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LEADING ARTICLE

Muscle Injuries in Sports: A New Evidence-Informed and Expert Consensus-Based Classification with Clinical Application

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Abstract Muscle injuries are among the most common injuries in sport and continue to be a major concern because of training and competition time loss, challenging decision making regarding treatment and return to sport, and a relatively high recurrence rate. An adequate classification of muscle injury is essential for a full understanding of the injury and to optimize its management and return-to-play process. The ongoing failure to establish a classification system with broad acceptance has resulted from factors such as limited clinical applicability, and the inclusion of subjective findings and ambiguous terminology. The purpose of this article was to describe a classification system for muscle injuries with easy clinical application, adequate grouping of injuries with similar functional impairment, and potential prognostic value. This evidence-informed and expert consensus-based classification system for muscle injuries 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). The goal of the classification is to enhance communication between healthcare and sports-related professionals and facilitate rehabilitation and return-to-play decision making.

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Key Points

The article describes a new evidence-informed and expert-consensus classification for muscle injuries.

The information contained under the initialism MLG-R (mechanism, location, grading, and re-injury) represents the most valuable information with clinical application.

The new classification should improve communication between health- and athlete-related professionals regarding muscle injuries.

1 Introduction

Muscle injuries are very common in soccer [1], rugby [2], American Football [3–5], Australian Football [6, 7], and track and field [8, 9]. The incidence of muscle injury may be as high as 31% in soccer and 28.2% in track and field [1, 9]. The muscles most commonly involved are biarticular with a complex architecture and containing a high proportion of fast-twitch fibers [1]. Ninety percent of injuries are caused by either excessive strain or contusion [10, 11]. In professional soccer, between 92 and 97% of all muscle injuries are located in the lower extremity: hamstrings (28–37%), quadriceps (19–32%), adductors (19–23%), and calf muscles (12–13%) [1, 12]. A European elite soccer team can anticipate up to 15 muscle injuries per season resulting in up to 223 days of training absence (27% of total time loss) and players missing 37 matches [1]. However, determining when a player is ready to return to play (RTP) following muscle injury is challenging because the recovery from injury is highly variable [13, 14]; premature RTP may be a factor in the observed high re-injury rates (12–43%) and prolonged time loss [1, 13, 15–19]. Significantly, professional soccer teams with lower season injury rates have a better performance in their national and international competitions [20, 21]. Therefore, muscle injuries are a major concern in sports medicine.

The severity of an injury can be determined by both direct and indirect means (i.e., clinically, through imaging studies, and through blood tests) [22]. Given that histological analysis of injured muscle tissue is not feasible as a routine diagnostic test, the description of injury severity is typically based on signs and symptoms, information about the mechanism of injury, and imaging studies. The mainstay for diagnosis and classification of muscle injuries has been a thorough history and physical examination, assisted by ultrasound and magnetic resonance imaging (MRI) studies. Several grading and classification systems for muscle injuries [23–33], specific muscles [34–36], or muscle groups [37, 38] have been published [39]. Some of these classification systems have been based on either clinical [23, 24] or imaging studies [25–27, 30], while others are based on a combination of clinical and imaging assessment [31, 32].

One of the recent combined classification approaches is the Munich consensus statement [31], which has been tested for validity [40]. In the validation study, it was concluded that the proposal was better for 'structural' compared with 'functional' injuries [40]. British Athletics has also proposed a muscle injury classification system, which has demonstrated reproducibility and consistency [41]. Their classification system recognises that injuries extending into the tendinous portion are associated with longer time loss and increased recurrence rate [41]. However, both of these classification systems use ambiguous terms, such as 'myofascial' by British Athletics and 'functional' in the Munich consensus. This may prevent universal use of both classifications.

An ideal classification system should include non-ambiguous terms, be easily applied, and describe objective findings that are clearly demonstrable [42]. Furthermore, a muscle injury classification system with real clinical value for clinicians, trainers, and athletes should have prognostic validity [43]. As a result, establishing a classification system exclusively based on clinical or imaging study data is challenging [39] and as such there is still not universal agreement on the utility and clinical application of the available classification systems [39, 42, 44].

The purpose of the present article was to describe a classification system for muscle injuries with easy clinical application, adequate grouping of injuries with similar functional impairment, and potential prognostic value.

