BARÇA INNOVATION HUB

MUSCLE INJURY GUIDE:

Prevention of and Return to Play from Muscle Injuries

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Ben Clarsen
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F-MARC Football for Health FIFA — FIFA Medical Centre of Excellence
Science & Medicine in Football
Oslo Sports Trauma Research Center

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Summary

Editor's biographies

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Ricard Pruna is a specialist in Sport & Exercise Medicine with a Masters in both 'Traumatology and Sports' and 'Biology and Sports' and additionally holds a PhD in 'Genetics and Injury in Football'. Ricard has a rich and vast experience in top-level football having been the first team doctor of FC Barcelona for over 20 years. He is also the Head of Medical Services at FC Barcelona, overseeing the medical strategy and staff of all medical aspects in the club, including professional sports in addition to his first team football duties.

Ricard's clinical interests lie in football medicine, muscle injuries, genetics, return to play, anatomy and injury diagnosis. He has many scientific publications in the football medicine areas and has received various awards for his scientific work, including, the Award for Medical Excellence from the Medical College University of Barcelona, a National and UEFA Award for research in sports medicine.

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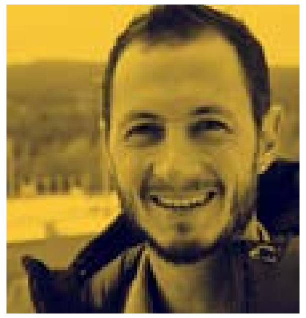
Thor Einar Andersen is a Professor and Head of football medicine research at the Oslo Sports Trauma Research Centre in the Department of Sports Medicine at the Norwegian School of Sport Sciences, Norway. He has a master degree in health administration from the University of Oslo. He is a trained physiotherapist, consultant physician, and specialist in Physical and Rehabilitation Medicine. His main research areas are football injury epidemiology, injury mechanisms and causes, as well as injury prevention.

Thor Einar is the Chief medical officer of the Medical Committee in The Football Association of Norway. He has served as team physician for the senior male national team from 2002-2014. He is medical director at the Norwegian FA Medical Centre and is a member of the board and director of elite sports in the football department at Nordstrand IF.

Thor Einar has a strong connection with high-level football having played professionally winning two Norwegian championships with IK Start, and represented Norwegian international youth teams (U15-U23).



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Ben Clarsen is a specialist sports physiotherapist at the Norwegian Olympic Training Center and a postdoctoral research fellow at the Oslo Sports Trauma Research Center (OSTRC). He has a bachelor degree in physiotherapy from the University of Sydney and a master degree in sports physiotherapy and PhD from the Norwegian School of Sport Sciences. He is a director of the IOC Diploma in Sports Physical Therapies and a lecturer on the sports physiotherapy master program at the Norwegian School of Sport Sciences. Ben has been physiotherapist for a number of professional road cycling teams, and the Norwegian and Australian national programmes. He is a senior associate editor of BJSM and was the senior editor of the 5th edition of Brukner and Khan's Clinical Sports Medicine textbook.

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Alan is Head of Research & Development for Arsenal Football Club and Co-head of Research & Innovation (with Assoc Prof Rob Duffield) at Football Federation Australia. Alan's background is as a fitness coach and sport scientist with over ten years experience working in professional club teams competing in Ligue 1, English Premier League, A-League, Scottish League and European competitions. He was Head of Sport Science and fitness coach of the Australian Socceroos at the 2014 FIFA World Cup and the U20 Young Socceroos at the 2013 World Cup.

Alan's research interests include injury prevention, recovery and performance in football. He holds a PhD in 'Injury Prevention in Elite Footballers' from Université de Lille 2 and a Msc in Strength & Conditioning from Edith Cowan University, Australia.

Alan is a member of the Football Research Group, Senior Associate Editor at British Journal of Sports Medicine, Associate Editor at Science and Medicine in Football and on the editorial board of Apunts which is a joint publication by the Conseil Catala de l'Esport and Barca Innovation Hub.

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Johann Windt is a Sports Medicine Data Analyst at the United States Olympic Committee. Before his current role at the USOC, he spent two years with the Vancouver Whitecaps Football Club (competing in the Major League Soccer) as a sport science data analyst. He is currently a PhD candidate at the University of British Columbia Canada. Co-supervised by Professors Karim Khan and Tim Gabbett, his doctoral work focuses on athlete monitoring and injury aetiology. Johann is also a member of the Football Research Group, which is an international research group collaborating closely with the Union of European Football Associations (UEFA) on various research projects related to football player health and performance.

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Steffan is a junior doctor at Chelsea and Westminster Hospital in London, and is passionate about pursuing a career in Sport and Exercise Medicine. He sits on the British Journal of Sports Medicine's editorial board as senior associate editor and helps lead the journal's social media channels. Steffan is also a board member of the Institute of Sport and Exercise Medicine, and has active research interests in concussion, return-to-play, and medical education.

BARÇA INNOVATION HUB

WHAT WE DO?

KNOWLEDGE

Exchanging ideas with the greatest minds around the world to develop cutting edge applied research projects. We have the commitment to share this knowledge to the new generation of sports industry professionals.

NEW PRODUCTS AND SERVICES

Leveraging our know how to partner with key stakeholders and create game changing technologies, processes and experiences which create value not only for the Club but for the whole society.

A RELEVANT ECOSYSTEM

Encouraging and connecting the sports business ecosystem: industry leaders, sport organizations, research centers, universities, entrepreneurs and start-ups.

OUR FOCUS

FC Barcelona aims to help change the world through sporting excellence via knowledge and innovation

We are looking to form an ecosystem to foster knowledge and innovation. This ecosystem is based on a model that promotes a culture of excellence and collaboration with prestigious brands, universities, research centres, start-ups, entrepreneurs, students, athletes, investors, and visionaries around the world.

By doing so, we aim to generate new knowledge and create new products and services that will be of benefit to our own athletes, members and fans, and society in general.

HOW?

Our knowledge and innovation activities are structured into 5 areas:

1. Medical services and nutrition
2. Sports performance
3. Team sports
4. Technology
5. Social science

Introduction to the Guide

0.1

PREVENTING AND TREATING MUSCLE INJURIES IN FOOTBALL

There are many physical and mental health benefits to training and playing football, however, there is also, unfortunately, one key adverse effect; an increased risk of injury, with muscle injuries being one of the most common that we see in elite football.
— With Ricard Pruna

Due to the negative effects that we know injuries have on performance, club finances and long-term player health, their prevention and optimal treatment (when they do occur) is an essential part of the football medicine and performance department. In particular, at FC Barcelona (and I am sure in many of the football clubs around the world) we see the role of the football medicine and performance department and staff as three-fold;

1. Protect our players' health
2. Maximise player and team performance
3. Ensure the scientific integrity of medical and performance programs delivered in FC Barcelona

At FC Barcelona we believe that the creation, integration and delivery of an effective and efficient medical and performance program requires an evidence led approach, using the best of research knowledge combined with our many years of practical experience. We also believe strongly in sharing our knowledge and experiences among the football and sports community globally.

In 2009, we published the first FC Barcelona Muscle Injury Guide with the aim of providing an insight into our philosophy and methods of preventing and treating muscle injuries. Then in 2015 we released our second Muscle Injury Guide. With each Guide we strive to progress on the last. We now have the great pleasure of launching our 2018 FC Barcelona Muscle Injury Guide: 'Prevention of and Return to Play from Muscle Injuries'. We see this Guide not as a progression on the previous two, but rather as a new concept and with a new direction. In the true spirit of FC Barcelona, we are 'mes que un club' (more than a club) and have welcomed into our football family, a number of internationally renowned sports medicine and performance practitioners and researchers to contribute with us on the practical recommendations that follow. We are truly grateful for the partnerships we have formed in the production of this Guide including; the Oslo Sports Trauma Research Centre and the Science and Medicine in Football Journal. Our aim is to provide you, the reader/practitioner with the most up to date knowledge and experiences from 60+ worldwide experts combined with the 'Barça Way'.

Our Muscle Injury Guide is not intended to be a 'must follow recipe', but rather to provide some key ingredients that you can adapt and integrate appropriately into your own practice. We hope you enjoy reading the combined knowledge and experiences of the many valued contributors included throughout.

Dr Ricard Pruna
Head of Medical Services, FC Barcelona

0.2

PARTNERSHIP WITH OSLO SPORTS TRAUMA RESEARCH CENTRE

The Oslo Sports Trauma Research Centre was established at the Norwegian School of Sport Sciences in 2000 as a research collaboration between the Department of Orthopaedic Surgery, Oslo University Hospital, Ullevaal, the Department of Sports Medicine, Norwegian School of Sport Sciences, and The Norwegian Football Association Medical Clinic (2015). Since 2009, the OSTRC has been recognised as a FIFA Medical Centre of Excellence and selected as one of four IOC Research Centres for Prevention of Injury and Protection of Athlete Health.

— With Thor Einar Andersen and Roald Bahr

The main objective of the Oslo Sports Trauma Research Centre has been to develop a long-term research program on sports injury prevention (including studies on epidemiology, risk factors, injury mechanisms, and interventions). The program focuses mainly on three sports (football, handball, and alpine skiing/snowboarding). We have addressed the most common (e.g. ankle, hamstrings) and the most serious (e.g. ACL, concussions) injuries seen in these sports.

In football, one focus has been on the preventive effect of eccentric hamstring training using the Nordic Hamstring exercise.[1] We have, in partnership with FIFA, also developed "The 11+", a warm-up program with exercises focusing on core stability, neuromuscular control, strength, balance, hip control and knee alignment in football.[2] In 2011, we conducted an intervention study in the Norwegian male professional league involving sanctioning of two-footed tackles as well as tackles with excessive force and intentional high elbow with an automatic red card to enforce the Rules of the Game.[3]

We have through several conferences, workshops, visits and meetings with FC Barcelona (FCB) and its medical staff, been inspired by the clubs' constant strive to implement best medical practice and scientific knowledge into their daily practice. In particular, we have been impressed by the FCB philosophy on training principles, diagnostic procedures and management of return to play after injury.

Both the Oslo Sports Trauma Research Centre and the FC Barcelona share a common understanding that scientists and practitioners should collaborate closely to bridge the gap between science and practice. We certainly believe developments in the area of football medicine will benefit from improved on- and off-field teamwork to answer the key research questions of the future.

Therefore, it is a great honour and pleasure for the Oslo Sports Trauma Research Centre to contribute in an exciting partnership with FCB to produce the FC Barcelona Muscle Injury Guide: Prevention of and Return to Play from Muscle Injuries. We are very much looking forward to this mutual collaborative effort and to continued projects in the near future.

1. Arnason A, Andersen TE, Holme I, Engebretsen L, Bahr R. (2008) Prevention of hamstring strains in elite soccer: an intervention study. Scand J Med Sci Sports;18(1):40-8

2. Soligard T, Myklebust G, Steffen K, Holme I, Silvers H, Bizzini M et al. (2008) Comprehensive warm-up programme to prevent injuries in young female footballers: cluster randomised controlled trial. BMJ;337:a2469

3. Bjørneboe J, Bahr R, Dvorak J, Andersen TE. (2013) Lower incidence of arm-to-head contact incidents with stricter interpretation of the Laws of the Game in Norwegian male professional football. Br J Sports Med;47(8):508-14

0.3

SCIENCE AND MEDICINE IN FOOTBALL JOURNAL'S SUPPORT

At Science and Medicine in Football, our mission is to advance the theoretical knowledge, methodological approaches and professional practice associated with the sport of football. In other words, we want to help bridge the gap between science/research and the practical setting. Essentially, we are an international, peer-reviewed journal interested in promoting evidence-based practice i.e. use of quality research knowledge with current best practice.

— With Tim Meyer and Franco Impellizzeri

We focus on many areas of football including, physiology, biomechanics, nutrition, training, testing, performance analysis, psychology and coaching. Additionally, sports science and medicine in football is key for us and our readership, with injury prevention and return to play current hot topics.

The FC Barcelona Muscle Injury Guide corresponds to our vision of bringing research and practice together. In this resource, FC Barcelona have brought together over 60 of some of the world's leading applied researchers and practitioners to share and perhaps most importantly, work together to combine their knowledge and experience into one voice.

Not only will this Guide provide a great practical recommendations' resource for football science and medicine practitioners worldwide, but should also help to drive forward meaningful applied research to further improve our field.

It is with great pleasure that we support this initiative by FC Barcelona. One aspect that we are particularly excited about is that various contributors involved in the Guide will progress on some of the chapters written within, by preparing scientific articles and submitting these to enter the Science and Medicine in Football peer review process. So, watch this space...

0.4

A LETTER OF SUPPORT FROM DR MICHEL D'HOOGE

In the medical world around football, great interest is given to articular and ligament lesions. At each medical congress, new techniques are presented in relation with important topics as anterior cruciate ligament tears of the knee, or posttraumatic ankle instability and others. One should, however, never forget that the most important injury in the world of football remains a muscle injury.
— With Michel Baron D'Hooghe, Chairman Medical Commission FIFA and UEFA

A lot remains to be studied, in the sphere of prevention, diagnosis and treatment of these injuries. Although the scientific world around our sport has spectacularly improved our medical assistance to the players, the impressive epidemiological studies of Prof Ekstrand and his team indicate that the number of muscular injuries did not decrease over the last years.

I remain convinced that, in different aspects, our approach of muscular injuries can be improved, and this as well in the preventive, pharmacological, surgical and conservative sphere.

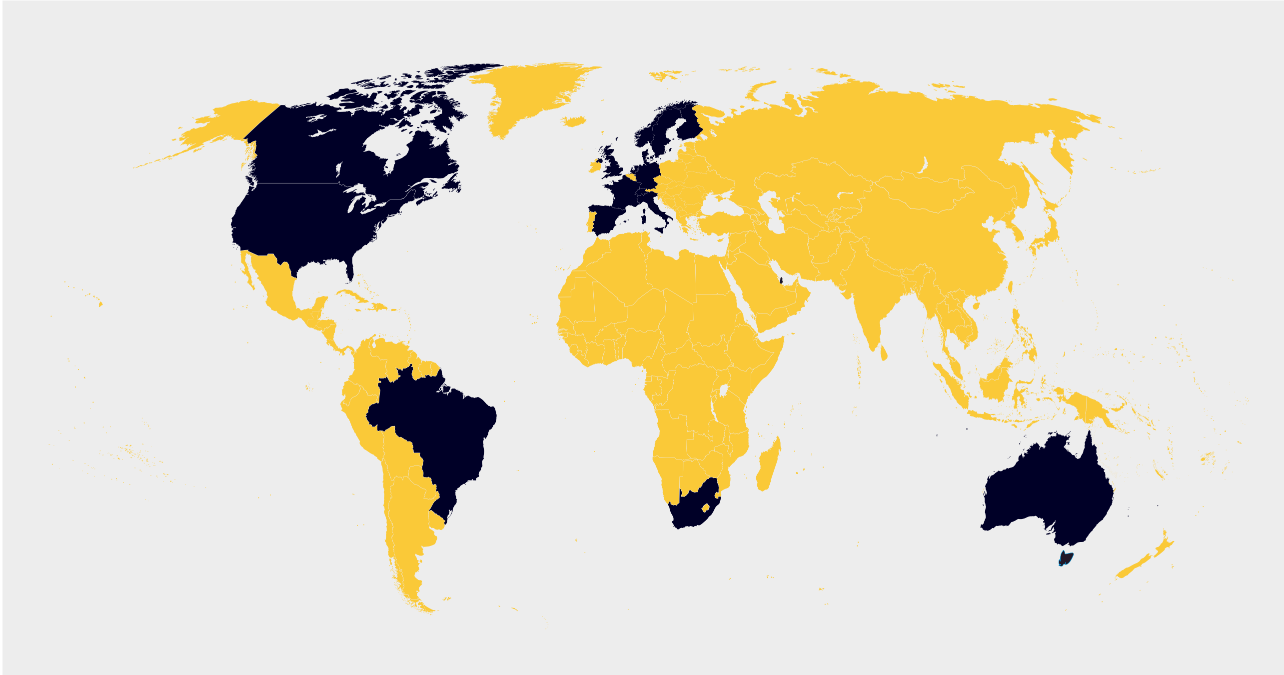
We must work together to improve our criteria for return to play, as the high number of re-injuries confronts us sometimes with our own deficiencies.

That is why this scientific work, the great medical guide of muscle injuries, is a gift to all practitioners, active in the field of football.

Many thanks to all the collaborators of this important book, which will greatly improve our care of the injured player.

0.5

INTERNATIONAL COLLABORATORS



Countries represented in the guide

Australia	Norway
Brazil	Northern Ireland
Canada	Qatar
Denmark	South Africa
Finland	Spain
France	Sweden
Germany	Switzerland
Holland	UK
Italy	USA

General Principles of Muscle Injury Prevention in Football

1.1.1

AN INTRODUCTION TO PREVENTING MUSCLE INJURIES

The objective of football is to win games and there are many factors (i.e. tactical, technical, physical and mental) interacting to achieve this objective. However, one key, contributing factor that the medical and performance team can influence is player availability i.e. through a lower impact of injuries (incidence and severity).

— With Alan McCall and Ricard Pruna

This makes sense, given that one would logically agree that having the best players available to play, enhances the likelihood of winning. A higher player availability means that the coach will have more players available to train and in turn more opportunity and time to work on tactics, technical aspects and team dynamics. There is also strongs cientific evidence to support this notion; less injuries have been associated with increased success in domestic league competition[1,2] and UEFA Champions / Europa League.[3] In addition to performance and success, injuries also carry with them a significant financial cost. It has been estimated that the financial cost of one player missing one month due to injury equates to an average of ~€500,000.[4] Remember that this is an average, imagine the costif this was a star player. A third important potential consequence of injury is an adverse effect on players' long term physical and mental health.[5]

While in an ideal world, we would be able to prevent all injuries from ever occurring, this is, in reality, impossible and our aim is really to minimise the risk of players suffering an injury. Life is full of risky decisions, from mundane ones to matters of life and death.[6] Risk is something that we must accept exists; even walking down the street has a meaningful (albeit small) risk for our safety.[7] The fact is,that injury is so complex, multifactorial and dynamic[8] that prevention must also be complex, multifactorial and dynamic. We should aim to identify and minimise known risk factors for injury while simultaneously identifying and maximising protective factors. Communicating the risks and the benefits of preventative strategies to key stakeholders (players, coaches, board level administrators etc) is essential if we are to succeed in at least reducing the risk and minimising the occurrence of injuries, and in particular muscle injuries which are one of the most common types of injuries that we are faced with.

The purpose of this opening chapter of the FC Barcelona Muscle Injury Guide: 'General Principles of Muscle Injury Prevention in Football' is to highlight, explain and delve into some of the key general principles to consider when the goal is to prevent muscle injury in footballers. Specifically, we will provide a new injury prevention model specific to team sports, followed by taking you through a journey of this model, providing practical guidelines along the way.

1.1.2

A NEW MODEL FOR INJURY PREVENTION IN TEAM SPORTS: THE TEAM-SPORT INJURY PREVENTION (TIP) CYCLE

Recently there has been growing interest in injury prevention for football and other team sports, including the development of models and frameworks to guide injury prevention efforts[1,2] , and improve understanding of injury aetiology[3,5].

— With James O'Brien, Caroline Finch, Ricard Pruna and Alan McCall

The most widely cited injury prevention model, called the 'sequence of prevention', was introduced by van Mechelen and colleagues in 1992.[2] This model builds on previous public health approaches[6] and consists of four key steps:

1. Establishing the extent of the injury problem
2. Identifying the key risk factors and mechanisms of injury
3. Introducing preventive strategies to mitigate the risk of injury
4. Evaluating the effectiveness of preventive strategies by repeating Step 1.

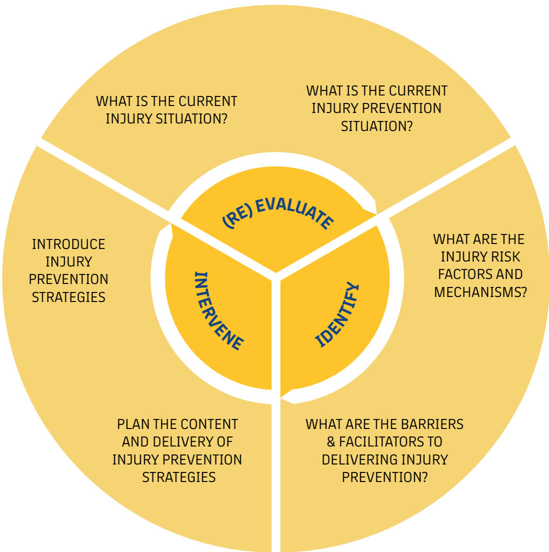


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Figure 1: The Team-sport Injury Prevention (TIP) Cycle

Phase 1: (Re) evaluate
Phase 2: Identify
Phase 3: Intervene

These phases incorporate key aspects of previous models,[1,2] along with important implementation aspects applicable to team sports such as football.

In 2006, Finch[1] introduced an extension of the van Mechelen model called the 'Translating Research into Injury Prevention Practice (TRIPP)' framework, which emphasises the key role of implementation aspects in achieving real-world injury prevention success. Subsequently, several further models have been proposed, each aiming to address potential limitations of previous models. These limitations include linear,[5,7] reductionist[8] or generic approaches,[9] a lack of operational steps[9,10] and the failure to incorporate player workloads.[4]

The applicability of each of these models will be context-dependent, with the majority being geared towards the conduct of injury prevention research,[1,2] and developing etiological theory.[5,8] However, practitioners working at the injury prevention "coalface" will be better served by a model more reflective of risk management approaches.[11,12] Such a model should be simple, directly applicable to the team's specific context and also acknowledge real-world implementation challenges. Furthermore, the model should reflect the cyclical nature of injury prevention, involving ongoing evaluation and adaptation of preventive strategies as opposed to a linear step-by-step process.

In the process of developing this Muscle Injury Guide, it became apparent that no existing model adequately reflects the everyday injury prevention approach of sports medicine and performance staff working in professional football teams. To remedy this, we developed a new model, the Team-sport Injury Prevention (TIP) cycle, specifically aimed at the sports team medicine/performance practitioner. It involves a simple continual cycle with three key phases (figure 1):

PHASE 1: EVALUATE

This phase involves evaluating the current "state-of-play" in your team. Addressing the question, "What is the current injury situation?" involves evaluating the type, incidence and severity/burden of injuries in the team. The second question, "What is the injury prevention situation?" involves analysing which injury prevention strategies are currently being used (or not used) and the reasons why. For example:

1. Is the team implementing evidence-based exercises (e.g. Nordic Hamstring[13] and the Copenhagen Adduction exercise[14])?
2. What is the team's current strategy for managing high-speed running load?
3. What recovery strategies are in place following match-play?
4. Is squad rotation being used?
5. Which other preventive strategies are currently in place, and with what rationale?

A detailed understanding of all team members' perceptions towards injury risk and injury prevention is important to inform subsequent phases in the cycle.

In addition to establishing what is being done, it is essential to determine precisely how these strategies are being carried out. For example, in the case of exercises, key considerations are the number and frequency of sessions, the exercise dose within these sessions (e.g. sets, repetitions, intensity) and also the quality of exercise execution.

PHASE 2: IDENTIFY

The next phase in the cycle involves exploring the risk factors and mechanisms of the injuries identified during the evaluation. This process will be primarily driven by the team's internal data (e.g. injury, tracking and monitoring data), along with consideration of established risk factors and mechanisms from the published literature. It is important to appreciate the multi-factorial nature of injury epidemiology,[4,8] assess injury risk at an individual player level[9] and consider the degree to which identified risk factors can be modified.

This second phase also involves identifying barriers and facilitators to implementing injury prevention strategies, which will strongly impact on the ultimate success of a preventive strategy. These factors will be context-specific, but recent research has highlighted a number of potential barriers/facilitators to implementing injury prevention exercise programs.[15,16] These relate either to the content and nature of the prevention program itself, or to how it is delivered and supported by players, coaches and team staff members. In large, multi-disciplinary sports medicine/performance teams there is potential for conflict among staff,[17,18] which can jeopardise the success of injury prevention efforts. Identifying these staff-related factors will inform the subsequent intervention phase.

PHASE 3: INTERVENE

The next phase involves planning both the content (what to do) and delivery (how to do it) of injury prevention strategies. This process will be influenced by the team's current situation, the identified injury risk factors and implementation barriers/facilitators, published injury prevention research and the team staff members' previous experiences from working in the field. Implementation research highlights the importance of securing administrative support for preventive strategies[10] and engaging all key partners in the design process.[19] In the professional football setting, this means involving club officials (who decide on club policy), coaches and team staff members (who deliver injury prevention) and key players (the targeted health beneficiaries) from the onset. Through involvement of all key partners in the design phase, context-specific strategies can be developed which have adequate support and account for barriers/facilitators in the team's specific context. The multi-factorial epidemiology of muscle injuries in football implies the need for multiple preventive strategies (e.g. load management, recovery strategies and specific exercise-based interventions).

ONGOING RE-EVALUATION AND MODIFICATION

Injury prevention is a dynamic, cyclical process. Having introduced or modified a preventive measure, ongoing evaluation is required. In the re-evaluation phase, successful implementation can be judged against metrics such as injury and physical performance data, team members' perceptions and the degree of fidelity to the injury prevention strategy (e.g. the number and quality of completed injury prevention exercise sessions). With continual progression through the model's three phases, the team's injury prevention strategy can dynamically evolve, responding to various changes in the team's environment (e.g. new players, new staff members and varying game schedules). While evaluation of certain metrics will occur on a daily basis in professional teams (e.g. wellness scores, workload data), it is recommended that teams also undertake more formal injury prevention evaluation, involving all key individuals, at least two or three times per season.

In the following chapters of this opening section on preventing muscle injuries we will take you through each of the 3 key phases in more detail.

1.2.1

EVALUATING THE MUSCLE INJURY SITUATION (EPIDEMIOLOGY)

Muscle injuries are one of the biggest medical problems in modern football, regardless of the playing level.[1,2] Specifically, muscle injuries represent almost one third of time-loss injuries and account for more than one-quarter of the overall injury burden as it was shown in the largest available study involving more than 9,000 injuries in men's professional football players in Europe.[2] Numbers from this investigation also reveal that on average, an individual player will sustain a muscle injury every other season.[2]

— With Markus Waldén, Tim Meyer, Matilda Lundblad, Martin Hägglund

MUSCLE INJURY LOCATIONS AND RATES

Most of the muscle injuries (92%) are located within the four big muscle groups of the lower limbs (hamstrings, quadriceps, adductors and calves).[2] A men's professional football team, typically consisting of a squad of around 25 players eligible for first team match play, can expect about 16 muscle injuries leading to time-loss each season (table 1).

