med 2016;50(5):273-80. doi: 10.1136/bjsports-2015-095788 [published Online First: 2016/01/14]

6. Delgado-Bordonau JL, Mendez-Villanueva A. The Tactical Periodization Model. In: Sum ME, ed. Fitness in Soccer: The science and Practical Application2014.

7. Buchheit M. The 30-15 Intermittent Fitness Test: accuracy for individualizing interval training of young intermittent sport players. J Strength Cond Res 2008;22(2):365-74.

8. Buchheit M, Mendez-Villanueva A. Changes in repeated-sprint performance in relation to change in locomotor profile in highly-trained young soccer players. J Sports Sci 2014;32(13):1309-17. doi: 10.1080/02640414.20_14.918272 [published Online First: 2014/06/01]

9. Buchheit M, Cholley Y, Lambert P. Psychometric and Physiological Responses to a Preseason Competitive Camp in the Heat With a 6-Hour Time Difference in Elite Soccer Players. Int J Sports Physiol Perform 2016;11(2):176-81. doi: 10.1123/ijspp.2015-0135 [published Online First: 2015/07/17]

10. Buchheit M, Simpson BM. Player tracking technology: half-full or half-empty glass? . Int J Sports Physiol Perform 2017;12((Suppl 2)):S235-S41.

2.4.1. Regenerative and biological treatments for muscle injury

1. Reurink G, Goudswaard GJ, Tol JL, et al. Therapeutic interventions for acute hamstring injuries: a systematic review. Br J Sports Med 2012;46(2):103-09.

2. Brock J, Golding D, Smith PM, et al. Update on the Role of Actovegin in Musculoskeletal Medicine: A Review of the Past 10 Years. Clinical journal of sport medicine: official journal of the Canadian Academy of Sport Medicine 2018

3. Lee P, Rattenberry A, Connelly S, et al. Our experience on Actovegin, is it cutting edge? International journal of sports medicine 2011;32(04):237-41.

4. Järvinen M, Lehto M, Sorvari T, et al. Effect of some anti-inflammatory agents on the healing of ruptured muscle: an experimental study in rats. J Sports Traumatol Rel Res 1992;14:19-28.

5. Rahusen FTG, Weinhold PS, Almekinders LC. Nonsteroidal anti-inflammatory drugs and acetaminophen in the treatment of an acute muscle injury. The American journal of sports medicine 2004;32(8):1856-59.

6. Thorsson O, Rantanen J, Hurme T, et al. Effects of nonsteroidal antiinflammatory medication on satellite cell proliferation during muscle regeneration. The American journal of sports medicine 1998;26(2):172-76.

7. Morelli KM, Brown LB, Warren GL. Effect of NSAIDs on Recovery From Acute Skeletal Muscle Injury: A Systematic Review and Meta-analysis. Am J Sports Med 2018;46(1):224-33. doi:

10.1177/0363546517697957 [published Online First: 2017/03/30]

8. O'Grady M, Hackney AC, Schneider K, et al. Diclofenac sodium (Voltaren) reduced exercise-induced injury in human skeletal muscle. Medicine and science in sports and exercise 2000;32(7):1191-96.

9. Mackey AL, Rasmussen LK, Kadi F, et al. Activation of satellite cells and the regeneration of human skeletal muscle are expedited by ingestion of nonsteroidal anti-inflammatory medication. The FASEB Journal 2016;30(6):2266-81.

10. Reynolds J, Noakes T, Schwellnus M, et al. Non-steroidal antiinflammatory drugs fail to enhance healing of acute hamstring injuries treated with physiotherapy. South African Medical Journal 1995;85(6)

11. Beiner JM, Jokl P, Cholewicki J, et al. The effect of anabolic steroids and corticosteroids on healing of muscle contusion injury. The American Journal of Sports Medicine 1999;27(1):2-9.

12. Foster TE, Puskas BL, Mandelbaum BR, et al. Platelet-rich plasma: from basic science to clinical applications. . The American journal of sports medicine 2009;37(11):2259-72.

13. Andia I, Abate M. Platelet-rich plasma in the treatment of skeletal muscle injuries. Expert Opin Biol Ther 2015;15(7):987-99. doi: 10.1517/14712598.2015.1038-234

14. Hamilton B, Tol JL, Almusa E, et al. Platelet-rich plasma does not enhance return to play in hamstring injuries: a randomised controlled trial. Br J Sports Med 2015;49(14):943-50.

15. Reurink G, Goudswaard G, Moen MH, et al. Platelet-rich plasma injections in acute muscle injury. New England Journal of Medicine 2014;370(26):2546-47.