2 Methodological Aspects

2.1 Procedures

An evidence-informed and expert consensus-based study was used. The methodology employed in the present research was based on previous publications related to consensus statements in medicine [45–47]. Three different centers (FC Barcelona Medical Department, Aspetar, and Duke Sports Science Institute) from three different continents (Europe, Asia, and North America), all with a high volume of muscle injuries and extensive experience in elite sports medicine were involved. The study was designed in three phases: (1) identify the existing evidence related to risk and prognostic factors for muscle injuries; (2) discuss these factors between two of the centers and establish a consensus based on the quality of studies in combination with experts' experience; and (3) elaborate the final classification. One of the authors (XV) first performed an electronic literature search to identify the risk and prognostic factors. The PubMed (MEDLINE) database was used to identify the relevant clinical studies in muscle injuries. The following search terms were employed and restricted to the English language: (muscle injury OR muscular injury OR muscle injuries OR muscular injuries OR muscle lesion OR muscular lesion OR muscle lesions OR muscular lesions OR muscle strain OR muscular strain OR muscle strains OR muscular strains OR muscle damage OR muscular damage) AND [(classification OR classifications OR rating OR grading OR severity) OR (risk factor OR risk factors OR prognostic factor OR prognostic factors OR predisposing OR predisposition)]. To be considered, articles were required to be original clinical research, but review articles were used to manually search for references potentially missed in the original literature search.

Two consensus meetings were held between two of the involved institutions (FC Barcelona and Aspetar). The results of the electronic literature search were initially presented (XV) and discussed between the four authors (GR, RP, LT, JAG) from FC Barcelona to determine the terms to bring to the first meeting. The first meeting of the two institutions was held in Doha in July 2013. Each topic was openly discussed during the meeting. All expert opinion and assessment of the included terms were taken into consideration and a first consensus position determined. The document from the first meeting was summarized and sent to all the authors involved in the meeting (XV, JT, BH, GR, RP, LT, JAG, RW, EW). A second review of the literature based on a manual search of references in the list of relevant studies and review articles was performed by one of the authors and the information extracted (XV). The information was then incorporated into a first draft of the classification system. This document was then reviewed by the authors from both institutions and a second meeting was scheduled. A time frame of 10 months was left between the two meetings to ensure adequate time for evaluation of the classification prior to the second meeting. Between the first and second meeting, the draft was developed iteratively based on comments from all authors.

A second meeting was held in Barcelona in May 2014 between the two institutions. All participants were given the opportunity to report concerns with the terms considered for the classification, and to critique and give personal opinion on the topic. A group agreement was achieved and a final preliminary document generated from this second meeting. This document was again sent to all participants at the two meetings (XV, JT, BH, GR, RP, LT, JAG, RW, and EW) and a time frame of 6 months given before the final consensus. During this period of 6 months, the draft evolved iteratively until agreement was achieved, and a final document was then approved by all involved participants. This final document was then sent to a FIFA Medical Centre for Excellence (Duke Sports Science Institute) to be evaluated by two authors (WEG and EAG). As a last stage, the final document was also sent to other professionals to provide a broad and multidisciplinary feedback on the new classification system: an expert radiologist in MRI (XA), an expert in ultrasound (RB), an expert and recognized orthopedic surgeon with a special interest in muscle injuries (JCM), a researcher with extensive experience in sports medicine investigation (KS), and another international expert in muscle injuries (NM). The comments and suggestions from these six authors (EAG, WEG, XA, RB, NM, JCM, KS) were incorporated into the final muscle classification, which was approved by all authors in October 2015.

2.2 Terms and Concepts Reviewed

A summary of the terms and concepts discussed in the meetings to be incorporated into the new classification is shown below.

2.2.1 *Mechanism of Injury: Direct or Indirect*

Classically, muscle injuries have been classified as direct or indirect [10, 48–50]. In the hamstring, indirect injuries are considered as being either a sprinting or stretching type, with a relationship between the injury mechanism, localization, and prognosis [51, 52]. Indirect muscle injuries are typically located close to a myotendinous junction (MTJ) [49, 51, 53–58], proximally or distally, or within an intramuscular tendon [37, 56, 59–62]. They have also been described on ultrasound and MRI as involving the periphery of a muscle (i.e., epimysium, fascia) [63, 64]. The age of the patient has been also shown to influence the location of muscle injuries [65].

Conversely, direct injuries are located where the contact occurs. Direct muscle injuries have been graded based on clinical signs [36]. If the muscle is contracted when the impact happens, the energy is best absorbed and consequently less histological damage is observed [11, 66, 67]. The size of direct muscle injuries is not well correlated with clinical signs and functional impairment [68], and such injuries usually have a better evolution with a shorter time to recovery in comparison to indirect injuries [69].

2.2.2 *Connective Tissue Organization*

The structure of the extracellular matrix (ECM) has been classically described in three layers: endomysium, perimysium, and epimysium. Currently, the ECM is considered a complex and interconnected structure [70–72], where “muscle fibers are embedded within a matrix of ECM that forms discrete layers that are mechanically interconnected” [73]. In this model, force generated by actin-myosin interaction is transmitted to the ECM and subsequently to the net of connective tissue. Focal ECM or muscle fiber injuries are reported to have negligible functional significance owing to the mechanical redundancy built into the ECM [73]. This connective tissue net structure and its role in force generation and transmission is a key factor in the signs, symptoms, and prognosis of muscle injuries [74]. In other words, the more ECM is injured the worse the prognosis [75–77].