MUSCLE GROUP	N. OF INJURIES
Hamstring	6
Quadriceps	3
Adductors	3
Calf	1-2
Other Locations	2-3

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Table 1 Average number of muscle injuries in a men's professional team per season (adapted from Ekstrand et al.[2])

Muscle injuries also occur at a high rate among, for example, female elite players and male youth academy players.[1,3] The muscle injury spectrum in those cohorts is essentially similar to high-level male players, whilst quadriceps injuries may be more frequent in early adolescence than in adulthood.[1]

HAMSTRING MUSCLE INJURIES

Hamstring injury is the single most common time-loss injury type representing 12% of all injuries in men's professional football.[2] In that study, 37% of all muscle injuries were in the hamstrings (figure 1). The injury rate during match play is almost nine times higher than during training (table 2). This means that a typical 25-player squad in men's professional football can expect about six hamstring injuries each season. Studies incorporating imaging modalities have shown that a clear majority of these injuries involve the long head of the biceps femoris, i.e. the typical 'sprinting injury'.[4,5]

Other studies on high-level male players have reported similar findings as those outlined above.[6,7] However, two studies on US collegiate players found a lower rate of hamstring injuries in female players,[8,9] whereas one study on Swedish elite players observed no sex-related difference in the rate of hamstring injuries[3]

MUSCLE GROUP	INJURY INCIDENCE	MATCH INJURY INCIDENCE
Hamstring	0.4 per 1000 hours	3.7 per 1000 hours
Quadriceps	0.3 per 1000 hours	1.2 per 1000 hours
Adductors	0.3 per 1000 hours	2.0 per 1000 hours
Calf	0.2 per 1000 hours	1.0 per 1000 hours

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Table 2
Muscle injury rate in men's professional football players (adapted from Ekstrand et al.[2])

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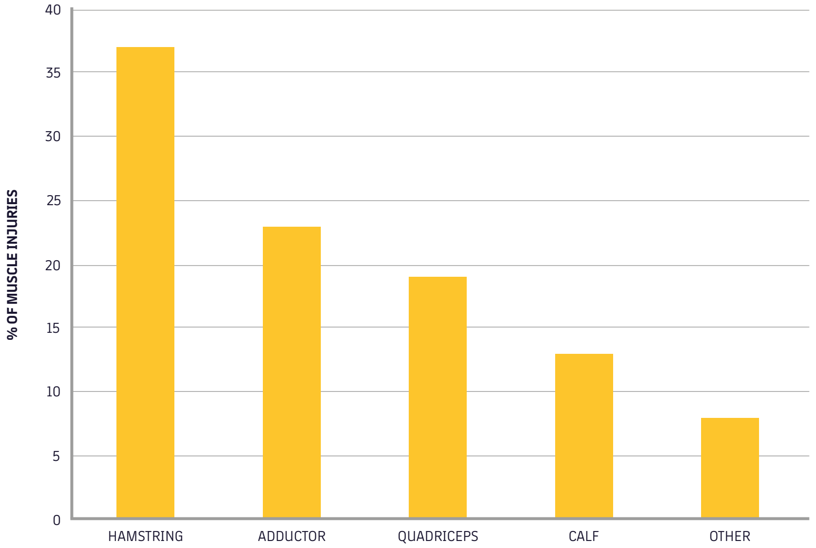

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Figure 1 Muscle injury location in men's professional football players (adapted from Ekstrand et al.[2])

QUADRICEPS MUSCLE INJURIES

Quadriceps injury represent 5% of all time-loss injuries and 19% of all muscle injuries in men's professional football (figure 1), which means that a 25-player squad can expect about three quadriceps injuries each season. Similar to the findings for hamstring injuries, the injury rate during match play is higher, approximately four times, than during training (table 2). Studies involving imaging modalities have shown that rectus femoris is the most common injury location in the quadriceps.[2,10]

ADDUCTOR-RELATED MUSCLE INJURIES

Each season a typical 25-player squad in men's professional football can expect four to five muscle injuries to the hip and groin.[2] The most relevant muscle groups from an injury perspective are the adductors and the hip flexors, whereas injuries in other muscles such as the abdominal, sartorius and tensor fascia latae muscles are less frequent,or even rare.[11-12] Adductor-related injuries are the second most common muscle injury among men's professional players representing 23% of all muscle injuries (figure 1) and 7% of all time-loss injuries.[2] A typical 25-player squad in men's professional football can therefore expect about three adductor-related muscle injuries each season (table 1). The injury rate during match play is more than six times higher than during training (table 2). Studies involving imaging modalities have documented that most of the adductor-related injuries involve the adductor longus.[12,13] Although less detailed, publications on male sub-elite or amateur players have reported similar findings on the location and rate of muscle injuries to the hip and groin.[14,15]

Finally, substantially less is known about hip and groin muscle injuries in youths and in female players, but a recent review on 34 epidemiological studies on football players concluded that hip and groin injury in general was twice as common in males as in females.[16]

CALF MUSCLE INJURIES

There is a lack of studies on lower leg muscle injuries in football, especially in females and in males from non-professional settings. However, one or two of all muscle injuries incurred by a typical 25-player squad in men's professional football will be located to the calf (table 1). In this sample, calf muscle injuries represented 13% of all muscle injuries (figure 1),and 4% of all time-loss injuries.[2] The calf muscle injury rate during match play is almost six times higher than during training (table 2). The classical injury involves the medial gastrocnemius, but less is known about soleus injuries even though these injuries probably are more frequent than once thought.[17]

MUSCLE INJURY BURDEN AND SEVERITY

Injury severity is commonly based on the number of days that the player is unable to train and compete due to injury. The average lay-off time due to a muscle injury is approximately two weeks with little variation between muscle groups.[2] About 10-15% of all injuries in the big four muscle groups are severe with a lay-off time longer than four weeks (table 3). There is a tendency that thigh and calf injuries are more severe than hip and groin injuries.

Higher grade hamstring injuries, as classified on MRI, are associated with longer lay-off, but there seems to be no differences in average lay-off between the three hamstring muscles (semimembranosus, semitendinosus and biceps femoris).[18]

The term injury burden is increasingly used in sports injury surveillance. It is a combined measure of frequency and severity and is usually expressed as the number of days lost per 1000 hours. Since the percentage of injuries in the severity categories and the average number of lay-off days are similar for the big muscle groups, the same pattern is seen as for the rates, with hamstring injuries having the highest and calf injuries the lowest burden (table 4).

MUSCLE GROUP	1-3 DAYS(%)	4-7 DAYS(%)	8-28 DAYS(%)	>28 DAYS(%)
Hamstring	13	25	51	11
Quadriceps	12	25	48	15
Adductors	18	31	41	10
Calf	14	25	48	13

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Table 3
Muscle injury severity according to lay-off in men's professional football players (adapted from Ekstrand et al.[2])

MUSCLE GROUP	INJURY BURDEN (days lost per 1000 h)
Hamstring	18.2 per 1000 hours
Quadriceps	10.3 per 1000 hours
Adductors	8.1 per 1000 hours
Calf	6.5 per 1000 hours

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Table 4
Muscle injury burden in men's professional football players (adapted from Ekstrand et al.[19])

MUSCLE INJURY TRENDS

Two recent studies from the UEFA Elite Club Injury Study have delineated muscle injury rates over time in men's professional football.[20 21] In the first report on 1614 hamstring injuries in 36 clubs between 2001 and 2014, there was an average annual increase of 2%,[20] and in the second report on 1812 hip and groin injuries in 47 clubs between 2001 and 2016, there was, in some contrast, an average annual decrease of 3% for adductor-related injuries.[21] Up to now, little is known about the injury trends in other cohorts or for other muscle groups.

1.2.2

EVALUATING THE MUSCLE INJURY SITUATION IN YOUR OWN TEAM

— With Alan McCall, Markus Waldén, Martin Hägglund and Ricard Pruna

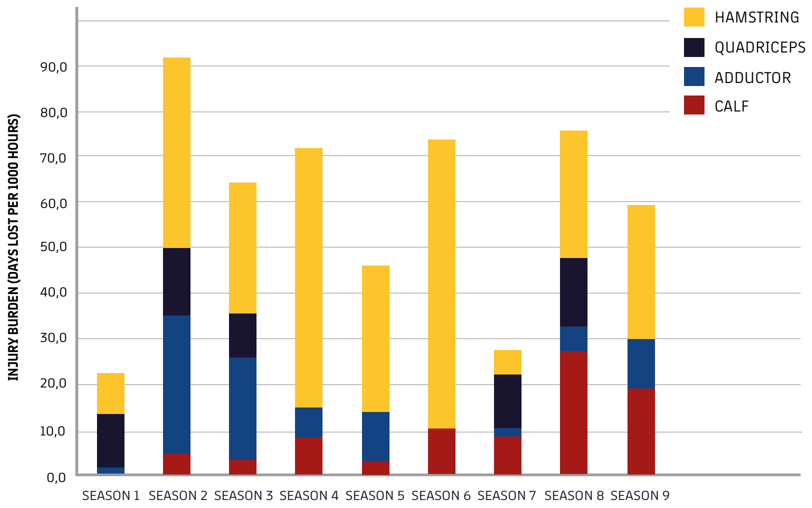

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Figure 1
Muscle injury burden in FC Barcelona during nine seasons: (2008/09 to 2016/17).

EVALUATING YOUR OWN TEAM'S INJURY SITUATION

The previous section has evaluated the muscle injury situation of professional football in general, i.e. studies using data from multiple teams and over various leagues, to highlight specific average characteristics and trends in injury epidemiology. While this information is essential to help guide our knowledge of injury in football and possible preventative strategies, it is essential that you evaluate the injury trends within your own team, as these can differ between and even within seasons. This is a key focus to ensure that your evaluation of the injury problem in your own team is accurate and that the subsequent strategies implemented in the Team-Sport Injury Prevention cycle are relevant.

As an example on why this is important, we illustrate in figure 1 the injury burden at FC Barcelona over 9 consecutive seasons (2008/09 to 2016/17). You will see that in line with the research literature, the hamstring injury burden is generally the main muscle injury we are faced with, however, you will also see that there are differences in the injury burdens of other muscle types. So, with continual (re) evaluation, it is possible to follow how the burden of muscle injuries varies. These insights then allow us to continually adapt our own preventative strategies to match the most current and relevant injury situation to our team.

1.3.1

RISK FACTORS AND MECHANISMS FOR MUSCLE INJURY IN FOOTBALL

— With Markus Waldén, Khatija Bahdur, Matilda Lundblad, Martin Hägglund

WHY AND HOW DO MUSCLE INJURIES OCCUR?

Most studies on potential risk factors for injury in football have addressed all injuries or injuries to the lower limbs in general and not muscle injuries specifically. There are, however, a number of risk factor studies on football players that have targeted hamstring injuries,[1] whereas risk factor data on quadriceps and calf muscle injuries in football are scarce.[2 3] Also, although there are many studies reporting on groin injuries among football players,[4] the majority of these report on hip and groin injuries combined and few studies on risk factors for groin injury in sports have reported data on groin muscles separately.[5 6]

The majority of the studies with risk factor data on muscle injuries in football have been carried out on professional or elite male senior players with considerably less literature on female and youth players. The findings on suggested risk factors are often identical or similar between studies but could occasionally be muscle-specific or even contradictory. Muscle injuries are, however, unlikely to result from a single risk factor, but rather as a consequence of several risk factors interacting at the time of the inciting event.[7]

In addition to traditional risk factor research, there are an emerging number of studies, mainly using systematic video analysis, describing injury mechanisms for typical football injuries such as concussions, lateral ankle sprains and anterior cruciate ligament injuries. Little is, however, known about football-relevant injury mechanisms or playing situations leading up to muscle injuries, and studies in this field are therefore urgently needed.

RISK FACTORS FOR MUSCLE INJURY

Risk factors in football have traditionally been divided into intrinsic (player-related), such as age and sex, and extrinsic (environmental-related) ones.[1] They can, however, also be categorized into non-modifiable (unalterable) and potentially modifiable (alterable) factors which might be more relevant from a prevention perspective (table 1).

INJURED TISSUES	NON-MODIFIABLE	MODIFIABLE
Intrinsic	Sex	Strength
	Age	Flexibility
	Previous injury	Fitness level
	Leg dominance	Psychological factors
Extrinsic	Playing level	Workload and congestion
	Playing position	Rules and regulations
	Playing activity	Equipment
	Time of season	Playing time
	Weather conditions	Playing surface

<
Table 1
Examples of modifiable and non-modifiable risk factors for muscle injury

NON-MODIFIABLE RISK FACTORS

SEX

One study on elite players showed a significantly higher rate of muscle strains in males compared with females, but no sex-related difference for hamstring injuries.[12] Similarly, a study on collegiate players also found a higher rate of muscle strains in males, but only during match play.[13] Moreover, studies on collegiate players report a lower hamstring injury rate in female players compared with their male counterparts.[14-16] In one of these studies, male players also had a lower recurrence rate than their female counterparts.[14] Finally, a recent systematic review identified that male players had a more than doubled aggregated groin injury rate compared with female players, although this comparison was not done for muscle injuries exclusively.[4] However, this is in line with recent data showing that both hip flexor,[17] and adductor strain rates were significantly higher in male players at the collegiate level.[16 17] In summary, the literature on sex as a risk factor for muscle injury in football is somewhat inconclusive, but it appears that male players have similar or higher groin and hamstring muscle injury rates compared with female players.

AGE

Age is a frequently studied risk factor for injury per se but is also important to adjust for when analysing other potential risk factors due to the apparent risk of confounding. The calf muscle injury rate was approximately doubled in male professional players older than the average age (>26 years), but there was no such age effect with adductor, hamstring and quadriceps injuries.[18] Similar findings were found in male elite players where older age (>23 years) was associated with a significantly higher percentage of calf muscle injuries, but again no association with adductor, hamstring and quadriceps injuries.[19] Similarly, increasing age was not associated with higher odds of sustaining hamstring injury in male amateur players,[20] but was so in two studies on male elite players.[21 22] The literature is also here somewhat inconclusive, but it appears that increasing age is associated with similar or higher muscle injury rates in male players.

In addition to the literature on senior players, recent data from FC Barcelona indicate that academy players have an increased frequency of rectus femoris injuries compared with professional players, whereas the reverse is seen for hamstring injuries.[23] No effect of age was, however, seen for groin muscle injuries in that study.

PREVIOUS INJURY

Previous injury is one of the most consistent and scientifically best validated risk factor for muscle injury.[1 5 6] In a large study on male professional players, previous injury was a significant risk factor (1.4 to 3.1 times higher rate) for all the big four muscle groups of the lower extremities (adductors, hamstrings, quadriceps and calf muscles).[18] Interestingly, a previous adductor and calf muscle injury also increased the quadriceps injury rate, and a previous adductor and hamstring injury increased the calf muscle injury rate in that study. Moreover, male elite players with previous groin and hamstring strains had seven and twelve times higher odds of sustaining new groin and hamstring strains, respectively.[21] Similarly, previous hamstring injury was associated with a significantly higher hamstring muscle injury rate in another study on male elite players,[22] and in male amateur players.[20] Although not specified for muscle injuries, male amateur players with previous acute groin injury in the latter cohort had more than doubled odds of sustaining future groin injury.[24]

There are, however, also a few studies showing no association with previous muscle injury. One study on male professional players showed in fact a significantly increased hamstring injury rate with no previous injury,[25] and two studies on female players showed no association between previous injury and future muscle injury; for thigh muscle injuries in youth players,[26] and for hamstring injuries in elite players.[27] In summary, a majority of studies have found previous injury to be a risk factor for future muscle injuries even if there are a few exceptions.

LEG DOMINANCE

Leg dominance in football is usually defined as the preferred kicking leg. Interestingly, both adductor and quadriceps injury rates are higher in the kicking leg,[18] which probably is due to increased exposure of high-risk player actions (shooting, passing, crossing, blocking, etc). Conversely, leg dominance has not been identified as a risk factor for hamstring injuries[18 28] and calf injuries,[18] probably due to other injury mechanisms involved.

PLAYING LEVEL

The influence of playing level on the muscle injury risk is currently under-studied, but it has been shown for hamstring injuries that the injury rate is highest and the recurrence rate is lowest at the highest professional level.[29] The same pattern with higher injury rates and lower recurrence rates at the professional level compared with amateur level is seen for injuries in general,[30] and there are therefore good reasons to assume that this would be similar also for other muscle injuries than hamstring injuries.

PLAYING POSITION

Goalkeepers carry a lower injury risk in general compared with outfield players and this seems to be the case also for adductor, hamstring, quadriceps and calf muscle injuries in male professional football players.[18 28 29] In one of these studies, it was also shown that forwards had the highest hamstring injury rate of all player positions.[29] Finally, goalkeepers also had fewest muscle injuries in a study on male academy players aged 8-16 years where the highest thigh injury rate was seen among midfielders.[31]

PLAYING ACTIVITY

It is well-known that the injury rate in general is several-fold higher in matches than during training regardless of the setting and playing level. Muscle injury rates are also higher, of approximately the same magnitude, during match play; the adductor, hamstring, quadriceps and calf muscle injury rates were, for example, 4-9 times higher during match play in male professional players.[32] A higher match injury rate has also been shown in other studies on male elite/professional players for groin muscle injuries,[21] hamstring muscle injuries,[21 28 33-36] and quadriceps muscle injuries,[34 35] as well as in studies on male and female players at the collegiate level.[14 15]

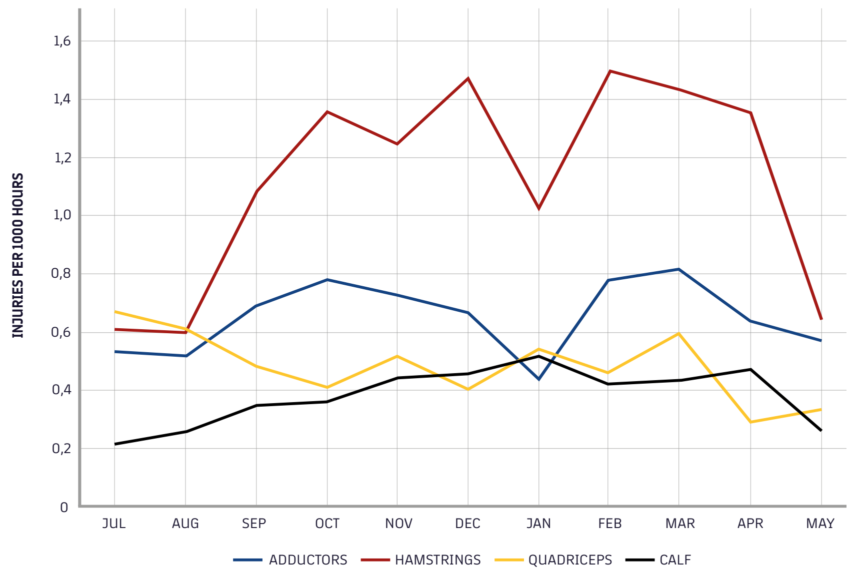

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Figure 1
Seasonal distribution of muscle injury in men's professional football players (adapted from Hägglund et al.[18])

TIME OF SEASON

For male professional players in teams with an autumn spring season, the rates of adductor, hamstrings and calf muscle injuries are significantly higher during the competitive season, whereas the reverse finding for is seen quadriceps muscle injuries with a higher injury rate during the pre-season period (figure 1).[18] Another study on male elite players showed that there was an accumulation of hamstring injuries in the spring season after the winter break.[36] Similarly, most thigh muscle injuries in male youth players occurred in September (after the summer break) and in January (after the winter break).[31]

WEATHER CONDITIONS

Although insufficiently investigated, there are currently no studies indicating that weather conditions, such as air temperature and evaporation, are associated with increased or decreased muscle injury rates in football. However, one study on male professional players showed no regional differences in adductor, hamstring, quadriceps and calf muscle injury rates between teams from northern Europe compared with teams from southern Europe, indicating that weather (and pitch) conditions are not equally important for muscle injuries as perhaps for other injuries such as ligament sprains and tendinopathies.[37]

MODIFIABLE RISK FACTORS

STRENGTH

Muscle weakness and strength imbalances are frequently suggested risk factors in the sports injury literature. A pioneer study carried out on a mixed cohort of athletes, mainly consisting of high-level male football players, with previous hamstring injury and recurrent strains and discomfort showed that muscle strength deficits were common and that a rehabilitation programme with normalisation of the muscle strength reduced the risk of re-injury.[38] Moreover, in a separate study on male professional players, the hamstring muscle injury rate was increased four-fold in players with thigh muscle strength imbalances compared with players without any muscle imbalances.[39] Similarly, male professional players with eccentric hamstring strength asymmetries at pre-season had four-fold higher odds of sustaining hamstring strain during the following season.[25] More recent research has shown that male professional players with hamstring injury were weaker during eccentric contractions than uninjured players, but between-limb imbalances did not infer a higher rate of hamstring injury.[40] Conversely, only one of 24 studied muscle strength variables was associated with increased hamstring muscle injury rate in a recent study on male professional players.[41] Similarly, hamstring strength had no association with future occurrence of hamstring muscle injury in female elite players.[27]

Male amateur players with weak adductor muscles had four-fold increased odds to sustain a future groin injury.[24] In addition, male elite and sub-elite players with ongoing adductor-related pain had lower hip adduction strength compared with asymptomatic control players,[42] a finding that was also seen in male amateur players with current groin pain.[43] In the latter study, previous long-standing groin pain (>6 weeks) during the preceding season was associated with lower hip adduction strength.[43]

There is no published data yet on the potential association between muscle strength deficits and/or imbalances and future calf muscle injury risk.[3]

FLEXIBILITY

Poor flexibility, sometimes also described as muscle tightness or reduced muscle length, has for long been suggested as a risk factor for muscle injury, but one of the first studies in the field showed that there was no difference in range of motion between male amateur players with or without hamstring strains.[44] In one subsequent study on male elite players, there was no difference in muscle tightness between players with and without muscle strains, but players with previous quadriceps strain had significantly shorter rectus femoris than those without strains.[33] In professional football, one study showed that male players with hamstring and quadriceps muscle injuries had lower flexibility in these muscles than uninjured players, whereas no difference was seen for adductor and gastrocnemius muscle injuries.[45] Similarly, male professional players with hip and knee flexor muscle strains had significantly lower range of motion in these muscle groups compared with uninjured players.[46] There is also more indirect evidence of muscle tightness as a risk factor in a study where hamstring-injured male professional players had significantly shorter fascicles of the long head of the biceps femoris than uninjured players.[40] Moreover, two studies on male professional players have found that found that decreased range of motion in the hip was significantly associated with muscle injury; lower hip flexion increased the odds for sustaining hamstring muscle injury,[47] and the total hip rotation (internal plus external) was lower in players who sustained adductor strains compared with uninjured players.[48] Finally, decreased hip abduction was a risk factor for sustaining new groin strain in male elite players.[21] In summary, there is some conflicting evidence on poor flexibility as a risk factor for muscle injuries in football and further well-designed studies appears to be needed.

FITNESS LEVEL

There is emerging evidence that poor intermittent aerobic fitness is associated with an increased odds to sustain lower limb injuries, especially muscle injuries, in male professional players.[49,50] Specifically, players with lower fitness level were unable to tolerate acute:chronic workloads of at least 1.25 and had a five-fold higher odds to sustain a lower limb injury compared with players on a higher fitness level in one of these studies.[49] Future studies in this field and on other fitness variables are, however, needed.

PSYCHOLOGICAL FACTORS

The literature in this field is still scarce compared with studies on physical factors. A recent cross-sectional study of male professional players, however, showed that players who had suffered at least three severe (>28 lay-off days) muscle injuries during their career had 2.6 times higher odds of reporting distress than players without previous severe muscle injuries.[51]

WORKLOAD AND CONGESTION

The influence of workload on sports injury risk has received a lot of interest in recent years with both high absolute and relative loads being associated with increased injury risk as shown in a recent review by the International Olympic Committee.[52] At the time of the publication of that paper, there were only a few studies on workload and injuries in football, but thereafter a number of studies on male professional players have been added; these studies show essentially the same findings by mainly including muscle injuries in their analyses.[49,50,53-55]

The influence of congested match periods on injury rates is another area of interest. It was recently shown that high match load in male professional players was significantly associated with an increased muscle injury rate during match play.[56] In that study, the overall muscle injury rate was significantly higher in league matches with ≤ 4 recovery days compared with ≥ 6 recovery days; significantly higher rates were also identified for hamstring and quadriceps injuries, but not for adductor and calf muscle injuries. This tallies with previous findings where the muscle injury rate in a men's professional team was more than five-fold higher in congested match periods with two matches per week compared with periods one match per week.[57] Looking at individual player match loads, it seems that six days or more are needed between match exposures to reach a baseline level of the muscle injury rate.[58]

RULES AND REGULATIONS

The majority of all muscle injuries (>90% regardless of muscle group) in male professional players occurred in non-contact situations with few match-related injuries being the result of foul play in the view of the referee.[32] Consequently, re-enforcements of the existing rules will probably have negligible impact on the panorama and burden of muscle injuries. However, as discussed further below, muscle injuries might be associated with fatigue and regulations on reducing individual playing time and/or increasing the recovery window between matches might therefore be of value.

EQUIPMENT

Currently, there are no studies indicating that any particular equipment, such as taping or type of footwear, are associated with increased or decreased muscle injury rates in football.

PLAYING TIME

Muscle injuries in male professional players tend to occur less frequently in the beginning of a match (or match halves);[32] there were fewer quadriceps injuries in the first quarter of the first half, fewer groin muscle injuries in the first quarter of the first and second halves, and more calf muscle injuries during the last quarter of the second half, whereas there was no differences between quarters for hamstring injuries. Other studies on male professional players have, however, shown that there could be a fatigue effect for hamstring injuries with more injuries occurring in the final quarter of the first and second halves ~~(Woods et al., 2004)~~, and in the later parts of training sessions and matches ~~(Dadebo et al., 2004)~~. Finally, thigh muscle injuries in male youth players have been shown to be more frequent in the end of the first half and then persisting throughout the second half ~~(Cloke et al., 2012)~~.

PLAYING SURFACE

Studies comparing artificial turf with natural grass have yielded conflicting findings. The first study comparing play on so-called third-generation artificial turf with natural grass, showed a significantly lower rate of lower extremity strains on artificial turf, but not for groin and hamstrings strains.[59] In a subsequent follow-up, also including female elite players, the same pattern was seen with a significantly lower muscle strain rate on artificial turf in male players, but with no difference between surfaces in

female players.[60] In that study, the rates of calf strain and quadriceps strain in male players were significantly lower on artificial turf during training and match play, respectively. Other studies on male professional players showed, however, neither a difference in the overall muscle strain rate,[61-63] nor for sub-analyses of the big muscle groups between third-generation artificial turf and natural grass.[61 62] Finally, in a study on male and female players at the collegiate level, there was no between-surface difference in the rate of lower extremity strains during match play and training for either sex, respectively.[16 64]

INJURY MECHANISMS

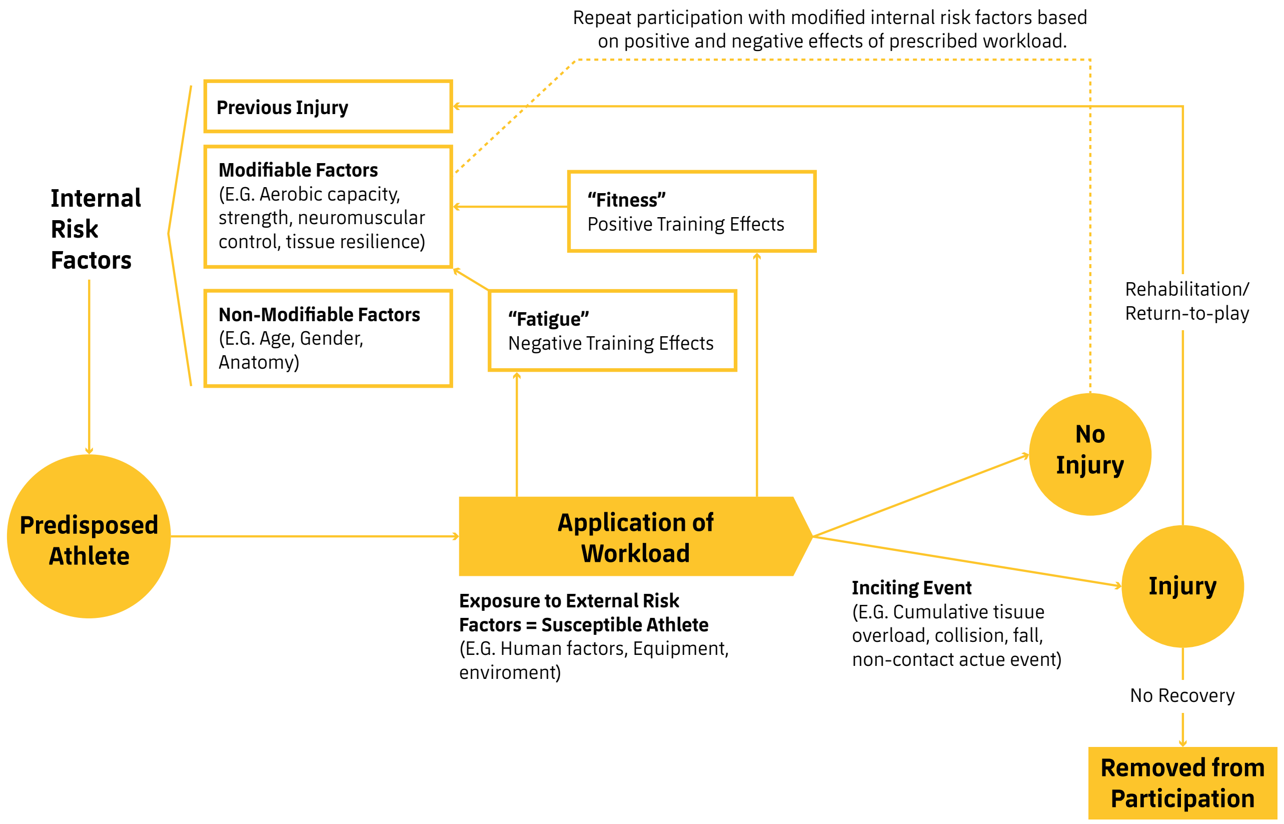
There is yet no published study that has used systematic video analysis for describing different injury mechanisms for playing situations leading up to muscle injuries in football. From epidemiological studies, however, it appears that a majority of hamstring injuries occur during sprinting or high-speed running also in football.[28 32 40] Conversely, many quadriceps injuries occur when shooting or kicking the ball and therefore mainly affects the dominant leg.[32] Kicking is also the most frequently reported injury mechanism for adductor longus injuries, which reaches its highest muscle activity and maximal rate of stretch in the swing phase of kicking.[65]

1.3.2

THE COMPLEX, MULTIFACTORIAL AND DYNAMIC NATURE OF MUSCLE INJURY

While risk factor identification is important, athletic injuries do not occur because of any single risk factor. Rather, injuries (muscle injuries included) occur as several risk factors interact at the time of an inciting event during training or competition (Figure 1).[1,2] In other words, athletic injury etiology is complex, dynamic, multifactorial, and context dependent.