16. Pas HI, Reurink G, Tol JL, et al. Efficacy of rehabilitation (lengthening) exercises, platelet-rich plasma injections, and other conservative interventions in acute hamstring injuries: an updated systematic review and meta-analysis. Br J Sports Med 2015;49(18):1197-205. doi: 10.1136/bjsports-2015-094879

17. Grassi A, Napoli F, Romandini I, et al. Is Platelet-Rich Plasma (PRP) Effective in the Treatment of Acute Muscle Injuries? A Systematic Review and Meta-Analysis. Sports medicine (Auckland, NZ) 2018 doi: 10.1007/s40279-018-0860-1 [published Online First: 2018/01/25]

18. Contreras-Muñoz P, Torrella J, Serres X, et al. Post-injury exercise and platelet-rich plasma therapies improve skeletal muscle healing in rats. Am J Sports Med 2017;45:2131-2141.

19. Bedair HS, Karthikeyan T, Quintero A, et al. Angiotensin II receptor blockade administered after injury improves muscle regeneration and decreases fibrosis in normal skeletal muscle. Am J Sports Med 2008;36(8):1548-54. doi: 10.1177/0363546508315470 [published Online First: 2008/06/14]

20. Kobayashi T, Uehara K, Ota S, et al. The timing of administration of a clinically relevant dose of losartan influences the healing process after contusion induced muscle injury. Journal of applied physiology (Bethesda, Md : 1985) 2013;114(2):262-73. doi: 10.1152/japplphysiol.00140.2011 [published Online First: 2012/11/17]

21. Terada S, Ota S, Kobayashi M, et al. Use of an antifibrotic agent improves the effect of platelet-rich plasma on muscle healing after injury. The Journal of bone and joint surgery American volume 2013;95(11):980-8. doi: 10.2106/jbjs.l.00266 [published Online First: 2013/06/20]

22. Heisterberg MF, Andersen JL, Schjerling P, Bülow J, Lauersen JB, Roeber HL, Kjaer M, Mackey AL Effect of losartan on the acute response of human elderly.skeletal muscle to exercise. Med Sci Sports Exerc. 2018;50(2):225-235. doi: 10.1249/MSS.0000000000001438.

23. McPherson S, Wilkinson N, Tiniakos D, et al. A randomised controlled trial of losartan as an anti-fibrotic agent in non-alcoholic steatohepatitis. PLoS One 2017;12(4):e0175717. doi: 10.1371/journal.pone.0175717 [published Online First: 2017/04/19]

24. Lacro RV, Dietz HC, Sleeper LA, et al. Atenolol versus losartan in children and young adults with Marfan's syndrome. The New England journal of medicine 2014;371(22):2061-71. doi: 10.1056/NEJMoa1404731 [published Online First: 2014/11/19]

25. Axelsson A, Iversen K, Vejlstrup N, et al. Efficacy and safety of the angiotensin II receptor blocker losartan for hypertrophic cardiomyopathy: the INHERIT randomised, double-blind, placebo-controlled trial. The lancet Diabetes & endocrinology 2015;3(2):123-31. doi: 10.1016/s2213-8587(14)70241-4 [published Online First: 2014/12/24]

26. Schneider M, Angele P, Järvinen TAH, Docheva D. Rescue plan for Achilles: therapeutics steering the fate and functions of stem cells in tendon wound healing. Adv Drug Deliv Rev 2018;129:352-375.

27. Mautner K, Blazuk J. Where do injectable stem cell treatments apply in treatment of muscle, tendon, and ligament injuries? PM R 2015;7(4 Suppl):S33-40. doi: 10.1016/j.pmrj.2014.12.012

28. Gaspar D, Spanoudes K, Holladay C, et al. Progress in cell-based therapies for tendon repair. Adv Drug Deliv Rev 2015;84:240-56. doi: 10.1016/j.addr.2014.11.02321.

29. Best TM, Loitz-Ramage B, Corr DT, et al. Hyperbaric oxygen in the treatment of acute muscle stretch injuries. The American journal of sports medicine 1998;26(3):367-72.

30. Maia MCC, Camacho ÓF, Marques AFP, et al. Hyperbaric oxygen therapy treatment for the recovery of muscle injury induced in rats. Diving and Hyperbaric Medicine:222.

31. Horie M, Enomoto M, Shimoda M, et al. Enhancement of satellite cell differentiation and functional recovery in injured skeletal muscle by hyperbaric oxygen treatment. Journal of Applied Physiology 2014;116(2):149-55.

32. Fujita N, Ono M, Tomioka T, et al. Effects of hyperbaric oxygen at 1.25 atmospheres absolute with normal air on macrophage number and infiltration during rat skeletal muscle regeneration. PloS one 2014;9(12):e115685.