Because of the important role of the ECM in clinical symptoms and severity of muscle injuries, an important component of the classification system is based on the evaluation of the amount and severity of the ECM damage. The amount of damage to the ECM depends on the mechanism of injury (direct or indirect) [78], the injury relationship with the MTJ (proximal or distal to the MTJ insertion; the more proximal to the MTJ insertion the injury is located, the greater the amount of damage to the ECM) [75], the percentage of the muscle cross-sectional area (CSA) (as defined by Slavotinek [79]) affected by the injury (degree of injury), and the presence of tendon involvement [76].

2.2.3 Prognostic Factors

There was a complete group consensus to include prognostic factors to the classification. Although some studies have based the prognostic factors on imaging studies, the group decided to design a classification that considers the inclusion of clinical and imaging characteristics as potential prognostic factors according to our experience and the available studies [37, 43, 80].

Regarding clinical characteristics, in a direct muscle injury, the force producing the injury is externally applied and the muscle damage occurs as a result of compression between the external force and the bone. This injury tends to be more superficial in contracted muscles and deeper when the muscle is relaxed at the time the trauma happens [11]. There are animal model studies regarding direct injury that show a deficit in contractile function, although the authors mention that “extrapolating the relationship between injury severity and functional loss to clinical situations is also limited since contractility was measured during maximal tetanus in an anesthetized animal” [81].

In indirect injuries, the force creating the injury is transmitted through the ECM [82]. The closer the injury location is to the MTJ attachment the greater the amount of ECM that will be injured and the more severe the clinical impairment [75]. The mechanism of hamstring muscle injury can also be related to injury location. Stretching injuries more often affect the proximal semimembranosus, in either the muscle or tendon tissue [51, 83]. Although it has been previously reported that proximal muscle injuries are associated with longer rehabilitation periods [51], this has not been confirmed in recent studies [13, 62, 84]. Other signs and symptoms used as prognostic factors are the time needed to walk pain free after a hamstring injury or specific functional characteristics. Injuries requiring more than 24 h before pain-free walking have been related to an expected time loss greater than 3 weeks [43]. For functional characteristics, active knee range of motion deficit after a hamstring injury may be a valid parameter to grade the injury severity and the expected recovery time in elite athletes [18, 37, 85]. The level of evidence for the influence of time to walk pain free and have an active knee range of motion on the prognosis of hamstring muscle injuries is still low.

Regarding imaging characteristics, MRI or ultrasound has been used to establish a relationship between evolution of the injury and type, location, tendon involvement, and extent of the injury [1, 13, 16, 17, 19, 37, 51, 62–64, 80, 83, 86–94]. Although imaging studies have good diagnostic value, their usefulness in predicting RTP using edema as a marker for injury is limited [95]. In the acute phase of injury, most of the existing evidence regarding prognostic value of imaging studies (mainly MRI based) is related to hamstrings and rectus femoris muscles [16, 90, 96]. These studies have tried to establish an association between different imaging measurements and time loss. Slavotinek reported that the percentage of the cross-sectional area (% CSA), the craniocaudal length, and the injury volume were the MRI parameters associated with time loss [79]. These parameters provide prognostic information owing to their relationship with the amount of disrupted fibers and the degree of dysfunction, and thereby suggest time to recovery. The strongest association with return to sport was related to the craniocaudal length adjacent to the MTJ [79]. It has also been observed that there is less time loss in patients with the clinical suspicion of a hamstrings injury but negative MRI [13, 16, 17, 62, 64, 80, 97]. There is also evidence regarding imaging-based prognostic factors from other muscles.

In rectus femoris injuries, it has been shown in MRI and ultrasound studies that when the central tendon is disrupted the recovery duration is longer [63, 98, 99]. The soleus muscle has also been investigated [94], reporting the prognosis and RTP according to injury location in the soleus muscle. The authors found that injuries in the central aponeurosis had a longer recovery time than injuries in the lateral and medial aponeurosis and myofascial sites [94]. Hence, in addition to the musculotendinous injury being a site of relevant pathology, the intramuscular tendon may be injured [76], with a variety of appearances on MRI. There is some evidence that these injuries require a prolonged rehabilitation time and may have higher recurrence rates [76]. As a result, it is important to recognize the tendon component of a muscle injury and its role in prognosis [41].

In summary, several parameters related to the extent of muscle injury and tendon involvement are potentially associated with duration of time loss from competition. These parameters may guide clinicians during the management of these injuries and therefore should be incorporated into a muscle injury classification system.