— With Natalia Bittencourt, Mario Bizzini, Johann Windt and Alan McCall



The complex, multifactorial nature of muscle injuries means that a given risk factor – e.g. low eccentric hamstring strength[4] – may only result in injury if accompanied by other risk factors, such as a previous hamstring injury and the presence of fatigue. Even this collection of risk factors may never cause injury if a player isn't exposed to activities (e.g. high-speed running and sprinting), which can trigger the inciting event.

The dynamic nature of etiology means that in the ever-changing football environment, many risk factors constantly change within- and between-days, weeks, months, and seasons.[1,2]

To better understand muscle injury risk in our players, adopting a complex systems approach has been proposed.[3] Namely, this approach will allow us to identify 'risk profiles' associated with injuries, rather than individual risk factors alone.

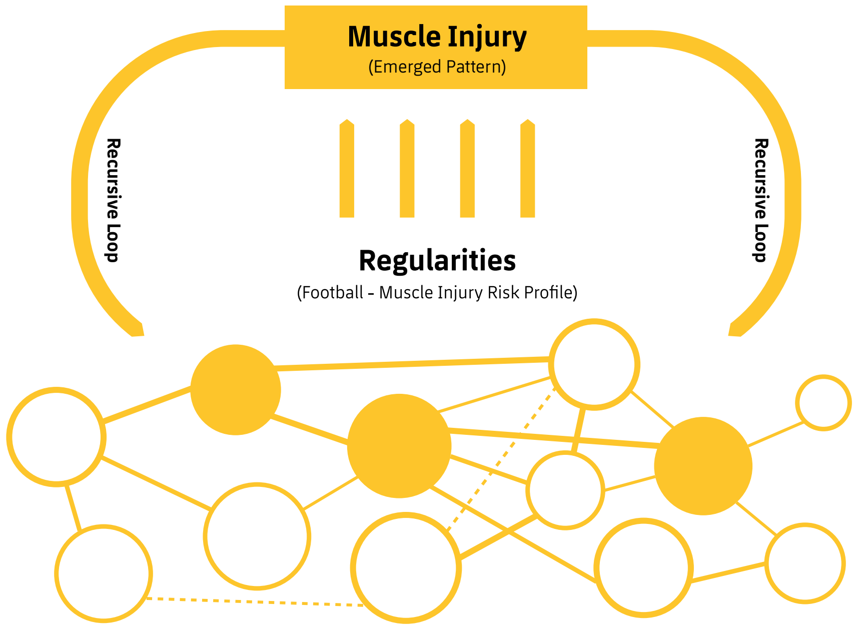
^
Figure 1
The workload—injury etiology model.[2] According to the model, every player will have a given internal predisposition to injury based on their collection of internal risk factors. Muscle injuries will occur during training or competition workloads during which they are exposed to external risk factors for injury, and potential inciting events. However, whether or not they experience an injury, the player's predisposition for injury dynamically changes with each training or competition session, as both positive (e.g. improved fitness) and negative (e.g. neuromuscular fatigue) occur.
Redesigned by FC Barcelona

IDENTIFYING RISK PROFILES

A complex patterns model considers patterns in risk factor relationships that may increase injury likelihood.[3]
In this model, risk factors and potential interactions result in a 'web of determinants' (figure 2). In each sporting context, one may use the model to determine patterns of relationships (interactions) between factors (regularities), what certain interactions produce (emerged patterns), as well as the regularities that may lead to injury (risk profile). [3] Notably, multiple risk profiles may exist for the same outcome (i.e. injury), since individual risk factors within the web of determinants may have varying effects, depending on other factors. For example, the consequences of factor A (i.e. weak eccentric muscle strength) will differ if it interacts with factor B (i.e., congested match schedule), factor C (i.e., previous injury), or both. Ultimately, identifying these regularities (i.e. risk profiles) may improve our understanding of injury etiology and inform future preventative interventions.

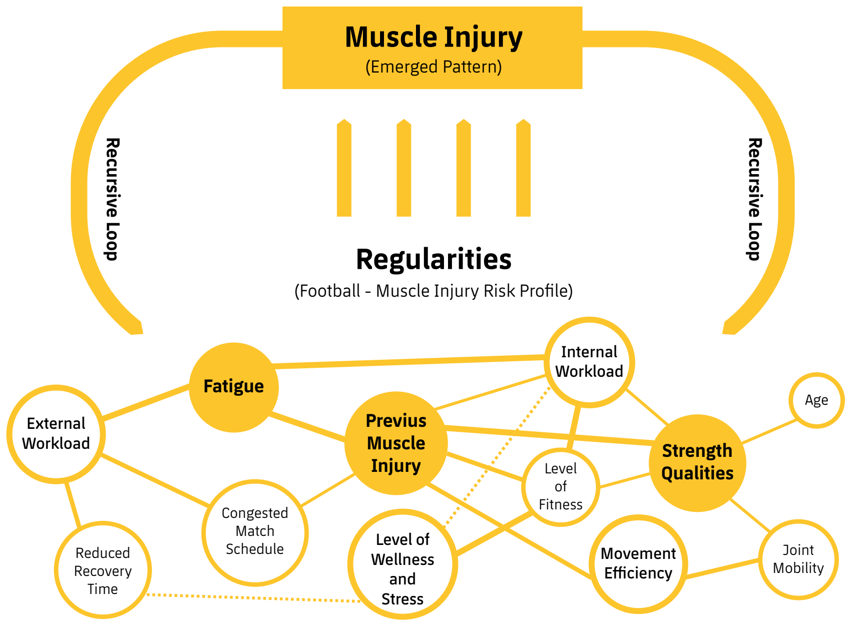
To our knowledge, there is currently no web of determinants that exists for muscle injury in football. Until future robust statistical analyses are carried out that identify the relevant factors and risk profiles, we encourage a critical thought process and the creation of potential webs of determinants. Below, we created an initial example of what a web of determinants for muscle injury in football may look like. Whilst not validated, our web is based on a combination of known evidence in the scientific literature and our practical experience, with the purpose of illustrating this concept.

Figure 2
Complex systems approach to muscle injuries in football. Factors associated with injuries form a web of determinants, and certain associations between these factors will be regularities that contribute to an emerged pattern/ outcome (in this case muscle injury). Redesigned by FC Barcelona



For football players, the main factors within our web of determinants (thicker nodes) are: 1) previous muscle injury; 2) fatigue and 3) strength qualities. The second level of nodes include: external and internal workload, movement efficiency, and psychological aspects. Within this theoretical web of determinants, players who exhibit a profile including a previous muscle injury, high fatigue levels and low strength are considered to be at an increased risk for muscle injury. Further, these three factors may interact, as previous muscle injuries will change the level of fitness, strength qualities, and may alter the fatigue process. FATIGUE is the global result of the relationship between external and internal workload. The player's external workload (work completed) is modulated by factors such as reduced recovery time and congested match schedule, which increase workload density and may add stress to the players, indirectly altering internal workload. Internal workload is influenced by player's internal characteristics, including physical fitness, strength qualities, and stress. PREVIOUS MUSCLE INJURY can change muscle tissue (e.g., scar and angle of peak torque), [5] which may produce muscle weakness and imbalance. Movement efficiency could therefore be altered, with other factors like joint mobility contributing. Finally, several of these previous factors, along with age, have the potential to modify STRENGTH QUALITIES.

Figure 3
Theoretical web of determinants for muscle injury in football. Redesigned by FC Barcelona



1.3.3

MUSCULOSKELETAL SCREENING IN FOOTBALL

It is common practice in professional sport to perform some manner of periodic health evaluation (PHE), commonly referred to as "screening". In elite football, 90% of the teams do some form of screening throughout the season.[1] Professional teams and football governing bodies aim to protect the health of the player through screening and monitoring to identify potential risk of injury, which, if possible, could positively impact performance, economical aspects at the club, and the health of players.[2,3]

— With Nicol van Dyk, Robert McCunn, Phil Coles, Roald Bahr

INTRODUCTION

Organisations such as the International Olympic Committee (IOC) and Fédération Internationale de Football Association (FIFA) have released guidelines on the screening of athletes and players, attempting to set a standard of care that would assist in the early detection of cardiovascular and other potential health (medical) risks.[4] Typically, this consists of (i) a comprehensive cardiovascular examination, (ii) a general medical evaluation (including blood tests) and (iii) musculoskeletal assessment to be performed on all players. Here, we will focus on the musculoskeletal component of screening.

Scientific evidence demonstrating how valuable musculoskeletal testing is, which are the best tests to use, and whether these test results are actually associated with muscle injury is unfortunately, scarce. This section contains important factors to consider when building your own battery of tests where the objective is to screen for some of the potential risk factors such as those identified in section 1.3.1. Importantly, these test results should be interpreted for the individual player, which allows appropriate intervention and decision-making by the medical staff, based on a combination of research evidence and current best practice. Although no emperical evidence exists, there is a growing consensus among practitioners that regular monitoring of risk factors will allow more appropriate and timely interventions.

WHY DO WE SCREEN?

At present, none of the tests used to perform the musculoskeletal screening or monitoring appropriately separate players who are at high risk of injury from the rest of the group.[6] These tests simply do not have the appropriate properties to perform such a function, and we continue to see the injuries that occur across all the players in the team, irrespective of their screening results. For injury prevention in elite football, large group based interventions are likely still key.

However, the interventions that we apply should ideally be monitored for each individual player, as adaptation and reaction to these interventions might differ between players, and individualization of these exercises might be necessary to ensure effectiveness is maximised.

The complex, multifactorial and dynamic nature of muscle injuries is becoming more and more accepted by practitioners,[5] and explained in the previous section. Although screening to predict future injury is not possible,[6] we screen each individual player to detect ongoing musculoskeletal conditions, identify health issues that may require intervention, create a rapport between practitioner and player, and identify how these aspects may impact team performance.

DETECTING CURRENT MUSCULOSKELETAL CONDITIONS

Screening performed for each individual player should focus on early identification of current health problems and assessing the status of 'old' injuries to prevent their recurrence.[7,8] Of course not every player would need an individual follow-up after screening. Value may be found in simply reassuring a player regarding the rehabilitation from a previous injury or management of physical symptoms. However, we might introduce a specific program for selected players, in particular those that have returned from previous injury, to ensure they reach their optimal level of performance after return to play.

ESTABLISH PERFORMANCE BASELINE AND HEALTHY STATE

Another reason to conduct screening is to establish a performance baseline for the player in the absence of injury or illness. For example, if a player sustains a hamstring injury during the season, the strength or functional tests performed during screening can represent a useful reference point for the practitioner to determine responses/success throughout the return to play process, and can assist in decision making during this period. Alternatively, if the club decides to add a specific training/strengthening programme during the season, a baseline test can assist the performance team to establish whether or not the program has been successful and where to target future injury prevention programs.

BUILDING THE PRACTITIONER-PLAYER RELATIONSHIP

The relationship between the player and the medical team is essential to build trust and create a safe environment where the player will openly and honestly share his/her concerns and physical information. This allows an optimal shared decision making process.[9] It is also an opportunity to provide education regarding certain health policies or injury prevention strategies and to receive both subjective and objective feedback from the players on their current health status.

MAIN COMPONENTS OF SCREENING

Screening is usually performed at the beginning of a season, although additional screening opportunities should be sought, such as a mid year review, or at the end of the season to establish off-season programs. We recommend end-of-season screening, which allows for the identification of ongoing musculoskeletal issues to receive attention before players resume training at the start of the next season.

Although the most comprehensive screening will likely still happen during the pre-season, musculoskeletal screening should sensibly be repeated throughout the season to determine how variables respond to training and competition for each individual player, as well as at a team level. This might assist the medical and performance team to make better informed decisions regarding the health of the players, as well as reducing their injury risk.

Once a battery of tests has been selected, it is important that they are standardized and if repeated, done so in the same way. Time of day, influence of practice sessions or training, and other external factors should be considered whenever possible to ensure that the screening measures used are consistent, and comparison with previous results are meaningful.

Ideally, the entire medical team should be involved in screening. Although the testing might be performed by specific members, it is important to have the team doctor, physiotherapist, and even manager present to emphasize the value and importance of the testing. Furthermore, it makes direct and immediate communication and interpretation of the results possible, allowing greater transfer of the results in a practically meaningful way.

Screening includes both a review and consideration of non-modifiable information (age, previous injury, etc), as well as modifiable potential risk factors (e.g. strength, flexibility, fitness, psychological status, workload, movement quality, and performance tests). Although many options are available, we have summarized some key components and their characteristics in table 1. Workload monitoring will be explained in detail in the upcoming 'Preventative Strategies' section.

	TESTS AVAILABLE	ADVANTAGES	DISADVANTAGES	CONSIDERATIONS
Strength[10-14] **Strength**	Isokinetic dynamometer (eccentric strength, side-to-side imbalances, functional ratios e.g. hamstring:quadriceps) Field devices (Nordbord®)[14] (eccentric strength, side-to-side imbalances) Hand held dynamometer (HHD) (isometric strength) Force platform (isometric strength, concentric power and/or eccentric duration e.g. during countermovement reactive strength e.g. from drop jump and between leg functional imbalances	Moderate accuracy and validity for all these tests Testing can be performed as part of training	Player buy-in, difficult for players competing in 2 matches per week Cost Requires expertise to interpret the data outputs e.g. graphs	When interpreting Nordbord strength results, it may be important to normalise it to body mass Isometric testing might be a safe alternative during congested periods in the season and form part of recovery monitoring
Flexibility[3,16,17] **Active & passive range of motion**	Straight leg raise test Sit and reach test Passive and active knee extension test Bent knee fall out (BKFO) Hip internal/external range of motion Dorsiflexion lunge test Thomas test Standing forward flexion test Knee-to-wall	Moderate accuracy and validity for all these tests Low cost, easy to perform Simple tests to inform daily physiotherapy interventions e.g. manual therapies	Player buy-in, difficult for players competing in 2 matches per week	When is the best time to perform the test? Before or after training Might be useful in return to sport decision making Could form part of recovery monitoring battery Can form part of a simple daily ‚general medical screen' Selection - can't use all of them
Movement quality[18-24] **Determine how well (controlled) movements are performed[23,24]**	Functional Movement Screen (FMS) Functional movement test 9+ Landing Error Scoring System (LESS) Soccer Injury Movement Screen (SIMS) Laboratory based jump-landing assessments	Low to moderate accuracy Holistic view of athleticism and movement patterns Easy to administer (once trained and players familiarised)	Large season to season variability in scores Subjective (excluding laboratory tests) Questionable link to injury risk	If used, consider the same assessors at minimum performing the scoring Careful interpetation of the results (i.e. many of these have shown no association with injury, and none of shown predictive accuracy)

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Table 1. Some available tests that could be included in the musculoskeletal screening protocol

INTERPRETATION OF THE RESULTS

FOR THE INDIVIDUAL

The test results for each individual player may be compiled to form an overview or holistic impression of the players' current status. Ideally, previous data on a particular player exists and allows comparison to a previous time point, or a moving average of ongoing monitoring of these factors, this may be used to determine whether a player has improved, worsened or stayed the same. Alternatively, the player may be compared with the rest of the team or data on the entire league, if available. This would indicate whether specific action or intervention may be needed on an individual level to improve his/her current status to be on par with the rest of the team (or league).

1. Overview of the players risk profile, and health status.
2. Compare to previous status or test results
3. Determinate specific interventions needed to address any identified musculoskeletal issues or risk factors

FOR THE TEAM

The results from the different screening measurements may allow the medical team to identify trends throughout the season. For instance, if the entire squad displays lower strength compared to the previous season, coupled with an increase in muscle injury, it might indicate effects of a pre-season training camp or inappropriate training methods. Such findings may help the overall management of the squad to protect the players from injury and avoid larger scale injury patterns.

Furthermore, it might assist in the design of group-based prevention programmes that are aimed at the entire squad. Certain key areas may be identified that need priority. Although a prevention programme would still contain all the elements needed to provide holistic prevention, some test data may help to tailor it to the team profile, which may improve the overall effectiveness of the intervention. It is important to present this information in a way that is understandable to the medical, performance and management team.[25]

1. Overview of the team status and health
2. Identify trends that develop during a season. (i.e, lower strength compared to the previous season, coupled with an increase in muscle injury).
3. Design group based prevention programmes that are aimed at the entire squad.
4. Certain key areas may be identified that are given higher priority

TAKE HOME MESSAGE

Although we cannot eliminate risk of injury, the goal of screening is to aid in the protection of our players, minimize risk, and contribute to their overall well-being, ultimately contributing to team success.

1.3.4

BARRIERS AND FACILITATORS TO DELIVERING INJURY PREVENTION STRATEGIES

Published information on barriers and facilitators to delivering injury prevention strategies is scarce,[1] but initial research on injury prevention exercise programs has identified a wide range of factors, relating either to the content and nature of the program itself, or how the program is delivered and supported by players, coaches and team staff members.[2,3]

— With James O'Brien and Caroline Finch

In relation to the program, examples of barriers include lack of individualisation, progression, variation and football specificity, along with the program being too long or too monotonous. Example of barriers relating to players include lack of acceptance/motivation regarding the program, fatigue, absences (e.g. national team, illness) and muscle soreness. In the case of coaches and team staff members, acceptance and support of the prevention program is a key factor. Other factors, relating to the team staff members who design and deliver preventive exercise programs (e.g. fitness coaches and physiotherapists), include lack of staff continuity, teamwork, communication and planning.[2]

Acceptance of and active support for injury prevention strategies are particularly important factors, applicable to several different groups (e.g. players, coaches and administrators). Successfully addressing these factors in order to increase "buy-in" may require tailoring messages to each of these different groups. Table 1 outlines some tips on what you could do to overcome some of the barriers that can limit the effectiveness of injury prevention programs.

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Table 1
Key messages for promoting injury prevention strategies in professional teams

TARGET GROUP	KEY MESSAGES
Club officials	Injuries are expensive. The costs to a professional club for a player being injured for one month can reach 500 000 Euros.[4] Teams with fewer injuries are more successful in both their national league and in UEFA competitons.[5]
Coaches and team staff members	Avoiding injury increases player availability for training and matches Having more players available can help in managing the physical demands on all players.[6] Injury prevention exercises can be easily incorporated into team training (e.g. warm-up and cool-down) with minimal time cost. Lower injury rates correlate with team success[5] Large randomised-controlled trials support the effect of injury prevention exercise programs in elite and sub-elite teams.[7-9] Avoiding injury can protect players from both the short- and long-term negative effects of injuries.[10]
Players	Injury prevention is important to keep you on the pitch, extend your career and invest in your long-term health.

1.4.1

STRATEGIES TO PREVENT MUSCLE INJURY

When we think of prevention strategies for muscle injuries, we typically think of exercises targeted at strengthening the muscles and related modifiable risk factors that exercise can influence. However, in contemporary professional football, we are moving away from the thought that preventing muscle injury means simply implementing specific exercises but rather looking at it as a more holistic strategy that is multifaceted.

— With Alan McCall and Ricard Pruna

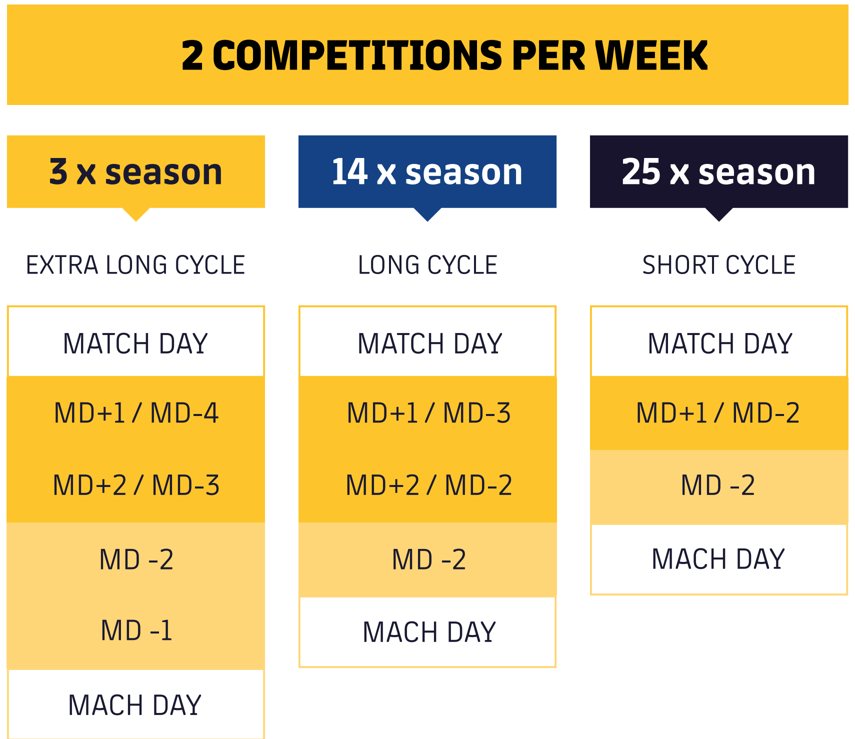

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Figure 1.
Typical match schedule of FC Barcelona during an in-season period

We only need to look at the playing schedule of elite level football teams to understand why we need to think bigger than just exercise alone. Elite football teams are regularly required to play in periods with 2 matches per week throughout the season e.g. domestic league, national cups, confederation competitions etc. Figure 1 illustrates the congested match schedule that FC Barcelona are typically exposed to. You will see that the majority (25 matches) are played with only 2 full days recovery, fourteen with 3 full days and only 3 where the recovery between matches is considered 'extra long' i.e. 4 full days. With such a congested match schedule it is difficult to plan any focussed, high-intensity exercise programs that may be able to help prevent muscle injury, at least for the regular playing squad. As such we need to look at other ways to minimise the risk of muscle injury and this calls for other 'preventative strategies'. Even for the non-playing or substitute squad, preventative strategies other than exercise-based should be beneficial to optimise the training process i.e. maximise performance and minimise injury.

During the process of putting the FC Barcelona Muscle Injury Guide together, we realised that there was limited scientific evidence for preventative strategies in the elite football environment. We therefore decided to perform a Delphi Survey of 18 elite teams from the Big 5 Leagues (England, France, Spain, Italy and Germany) to ask performance practitioners what they do and what they consider to be important strategies to prevent muscle injury in their players. The Delphi survey process involves various rounds of questionnaires in which we ultimately come to a consensus among the respondents as to the most effective strategies to prevent muscle injury and how to integrate these into the football program. The following sections on preventative strategies are based on the results of this Delphi process in addition to what we know from the scientific literature and the FC Barcelona practical experience.

The overall results of our Delphi survey of the Big 5 leagues revealed the most effectively perceived preventative strategies to prevent muscle injury (table 1). We will now go through each of these in more detail, providing practical recommendations on implementation in practice.

PREVENTATIVE STRATEGY	EFFECTIVENESS RATING
Overall control of load / management of the training week	+++
Exercise based strategies	+++
Recovery strategies	++
Consideration of previous injury	++
Team communication and ability to work together	++

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Table 1 Perceived effectiveness of strategies to prevent muscle injury in elite footballers (EBMIP Delphi Survey results)

Key to perceived effectiveness:

+++ Very Effective
++ Effective
+ Somewhat Effective

THE BARÇA WAY

At FC Barcelona, we do not consider injury prevention to be made up of one specific strategy, but rather the simultaneous integration of many strategies, which alone, cannot 'prevent' an injury.

Instead it is most likely, the combination of many strategies including, controlling the training load, maximising recovery, optimising communication in addition to performing a variety of specific exercises etc as the best way to reduce the risk of our players incurring a muscle injury.

1.4.2

CONTROLLING TRAINING LOAD

Athlete monitoring is now common practice in high performance football. Fundamentally, athlete monitoring involves quantifying the players training load and their responses to that training. The main reasons for monitoring players are that it can provide information to refine the training process, increase player performance readiness and reduce risk of injury and illness. Through a systematic approach to data collection and analysis an improved understanding of the complex relationships between training, performance and injury can be obtained.

— With Aaron J Coutts

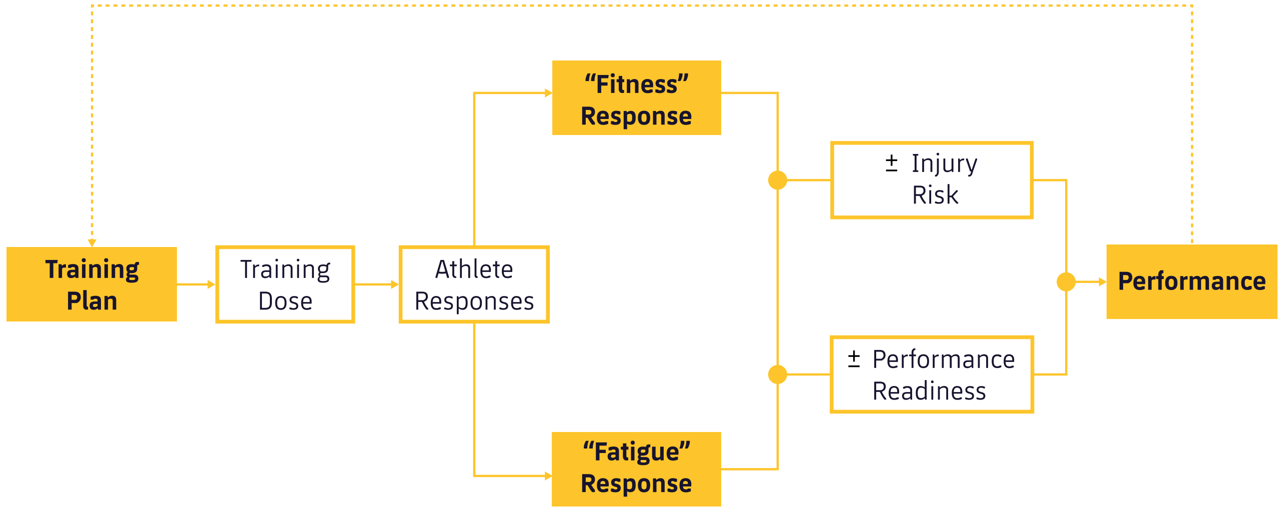

Figure 1 Conceptual model for athlete monitoring systems (modified from Coutts, Crowcroft, Kempton[1]).

THEORETICAL BASIS OF ATHLETE MONITORING

The main aim of athletic training is to provide a stimulus that is effective in improving the players' capacity to perform. For positive training adaptations to occur, the balance between training dose and recovery (i.e. rest and/or recovery interventions) needs to be obtained. At the simplest level, the performance responses can be explained by the fitness-fatigue model first described by Banister, Calvert, Savage, Bach [2]. The fitness-fatigue model is a simple approach to quantify a dose-response relationship of training load to fitness, fatigue and performance. In its simplest form, the model estimates performance outcomes as a result of the fitness and fatigue responses that result of the training dose applied through training. According to the model, fitness was referred to as the average weekly training dose completed in the previous 4 weeks whilst the fatigue was determined as the training load completed during the most recent week.

TRAINING LOAD MEASURES

The training dose applied and experienced by athletes - commonly referred to as the training load – can be measured using a variety of methods and is typically categorised as either an internal or external training load [3]. The external load is the training dose applied to the athletes and is commonly monitored using microtechnology devices (e.g. GPS) and athlete tracking systems whilst the internal training load is the load experienced by the athlete and is measured using physiological (e.g. heart rate) and/or perceptual (e.g. perception of effort) tools. Due to the nature of the physical demands of football (i.e. it requires players to complete high-intensity, intermittent exercise), total distance travelled, distances covered at higher running speeds (e.g. >14.5 km/h, sprint efforts (i.e. efforts > 23 km/h) and the number of accelerations and decelerations are the most commonly used metrics used to quantify the external training load in football. Whilst there are many other variables that can be obtained from various athlete tracking devices (e.g. estimated metabolic power, accelerometer loads, etc.), an approach with relatively few variables that have good measurement precision and supported by a strong proof of concept are recommended for load monitoring.