33. Staples JR, Clement DB, Taunton JE, et al. Effects of hyperbaric oxygen on a human model of injury. The American journal of sports medicine 1999;27(5):600-05.

34. Mekjavic IB, Exner JA, Tesch PA, et al. Hyperbaric oxygen therapy does not affect recovery from delayed onset muscle soreness. Medicine and science in sports and exercise 2000;32(3):558-63.

35. Webster AL, Syrotuik DG, Bell GJ, et al. Effects of hyperbaric oxygen on recovery from exercise-induced muscle damage in humans. Clinical Journal of Sport Medicine 2002;12(3):139-50.

36. Rantanen J, Thorsson O, Wollmer P, et al. Effects of therapeutic ultrasound on the regeneration of skeletal myofibers after experimental muscle injury. Am J Sports Med 1999;27(1):54-9. doi: 10.1177/03635465990270011701 [published Online First: 1999/02/06]

37. Wilkin LD, Merrick MA, Kirby TE, et al. Influence of therapeutic ultrasound on skeletal muscle regeneration following blunt contusion. Int J Sports Med 2004;25(1):73-7. doi: 10.1055/s-2003-45234 [published Online First: 2004/01/30]

38. Markert CD, Merrick MA, Kirby TE, et al. Nonthermal ultrasound and exercise in skeletal muscle regeneration. Archives of physical medicine and rehabilitation 2005;86(7):1304-10. [published Online First: 2005/07/09]

39. Aaron SE, Delgado-Diaz DC, Kostek MC. Continuous Ultrasound Decreases Pain Perception and Increases Pain Threshold in Damaged Skeletal Muscle. Clinical journal of sport medicine : official journal of the Canadian Academy of Sport Medicine 2017;27(3):271-77. doi: 10.1097/jsm.0000000000000343 [published Online First: 2016/07/21]

40. Järvinen TA, Järvinen TL, Kääriäinen M, et al. Muscle injuries: biology and treatment. The American journal of sports medicine 2005;33(5):745-64.

41. Bayer ML, Magnusson SP, Kjaer M. Early versus Delayed Rehabilitation after Acute Muscle Injury. New England Journal of Medicine 2017;377(13):1300-01. doi: 10.1056/NEJMc1708134

42. Mendiguchia J, Martinez-Ruiz E, Edouard P, et al. A Multifactorial, Criteria-based Progressive Algorithm for Hamstring Injury Treatment. Med Sci Sports Exerc 2017;49(7):1482-92. doi: 10.1249/mss.0000000000001241 [published Online First: 2017/03/10]

43. Askling CM, Tengvar M, Thorstensson A. Acute hamstring injuries in Swedish elite football: a prospective randomised controlled clinical trial comparing two rehabilitation protocols. Br J Sports Med 2013;47(15):953-9. doi: 10.1136/bjsports-2013-092165 [published Online First: 2013/03/29]

44. Askling CM, Tengvar M, Tarassova O, et al. Acute hamstring injuries in Swedish elite sprinters and jumpers: a prospective randomised controlled clinical trial comparing two rehabilitation protocols. Br J Sports Med 2014;48(7):532-9. doi: 10.1136/bjsports-2013-093214 [published Online First: 2014/03/13]

2.4.2. Surgery for muscle injuries

1. Sarimo J, Lempainen L, Mattila K, et al. Complete proximal hamstring avulsions: a series of 41 patients with operative treatment. Am J Sports Med 2008;36:1110-1115.

2. Lempainen L, Sarimo J, Heikkilä J, et al. Surgical treatment of partial tears of the proximal origin of the hamstring muscles. Br J Sports Med 2006;40:688-691.

3. Järvinen TA, Järvinen TL, Kääriäinen M, et al. Muscle injuries: biology and treatment. Review. Am J Sports Med 2005;33:745-764.

4. Lempainen, L. Thesis. Surgical treatment of hamstring injuries and disorders – the clinical spectrum from chronic tendinopathy to complete rupture. University of Turku, Turku, Finland, 2009. http://www.doria.fi/bitstream/handle/10024/43989/AnnalesD840Lempainen.pdf

5. Brukner P, Connell D. 'Serious thigh muscle strains': beware the intramuscular tendon which plays an important role in difficult hamstring and quadriceps muscle strains. Br J Sports Med 2016;50:205-208.

6. Lempainen L, Kosola J, Pruna R,et al. Central tendon injuries of hamstring muscles: case series of operative treatment. Orthop J Sports Med 2018;6:23259671187_55992.

7. Koulouris G, Connell D. Hamstring muscle complex: an imaging review. Radiographics 2005;25:571-586.