3 New Classification System

The new classification system proposed for muscle injuries was elaborated after the final consensus between the three institutions and is summarized in Table 1. For the purpose of this article, the hamstrings muscle group will be considered. The classification includes four main categories related to parameters with clinical and prognostic relevance: mechanism of injury (M), location of injury (L), grading of severity (G), and number of muscle re-injuries (R). The classification can be therefore abbreviated as MLG-R (Table 1). Category M stands for direct and indirect muscle injuries. Subcategories of the mechanism (M) category were created to define stretching type (sub-index S) and sprinting-type (sub-index P) indirect hamstring muscle injuries (Table 1). Category L (location) was subdivided into injuries located at the proximal, middle, or distal third of the muscle belly, with injuries further subclassified according to the relationship with the MTJ (Table 1). For the purpose of this article, muscle belly is defined according to Askling criteria but considering three portions (proximal, middle, and distal) instead of two [100]. The criteria for the MRI measurements have been previously described [79]. For the grading (G) category, the injury is evaluated on T2-weighted MRI (the presence of a hyperintense signal is considered positive), and the consensus was that an MRI should be performed between 24 and 48 h following injury. If more than one muscle is injured, the muscle with the greater area of signal abnormality or architectural distortion will be considered the primary site of injury and grading criteria will be taken for that particular muscle. Only the presence or absence of edema is recorded for grades 1 and 2 (Table 1); no differentiation is made between different volumes of edema. A recurrence (R) is defined as an injury of the same type and location as the index injury occurring during the first 2 months after return to full competition [1].

Injuries affecting the same MTJ, its intramuscular tendon or fibers associated with it (even in a different location), will also be considered a re-injury. As an example, if the first injury of the long head of biceps femoris affects the proximal MTJ in the proximal third of the muscle belly and another injury occurs within the next 2 months but located in the middle third of the muscle belly in fibers related to the proximal MTJ, this would be considered a re-injury. By contrast, if the second injury is located around or affecting the distal MTJ (a different MTJ from the initial injury), it would not be considered a re-injury. In other words, a re-injury is the occurrence of a muscle injury affecting the same muscle and MTJ as the initial injury. Figures 1, 2, 3, 4 and 5 show examples of muscle injuries classified using the MLG-R system.

4 Discussion

The principal purpose of this article was to propose a classification system for muscle injuries capable of describing the injury, with useful clinical application, a quick learning curve, and the potential to provide prognostic value. Based on existing evidence and our group's clinical experience, we considered that the mechanism of injury (M), injury location (L), MRI-based grading (G), and previous muscle injuries (R) as the most important factors to be included. Although this classification was designed with the aim of being applied to any muscle group, it initially described injuries to the hamstring muscles (Table 1). Subsequent studies will be conducted to report modification of this classification system to include other muscle groups and validate its content.

An important aspect of any consensus classification is the use of clear, non-ambiguous, and least-subjective terminology and also that the concepts included account for the highest level of consensus among experts. 'Myofascial' is a term widely used, representing a different injury location with a different clinical evolution and prognosis [27, 30, 63, 64, 98, 99, 101–105]. The term myofascial is ambiguous, and other terms such as 'peripheral' [63], 'myoaponeurotic' [106], 'epimysial' [55, 64, 107], or 'distal aponeurosis' have been suggested [90, 108]. The uniform definition and appropriate use of all these terms remain difficult but necessary for effective communication between healthcare providers and researchers [109, 110]. A recent article has suggested a classification for the fascia, defining its terminology, and describing its function and histological features [109]. As a result of this complexity, this classification describes the anatomical location of the injury and its relationship with the MTJ so that the term fascia is no longer needed, thereby avoiding terminological confusion.

One of the concepts that we analyzed and discussed in the present consensus was the definition of functional or non-structural disorders that was suggested in another classification system [31]. We believe non-structural or

Table 1 Summary of the muscle classification system

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 re-injury 2: 2nd re-injury …
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 re-injury 2: 2nd re-injury …
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 re-injury 2: 2nd re-injury …
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		

CSA cross-sectional area, *FSE* fast spin echo, *FSPD* fat saturated proton density, *MRI* magnetic resonance imaging, *MTJ* myotendinous junction, *STIR* short tau inversion recovery

functional disorders should not be incorporated into our new muscle injury classification system at this moment. As other authors have pointed out, functional disorders related to muscle injuries require further investigation to be better understood [31, 42, 111]. The diagnosis of muscle distortion is not yet well understood and remains subjective, which makes the acquisition of solid epidemiological data difficult. The time loss related to functional disorders reported in some series is high [13, 40], but the influence of several external factors on this time loss cannot be discarded. Interestingly, Malliaropoulos et al. have reported a functional classification for posterior thigh muscles [37], including information on the ECM damage [73]. Unfortunately, this functional grading system has not been extensively used nor has it been explored for other muscle groups. Furthermore, delayed-onset muscular soreness should not be incorporated as a muscle injury because delayed-onset muscular soreness may be more of an adaptive process than an injury per se [112–117]. While histological disturbances might be present, their origin appears related to intense activity for which the muscle is unprepared [116, 118].