Unfortunately, the important activities that require high speeds and/or accelerations – which have been reported to be important constructs of load in football[4] - tend to be more difficult to accurately quantify with current technology. Indeed, despite recent improvements with increased sampling rate and improved chipsets,[5,6] GPS devices cannot yet precisely assess players accelerations/decelerations characteristics using intensity-based

thresholds[7]. To overcome this limitation, it is recommended that averaging the acceleration/deceleration demands during training and match play may be a more appropriate method compared to threshold-based methods.[8]

The internal training load is the response of the player to the external load applied and is usually measured using heart rate or the session-RPE method.[9,10] The session RPE-method requires players to rate their perceived intensity of a session according to a standard rating of perceived exertion (RPE) scale (see Figure 2). The load for a session is then determined as the product of the session duration and the players RPE. For example, a 40-minute session rated as being 'hard' by a player would provide a load of 200 arbitrary units (i.e. 5 x 40 min = 200 AU).

0	Nothing at all	"No I"
0.3		
0.5	Extremely weak	Just noticeable
0.7		
1	Very weak	Light
1.5		
2	Weak	
2.5		
3	Moderate	
4		
5	Strong	Heavy
6		
7	Very strong	
8		
9		
10	Extremely strong	"Strongest I"
11		

Figure 2 The category-ratio (CR10) scale of perceived exertion [11] commonly used in determination of the session-RPE training load.

Heart rate measures may also be used to assess the internal training load during football, but due to the technical and practical issues such as the high risk of technical issues and data loss and a low level of player compliance in measurement, the session-RPE method is the most widely recommended approach.[12] An additional advantage of the session-RPE method over heart-rate derived approaches is that loads can easily be obtained from all types of training, including cross training and resistance training which are common in football. However, despite this a recent report showed that heart rate was more widely adopted in top level clubs than the session-RPE method, likely due to the reservations of players and coaches in providing RPE following match play.[13]

Many performance practitioners measure these variables during each training session and use this information to assess player output during training and to understand longitudinal changes in training load for individual players. However, the best use of these data is when they are stored and the historical data are used to understand the loads applied to players over the short and longer-term and this information can be used to identify risks of players who may be at risk of injury or reduced performance.

MEASURING THE PLAYER'S RESPONSE

Measuring the players response to training is also a basic aspect of athlete monitoring systems in football.[14] Common responses that are of interest to scientists include player fatigue, sleep and muscle soreness, although other factors (e.g. mood, stress etc.) are also commonly assessed. These factors are often assessed using short customised questionnaires which are relatively simple to administer to players, often using cloud-based computing applications.[15] Notably, it has recently been shown that various customised single item psychometric measures - such as perceptions of fatigue, mood, soreness and fatigue have greater sensitivity to acute and chronic training loads than commonly used objective measures.[14]

Objective response markers (e.g. heart rate and biochemical markers) have also been suggested as useful components of athlete monitoring systems. Specifically, markers such as muscle damage markers, heart rate variability, hormonal and immune measures have shown to respond to changes in training intensity and dose and have been associated with overreaching in a variety of athletes.[16,17] However, due to logistical issues such as the invasiveness of drawing blood or obtaining saliva samples from players, along with the costs and time for analysis, these measures are not suited for daily monitoring.

Recent research has shown that systems that consist of multidimensional measures of load and response are most appropriate for monitoring athletes.[18] Moreover, these monitoring systems should consist of valid and reliable measures that are simple to collect and of low invasiveness to players. When training load and response data are interpreted in the context of each other and with the current training goals, performance practitioners are able to make training decisions at the individual level of the player that can inform performance and reduce injury risk.

USING TRAINING LOAD DATA TO MAKE DECISIONS ABOUT FUTURE TRAINING

Recent research has shown that systems consisting of multidimensional measures of load and response are most appropriate for monitoring athletes.[18] When training load and response data are interpreted in the context of each other and with the current training goals, performance practitioners are able to make training decisions at the individual level of the player that can inform performance and reduce injury risk.

Common training or periodisation errors can be avoided using a systematic approach to load monitoring and by following some common-sense rules in prescribing training. Basic heuristics for avoiding training errors follow the Goldilocks' approach to training prescription such that we should avoid players completing too much work (increasing fatigue), avoid players completing too little training (under prepared) or changing workloads too quickly (acute stress-response).

Through monitoring of the load data, we can assess for acute changes in these load metrics during the previous week or longer-term changes over the past month (i.e. chronic load). Indeed, increases in week-to-week training load of more than 15% from the preceding week increases injury risk ~50%.[19] Another simple check commonly used by performance practitioners is to check how the recent change in training load compares to the chronic load. Now commonly referred to as the acute-to-chronic workload load ratio (ACWR),[20] this measure has recently been associated with elevated injury risk when the ACWR exceeds 1.50 or is less than 0.80.[21] Importantly however, performance practitioners should be aware that this measure cannot be used to predict injury, but used as a rule of thumb when making decisions about future training decisions.

These data can also be used to ensure we build robust players through appropriate exposure to training loads, with the general goal for players to maintain moderate-to-high workloads, whilst minimising high variation in the ACWR. Conversely, we should also avoid having players being underprepared by completing low chronic loads, combined with extreme ACWRs as this has been associated with high injury risk.

Load monitoring systems can also be used to help ensure players are being prepared for the demands of match play.

In particular, frequent exposure to higher sprint speeds and distances have been shown to reduce injury risk in both Gaelic football[22] and professional Australian Rules football players.[23] As a general rules, exposing players to speeds >90% maximum sprint speeds 1-2 per week along with providing sufficient long term exposure to sprint speed distances may provide a prophylactic effect against injury.[22] Similar variables could be included in a football player monitoring system to ensure are prepared for the high speed demands of match play.

Making decisions to intervene on training for a player is usually a collective decision between sport science, medical and coaching staff using data from monitoring systems but also the collective expertise on the group. Specific risk markers need to be developed for each group or athletes and according to the specific system and markers that are available. However, the common scenarios for risk are elevated loads, spikes in load following periods of low or high chronic loads, inappropriate recovery/rest periods from previous intense efforts. Table 1 provides examples of scenarios that may be used to identify players at risk.

HIGH RISK SCENARIOS	
Overload	
ACWR spike	Very high ACWR as determined by sessions categorized in the top 20%
Week-to-week change	Previous (2-weeks ago) to current week (last 7 days) change >15%
Very high chronic load	Very high 4-week chronic load for current season
Acute workload ceiling	Individual's highest 1-week acute load for the current season
Chronic workload ceiling	Individual's highest 4-week chronic load for the current season
Over expose to speed	>4 sessions in a week with exposure to high sprint speeds >90% maximum speed
Underload / Under prepared	
ACWR trough	Very low ACWR as categorized by sessions in the lowest 20%
Very low chronic load	Very low 4-week chronic load as determined by sessions in the lowest 20%
Exposure to maximal speed	Week with low exposure to maximal speed (<85% maximum sprint) prior to intense speed session or match
Acute Response Alerts	
Increased soreness	Elevated muscle soreness >1.5 standard deviation from usual levels, combing with plan for high speed or high load session
Multiple wellness alerts	Sustained period for reporting multiple response markers > 1.5 standard deviation from usual levels.
Perfect Storm	Low chronic loads, elevated ACWR with increased report of soreness, fatigue and/or sleep

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Table 1 Example of increased risk metrics available from player monitoring systems (adapted from Colby, Dawson, Peeling, Heasman, Rogalski, Drew, Stares [23])

TAKE HOME MESSAGE

Athlete monitoring systems are now common-place in football. The goal of these systems is to monitor how individual players are responding to training. Fundamental measures that should be incorporated in these systems include quantifying training load, and the players response to this load. Following this, correct interpretation of the data requires that all changes be contextualised in relation to the actual training load completed by the player, whilst accounting for the magnitude of change required for practical importance in monitoring the training response. In practice, these measures can be used to inform coaches and sport science staff on individual players. If collected carefully and interpreted effectively, important feedback can be provided to players and coaches that enhances their readiness to perform and reduces their injury risk.

1.4.3

RECOVERY STRATEGIES

Our Delphi survey revealed recovery as an effective strategy to prevent muscle injury in elite footballers. Although fatigue has been highlighted by football practitioners as one of the most important non-contact injury risk factors in elite players,[1] it is surprising that the actual scientific level of evidence for fatigue and injury is currently weak.[2]

— With Abd-Elbasset Abaidia, Gregory Dupont, Antonia Lizarraga and Shona Halson

There are, however, several, indirect sources of evidence that can be extrapolated to suggest a plausible link between fatigue and injury in footballers. For example, injuries are more common at the end of each half during professional matches,[3,4,5] whilst there is also a known significant reduction in muscle force at the end of matches.[4] A study of a French Ligue 1 professional football team[6] also provides indirect evidence to support the fatigue-injury belief of practitioners, in which the authors observed that a significantly lower than normal recovery time between high-intensity actions prior to injury was evident (35.6+/-16.8 s vs. 98.8+/-17.5s).

Finally, further support lends itself with the widely accepted and established finding that, periods of match congestion (e.g. weeks with multiple matches) significantly increases the risk of injury.[7,8] Elite football teams are regularly exposed to periods of match congestion (e.g. 2 to 3 matches per week with typically 3 to 4 days recovery between) in which the time allowed between matches may be insufficient to restore normal homeostasis within players [9] i.e. to fully recover. A recent multi-team, multi-year study performed by the UEFA Football Research Group [7] showed that muscle injury rates were 21% lower when there were 6 days or more recovery compared to 3 or less days. These results show that a recovery period from 48h to 96h between two matches is associated with an increased injury risk, suggesting insufficient time to fully recover. Recovery strategies aimed at accelerating the time for players to fully recover may therefore be useful in the overall injury prevention strategy.

ACCELERATING RECOVERY: WHAT RECOVERY STRATEGIES TO USE (AND WHY)

TAKE HOME MESSAGE

Consuming proteins after a match enables repair of muscle damage following exercise. Scientific evidence has shown a beneficial effect of a protein dose of 20–40 g, including 10–12 g of essential amino acids and 1–3 g of leucine on muscle protein synthesis rates.[10] Optimization of the resynthesis of muscle glycogen stores is effective when consuming carbohydrates with a high glycemic index. An intake of 1.2 g carbohydrate per kg per hour immediately after a match, at 15-60 min intervals for up to 5h, enables maximum resynthesis of muscle glycogen stores.[11] Post-game re-hydration is an important issue, it is recommended to consume a fluid (150% of body mass lost) with a high amount of sodium (500 to 700 mg.l-1 of water).[12]

SLEEP

The recovery process may be affected and recovery kinetics slowed following a perturbed sleep at night.[14] Indeed sleep is often considered the best recovery strategy available to athletes, and it is critical to manage sleep disturbances when playing multiple games per week. Many elite footballers complain of sleep difficulties after night matches, which may be due to physiological factors (fatigue, soreness, temperature), psychological factors (arousal, stress) or environmental factors (bright light, travel requirement, room environment). Optimizing sleep may be possible by sleeping at least 8 to 10 hours, and increasing sleep hygiene by measures such as switching-off lights, decreasing the temperature of the room, limiting screen time and social media use, and adapting the food ingested in the afternoon by avoiding drinks such as coffee or tea. If the first night's sleep is poor, it should be compensated with a nap the following day.[13]

COLD-WATER IMMERSION

Immersing the body into water with a temperature of 10°C for an exposure period of 10 minutes immediately after muscle-damaging exercise session is beneficial for recovery.[14] Results have consistently shown a beneficial effect of this strategy on force, sprint and jump recovery.[15,16] While the use of acute cold-water immersion is supported by research, the effect of chronic use of immersion has been questioned.[17] This is due to the potential role that cold water immersion may play in reducing adaptation. Therefore, a periodised approach is likely best, whereby cold water immersion is used acutely to influence performance (for example during congested schedules) and limited or reduced at other times (pre-season or weeks with only one match).

Figure 1
Schematic representation of a recovery protocol following a football match

COMPRESSION GARMENTS

Wearing compression garments following a match may have beneficial effects on recovery kinetics. The effectiveness of compression garments on muscle force and power is underpinned by scientific evidence.[18-20] It is recommended to wear compression garments with a high level of pressure (for example: 15mm Hg at the thigh level and 25 mm Hg at the calf level) until bed time and the days following the match.[21] Some individuals may prefer to sleep in the garments for additional recovery benefits, however they should not be worn if sleep is disturbed.

THE DAY AFTER THE MATCH

UPPER LIMB STRENGTH TRAINING

Scientific evidence for effective recovery strategies the day following a match is scarce. Teams typically perform low intensity and low volume exercise based strategies such as active recovery run, pool session, or bike and tend to avoid rigorous intense activities. While only preliminary evidence, performing an upper-limb strength training session the day after fatiguing and muscle damaging lower-limb exercise may accelerate the recovery kinetics of concentric force.[22] This strategy may be implemented the day after a match. It also represents a time-efficient modality to enhance upper-limb strength in players that may not be possible later in the week or allows an additional exposure to such training.

MASSAGE

Massage may have a beneficial effect on decreasing muscle soreness and on increasing the perception of recovery.[12] The best results on muscle soreness are obtained with a combination of effleurage, petrissage, tapotement, friction and vibration techniques and for a duration of 5 to 12 minutes.

IMPORTANT CONSIDERATIONS

INDIVIDUAL VARIATION

Due to the fact that individuals will likely have different levels of fatigue/soreness, a different time course of recovery and respond differently to specific recovery strategies, an individualized approach to recovery may be necessary. Some players may respond positively or negatively to different strategies, and therefore consideration should be given to finding the optimal strategy for each player based on performance and perceptual data if possible.

THE FUTURE OF RECOVERY

While the area of recovery research is relatively new in comparison to other fields in physiology and nutrition, future areas of interest include periodisation of recovery, individualisation of recovery, psychological recovery (meditation, relaxation, mindfulness) and how athletes recover from mental fatigue.

1.4.4a

EXERCISE-BASED STRATEGIES TO PREVENT MUSCLE INJURIES

Exercise is one of the most common preventative strategies implemented by football teams to prevent muscle injury.[1] The following summary and recommendations are a combination of relevant scientific research findings with current best practice.

— With Maurizio Fanchini, Eduard Pons, Franco Impellizzeri, Gregory Dupont, Martin Buchheit and Alan McCall
**Special contribution from Nick van der Horst, Ida Bo Steendhal and the EBMIP Delphi Group*

Specifically, this chapter is based on the results of an internally performed systematic review and expert led Delphi survey of key football performance practitioners operating in teams from the Big 5 Leagues (Bundesliga, English Premier League, La Liga, Ligue 1, Serie A) and combined with the philosophy and practices of FC Barcelona medical and performance staff.

Our systematic review showed that there is no convincing evidence for many exercise-based strategies to prevent muscle injury in elite football players. Our results highlighted a low quality of studies (systematic reviews and randomized control trials) and overall weak scientific evidence supporting eccentric exercise to prevent hamstring injuries. The Delphi survey revealed (Table 1) the perceptions of elite level practitioners regarding the effectiveness of various exercise types to prevent muscle injuries in footballers. The following piece will focus primarily on the two most highly rated exercise types; high-speed / sprint running and eccentric exercise. A secondary emphasis highlights the importance of a multi-dimensional approach to exercises based prevention and other potentially effective exercises that can be incorporated into the prevention program.

PREVENTATIVE EXERCISE TYPE	EFFECTIVENESS RATING
High-speed running / sprinting	+++
Eccentric	++
Concentric	+
Isometric	+
Plyometrics (Horizontal & vertical orientations)	+
Activation / coordination (e.g. sprint movements & mechanic drills	+
Flexibility (dynamic & static)	+
Core stability	+
Multi-joint exercises (e.g. Olympic lifting, squats, functional strength)	+ to +++
Single leg strength and stability	+ to +++
Agility	+ to +++
Kicking (shooting, crossing, long passes)	+ to +++
Resisted sprints (e.g. sleds, parachutes)	+ to +++

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Table 1
Perceived effectiveness of exercise strategies to prevent muscle injury in elite footballers (EBMIP Delphi Survey results)

Key to perceived effectiveness:

+++ Very Effective.
++ Effective.
+ Somewhat Effective.
+ to +++ No consensus as to precise effectiveness.

HIGH-SPEED RUNNING AND SPRINTING (HSR)

During running and sprinting i.e. at high velocities (HSR), lower limb muscle-tendons systems experience high values of torque at stance and late swing phases. During the stance phase, muscles of the hip and knee work to both counteract the ground reaction force and generate propulsion. Muscles of the ankle and foot systems contract eccentrically and concentrically (with higher power compared to knee and hip joints muscles) to absorb the ground reaction force and to push the body forward to the subsequent swing phase.[2] During the swing phase, muscles control the movement direction of the limb extremity with hamstrings muscles responsible for both hip extension and knee flexion.[2] The high power expressed by the muscles results in high horizontal net force that maximize the forward propulsion.[2] A lower maximal horizontal force output during sprinting has been proposed as a possible risk factor and mechanism for hamstring muscle injury in football, especially in players with a high maximal running velocity.[3] Specific focus on HSR within the training program should therefore be considered important to expose and condition the lower limb muscles in a specific manner to cope with the demands of football training and match-play. Importantly, reaching HSR velocities requires the player to accelerate and given the nature of football, then decelerate and change direction and change intensity with and without the ball (e.g. dribbling, passing, shooting) according to the context of the game.[4,5] These situations, requiring neuromuscular load[6] can present potentially injurious situations and therefore exposing players to these high-intensity actions (HIA) is also recommended within the muscle injury prevention strategy. Exposure to targeted HSR and HIA can have the additional benefit of developing physical qualities such as intermittent aerobic fitness that has been shown to protect players from lower limb injury.[7]

HOW TO INTEGRATE HSR AND HIA INTO THE FOOTBALL TRAINING PROGRAM?

The nature of football as a running based sport means that the coaches' normal football training sessions inevitably involve a varied amount of contribution of HSR and HIA depending on the type and duration of the session. We recommend that wherever possible, HSR and HIA should be integrated into the coaches' typical football drills. While, ideally HSR and HIA targeted sessions are integrated seamlessly into normal training, it is also appropriate to prescribe separate football specific drills and generic running (e.g. maximal aerobic speed, repeated straight line sprints etc) to ensure players are exposed to sufficient amounts of this type of preventative and performance based training.

While not in football (soccer), it has been shown in Gaelic Football[8] that players producing moderate (> 6 to 10) exposures (i.e. the number of athese activities performed) of →95% of their maximal running velocity within the week were at reduced risk of lower limb injury, while both low (<5) and high (>10) exposures increased the risk of injury. Importantly, a high chronic overall training load (all trainings) allowed players to tolerate higher exposures (between 10 and 15) ≥95% without increasing the risk of injury. Additionally, minimal exposure to HSR efforts (i.e. maximum speed and sprint volume) has been shown to be a risk factor for injury in Australian Rules Footballers. (Please refer back to section 1.4.2. Controlling Load with Prof. Aaron Coutts).

Position specific HSR and HIA should be developed to contextualize running bouts in relation to tactical activities, the work-to-rest ratio and method of recovery can be manipulated as well as the introduction of change of direction and turns to simulate specific match and positional patterns.[9,10] An integrated approach of physical, tactical and technical elements is also time efficient and well accepted and liked by players and coaches, and therefore buy in is likely to be greater. It is important to individualise the prescription of HSR and HIA according to each player's individual match and positional activity, there is no one size to fit all.

WHEN IN THE TRAINING WEEK, TO PERFORM HSR AND HIA?

There is no strong scientific evidence to guide when the optimal time is in the training week to perform specifically focussed HSR and HIA training and there are likely various possibilities depending on a number of factors, including but not limited to; the number of days from the last match and the next match (e.g. 2 to 6 + days), starters versus non-starters/ substitutes, loads performed and experienced during the match, the planned content of the coaches football session, individual players needs, strengths, weaknesses, likes and dislikes, current and on-going medical issues, whether or not they are accustomed and adequately prepared to be exposed to and tolerate such demanding exercise.

We recommended in general, (based on our expert led Delphi survey) that during periods of 1 match per week (i.e. >5 days full recovery between matches), HSR and HIA specific exercise is performed on Matchday -3. During periods with ←4 days recovery between matches, it is generally considered to perform football training only as the HSR and HIA targets will most likely be achieved during the games. Within even a congested fixture list, coaches normal training will involve higher running intensities (including sprints), and therefore it is likely not necessary to perform any additional work. It is even possible to perform HIA drills i.e. short acceleration, deceleration and change of direction drills (typically coined speed & agility by players) on the M-1 as long as a low volume and adequate recovery times between repetitions are respected. Anecdotally, many players actually enjoy performing these types of activities on the M-1 (e.g. as part of the warm up or after the session) as it makes them feel "sharp" for the match the next day.

NON-STARTERS / SUBSTITUTES

It is important to remember that while the playing squad is 11 players, the typical elite football squad comprises ~ 25 + players and not all can play. It is imperative that players not playing regularly are also prepared for the rigorous demands of a match not only from an injury perspective but also from a performance standpoint. Carling and colleagues[11] found that substitutes directly winning more games was one of the potential contributors to a championship winning season compared to 4 other non-winning seasons. Therefore, careful consideration should be given to these players and although involved in the same main training sessions as the starting players, they will likely require additional HSR and HIA to ensure they are prepared if called upon. Specifically, it is recommended that non-starters and substitutes perform additional HSR and HIA exercise on M+1 or M+2 (but not on both), depending on the training schedule e.g. days off, upcoming match etc.

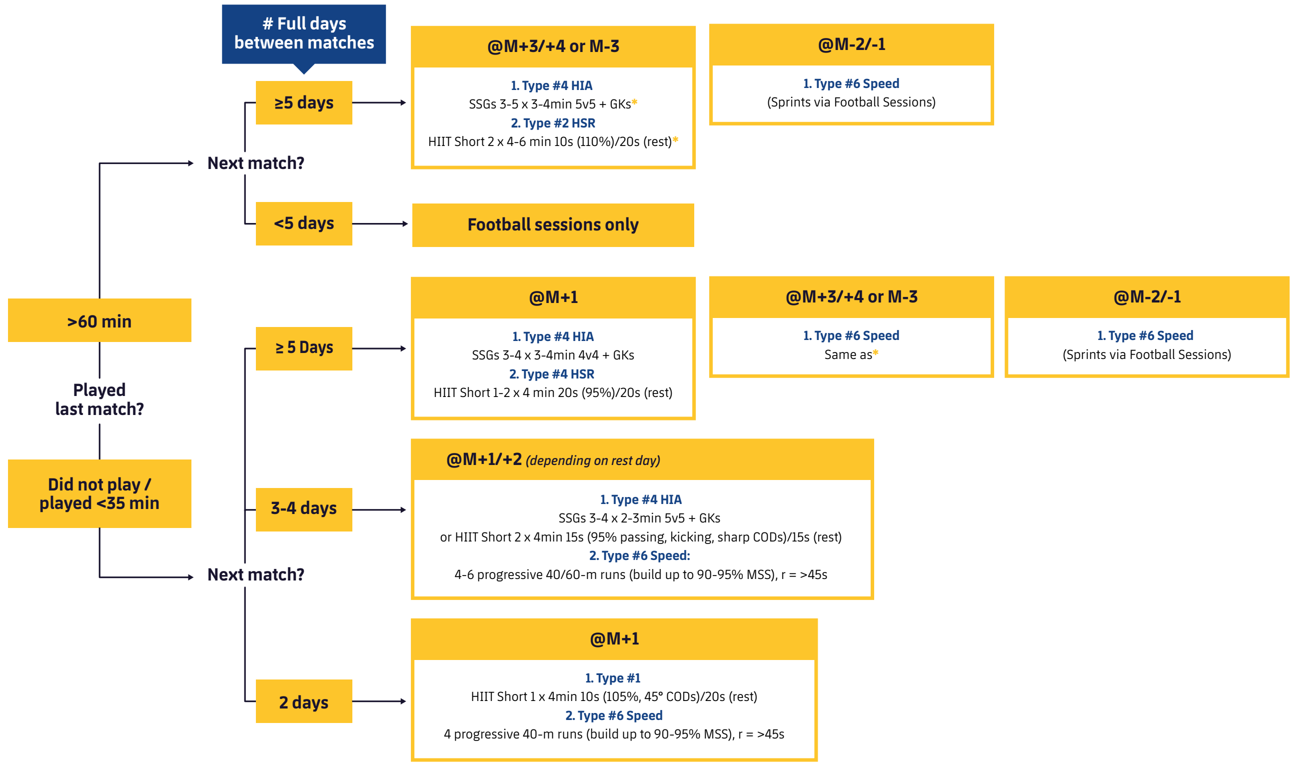

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Figure 1
Decision process when it comes to programming the different running e.g. High-intensity intermittent training (i.e. HSR & HIA) drills with respect to competition participation and matches macrocycles. Note that only HIIT sequences are shown – most sessions would also include technical and tactical components and possession games. SSGs: small-sided games. HIA: high-intensity activities (> 2ms2 accelerations, decelerations and changes of directions). HSR: high-speed running (>19.8 km/h). The different HIIT types are the following: 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 1) but with a greater degree of neuromuscular strain, Type #3) metabolic as 1) with a large anaerobic large glycolytic energy contribution but limited neuromuscular strain, Type #4) metabolic as with 3) but with both a large anaerobic glycolytic energy contribution and a high neuromuscular strain, Type #5) a session with limited aerobic demands but with a anaerobic glycolytic energy contribution and high neuromuscular strain Type #6)not considered as HIIT) with a high neuromuscular strain only, which refers to typical speed and strength training for example. Note for all HIIT Types including a high neuromuscular strain, possible variations exist in the form of this neuromuscular strain, i.e. more oriented toward HSR (likely associated with a greater strain on hamstring muscles) or HIA (acceleration, decelerations and changes of directions, likely associated with a greater strain of quadriceps and gluteus muscles). Note for example that Type #1 can be achieved while using 45°-CODs, is likely the best option to reduce overall neuromuscular load (decreased absolute running velocity and no need to apply great force to change of direction, resulting in a neuromuscular strain lower than straight line or COD-runs with sharper CODs.) Reference (for both HIIT types and Figure): Science and Application of High Intensity Interval Training, Laursen P, Buchheit M. Human Kinetics, In Press.

ECCENTRIC EXERCISE

In our expert led Delphi survey, exercises with an eccentric focus were rated as the 2nd most important exercise mode to prevent muscle injury in elite footballers. This is in line with the perceptions of worldwide Premier League,[1] UEFA Champions League[12] and National teams competing in the FIFA World Cups.[13] Eccentric exercise may be particularly useful as they target various modifiable risk factors including; eccentric strength, optimal angle of peak torque and muscle architecture e.g. fascicle length[14]. It is likely that these reasons explain why this exercise mode is favoured by practitioners not only in football but also in many other team sports.[15] Importantly, player buy in and the quality to which the exercises are performed are likely key to ensuring optimal adaptations and beneficial effects on muscle injuries.[12-16] As such, exercise with an eccentric focus should be considered in the overall injury prevention program for footballers and buy in and quality execution of these should be encouraged and monitored by practitioners.

WHEN IN THE TRAINING WEEK TO PERFORM THE MAIN ECCENTRIC EXERCISES?

As with high-speed running and sprinting exercise, there is no clear scientific evidence as to when is the best period to perform the main eccentric exercises during the football training week. There are a number of similar contextual factors running based training that need to be considered surrounding the decision of when is most appropriate to include eccentric exercise.

In general, when playing 1 match per week and 6 days recovery between matches, the most appropriate day is perceived to be on M+ 3 (M-4 from the next match). This timescale likely allows opportunity for muscles to recover from the previous match and enough time for them to recover again before the next match 4 days later e.g. Saturday – Tuesday – Saturday.

When the recovery between matches is 5 full days (e.g. Saturday – Friday) the preferred day is again on the M+3, however this will also correspond to a M-3 i.e. 3 days before the next match. While only preliminary evidence, it has been shown in semi-professional football players that performing eccentric exercise on the M+3 i.e. M-3 during a week with 5 full days recovery resulted in elevated levels of creatine kinase and hamstring muscle soreness 24h before the next match.[17] However, perhaps importantly was that muscle function (i.e. muscle force) was not affected. Muscle force is considered the gold standard measure of muscle damage[18] and may be more useful to inform injury risk estimation. It is also vital to consider if players are accustomed to performing eccentric exercise as this may allow them to perform such exercise on a M-3 in a 5 day week without experiencing any muscle soreness.

During periods with <4 days it is generally considered that specific high-intensity type eccentric exercise is not necessary. There may however be options to include low intensity, low volume eccentric type exercises coined as 'activation' exercises.. The specific muscle section of this Guide will provide further details on specific eccentric exercise types e.g. for the hamstring, adductor, quadriceps and calf.

PERFORMING ECCENTRIC EXERCISES BEFORE OR AFTER THE FOOTBALL SESSION?

Once we have decided on the day to perform the eccentric session, another key question for practitioners is when to implement it i.e. before (non-fatigued) or after (fatigued) football training? While scientific evidence is limited currently, there are some preliminary findings suggesting that specific timing of the eccentric exercise around the football session may result in different adaptations that could contribute to reducing muscle injury risk.