The present classification does not include terms such as 'strain' or 'tear' to avoid misunderstanding. We believe the

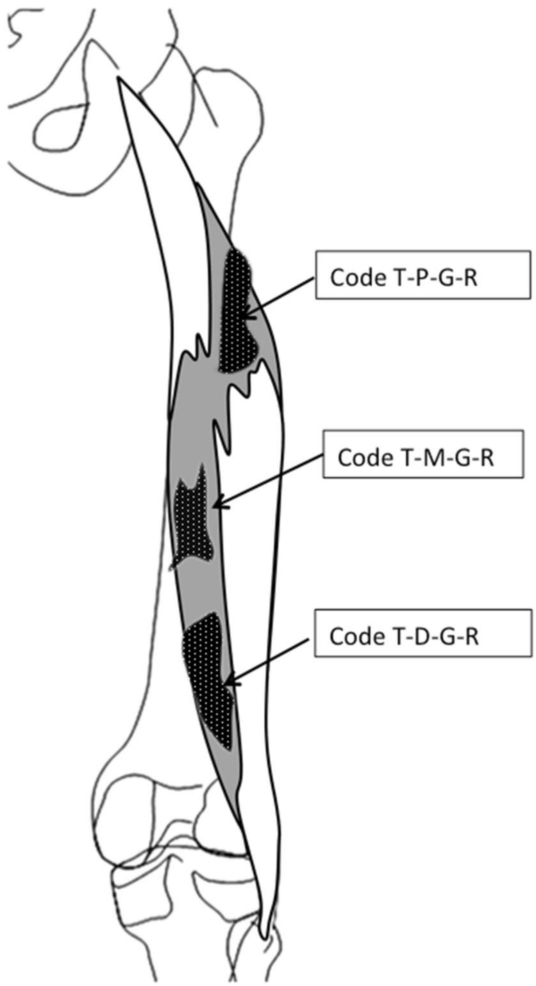

Fig. 1 Examples of codifications for biceps femoris long head (BFlh) direct injuries. *T-P-G-R* a BFlh direct injury located at the proximal third of the muscle belly, plus the corresponding grade and number of re-injuries. *T-M-G-R* a BFlh direct injury located at the middle third of the muscle belly, plus the corresponding grade and number of re-injuries. *T-D-G-R* a BFlh direct injury located at the distal third of the muscle belly, plus the corresponding grade and number of re-injuries

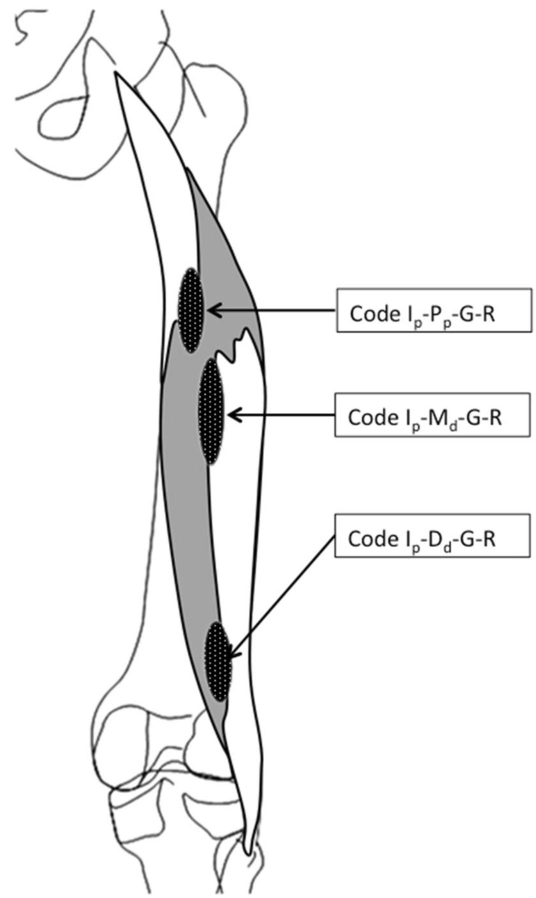

Fig. 2 Examples of codifications for biceps femoris long head (BFlh) indirect injuries, sprinting type. I_p-P_p-*G-R* a BFlh indirect injury sprinting type located in the proximal third of the muscle belly and related to fibers from the proximal myotendinous junction (MTJ), plus the corresponding grade and number of re-injuries. I_P-M_d-*G-R* a BFlh indirect injury sprinting type located in the middle third of the muscle belly and related to fibers from the distal MTJ, plus the corresponding grade and number of re-injuries. I_P-D_d-*G-R* a BFlh indirect injury sprinting type located in the distal third of the muscle belly and related to fibers from the distal MTJ, plus the corresponding grade and number of re-injuries

terms direct/indirect can be used to refer to the mechanism of injury. The location of the injury has been considered an important factor for the present classification. As a consequence, a thorough knowledge of the muscle's anatomy and especially their MTJ and intramuscular tendons is needed to correctly use the present muscle injury classification. Fiber disruption at the MTJ has proven to be a strong prognostic factor for longer recovery in studies where the RTP decision making was not blinded for the MRI results [63, 98, 99]. Several questions regarding how to deal with intramuscular tendon disruptions in regard to their treatment or rehabilitation programs have been considered by some authors [98]. As previously mentioned, recent studies have concluded that injuries affecting the intramuscular tendon in hamstring and quadriceps are associated with a longer time loss and may necessitate modification of the type of treatment used [76].

The present classification has incorporated an MRI-based grading system. The classification has incorporated the % CSA to grade indirect muscle injuries in an attempt to quantify the structural damage in an objective and reliable manner [96]. Given the three-dimensional disposition of the ECM, the important factor is not the length but the percentage of ECM disrupted relative to the total in the transverse plane. While the volume injured would represent the same injury degree, % CSA is believed to be an easier parameter to obtain from the MRI. Injuries are graded as the relationship between the injury's maximal anteroposterior and transverse area in the axial plane, and the muscle's CSA at the same point [17, 62, 64, 79]. This ability to

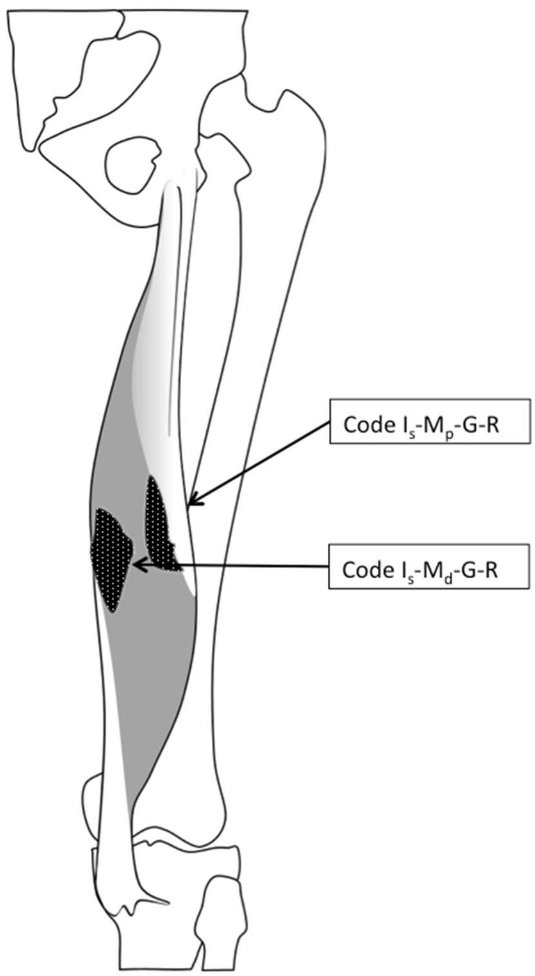

Fig. 3 Examples of codifications for semimembranosus (SM) indirect injuries, stretching type. *I_s-M_p-G-R* a SM indirect injury stretching type located at the middle third of the muscle belly and related to fibers from the proximal myotendinous junction (MTJ), plus the corresponding grade and number of re-injuries. *I_s-M_d-G-R* a SM indirect injury stretching type located at the middle third of the muscle belly and related to fibers from the distal MTJ, plus the corresponding grade and number of re-injuries