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BEFORE THE SESSION

One potentially modifiable risk factor for muscle injury are increases in fascicle.[19] Performing eccentric exercise before the training session has revealed fascicle length increases but not when performed after the session. [20] Similar chronic adaptation of peak torque production of the hamstring muscles has been shown to be similar when eccentric exercise is performed before and after the training session.[20]

AFTER THE SESSION

A training intervention where eccentric exercise is performed after the session has shown to increase muscle thickness and pennation angle[21] as well as a chronic adaptation towards an improved ability of players to maintain their eccentric strength at half-time and upon cessation of a simulated football match versus those performing in a fresh state before training.[22]

CONSIDERATIONS WHEN DECIDING BEFORE OR AFTER THE FOOTBALL SESSION

An important consideration when planning the timing of the eccentric exercise session is that an acute effect of eccentric exercise performed before the training session may result in muscle fatigue that could actually increase the probability to sustain an injury in the subsequent session.[21] Therefore, as a practitioner you should consider carefully the context surrounding the planned eccentric exercise; in particular consideration of the coaches training session and determine the risk:benefit of performing such exercises before or after the session. This is best done at the individual player level also. It has been recommended that eccentric exercise performed both before (fresh) and after (fatigued) is likely optimal to the injury prevention program.[23] This is in line with the actual practices of the expert practitioners from the Big 5 leagues.

EXERCISE-BASED INJURY PREVENTION STRATEGIES SHOULD BE MULTI-DIMENSIONAL

While this section has focussed on running and eccentric exercise specifically, in reality, the injury prevention program is and should be multi-dimensional that includes various other exercise modes. Therefore, the global injury prevention program should not be limited to HSR, HIA or eccentric exercise alone but involve the addition of other exercises targeting modifiable risk factors. Table 1 illustrates the wide array of exercise types available to the practitioner who wants to reduce injury in his/her team. While there is limited evidence for many of these exercise types e.g. plyometrics, flexibility, core stability, static and dynamic flexibility, activation etc to prevent muscle injuries of the lower limbs in footballers, they should also be considered due to their perceived effectiveness and widespread use in elite football teams i.e. current best practice.

PLYOMETRICS, CORE AND MULTI-JOINT EXERCISES

Plyometric exercises are commonly used to improve sprint and jump performance in team sport in addition to increasing the neuromuscular control and lead to less torque working on the knee.[24] The introduction of plyometric exercises into the injury prevention program could be promising however several parameters of load (volume, intensity, frequency) should be accurately evaluated during the design of the training program. Specific exercises targeting the motor control of the core muscles have been found to result in fewer games missed in Australian Footballers,[25] however, multi-joint exercises such as the squat and deadlift are at least and in some cases more effective in the activation of core muscles.[26] An important consideration for the practitioner is that the inclusion of other exercise modes such as plyometrics and multi-joint exercises should be performed in both vertical and horizontal orientations. Using both orientations in the football training program has been shown to improve neuromuscular performance of players in comparison to vertically oriented only exercises.[27]

FLEXIBILITY

There is no clear evidence for lower limb flexibility alone to reduce muscle injuries, however they have been integrated into global prevention programs that have shown beneficial effects on muscle injury.[28-29] Static and dynamic lower limb flexibility training may logically be useful to allow the hip and knee muscle to move within ranges of motion necessary during kicking and sprinting.

EFFECTIVENESS OF MULTI-DIMENSIONAL INJURY PREVENTION PROGRAMS ON MUSCLE INJURY IN FOOTBALLERS

Although scarce, there is some scientific evidence for the use of multi-dimensional injury prevention programs in elite footballers. In 2005, Verrall and colleagues[30] found that a global prevention program incorporating sport specific running drills, high-intensity interval anaerobic training, strength training and flexibility resulted in a significant reduction in hamstring muscle injuries and the number of competition games missed. Owen et al.[28] implemented a multi-dimensional prevention program in elite European footballers incorporating eccentric, general strengthening exercises, dynamic flexibility, core, balance, coordination and agility based runs into the overall football training program resulting in significantly less muscle injuries in players.

KEY PROGRAM VARIABLES FOR EXERCISE BASED STRATEGIES

There is no one specific guideline on the optimal programming e.g. sets, repetitions, loads etc for exercise-based strategies, however there are some general guidelines that can be adopted according to the goal of your program. Below we provide a table (table 2) with some potential options for key programming guidelines adapted from Dupont and McCall in the Soccer Science textbook by Tony Strudwick.[31]

Table 2
Potential key programming variables and considerations when implementing exercise-based strategies'
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	ACTIVATION/LOW LOAD EXERCISES	HYPERTROPHY	STRENGTH	POWER	SPEED
Sets	2 to 6 (in total for full session)	3 to 6 (in total for full session)	2 to 6 (in total for full session)	2 to 6 (in total for full session)	2 to 6 (in total for full session)
Reps	6 to 12 (or time based e.g. 10 to 20s)	6 to 12 (per exercise)	1 to 8 (per exercise)	1 to 10 (per exercise)	1 to 10 (per exercise)
Load	+ No load / elastics / low external loads / manual resistance	70% to 85% 1RM (6RM to 12RM)	≥ 80% (1 repetition maximum i.e. RM to 8RM)	0% to 80% 1RM	0% to 30% of body mass
Rest	Self-determined (how you feel)	1 to 2 mins	2 to 5 mins (3 mins preferred)	2 to 5 mins	2 to 5 mins
Velocity	Controlled – focus on movement quality	Eccentric – moderate to slow (2 to 3 sec) Concentric – fast intention (1 to 2 sec)	Eccentric – moderate to slow (2 to 3 sec) Concentric – fast intention (1 to 2 sec)	Eccentric – fast to moderate (<1 sec to 2 sec) Concentric – as fast as possible	As fast as possible
Frequency	Possible on each training day (including match warm-ups) Vary the exercises if doing daily	Pre-season – 2 to 3 times per week In-season – 0 to 3 times per week (depending match schedule)	Pre-season – 2 to 3 times per week In-season – 0 to 3 times per week (depending match schedule)	Pre-season – 2 to 3 times per week In-season – 0 to 3 times per week (depending match schedule	Pre-season – 2 to 3 times per week In-season – 0 to 3 times per week (depending match schedule)
Number of exercises	3 to 6	4 to 6	3 to 6	3 to 6	3 to 6
Type of exercises	Balance / Proprioception Flexibility (dynamic & static) Movement based drills (e.g. sprint movement drills) Core stability exercises Specific muscle activation	Traditional resistance exercises	Traditional resistance exercises	Ballistic exercises Plyometrics Olympic style lifts Traditional resistance exercise (explosive mode)	Straight line acceleration (0 – 10m) Soccer specific acceleration Explosive and leading starts Longer sprint running (20 – 40m) Sled Running Downhill & Uphill sprints
Main effects	> range of motion > movement quality > activation > balance and proprioception	> max strength > muscle mass	> max strength > muscle mass (*less extent than hypertrophy training)	> power > sprinting/acceleration > jump > rate of force development > change of direction ability	> acceleration > rate of force development > change of direction ability
Special considerations	Focus on quality movement execution of the exercise rather than load or speed of movement	Do not perform lower body in 2 days prior to match or in 2 days following the match Focus on quality movement execution of the exercise rather than load or speed of movement	Focus on quality movement execution of the exercise. If quality suffers, reduce the load Do not perform lower body in 2 days prior to match or in 2 days following the match	Perform during hardest session of the week Focus on quality movement execution of the exercise. If quality suffers, reduce the load Possible to perform during day before game with lower sets, repetitions and low load for 'activation'	Perform during hardest session of the week Focus on quality movement execution of the exercise. If quality suffers, reduce the load Possible to perform during day before game with lower sets, repetitions and load for 'activation'

1.4.4b

EXERCISE SELECTION FOR THE MUSCLE INJURY PREVENTION PROGRAM

At FC Barcelona, it is our belief that any one exercise or exercise session performed in isolation, cannot prevent a muscle injury from occurring e.g. doing a set of Nordic hamstrings alone is not enough to stop a hamstring muscle strain, but then neither is any other strategy on it's own
— With Xavi Linde, Juanjo Brau and Ricard Pruna

The idea is that, specific exercise strategies can add to the overall strategy to try and reduce the risk of a muscle injury occurring. When performing exercises within the overall prevention strategy we have some key considerations;

1. Variation - It is important to train using a variety of exercises, with varying number of sets, repetitions and rest durations. We also believe that continual adjustment of stimulus is necessary through manipulation of the surface type, resistances and decision-making. The main objective is not to make the exercises a restricted, closed and predictable task, but rather to simulate a variety of situations. In the gym there are many exercises available to choose from and varying these is a key component of our exercise-based muscle injury prevention program.
2. Continuing with the concept of variation, as well as gym based exercise strategies, we aim to implement specific exercises outside in the field, where different surfaces such as sand, artificial and natural grass, uphill & downhill running tracks can be used. By using such surfaces it is possible to propose different circuits to achieve our objectives of generating the specific demands that players require.
3. We believe that working within a full range of motion while performing exercises is important for muscles. Many of our exercises are performed with active tension stretching, which of course we can guide, but we also allow the player to develop this tension him/herself. The own feeling of the player performing the stretch will help to achieve the maximal range of motion as well as adjust the intensity of exercises according to his/her sensation.
4. With exercise strategies it is important to train with functional patterns related to movements performed by players on the pitch and in matches. Of course, it is sometimes necessary to perform some specifically focussed exercises (such as leg curl, leg extension etc) e.g. to build basic strength, however, building strength during functional patterns with bodyweight, free weights and elastic resistances all form a part of our training, using both closed-chain kinetic and open-chained exercises.
5. Following the theme in number 4 above, we favour closed kinetic chain exercises where possible in order to train muscles in the specific patterns that they are used to during football activities.

In the following chapters focussing on exercise selection for specific muscles, we provide a variety of exercises that practitioners can choose from according to their needs. We want to re-emphasise that exercise-based strategies are just one component of the overall muscle injury prevention program.

1.4.4c

EXERCISE SELECTION: HAMSTRING INJURY PREVENTION

As highlighted previously, the hamstring muscles are the most frequently injured muscles in elite footballers and carry with them the highest injury burden (days lost). The contribution of the hamstring muscles (i.e. biceps femoris long and short heads, semitendinosus and semimembranosus), and their responses to exercise vary according to the type of exercise performed[1]
— With Maurizio Fanchini, Xavier Linde, Juanjo Brau, Edu Pons and Nicol van Dyk

Exercises can be differentiated between hip-extension-based, knee-flexion-based and multi joints-based (Table 1). Hip-extension-based exercises (Table 1) provide higher activity of biceps femoris long head instead of the knee-flexion exercises (Table 1) that activate more the semitendinosus.[1-3] Multi joint based exercises such as lunges involve mainly the proximal part of the adductor magnus and biceps femoris long head.[4] The lunge and squat exercises eccentrically involve the hamstrings to control the hip during knee flexion. In addition, kettlebell swings activate more semitendinosus and semimembranosus (medial hamstrings) compared to biceps femoris (lateral hamstring), which may be important for sprinting.[5]

The majority of hamstring injuries happen whilst players are sprinting or accelerating, and it has been suggested that activations patters in each hamstring muscles are not uniform during maximal sprint.[6,7] During the early stance phase of acceleration, hip-extension is dominant, and there is higher activity of the biceps-femoris long head compared to semitendinosus. During the late stance and terminal mid-swing of a maximal sprint the semitendinosus demonstrates higher activity compared to the biceps femoris long head.[8]

Scientific evidence for the optimal hamstring exercises is weak, however a combination of different exercises should be included in a hamstring injury prevention protocol,[9] targeting all hamstring muscles. This protocol should also focus on the implementation of sprinting and high speed running exercises, as well as on the preservation of flexibility all of which are likely key to reducing the risk of injury.

IMPLEMENTATION REASON	EXERCISE	CLASSIFICATION
Activation / strength endurance / strengthening (low intensity injury prevention	Good morning	Hip-extension
	Bilateral deadlift	Hip-extension
	Hip hinge	Hip-extension
	Bilateral supine bridge	Hip-extension
	Unilateral supine bridge	Hip-extension
	Russian belt	Hip-extension
	Single leg deadlift	Hip-extension
	Single Leg Romanian Deadlift	Hip-extension
	Single leg Sliders	Knee-flexion
	Nordic Hamstring	Knee-flexion
	Glut-ham isometric	Multi joints
	Razor curls	Multi joints
	Bulgarians	Multi joints
	Reverse lunging	Multi joints
Strength	Lying hip flex/extension with versa pulley	Hip-extension
	Leg curl (sitting, standing, prone)	Knee-flexion
	Leg curl with isoinertial devices	Knee-flexion
	Standing hip extension with resistance (elastic bands, cable)	Hip-extension
Plyometrics and performance conditioning	Thrusts (Final swing phase and contralateral hip extension).	Multi joints
	Lunges and multidirectional movements with versa pulleys	Multi joints
	Foot catch exercise (very functional regarding sprint)	Multi joints
	Kettlebell swings	Multi joints
	Sprinting and High speed running	Multi joints
Flexibility	Dynamic and static stretching	
	The Extender	
	The Glider (also useful for strengthening)	

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Table 1
Examples of exercises that may be included in a prevention program for hamstring muscle injuries

THE BARÇA WAY

We perform a variety of hamstring focussed exercises using devices, manual resistance and elastic bands, switching between standing, sitting and lying in addition to eccentric, isometric and concentric contractions. In particular multi-joint exercises such as the squat, lunges, step ups (figures 1A to 1C), and single/double leg bridges on stable and unstable surfaces are used to train functional patterns (1D to 1F). We also place high importance on active stretching of the posterior chain before, in-between and following gym based exercises (figures 2A to 2C). Kick-backs (figure 3) are used to train the glute and hamstring muscles.

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Figures 1A, 1B and 1C.
Squat, lunge, step ups (respectively)

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Figure 1D.
Single leg bridge on stable surface

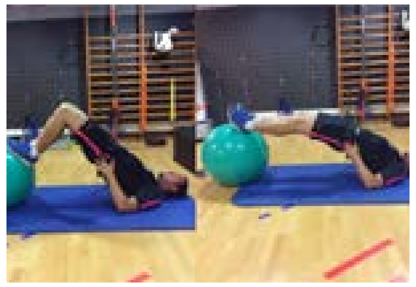

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Figure 1E.
Double leg bridge on unstable (swiss ball) surface

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Figure 1F.
Isometric single leg bridge on unstable (bosu ball) surfacee

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Figures 2A, 2B, 2C
Active stretches of the posterior chain

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Figures 3
Kick-backs with elastic band

1.4.4d

EXERCISE SELECTION: QUADRICEPS INJURY PREVENTION

The rectus femoris is a bi-articular muscle of the quadriceps, and of the quadriceps muscles, it is the most susceptible to injury in footballers. Rectus femoris injuries usually occur in open kinetic chain (OKC) movements, when players are sprinting or kicking.[1] These actions can involve hard eccentric contractions and fast and forceful change of muscle action. There is scarce evidence for the effectiveness of specific exercise types to prevent rectus femoris injury in footballers.

— With Maurizio Fanchini, Xavier Linde, Juanjo Brau, Edu Pons and Andreas Serner

However, a clinically relevant review combining limited scientific findings and expert opinion in regards to quadriceps injury prevention[2] recommends that, rectus femoris injury prevention strategy should include targeting general flexibility of the lower limb muscles, ensuring adequate balance between concentric and eccentric strength of the hip flexors and knee extensors, and adequate core stability.[2]

When focusing on minimizing injury risk, both basic prevention exercises and more functional/football specific exercises may be incorporated. Basic prevention exercises are usually differentiated between open and closed kinetic chain (OKC and CKC). Open kinetic chain exercises refer to movements that are performed with the most distal aspect of the extremity moving freely and non-weight-bearing, whereas CKC exercises correspond to multi-joint movements performed in weight bearing or simulated weight bearing with a fixed distal extremity.[3]

The simple leg extension is an OKC exercise frequently used to strengthen the quadriceps (with different type of contraction's combinations and resistance: weight pack, elastic bands, cables, active physiotherapist resistance). Performing CKC (e.g. leg press, squats, lunges) exercises results in more simultaneous activation of the four different muscle portions of the quadriceps, and can provide a more balanced initial quadriceps activation[3] compared to OKC exercises. A limitation of the CKC exercises is that they are often performed with hip flexion and therefore may be more relevant for the vastii muscles than for the rectus femoris specifically. As rectus femoris strains are considered to occur at long lengths with both hip extension and knee flexion, exercises improving the capacity of the muscle to withstand rapid high loads at long lengths should be considered. A 4-week eccentric exercise program has been shown to increase the length of the knee extensor muscles (i.e. "shift the peak of the torque–angle curve in the direction of longer muscle lengths").[4] For simple implementation of an eccentric quadriceps strengthening exercise, the Reverse Nordic Hamstring exercise[2] can be implemented on the pitch without equipment. In order to target the rectus femoris at full length, an OKC exercise may be implemented, for instance using a cable pulley with the strap fixed around the ankle to incorporate a simultaneous hip flexion and knee extension. Whilst kicking, iliacus and psoas are also highly activated to produce hip flexion force.[5] Therefore, improving proximal hip strength with a specific focus on the deep hip flexors, as well as knee extension strength may also be appropriate targets to reduce rectus femoris injury.

Considering the primary injury mechanisms of kicking and sprinting, these actions should receive extra attention in relation to rectus femoris injuries with specific monitoring. Although no specific evidence is available, the approach may simply be to avoid large fluctuations in the amount of sprinting and kicking, and ensure that the training loads meet the requirements of the individual players. It could potentially also be relevant to training these functions with added resistance.

Finally, considering common practice in elite teams, as covered in the general principles of exercise prevention strategies section of this guide (Table 1), plyometric and multi-joints exercises should also be included in a multi-dimensional program. Specific exercises (e.g. plyometrics, sprints, accelerations, decelerations, agility) are usually adopted to enhance explosiveness, and can be implemented during on-field session in technical exercises.

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IMPLEMENTATION REASON	EXERCISE	CLASSIFICATION
Activation / strength endurance / strengthening (low intensity injury prevention	Seated leg extension with elastic bands or cables	Knee extension/Hip flexed/ OKC
	Standing leg extension with elastic bands or cables	Knee extension/Hip flexed/ OKC
	Lying leg extension with elastic bands or cables	Knee extension/Hip extended/OKC
	Mini-squats	Knee extension/Hip extension/CKC
	Lunges	Knee extension/Hip extension/CKC
	Reverse lunge	Knee extension/Hip extension/CKC
	Reverse Nordic Curl	
	Reverse Russian Belt	
Strength	Seated leg extension machine	Knee extension/Hip flexed/ OKC
	Hops to stabilisation (forward, lateral, backwards)	
	Horizontal Leg press	Knee extension/Hip extension/CKC
	Inclined Leg press	Knee extension/Hip flexed/ CKC
	Squats	Knee extension/Hip extension/CKC
	Yo-Yo Multigym (eccentric overload leg press)	Knee extension/Hip extension/CKC
	Yo-Yo squat (eccentric overload)	Knee extension/Hip extension/CKC
	Yo-Yo leg extension (eccentric overload)	Knee extension/Hip flexed/ OKC
Plyometrics and performance conditioning	Plyometrics	Knee extension/Hip extension/CKC
	Down-hill sprinting	
	Sledge accelerations	
	Accelerations/decelerations	
Flexibility	Sliding board (dynamic stretching)	
	TRX inverted lunge	

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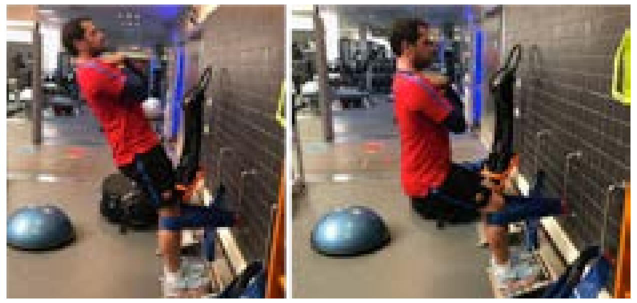
Table 1
Examples of exercises that may be included in a prevention program for quadriceps muscle injuries

THE BARÇA WAY

Our approach to exercise selection for quadriceps muscle injury prevention focuses on a variety of open and closed chain kinetic exercises on stable and unstable surfaces in order to provide a wide array of stimuli to the players. As with the hamstrings, multi-joint single and double leg exercises such as the squat, lunge and leg press can be prescribed (see hamstring exercise selection section). Exercises with an eccentric focus are emphasised (figures 1A and 1B) in addition to training functional patterns (figures 2A and 2B). Finally, as with other muscle groups, we prescribe active stretching of the quadriceps, before, during and following specific exercises (figures 3A and 3B). Field based exercises include downhill sprinting, plyometrics and sled running.



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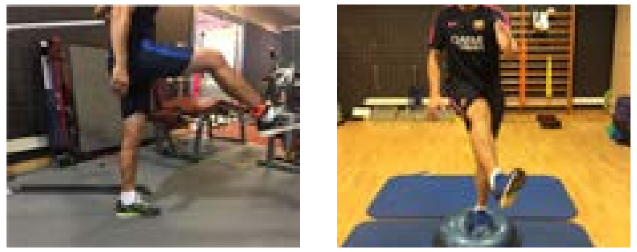
Figures 1A and 1B
Quadriceps exercises with an eccentric focus



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Figures 2A and 2B
Training quadriceps functional patterns

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Figures 3A and 3B
Active stretching of the quadriceps

MUSCLE INJURY GUIDE:
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1.4.4e

EXERCISE SELECTION: ADDUCTOR INJURY PREVENTION

During football training and match-play, the adductor muscles are often placed under high loads, especially during high-speed running, hard changes of direction with accelerations and decelerations and kicking.[1,2] Among the adductor muscles the adductor longus has been found to be the most frequently injured (i.e. 62% of injuries) and therefore, exercises targeting the strengthening of this muscle should be incorporated into the global exercise-based adductor injury prevention program.

— With Maurizio Fanchini, Xavier Linde, Juanjo Brau, Andrea Mosler and Joar Haroy

The activation of this muscle from different hip-adduction exercises has been examined in various studies.[3-5] These studies showed that the adductor longus is preferentially activated during ball-squeeze exercises, the Copenhagen Adduction exercise and the hip adduction with elastic bands.[3-5] These aforementioned exercises have been shown to be superior at activating the adductor longus compared to other adductor focussed exercises such as rotational squats, sumo squats, standing adduction on a Swiss ball, side lunges, side-lying hip adduction and supine bilateral hip adduction.[3,5] However differences between methods in the studies (for example EMG assessment and frequency collection, signal filtering and exercise load) doesn't allow an accurate draw-up of intensity-based guided ranking of the most used exercises. Several exercises (Table 1) can be included in on-field warm-up as they can be performed at any training facility without requiring special equipment.

The effect of strength exercises on adductors muscles has been examined in various studies on soccer players.[6,7] One study reported an increase of eccentric hip-adduction strength after 8-weeks strength training with elastic band on adductors muscles, and therefore could be incorporated into a injury prevention program.[5,6] Another study by Ishøi et al.[7] showed an increase of eccentric hip adduction and abduction strength of 36% and 20% in Danish football players after 8-weeks of a progressive in-season protocol with the Copenhagen Adductor exercise. In regard to its effect on muscle injuries, a study by Haroy and colleagues (currently in review) showed a 41% reduction in groin related injuries in sub-elite footballers in Norway with the integration of the Copenhagen Adductor exercise into the injury prevention program (Haroy et al., in review).

Different exercises should be incorporated in a global exercise-based injury prevention program, for example a study examining a combination of adductor and abdominal strengthening, jumping, coordination exercises and stretching found a 31% (albeit non-significant) reduction in groin related injuries in amateur footballers.[8,9] Therefore a preventative exercise program should be multi-dimensional, including not only exercises targeting the specific muscle (such as the Copenhagen Adductor protocol), but also sport specific activity and performance conditioning exercises (Table 1) as suggested in the general principles of injury prevention in the present guide.

IMPLEMENTATION REASON	EXERCISE
Activation / strength endurance / strengthening (low intensity injury prevention	Side-lying hip-adduction
	Ball squeezes (45-cm Swiss ball between knees)
	Side lunges
	Isometric adduction with a ball between ankles
	Standing hip adduction on Swiss ball
	Rotational squats (with elastic band around knees)
	Sumo squats
	Supine bilateral hip adduction
Strength	Copenhagen Adduction
	Hip adduction with elastic band/cable
	Hip adductor machine
	Sliding hip abduction/adduction
	Side-lying hip adduction with conic pulley (eccentric)
Plyometrics and performance conditioning	Agility (turns, change of directions)
	Sprints and High speed running
	Hops (forward and lateral)
	Carioca and sliding runs
	Lateral running
Flexibility	Sliding hip abduction
	Stretching of lower limb
	Dynamic stretching of lower limb

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Table 1
Examples of exercises that may be included in a prevention program for adductor muscle injuries

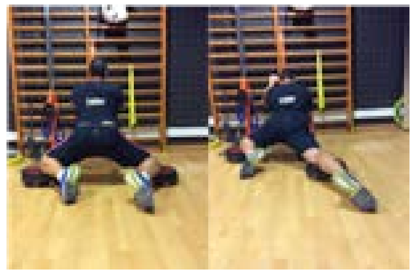

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Figure 1
Active stretching and mobilisation of the adductor muscles

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Figure 2A to 2D
Adductor strengthening using seated, lying, standing and manual resisted exercises

THE BARÇA WAY

We use active mobilisation and stretching of the hips and adductor muscles (figure 1). A variety of exercises are incorporated on stable and unstable surfaces, standing, sitting or lying and sometimes with manual resistance (figures 2A to 2D). Exercises such as the side lunge train allow us to train using functional patterns in the gym (figure 3). Finally, we like our players to train with a focus on proprioception on the hip and core muscles (figure 4).

^
Figure 3
Side lunge (can be performed with or without weight).

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Figure 4
Proprioceptive exercise for the hip and core muscles.

1.4.4f

EXERCISE SELECTION: CALF INJURY PREVENTION

Despite a lack of scientific evidence, there are a number of exercises and training activities that are likely useful in calf muscle strain injury prevention. The role of these exercises is to train the calf muscles to function optimally and to make the triceps surae more resilient to injury. Different variations of calf raise involving the knee in a straight (soleus and gastrocnemius) and flexed (soleus) position should be incorporated to fully promote calf muscle function.[1]
— With Tania Pizzari, Brady Green, Karin Silbernagel and Anthony Schache

These exercises can be classified according to the adaptations they are intended to bring about in the calf muscles: muscle activation, strength-endurance, maximal strength, plyometric and explosive muscle action, and flexibility and mobility. Due to the different nature of these exercises, they are best implemented during different parts of the overall training program. For example, calf muscle strengthening may be completed as part of the lower body-strengthening program, while plyometric drills can be performed during field-based training sessions as part of the on-field warm up (Table 1).

THE BARÇA WAY

Calf exercises are performed on stable and unstable surfaces, providing the player with a variety of stimuli (figures 1A to 1C) to on simultaneously with coordination drills of the lower and upper body are a key component of our exercise based preventative program for calf muscle injury (figures 2A to 2C). Running technique is trained using elastic bands, placing more stimulus on the calf muscles (figures 3A & 3B). As with the hamstring muscles, a key focus during the gym based exercises is to perform active stretching before, in-between and following the exercises (figures 4A & 4B).
While calf exercises such as those mentioned above, form part of our preventative program for calf muscle strain injury, we want to emphasise that managing the on-field loads has more emphasis for us.