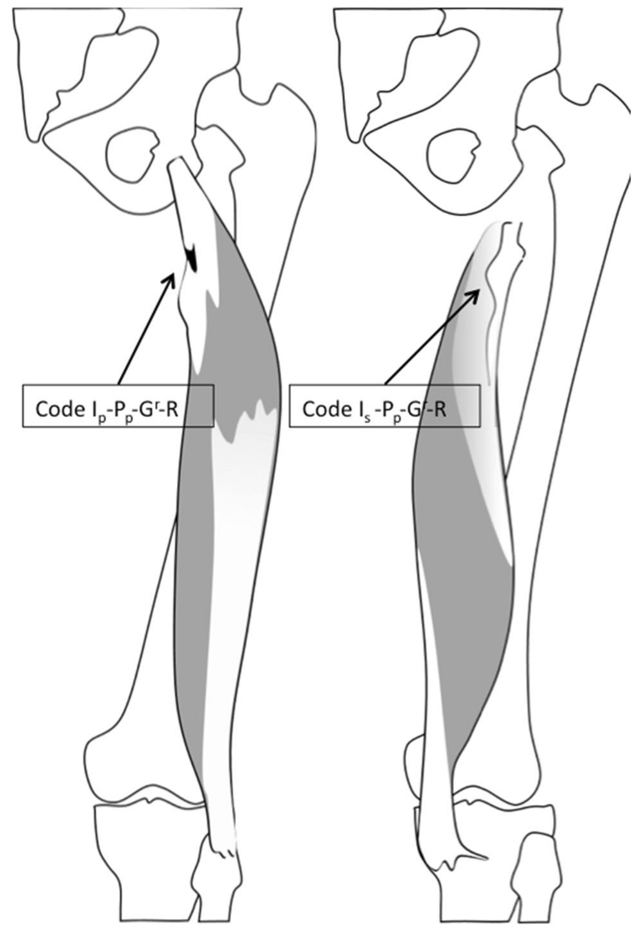

Fig. 4 Examples of codifications for indirect biceps femoris long head (BFlh) and semimembranosus (SM) injuries with tendon gap, retraction, or loss of tension. *I_p-P_p-G^r-R* a BFlh indirect injury sprinting type located at the proximal third of the muscle belly and related to fibers from the proximal myotendinous junction (MTJ), plus the corresponding grade describing the tendon extension and number of re-injuries. *I_s -P_p-G^r-R* a SM indirect injury stretching type located at the proximal third of the muscle belly and related to fibers from the proximal MTJ, plus the corresponding grade describing the tendon extension and number of re-injuries

grade ECM damage needs to be demonstrated in further research. However, the relationship between extension and severity of the injury is not a new idea [98]. Several authors have used the MRI to grade muscle injuries and evaluate injury severity and rehabilitation time in football players, or to create an MRI-based scoring scale predictive of return to sports using the percentage of CSA [13, 38, 40].

One of the pitfalls of any grading system is to avoid subjective information. 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 [75–77]. The ultimate goal of the damage quantification (% CSA) would be to evaluate the injury severity as time loss [13, 43], and as a marker of strength impairment [116]. The use of this objective grading system in a large sample will help better define the grades based on its prognostic value, and whether or not the prognosis can be estimated as a continuous variable, or by use of a cut off point of % CSA. Special mention should be made for grade 0 injuries, which represent clinically evident muscle injuries with negative MRI. This grading category has been adopted because it represents a group of injuries with a better prognosis but which still have unclear and debatable significance [31, 40, 42, 119].

Re-injury was one of the parameters of the present classification system where an easier consensus was reached. Re-injury is an important predictor for a longer recovery period compared with first-time injury