POSITION	KEY DEMANDS
Activation / Strength endurance / strengthening	Calf raise in knee extension (target gastrocnemius and soleus)
	Calf raise in knee flexion (mainly target the soleus)
Strength	Standing calf raise machine (Single leg standing calf raise in machine or Smith machine or free weights or isoinertial machine)
	Seated calf raise machine
Plyometrics and performance conditioning	Hopping drills
	Bounding drills
	Sprint and footwork drills (Marching A skips) (B skips)
	Hill runs (Forwards running up a hill)
Flexibility	Local calf stretch in knee extension
	Local calf stretch in knee flexion
	Global posterior line stretches (Long sitting) (Single leg downward dog)

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Table 1
Examples of exercises to include in the prevention program for calf muscle injury

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Figure 1A. Calf exercises on stable surface

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Figure 1B & 1C. Calf exercises on unstable surface

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Figures 2A, 2B and 2C. Calf exercises combined with coordination exercises.surface

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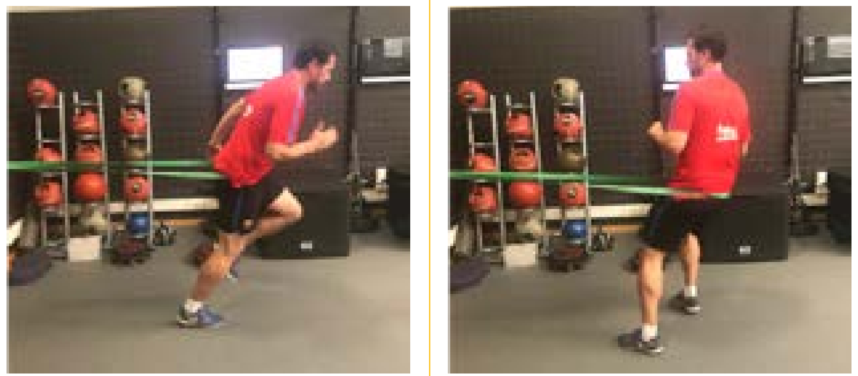

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Figures 3A and 3B. Training running technique using elastic bands

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Figures 4A and 4B. Active stretches of the calf and soleus muscles

1.4.5

COMMUNICATION

Another of the most important injury prevention strategies as highlighted by elite football practitioners from the 'Big 5' Leagues in our Delphi Survey was 'communication'. A common opinion among football practitioners is that, to maximise the preventative effects of strategies such as controlling load and implementing exercise and recovery strategies, we must be able to communicate effectively with key stakeholders such as players and coaching staff, as well as among ourselves.

— With Mike Davison and Ricard Pruna

Good internal communication should help in the implementation of preventative strategies and perhaps more importantly, gain the 'buy in' of players and coaches. Whilst there is currently no scientific evidence for the effectiveness of communication to prevent muscle injury in elite football specifically, it makes sense that effective communication could be beneficial to maximise injury prevention strategies. A UEFA-led survey of 33 of the 34 Champions League teams competing in the 2014/15 season, revealed 'internal communication' as one of the most important risk factors for non-contact injury (muscle injury being a large component of non-contact injuries), and successful buy in from players and coaches as crucial to the success of injury prevention strategies.[1] The following is a philosophical view of how effective communication may help in the elite football setting and provides some examples of the FCB philosophy regarding communication.

WHAT IS COMMUNICATION?

Communication is simply the act of transferring information from one place to another. Although this is a simple definition, in a high-pressure environment such as that in elite football, it becomes a lot more complex. Successful communication can be considered as a combination of several important factors. Firstly, the right language needs to be used. Secondly, it is important to know the audience, considering their own injury experience, their cultural context, and their potential heuristics and biases. Finally, it is important to evaluate and ensure that the desired message has reached its target, and has been understood.

CATEGORIES OF COMMUNICATION

There are various categories of communication, of which more than one may occur or interact at any time. The different categories of communication include:

- Spoken or Verbal Communication: e.g. face-to-face, telephone
- Non-Verbal Communication: e.g. body language, gestures, how we dress or act
- Written Communication: e.g. e-mails, reports and medical notes
- Visualisations: e.g. graphs, charts, photos and other visualisations can communicate messages

Professor Albert Mehrabian is internationally well known for his publications on the relative importance of verbal and nonverbal messages. Some of the key findings from Mehrabian's work,[2-5] include; (i) 7% of the understanding of the message comes from the feelings and attitudes in the words that are spoken (verbal communication), (ii) 38% of the understanding of the message comes from the feelings and attitudes invoked by the words that are said (paraverbal communication), (iii) 55% of the understanding of the message comes from the feelings and attitudes translated in facial expression (non verbal communication).

We have to recognise there are many types of communication at play in a football club. They range in setting, in structure and in forms of interaction. However, it is often not the information itself that is important for the outcome, it is the way it is delivered. In the emotionally and often paranoid setting of a football club, the body language and tone dominate. Thinking more specifically about Football Medicine, the diversity and scope of potential conversations and communications is wide. Perhaps it is the widest in the football club environment, and this means that the doctors, physiotherapists, fitness coaches, sports scientists and team psychologists need to be skilled in communication to be effective.

WHY IS IT LIKELY TO BE IMPORTANT IN FOOTBALL?

Simply put, communication is at the heart of every successful organisation. It disseminates the information needed to get things done, and builds relationships of trust and commitment. Without it, team members end up working in silos with no clear direction, with vague goals and little opportunity for improvement. A team with high quality communication between different roles are likely to have good collaborations, and benefit from multiple perspectives in making informed decisions, for instance in those regarding players' well-being.

However, team morale can plummet when communication is ambiguous, unfocused, lacking in important details and where it does not allow for genuine two-way dialogue. A situation like this, where this low quality of internal communication, is one where there is increased risk of misunderstandings, one-sided decision-making and wrongful decisions.

We know from experience that organisational stress can have a negative impact on player welfare. An organisation with a lot of miscommunication, where members experience a lack of or insufficient information, and where their opinions are not considered, might create stress on staff and players. Football is a dynamic industry and with a constant transfer of coaches and players from different nations between different clubs, where the workplace can change from one day to another, there are common cultural as well as communication challenges to overcome.

It is therefore crucial for the Football Medicine and Performance team to try to maintain consistency and high quality levels of internal communication irrespective of organisational change, in order to avoid a potential deleterious effect on injury burden, and player welfare.

INTERRELATED WORK, PART OF PREVENTION

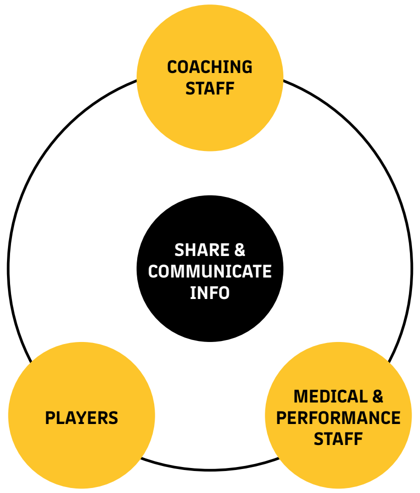

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Figure 1
A key component of the multi-faceted injury prevention program in FC Barcelona

THE BARÇA WAY

The Medical and Performance team have to be confident as well as willing and able to communicate their recommendations using simple language and even drawings to clearly illustrate their points and recommendations.

We need to be patient and take the time to educate the players, coaching staff and board members on key medical and performance concepts.

It is essential that we are honest and act in the best interests of the players, the club and fellow staff and not concerned with our own ego.

1.5

CONTINUOUS (RE) EVALUATION AND MODIFICATION OF PREVENTION STRATEGIES

A key phase of the Team Sport Injury Prevention (TIP) cycle is ongoing (re) evaluation of the injury situation to find out whether prevention strategies are actually having an impact. Are any new or different injury patterns emerging? This information is essential to allow the medical and performance team to adapt to a constantly changing injury landscape and ensure maximum prevention effectiveness over time.
— Alan McCall, Ben Clarsen, James O'Brien and Robert McCunn

RE-EVALUATING THE LANDSCAPE OF MUSCLE INJURIES IN YOUR TEAM

The key to ongoing evaluation of the injury landscape in your team throughout the entire season is injury surveillance.[1] The medical and performance team should record injuries consistently to ensure that data is comparable within and between seasons. We recommend using well-established injury definitions from published research. In this way, practitioners can compare not only within their own team, but also with data published in the scientific literature. Specifically, injury definitions and collection procedures should follow the guidelines set out in the 2006 Consensus Statement for the definition and data collection procedures for football (soccer) injuries.[2] This method is also used by the UEFA Elite Club Injury Study (ECIS), which provides insights into the largest database of football injuries anywhere in the world. The key aspects of the UEFA ECIS method include:

- An injury is defined as any physical complaint sustained by a player that results from a football match or training and leads to the player being unavailable to take full part in future football training or match-play (i.e. time loss).
- A player is considered injured until the club medical staff clear the player for full participation in training and availability for match selection.
- Injury severity corresponds to the number of days absence due to the injury.
- Individual player exposure (in minutes) for all training sessions and matches should be recorded to allow calculation of injury statistics.

Recording this information correctly is essential to the subsequent interpretation and actions decided. There are two particularly useful methods to calculate, report and monitor the muscle injury situation within your club (and indeed all injury types can be recorded this way), allowing accurate comparison to the published research literature.

1. Injury Incidence – corresponds to the rate of injuries and is calculated and reported as a number of injuries per 1000 hours of exposure (e.g. match exposure, training exposure and match + training exposure). For example, if a team has 10 injuries during 5,000 hours exposure, the injury incidence is 2 injuries for every 1,000 hours.* equation: #injuries/1000 hours of exposure
2. Injury Burden – corresponds to the cross product of severity AND incidence i.e. provides a combination of the rate of injury as well as a measure of loss i.e. days lost due to the injury (total number of days lost per 1000h). For example, if a team has 10 injuries during 5,000 hours exposure, each resulting in an average absence of 10 days, the injury burden is 20 days for every 1,000 hours. *equation: #days absence/1000 hours of exposure

WHY IS INJURY BURDEN SO IMPORTANT?

Although injury incidence can be useful to provide an evaluation of how often injuries will occur in your team, it says nothing about how severe they are. In contrast, burden measures incorporate both injury likelihood and severity.[1] This approach has been used for many years in rugby union[3] as well as in the UEFA ECIS during the last decade.[4,5]

Burden is best illustrated using a risk matrix illustrating injury likelihood (incidence) and severity (time loss).[1] Figure 1 illustrates the incidence plotted against the severity of various injuries, with the lighter to darker yellow shading representing the burden. This figure highlights the importance of evaluating both incidence and severity and how reporting one alone, does not provide the full picture of the muscle injury landscape in your team.

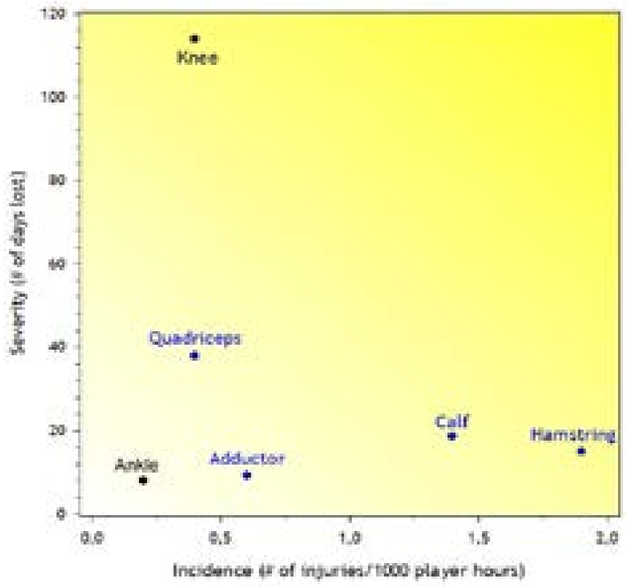

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Figure 1
Injury risk matrix showing reporting the incidence AND severity of various muscle injury locations and joint injuries for comparison. The yellow shading represents the injury burden i.e. the lighter the yellow shading, the lower the injury burden and vice versa, the darker the yellow shading, the greater the injury burden.

EVALUATING CURRENT INJURY PREVENTION PRACTICES IN YOUR CLUB

In addition to collecting injury data, it is essential to evaluate the injury prevention situation in your club. Are prevention strategies affecting the injury situation? Are they being consistently implemented? What do players and coaches think of the strategies? There is no gold standard for how these questions should be answered – it requires combining a quantitative (i.e. measurable, data-driven) and a qualitative approach.

In general, quantitative data tells us the what and the when (e.g. injury types, locations, incidences and burdens), whereas qualitative data may tell us the how and the why. For example, a qualitative approach is needed to investigate why a particular preventative strategy might be popular with players and coaches, and another one unpopular. A multitude of factors influence the injury prevention behaviour of players, coaches and team staff members. Even strategies shown to be highly effective in controlled research studies may not be utilised by players, coaches and support staff in the real world. The Nordic hamstring exercise is a perfect example of this conundrum; scientific evidence shows the exercise reduces the risk of initial hamstrings injuries by 59% and recurrent injuries by 86%, (though not in elite players) yet a majority of UEFA Champions League teams do not use it.[6] Qualitative research methods can be an important tool for understanding the reasons behind your team's injury prevention situation.

Qualitative methods include, but are not limited to, interviews, focus groups and surveys.[7] While it may seem unnecessarily over complicated to refer to 'qualitative data collection' instead of simply 'talking to your colleagues', incorporating scientific rigour to the process can be valuable. Using tools such as standardised surveys and semi-structured interviews, and considering factors such as how, when and where you ask certain questions might allow you to collect more relevant, systematic insights and present your conclusions with credibility. Table 1 provides some suggestions for employing qualitative methods to evaluate the injury prevention situation in your team, taking the implementation of the Nordic Hamstring Exercise (NHE) program as an example:

WHO TO ASK*	HOW TO ASK	WHEN TO ASK	WHAT TO ASK (Ex)
Players	Surveys	As part of routine team meetings	How many of the planned NHE sessions were carried out?
Football coaches	Focus groups	Formal injury prevention evaluation sessions	Were the correct number of sets and repetitions performed?
Medical and performance staff	Interviews	Individual player performance reviews	What was the quality of exercise execution?
Club officials			Do you see any benefits of using the NHE program?
			Does the program have any negative side-effects?
			Are there any barriers for using the NHE program?
			Was the program modified? (Why?)
			Do you use alternate strategies? (Why?)
			Do you intend to continue using the NHE program?
			Could the NHE program be adapted to better fit your team's situation?

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Table 1
Suggestions for employing qualitative evaluation in a team setting

* It is important to ask individuals from all the groups involved in the injury prevention strategy; players (who perform the program); team staff members (who deliver the program) football coaches (who often act as "time-keepers") and club officials (who determine club policy and provide resources e.g. financial).

Acknowledging the fast and frenetic pace of football, continual evaluation is crucial in this phase of the Injury Prevention cycle. This will allow the medical and performance team to audit and identify emerging patterns in the injury situation and take subsequent action. Although it may be normal to discuss the injury situation in daily and weekly medical meetings, we recommend a more formal evaluation performed 2 to 3 times per season, including coaches, other support staff and even some players. During this evaluation, injury statistics, qualitative analyses and reviews of injury prevention research and innovative strategies can be discussed in depth.

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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.

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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 making his or her return 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

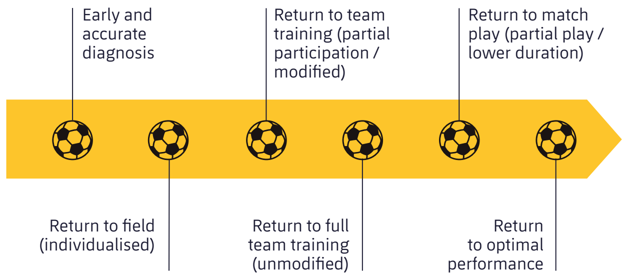

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Figure 1
Football return to play continuum (adapted from Ardern et al.[1])

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.

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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 performing, 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 the notion 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 focus attention and temporo-spatial control.

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Figure 2
Football-specific d high cognitive demands while preforming 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

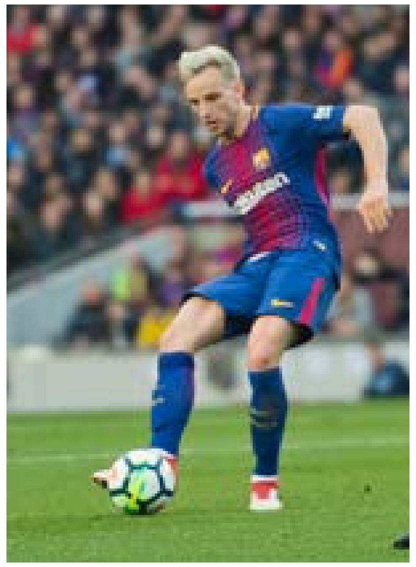
Knowing the exact injury location is arguably the most important factor in predicting RTP time. This is why, at FC Barcelona, clinical assessments are performed and high-quality MRI images are taken as soon as possible after muscle injuries occur. Knowing whether any tendon or bony tissue is involved 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

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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.

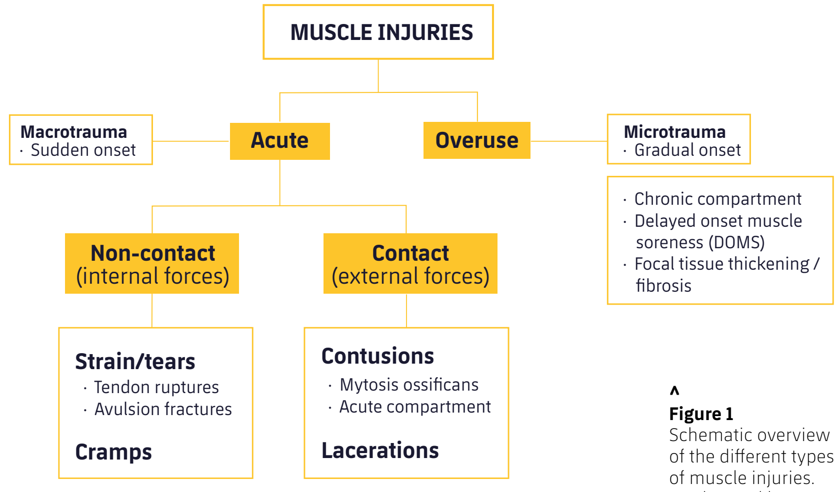

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Figure 1
Schematic overview of the different types of muscle injuries. Tendon and bone injuries (avulsion fractures) are included as sub-classifications of muscle strain injuries, as they may appear to be muscle injuries with similar mechanisms and 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.

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.

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.

< **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 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.

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

MUSCLE INJURY GUIDE:
PREVENTION OF AND RETURN TO
PLAY FROM MUSCLE INJURIES

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.

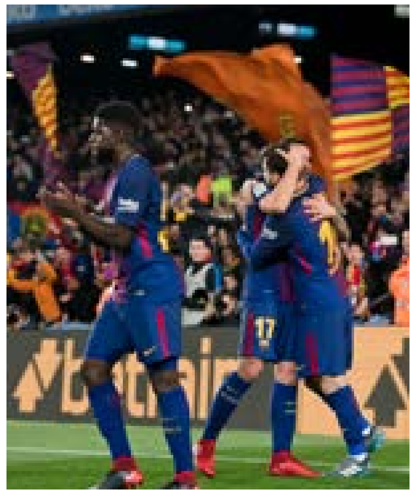
MUSCLE INJURY GRADING AND CLASSIFICATION SYSTEMS

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.

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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	

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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

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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

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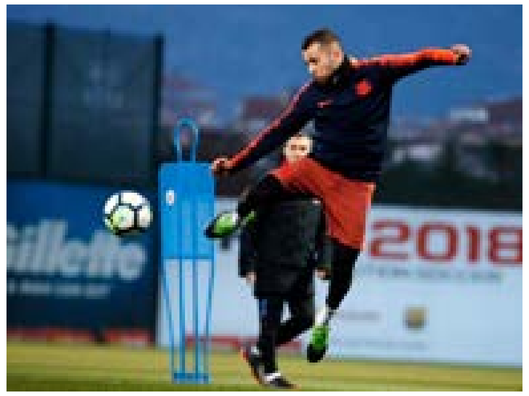
Table 6
Classification of Quadriceps contusion. Adapted from Jackson & Feagin (1973), in Kary et al. (2010)[7] and Brukner & Kahn (2017)[12]



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

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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).

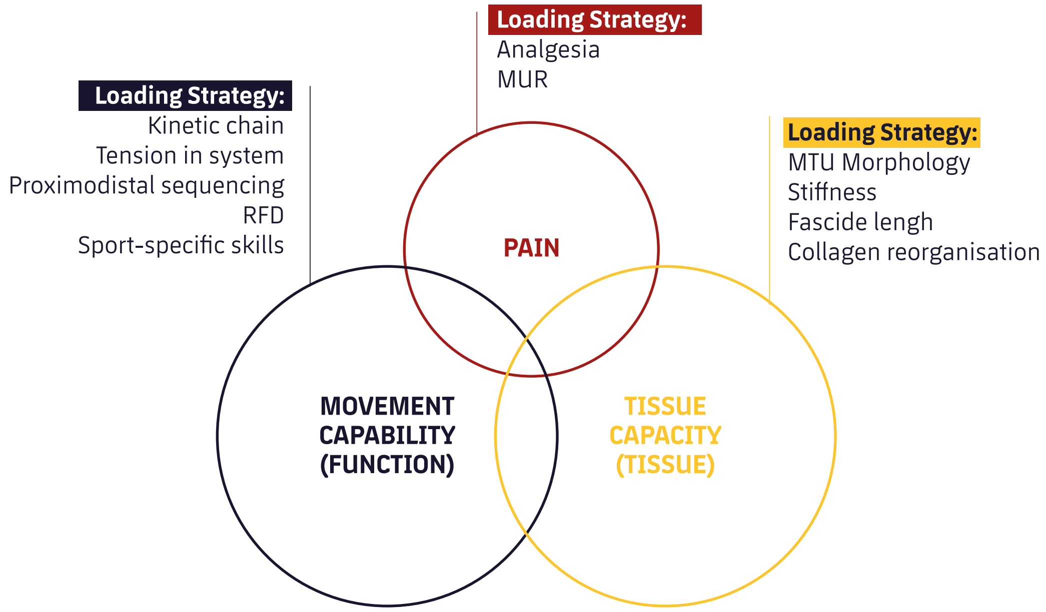

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Figure 1
What Are the Goals of Loading? MUR = Motor Unit Recruitment, RFD= Rate of Force Development

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

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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.

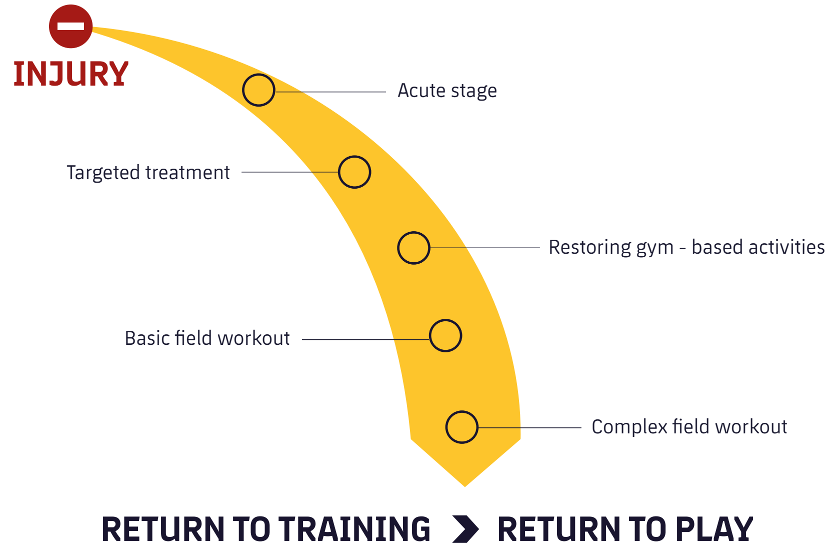

Figure 2
The FC Barcelona 'Return to Play Process'

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 throu-gh 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 stret-ching, 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 parti-cular 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 phases1); 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.

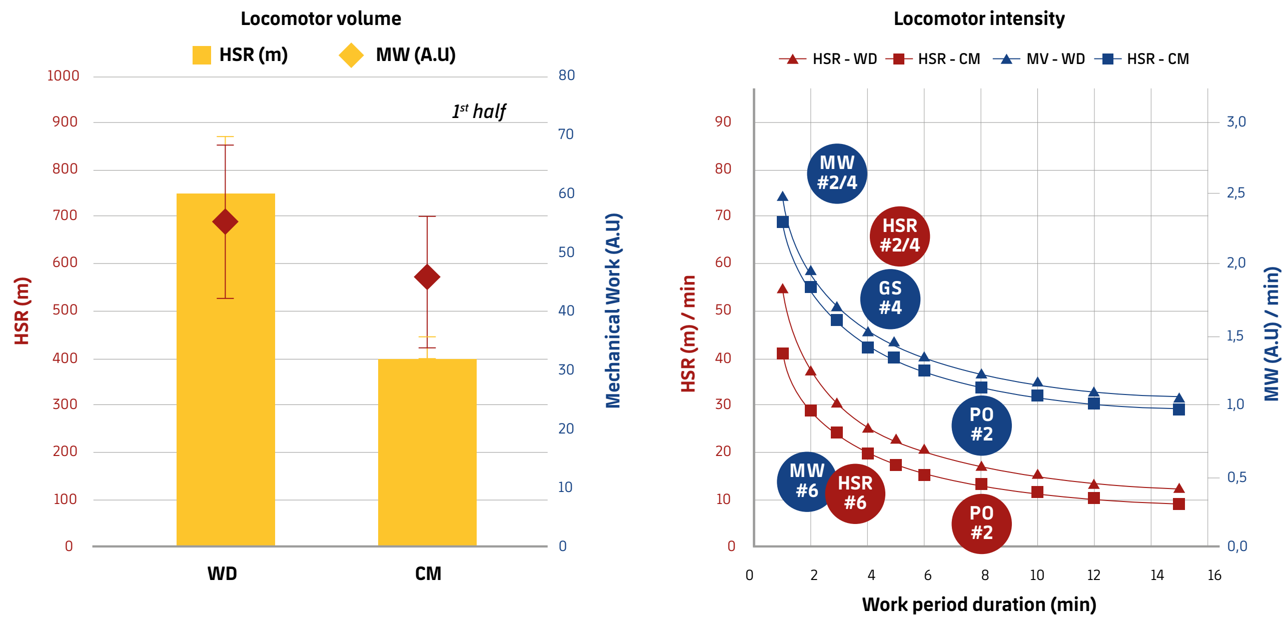

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Figure 1
Summary of the worst case-scenarios for locomotor volume demands (± standard deviation, SD) during League 1 and Champions League matches (1st half) for a wide defender (WD) and a midfielder (playing as a '6', CM), in terms of volume (left 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 4 coloured circles refer to 4 of the specific training drills within S4 sessions, as indicated in Table 1 (HSR) and 2 (WM). #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 #44 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 to transition 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 and. They should also perform some individual conditioning work post session (in relation to the injury and individual game demands) (table 1 and 2).

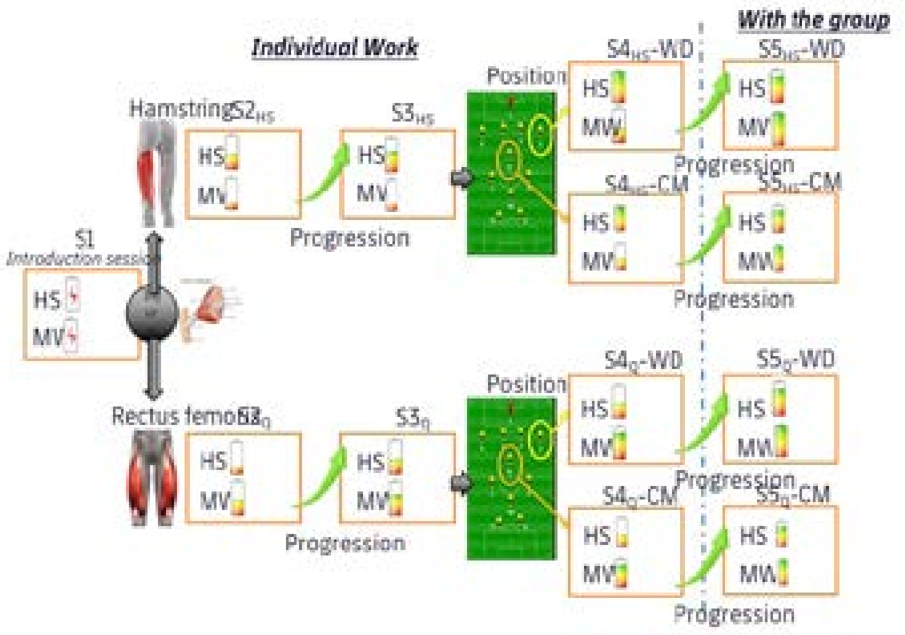

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Figure 2
Example of four sequential RTP load progressions in terms of volume and intensity of locomotor demands, i.e., high-speed running (HSR) and mechanical work (MW). The sessions are designed for two very common muscle injuries (i.e., hamstrings, 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.

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S1: Introduction session

- Low-intensity running 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 SHS-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).

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

Distance to run are provided for 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.

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

S1: Introduction session

- Low-intensity running 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).

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.
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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], 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). 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.[1-4] 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[1-4].