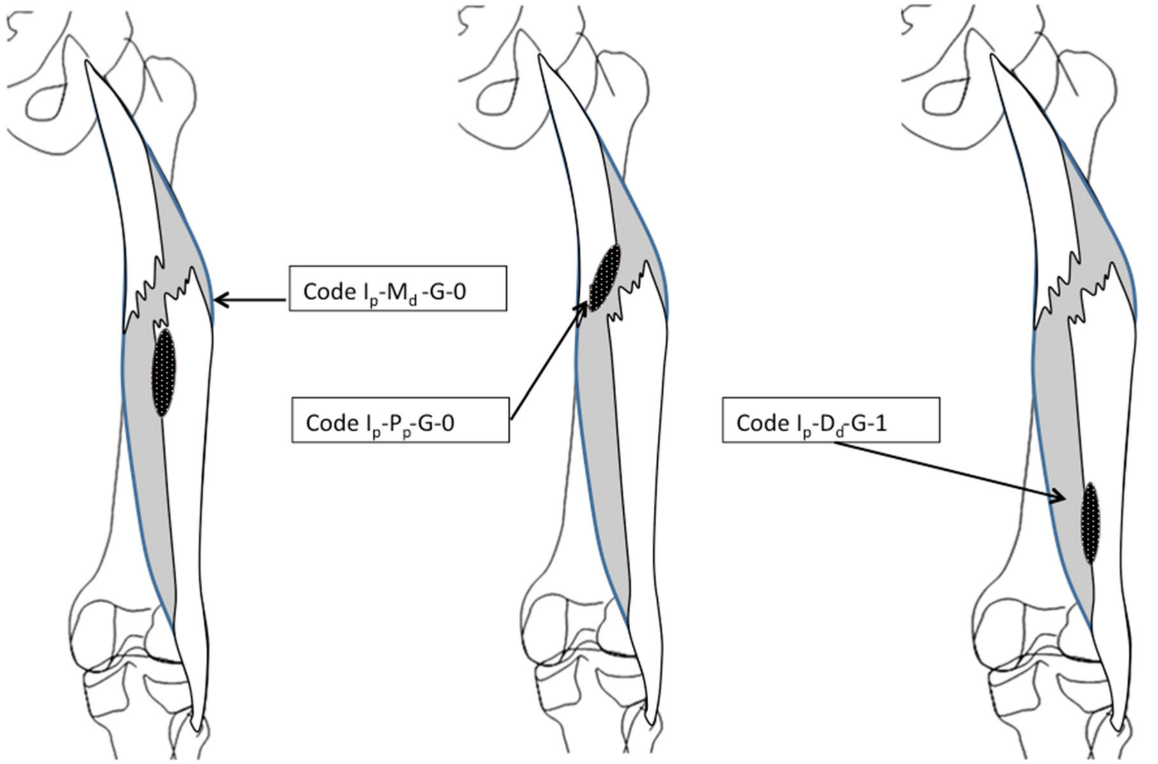

Fig. 5 Example of codification for re-injuries. I_p-M_d-G-0 a first episode biceps femoris long head (BFlh) indirect injury sprinting type located at the middle third of the muscle belly and related to fibers from the distal myotendinous junction (MTJ), plus the corresponding grade and number of re-injuries (0). If a second episode happens in the next 2 months in the same muscle, I_p-P_p-G-0 a BFlh indirect injury sprinting type located at the proximal third of the muscle belly and related to fibers from the proximal MTJ, plus the corresponding grade and number of re-injuries (0). I_p-D_d -G-1 a BFlh indirect injury sprinting type, located at the distal third of the muscle belly and related to fibers from the distal MTJ, plus the corresponding grade and number of re-injuries (1)

[1, 13, 29, 68, 115]. Therefore, this parameter should be included in the classification of muscle injuries.

Areas of further research to improve this classification system would include the clarification of the role of pain location, distance to insertion, or time to walk pain free in muscle injuries. The incorporation of the percentage of strength loss compared with the contralateral muscle or a previous ipsilateral test may also be considered in the future. In addition, the incorporation of the type of muscle involved may be considered given the fact that injuries of muscles with complex intramuscular tendon anatomy can be more challenging [102]. Finally, the present classification needs to be validated, and further prospective studies should help determine its prognostic value [119].

The present classification system has some limitations. First, this is only a theoretical model that still needs to be validated. Second, part of the information contained in the classification originated from the literature search is mostly related to research conducted for hamstring and rectus femoris injuries. Its applicability to other muscle groups needs to be further investigated. Third, the grading category is based on tendon injury, edema presence/absence, and architectural distortion or gap quantification, but not on edema quantification. There are currently no objective data yet to establish a cut-off point for the degree of muscle injury with a good prognostic value. Therefore, all injuries with a measureable gap would be coded as grade 3 and the corresponding % CSA would be added as a sub-index. A future aim would be to objectively establish the degrees of muscle injury with better prognostic value.

However, the present classification also has some strengths. This classification system is based on the currently available research and experience of clinical experts from three institutions with experience in a assessing a high volume of muscle injuries. We believe another strength is the detailed definition of the grading levels and its potential prognostic value and easy clinical application for health-related professionals (i.e., physicians, physiotherapists, and trainers). The classification can help to improve clear communication between healthcare and sports-related professionals and assist them in the decision making regarding rehabilitation protocols and RTP [93, 120–128]. In addition, we believe it is a flexible and open system, allowing future adaptation to incorporate any subsequent knowledge shown to be relevant to prognosis or diagnosis.

5 Conclusions

This evidence-informed and expert consensus-based classification system for muscle injuries is based on an initialism system: MLG-R. It describes the mechanism of injury (M), location of injury (L), grading of severity (G), and number of muscle re-injuries (R). The classification may help to improve communication between healthcare and sports-related professionals and assist in the decision making regarding rehabilitation protocols and RTP. Validation studies are required to establish the veracity and utility of this system by describing its prognostic value.

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Compliance with Ethical Standards

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Conflict of interest Xavier Valle, Eduard Alentorn-Geli, Johannes L. Tol, Bruce Hamilton, William E. Garrett Jr., Ricard Pruna, Lluís Til, Josep Antoni Gutierrez, Xavier Alomar, Ramón Balius, Nikos Malliaropoulos, Joan Carles Monllau, Rodney Whiteley, Erik Witvrouw, Kristian Samuelsson, and Gil Rodas declare that they have no conflicts of interest directly related to the content of this article.

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