— 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.[1-4]

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.[1-4]

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,[5,6] 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.[7]

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.[8,9] Furthermore, NSAIDs do not delay myofibre regeneration.[10]

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).[11] 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[12,13] More recently, NSAIDs were shown to enhance skeletal muscle regeneration and remodeling in young humans with skeletal muscle injury.[13] However, NSAIDs did not accelerate the recovery from severe hamstring injury.[14]

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.[8-15]

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.[16] In vitro- as well as experimental studies have indicated that PRP could enhance the recovery of different sports injuries, among them, skeletal muscle ruptures.[17]

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).[18,19] Recent meta-analyses have shown that PRP does not shorten "return to play"-time nor reduce the recurrence rate of the injury.[20,21] 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.[22-24] 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.[25,26]

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 or 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.[27-30]

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[31], but another two randomized controlled trials found no or very little beneficial effects.[32,33] 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 ULTRASOUND (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.[34-36]

CLINICAL EVIDENCE

Randomized controlled trial showed that TUS reduced pain and improved recovery after DOMS[37]. 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.[38]

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.[1]

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.[1-4]

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 the 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.[1-4] By adhering to these protocols, the injured athletes can recover from serious skeletal muscle injuries as fast and effectively as possible.[1-4]

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.

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RTP from Specific Muscle Injury

3.1

RETURN TO PLAY FOLLOWING HAMSTRING MUSCLE INJURY

In this section, we build upon the general principles described earlier in the guide, with specific reference to hamstring muscle injuries.

— With Thor Einar Andersen, Arnlaug Wangensteen, Nicol van Dyk and Ricard Pruna

MAKING AN ACCURATE DIAGNOSIS

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

PATIENT HISTORY

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

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

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

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

PHYSICAL EXAMINATION

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

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

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

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

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

IMAGING

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

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

MUSCLE INJURY GUIDE:
PREVENTION OF AND RETURN TO
PLAY FROM MUSCLE INJURIES

ESTIMATING RTP TIME

LOCATION AND EXTENT OF TISSUE DAMAGE

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

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

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

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

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

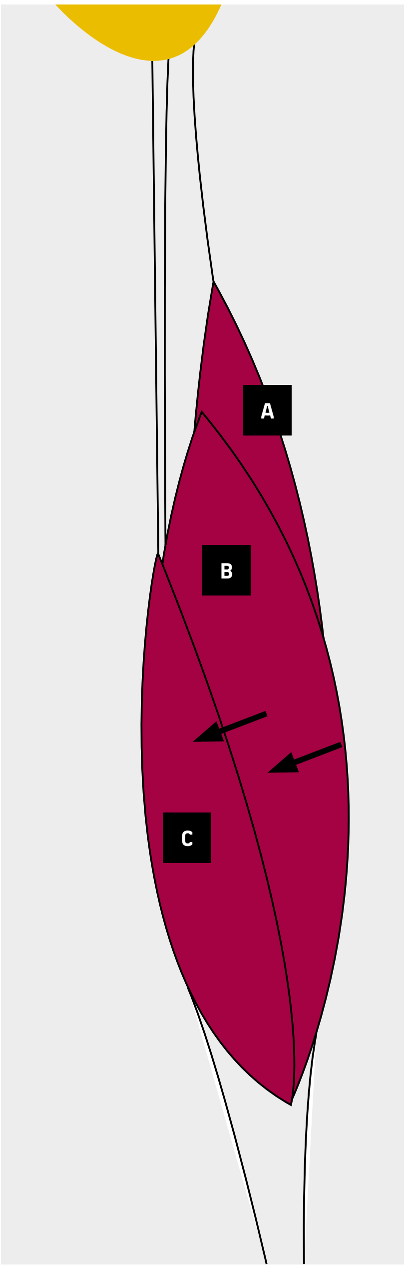

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Figure 1
Illustration of the semimembranosus sections A, B and C (refer to table 1). Adapted based on Woodley J and Mercer SR. Hamstring muscles: Architecture and Innervation. Cells Tissue Organs, 2005;179:125-141.

PLAYER-SPECIFIC FACTORS

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

FOOTBALL-SPECIFIC FACTORS

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

HAMSTRING MUSCLE TESTING

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

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

STRENGTH TESTING

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

POSTERIOR THIGH FLEXIBILITY

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

EXERCISE PRESCRIPTION FOR HAMSTRING INJURIES

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

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

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

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

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

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

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

EXERCISES TO OPTIMISE TISSUE HEALING AND RESTORE PERFORMANCE

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

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

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

ACUTE STAGE

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

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

TARGETED TREATMENT

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

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

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

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Figure 2:
Active tension stretching towards extension

FOCUSED MUSCLE ACTIVATION

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

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

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Figure 3:
Isometric exercises

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Figure 4:
Concentric exercises against manual resistance

RESTORING GYM-BASED ACTIVITIES

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

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

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

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

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Figure 5A:
Two leg bridge

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Figure 5B:
One-leg bridges

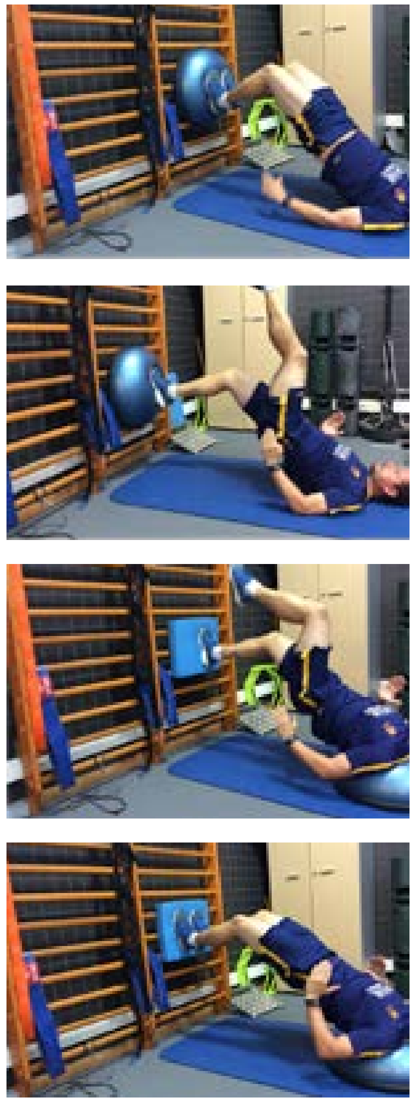

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Figure 6:
Bridges and one-leg bridges with increased ranges and various surfaces

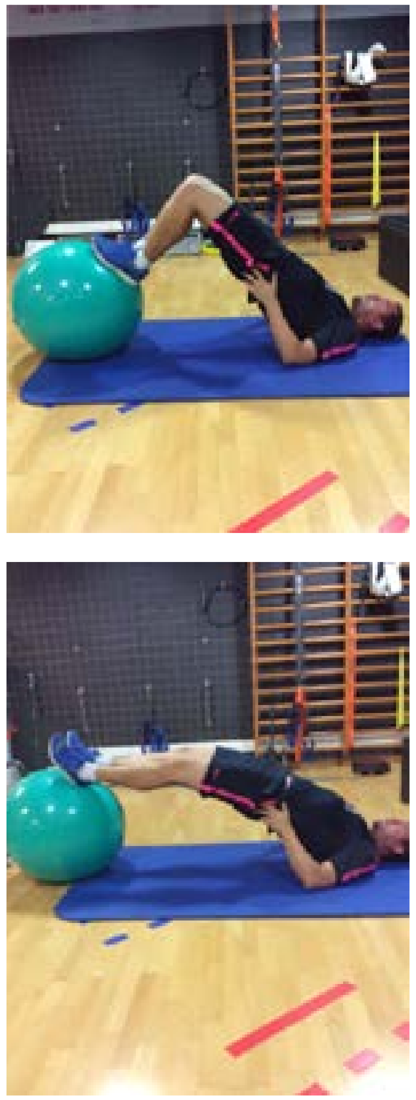

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Figure 7:
Bridges combined with knee extensions (eccentric phase) (and knee flexion curls (concentric phase)

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

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

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

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Figure 10:
Various active stretching and dynamic mobility exercises

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

RUNNING PROGRESSION

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

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

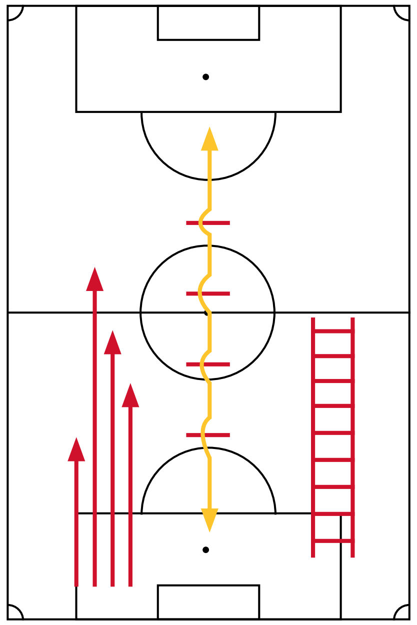

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Figure 12:
Examples of early running in the field

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

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

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

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

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

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

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

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

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

RETURN TO PLAY EXAMPLE FROM FC BARCELONA

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

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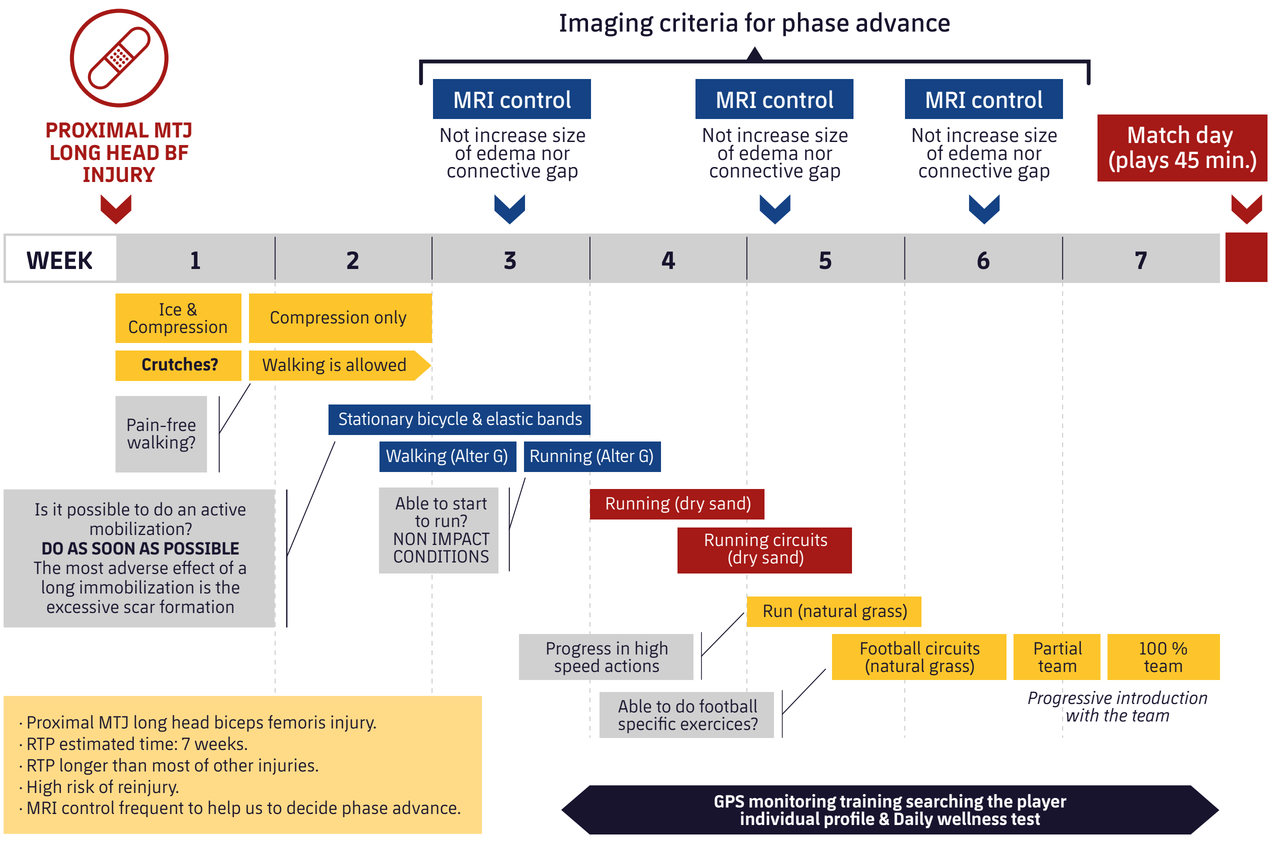

THE BARÇA WAY:

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

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

SURGICAL TREATMENT OF HAMSTRING INJURIES

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

— With Lasse Lempainen, Sakari Orava and Janne Sarimo

INDICATIONS FOR EARLY SURGERY

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

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

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

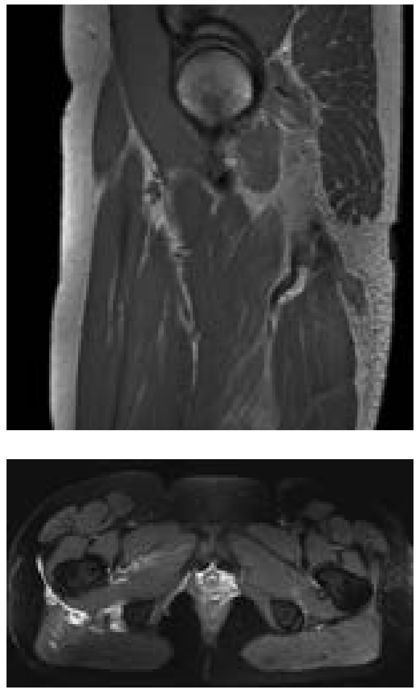

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Figure 14 A-B:
Complete 3-tendon proximal hamstring rupture with a clear retraction on the right side (axial and sagittal images).

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

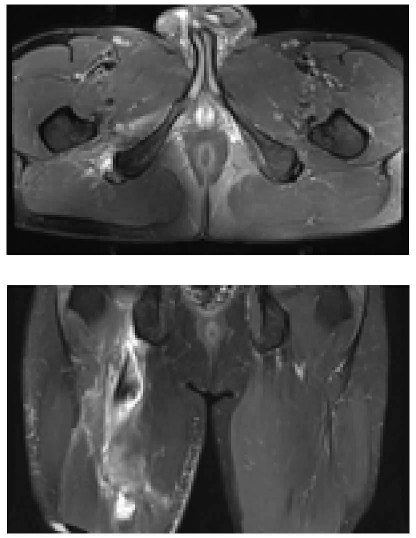

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Figure 15 A-B:
Isolated complete proximal SM tendon rupture with a clear retraction from the ischial tuberosity on the right side (axial and coronal images).

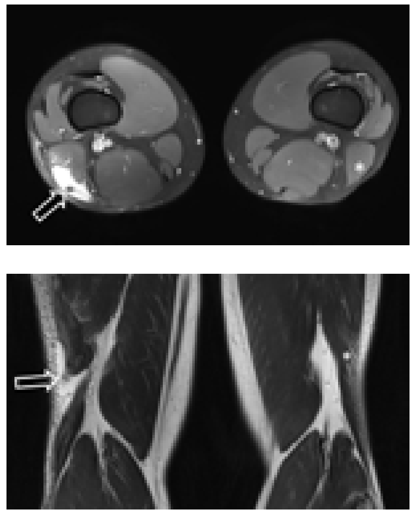

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Figure 16 A-B:
Distal rupture of the long head of the BF at the myotendinous junction. A coronal image (B) shows the retracted BF muscle (axial and coronal images).

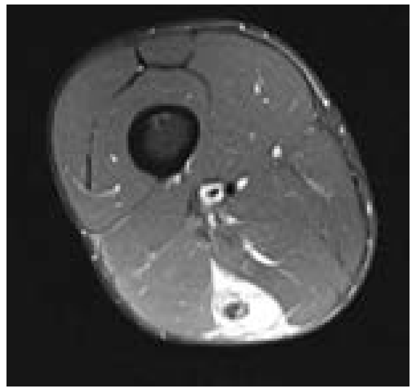

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Figure 17 A-B:
Distal rupture of the ST at the myotendinous junction. A sagittal image (B) shows loose and retracted ST muscle belly (axial and sagittal images).

PROGNOSIS FOLLOWING EARLY SURGICAL REPAIR

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

INDICATIONS FOR DELAYED SURGERY

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

INCOMPLETE HEALING OF AVULSION SITE

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

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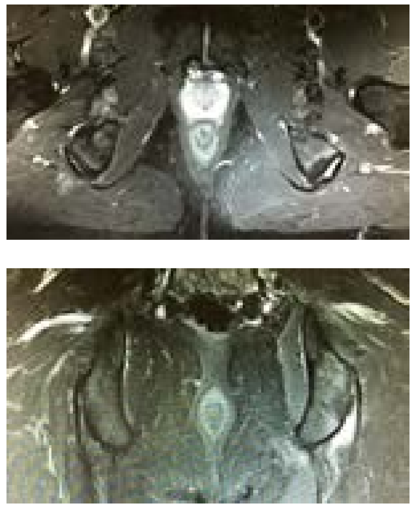
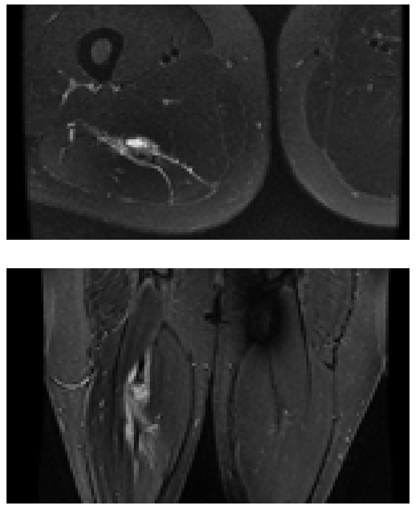


CENTRAL TENDON INVOLVEMENT

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



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

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

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

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

OTHER CAUSES

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

CONCLUSION

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

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

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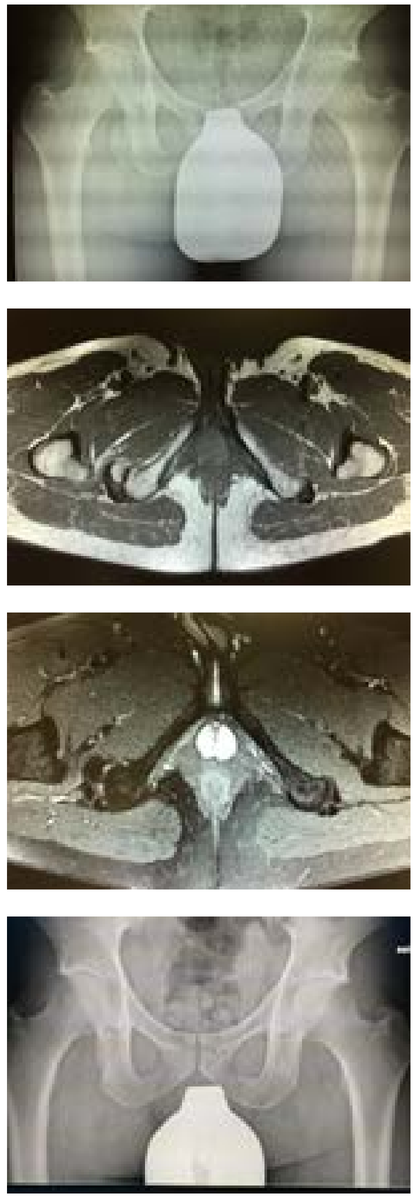
Figure 20 A-D:
Heterotopic ossification next to the right ischial tuberosity causing sciatic nerve impingement. A; x-ray before operation. B and C; mri axial view. D; x-ray taken after operation.



3.2

RETURN TO PLAY FOLLOWING QUADRICEPS MUSCLE INJURY

In this section, we build upon the general principles described earlier in the guide, with specific reference to quadriceps muscle injuries.

— With Phil Glasgow, Mario Bizzini and Andreas Serner

MAKING AN ACCURATE DIAGNOSIS

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

PATIENT HISTORY

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

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

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

PHYSICAL EXAMINATION

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

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

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

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

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

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

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

IMAGING

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

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

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

ESTIMATING RTP TIME

LOCATION AND EXTENT OF TISSUE DAMAGE

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

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

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

Table 1:
Estimated RTP times for quadriceps muscle injuries based on location and tissues involved
v

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

PLAYER-SPECIFIC FACTORS

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

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

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

FOOTBALL-SPECIFIC FACTORS

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

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

QUADRICEPS MUSCLE TESTING

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

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

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

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

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

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

QUADRICEPS MUSCLE TESTING

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

INTRA- VERSUS INTERMUSCULAR HAEMATOMA

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

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

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

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

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

EXERCISE PRESCRIPTION FOR QUADRICEPS MUSCLE INJURIES

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

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

EXERCISES TO OPTIMISE TISSUE HEALING AND RESTORE PERFORMANCE

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

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

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Figure 1A:
Compressive Bandage for Quadriceps Strain

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Figure 1B:
Game Ready

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Figure 1C:
Normatec

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

TARGETED TREATMENT

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

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

FOCUSED MUSCLE ACTIVATION

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

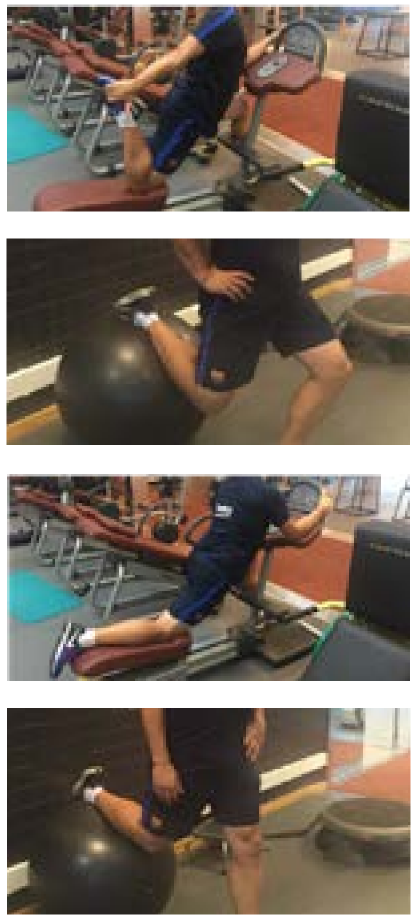

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Figure 2:
Dynamic mobility and active tension stretching

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

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Figure 3:
Focused Muscle Activation

RESTORING GYM-BASED ACTIVITIES

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

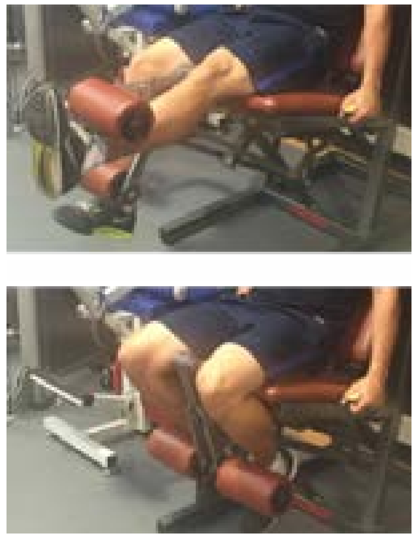

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Figure 4:
Seated leg extension

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Figure 5:
Cable kicking

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

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Figure 6:
Reverse Nordics

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

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

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

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

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

Players should be progressively exposed to acceleration, deceleration and change of direction to enhance the force absorption capabilities of the quadriceps.[37] Attention should be given to challenging players in a wide range of positions and activities in order to build greater resilience.[38,39] Multi-directional running through the execution of simple football skills can be included in

football circuits. Familiar training drills can be introduced and progressed in terms of complexity and decision making (see below) before returning to field sessions with the squad.

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

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

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

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

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

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

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Figure 9:
Copenhagen Adductor exercise

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

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Table 2:
Kicking
Progressions

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

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

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

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

MUSCLE INJURY GUIDE:
PREVENTION OF AND RETURN TO
PLAY FROM MUSCLE INJURIES

RETURN TO PLAY EXAMPLE FROM FC BARCELONA

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

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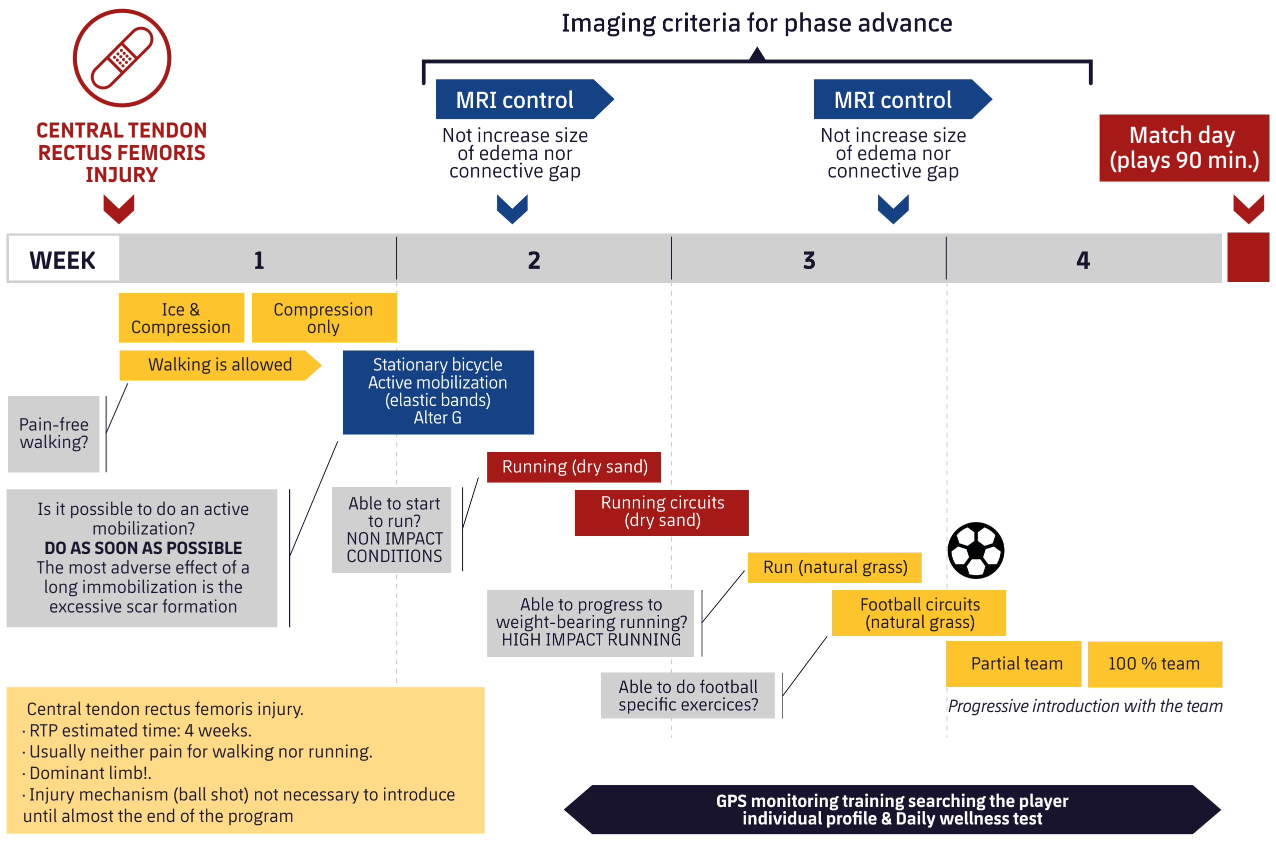


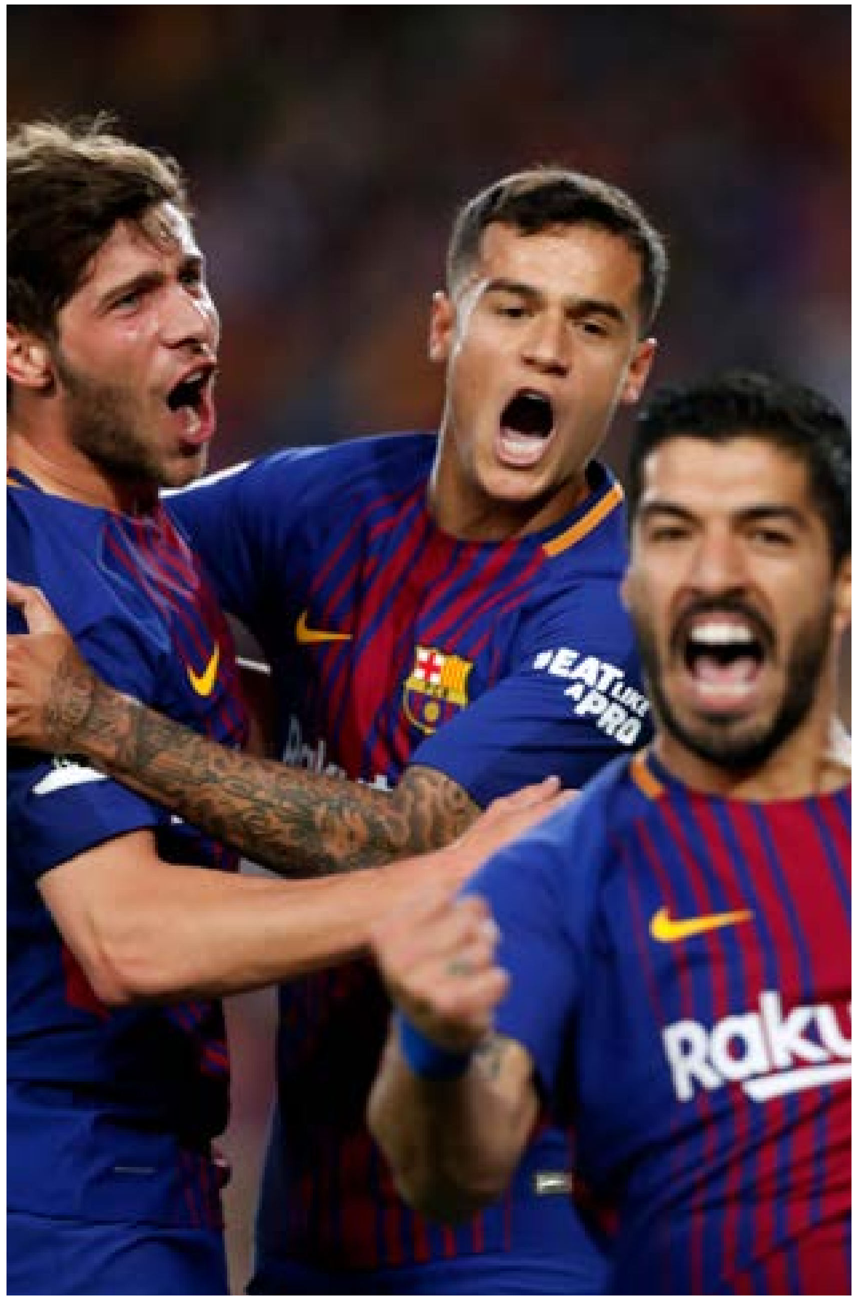
THE BARÇA WAY:

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

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

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

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



SURGERY FOR RECTUS FEMORIS MUSCLE INJURIES

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

— With Lasse Lempainen, Sakari Orava and Janne Sarimo

PROXIMAL RUPTURES

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

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

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

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

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

MID-SUBSTANCE RECTUS FEMORIS RUPTURES

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

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

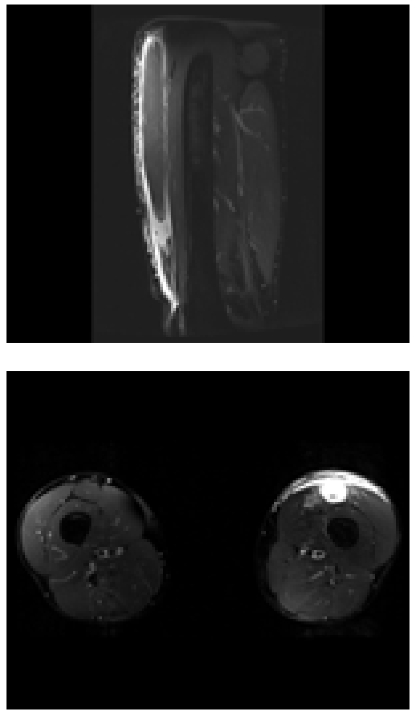


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Figure 11 A-B:
Complete mid-substance rectus femoris muscle rupture (sagittal and axial images).

MUSCLE INJURY GUIDE:
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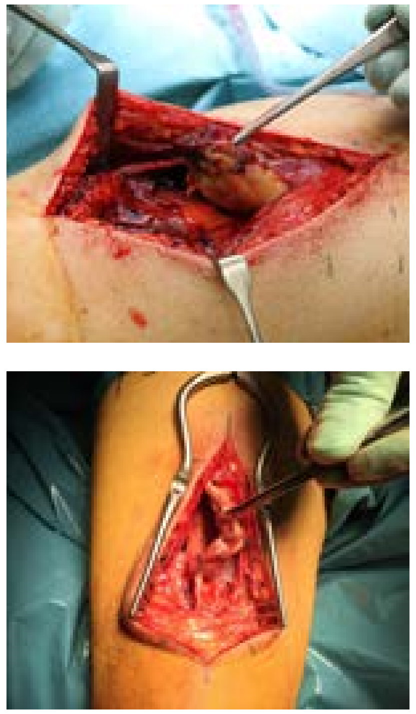

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Figure 11 C-D:
Perioperative photos of complete rectus femoris rupture with clear gap between ruptured ends.

CENTRAL TENDON RUPTURES

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

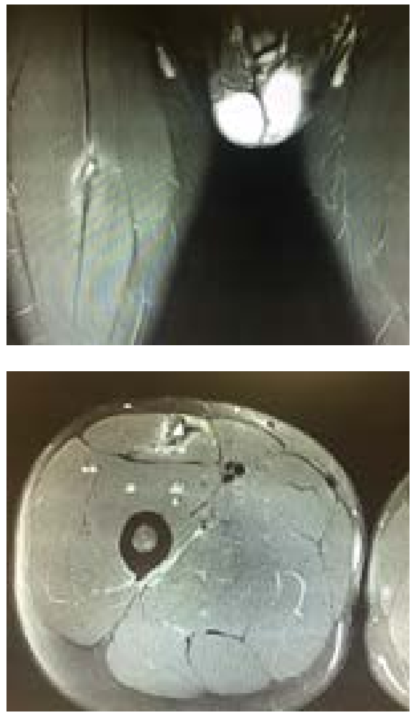

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Figure 12 A-B:
Recurrent central tendon rupture of the rectus femoris at the right side (coronal and axial images).

QUADRICEPS TENDON RUPTURES

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

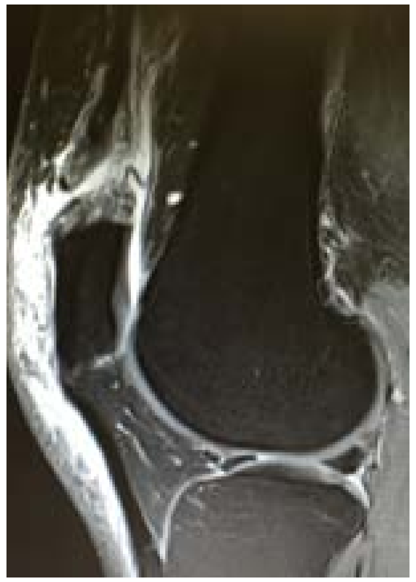

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Figure 13
Partial quadriceps tendon rupture (sagittal image).

CONCLUSION

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

3.3

RETURN TO PLAY FOLLOWING GROIN MUSCLE INJURY

In this section, we build upon the general principles described earlier in the guide, with reference to acute groin muscle injuries, specifically, injuries to the adductor, hip flexor and abdominal muscle groups.

— With Andrea Mosler, Andreas Serner, Joar Harøy, Jonas Werner and Adam Weir

MAKING AN ACCURATE DIAGNOSIS

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

PATIENT HISTORY

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

PHYSICAL EXAMINATION

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

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

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

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

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

IMAGING

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

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

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

ESTIMATING RTP TIME

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

LOCATION AND EXTENT OF TISSUE DAMAGE

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

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

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

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

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

PLAYER-SPECIFIC FACTORS

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

FOOTBALL-SPECIFIC FACTORS

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

GROIN MUSCLE TESTING

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

STRENGTH

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

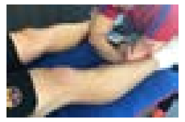
TEST	DESCRIPTION
SQUEEZE 0°[15] 	Player lies supine with 0° hip flexion and legs abducted to the length of the tester's forearm. The HHD is placed 5 cm superior to the medial malleoli. Player squeezes their ankles together, against the HHD and examiner's hand, with maximal force, without lifting the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

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Figure 1
Groin muscle tests using hand-held dynamometry

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

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

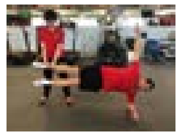
TEST	DESCRIPTION
SIDE PLANK[19] 	Players are instructed to lift their hips off the bed (or floor) by supporting their weight through their feet and forearm The head, trunk and legs to be placed in line with each other Players are then instructed to hold this position for as long as possible. Standardized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

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Figure 2
Groin muscle tests using hand-held dynamometry

ENDURANCE

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

RANGE OF MOTION

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

FUNCTIONAL TESTS

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

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

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

EXERCISE PRESCRIPTION FOR GROIN MUSCLE INJURIES

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

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

EXERCISES TO OPTIMISE TISSUE HEALING AND RESTORE PERFORMANCE

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

TARGETED TREATMENT

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

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

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

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

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Figure 3
Supine eccentric hip adduction against manual resistance

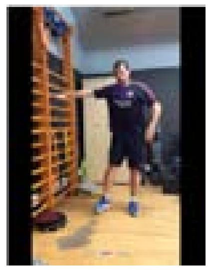

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Figure 4
Concentric and eccentric adduction against the resistance of an elastic band or cable pulley

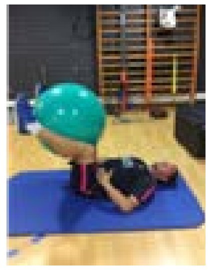

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Figure 5
Hip extension with isometric adduction using a fit ball

RESTORING GYM-BASED ACTIVITIES

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

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

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

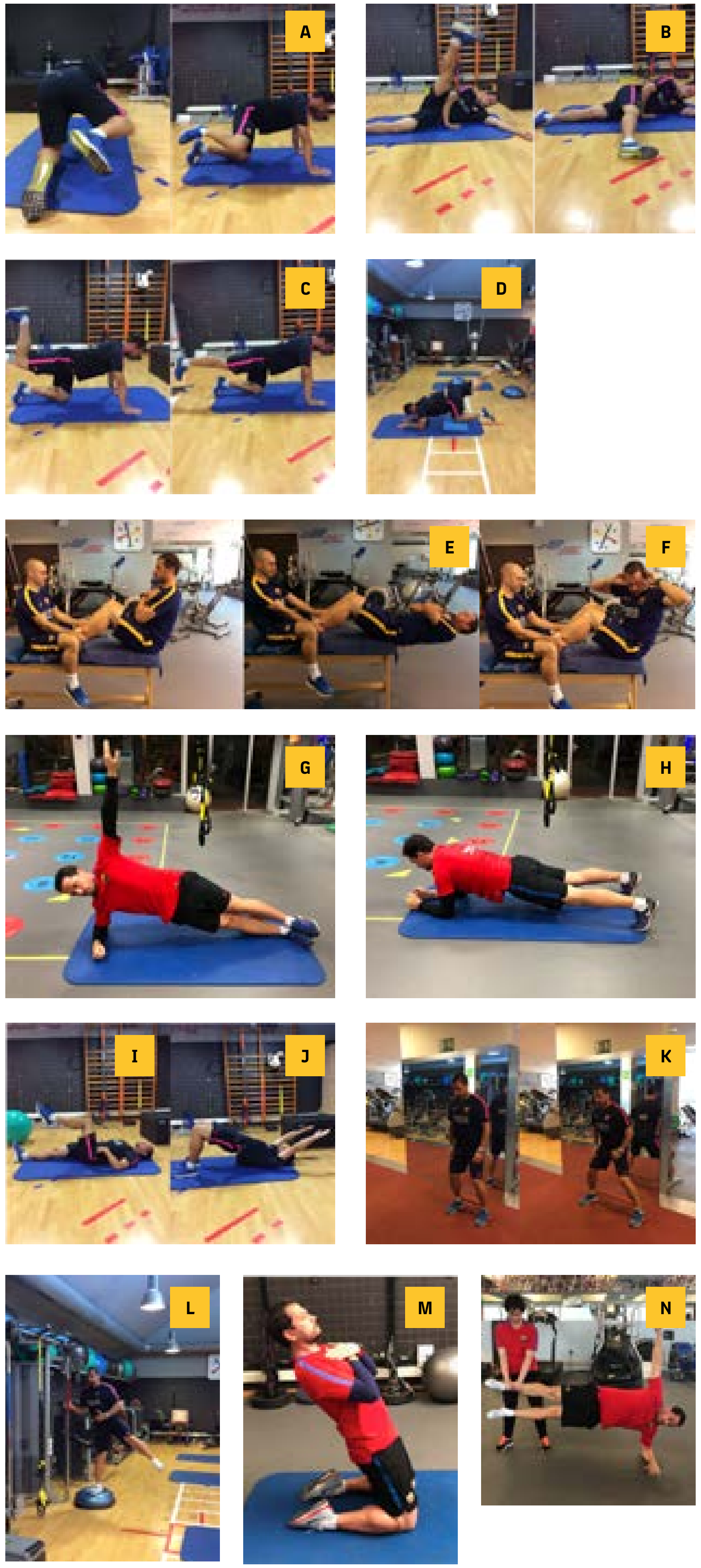

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Figure 6A. "doggie" exercises and 6B. Hip abduction at 90º flexion.
Figure 6C. Hip extension in 4-point kneeling and figure 6D "superman"
exercise. Figure 6E. Straight and 6F oblique sit-ups with high concentric and eccentric load. Figure 6G side plank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

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

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Figure 7
Functional gym exercises

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

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

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

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

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

The aim of the final phase of the RTP process is to train the player to return to their required level of play with a minimal risk of re-injury. Therefore, it is important to focus on training and testing all potentially injurious actions, in addition to training the player to cope with his/her usual and worst-case scenario loads of playing football. Many groin muscle injury movements are influenced by the close presence of an opponent causing a rapid decision-making process influencing player movements, resulting in injury risk. Therefore, training reactive/unanticipated actions, in addition to pre-planned actions, are essential in the RTP process, not only

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

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

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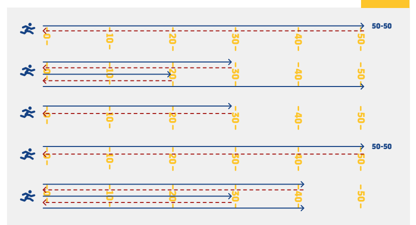

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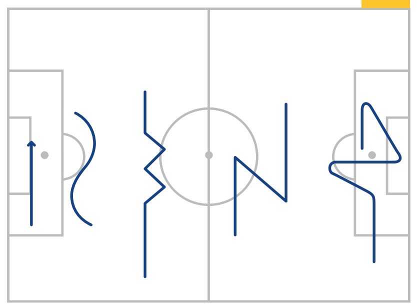

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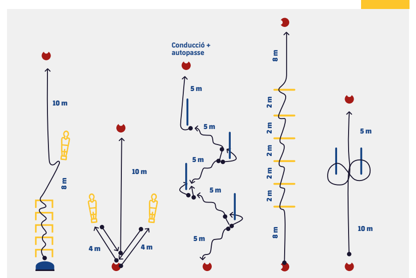

from the perspective of minimising re-injury risk but also for ensuring optimal performance (see section 2.3.2 for more detailed information). For timed change of direction and agility drills, tests such as the T-test and the Illinois Agility Test have shown good reliability.

RETURN TO PLAY EXAMPLE FROM FC BARCELONA

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

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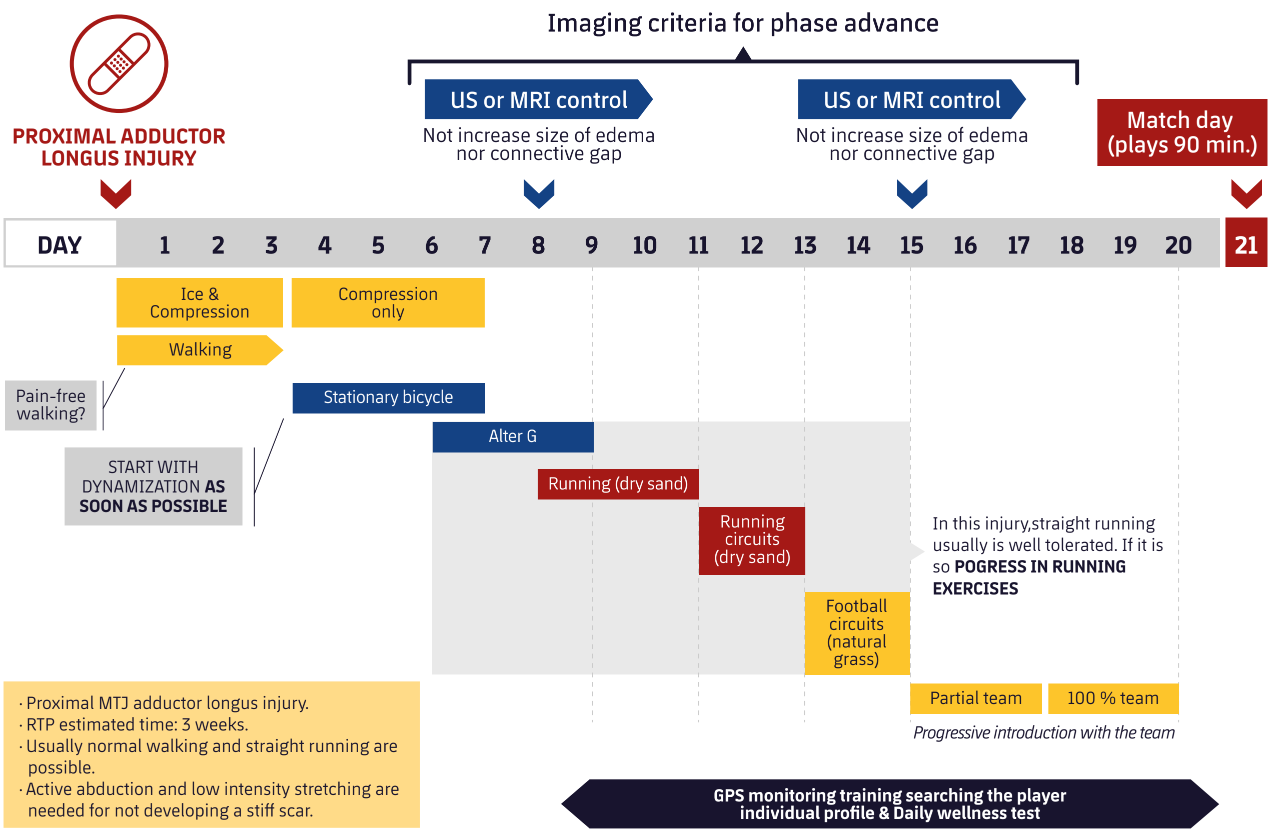

THE BARÇA WAY:

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

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

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

SURGERY FOR ADDUCTOR MUSCLE INJURIES

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

— With Per Holmich

INDICATIONS FOR SURGERY

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

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

TREATMENT – DISTAL INSERTIONAL LESION

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

TREATMENT – MTJ LESION

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

TREATMENT – PROXIMAL INSERTIONAL LESION

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

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

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

SURGICAL TECHNIQUE

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

3.4

RETURN TO PLAY FOLLOWING CALF MUSCLE INJURY

In this section, we build upon the general principles described earlier in the guide, with specific reference to calf muscle injuries.

— With Tania Pizzari, Brady Green, Karin Silbernagel, and Anthony Schache

MAKING AN ACCURATE DIAGNOSIS

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

PATIENT HISTORY

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

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

PHYSICAL EXAMINATION

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

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

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

IMAGING

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

ESTIMATING RTP TIME

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

LOCATION AND EXTENT OF TISSUE DAMAGE

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

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

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

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

PLAYER-SPECIFIC FACTORS

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

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

FOOTBALL-SPECIFIC FACTORS

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

CALF MUSCLE TESTING

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

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

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

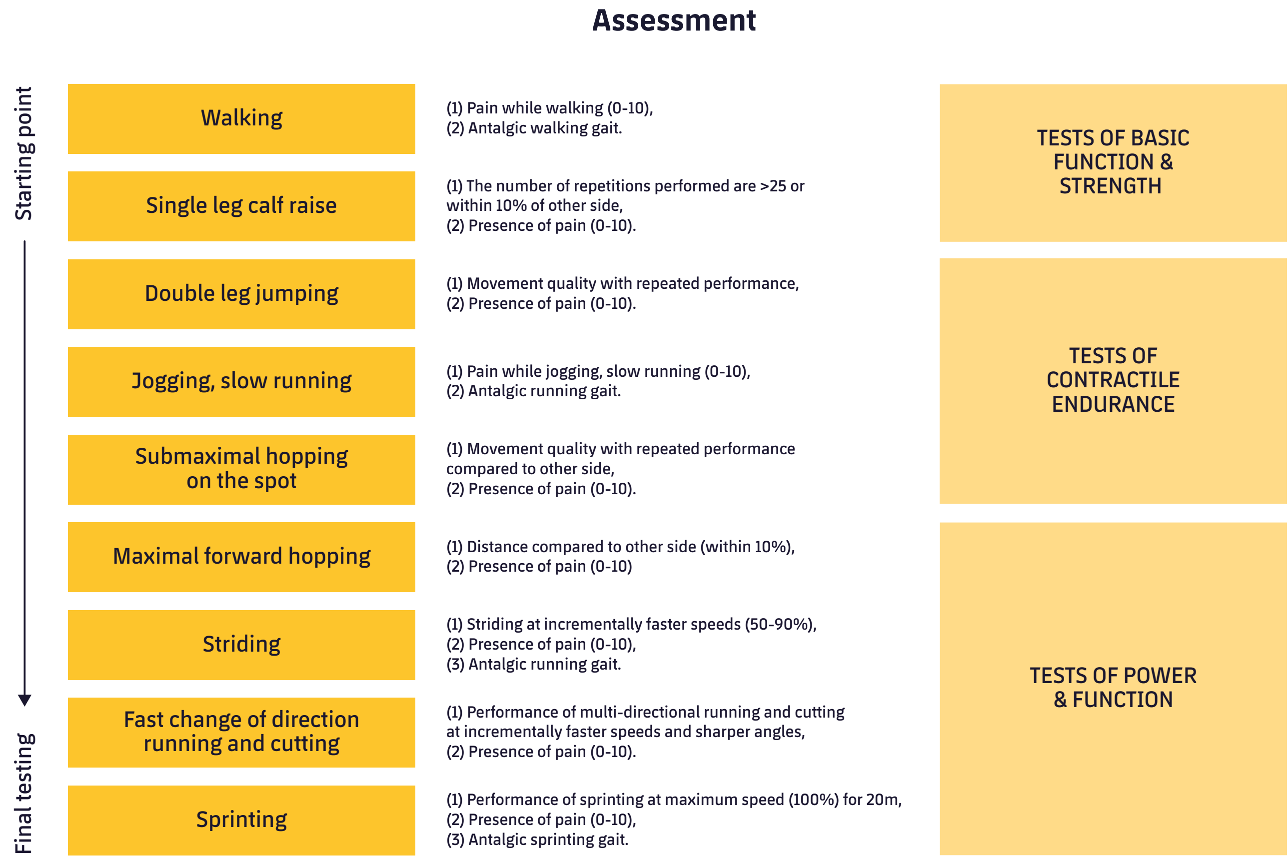

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Figure 1:
Graduated functional testing battery for calf muscle strain injuries.

EXERCISE PRESCRIPTION FOR CALF INJURIES

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

EXERCISES TO OPTIMISE TISSUE HEALING AND RESTORE PERFORMANCE

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

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

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

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Figure 2A:
Standing calf raise

Figure 2B:
Seated calf raise

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

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

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

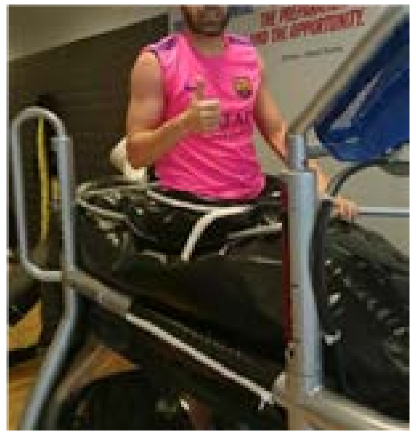

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Figure 3:
Alter-G treadmill

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

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

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

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

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

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Figure 4:
Bilateral jumping

Figure 5:
Unilateral hopping/
jumping

RESTORING FOOTBALL-SPECIFIC FITNESS, SKILLS AND COGNITION

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

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

RETURN TO PLAY EXAMPLE FROM FC BARCELONA

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

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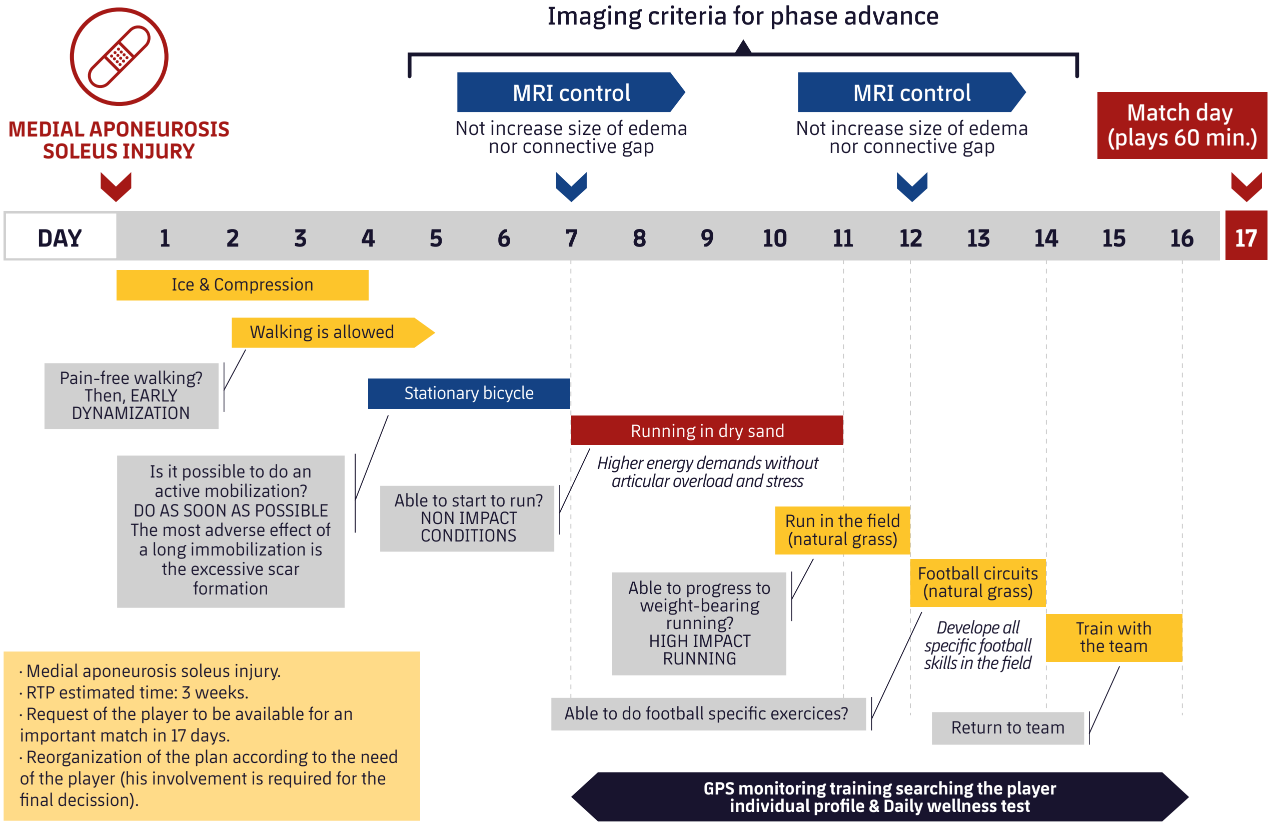

THE BARÇA WAY:

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

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

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

SURGERY FOR CALF MUSCLE INJURIES

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

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

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

INDICATIONS FOR EARLY SURGERY

ACHILLES TENDON RUPTURE

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

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

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

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

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

COMPARTMENT SYNDROME

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

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

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

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

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

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

INDICATIONS FOR DELAYED SURGERY

MUSCULOTENDINOUS AND INTRAMUSCULAR TENDON INJURY

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

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

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

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

ACHILLES TENDINOPATHY

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

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

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

TAKE HOME MESSAGE

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

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

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

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

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

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MUSCLE INJURY GUIDE:
PREVENTION AND TREATMENT
OF MUSCLE INJURIES

CHAPTER 3

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

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

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

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MUSCLE INJURY GUIDE: PREVENTION OF AND RETURN TO PLAY FROM MUSCLE INJURIES