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► To cite this version:

Vincent Fontanier, Arnaud Bruchard, Mathieu Tremblay, Riaz Mohammed, Sophia da Silva-Oolup, et al.. Classification of myo-connective tissue injuries for severity grading and return to play prediction: A scoping review. *Journal of Science and Medicine in Sport*, 2025, 28 (1), pp.46-55. 10.1016/j.jsams.2024.07.016 . hal-04948738

HAL Id: hal-04948738

<https://hal.science/hal-04948738v1>

Submitted on 14 Feb 2025

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Review

Classification of myo-connective tissue injuries for severity grading and return to play prediction: A scoping review



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ARTICLE INFO

Article history:

Received 5 December 2023

Received in revised form 28 June 2024

Accepted 25 July 2024

Available online 8 August 2024

Keywords:

Classification

Grading

Return to sport, muscle injury, soft tissue injuries

ABSTRACT

Objectives: To conduct a systematic literature search to identify currently used classifications of acute non-contact muscle injuries in sporting adults.

Designs: Scoping review.

Methods: A systematic literature search from January 1, 2010 to April 19, 2022 of Medline and SPORTDiscus yielded 13,426 articles that were screened for eligibility. Findings from included studies were qualitatively synthesized. Classifications and their grading, as well as outcomes and definitions were extracted.

Results: Twenty-four classifications were identified from the 37 included studies, most of which had low evidence study designs. Majority (57 %) of classifications were published after 2009 and were mostly developed for hamstring or other lower limb injuries. The six most cited classifications accounted for 70 % of the reports (BAMIC, modified Peetrans, Munich, Cohen, Chan and MLG-R). Outcome reporting was sparse, making it difficult to draw conclusions. Still, significant relationships between grading and time to return to play were reported for the BAMIC, modified Peetrans, Munich and Cohen classifications. Other classifications either had a very low number of reported associations, reported no associations, reported inconclusive associations, or did not report an assessment of the association. Other outcomes were poorly investigated.

Conclusions: There is no agreed-upon use of muscle classification, and no consensus on definitions and terminology. As a result, reported outcomes and their relationship to severity grading are inconsistent across studies. There is a need to improve the generalizability and applicability of existing classifications and to refine their prognostic value. High-level evidence studies are needed to resolve these inconsistencies.

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Practical implications

- 1) There is no agreed-upon use of muscle injury classification, and no consensus on definitions and terminology.
- 2) One of the major pitfalls of existing classifications is their lack of generalizability and applicability, as they were mostly developed for

lower extremity injuries and used imaging modalities as their standard objective criterion.

- 3) Classifications may be helpful in decision making but are not accurate enough to predict time to return to play.

1. Introduction

Muscle injuries encompass a wide range of conditions that share a common feature of lesions to functional elements of the muscle tissue.^{1,2} These injuries are remarkably prevalent in professional football, accounting

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for 63.1% of all injuries, with an incidence rate of 4.6 injuries per 1000 h of exposure, as reported by a recent epidemiological meta-analysis.³ Despite not being the most severe injuries in terms of time to return to play (TTRTP), their frequency makes them a significant burden in professional sports. Their cumulative economical cost and TTRTP are comparable to that of ligament-joint injuries.⁴ Part of this burden can be attributed to the difficulty in the evaluation and management of these injuries.⁵ While a suspected injury can be easily diagnosed through a combined use of the medical history, physical examination, and imaging, establishing a prognosis for follow-up, rehabilitation and return to play (RTP) remains challenging.⁵ The primary reason for this challenge is a lack of a universally accepted comprehensive and evidence-based framework for prognosis.⁶

Since the latter half of the 20th century, numerous attempts have been made to classify muscular injuries.⁷ Classifications allow injuries to be categorized, overcoming their multifactorial aspects and determinants, and providing a gradation which is informative regarding the severity of the injury. The first classifications were developed to provide a practical way to grade injuries based on functional and clinical testing. They assumed that the degree of functional loss correlated with the extent of the injury and ultimately with the severity of the injury, but this had never been thoroughly tested.⁷

At the end of the 20th century and with the advent of imaging techniques, attempts were made to refine the existing classifications in order to incorporate an imaging-based assessment of the architectural disruption caused by the injury.^{8,9} While this novelty offered the promise of a more tangible assessment of severity that should be correlated to prognosis. However, the associations between magnetic resonance imaging (MRI) findings and TTRTP remained inconclusive.¹⁰ In addition, the seemingly negligible added value for prognosis, imaging modalities, with their controversial terminology and evaluation, introduced further complexity to the description and evaluation of muscle injuries.^{6,11,12}

In the last decade, there has been growing recognition of the discrepancies in the definition, terminology, assessment, classification, and management of muscle injuries.⁶ As a result, several expert consensus have attempted to overcome these heterogeneities.^{12–18} Numerous modern classifications have emerged from these suggestions (e.g. 17–19). These were based on earlier classifications and proposed a more detailed description of the injury. The variables incorporated into these grading systems encompass the extent, exact location, tissue type involved and the etiology of the injury.

Several limitations of these modern classifications have been pointed out.¹² Most importantly, how grading corresponds with prognosis is still unclear. Furthermore, there are concerns about reliability, validity, agreement and generalizability of these classifications.²⁰

While various groups have identified these limitations,^{6,12,17,18} a systematic literature search to clearly identify knowledge gaps, discrepancies, and the prognostic value of classifications has never been carried out.

Despite the existence of extensive narrative reviews (e.g. 6,7,12), no exhaustive list of available classifications for grading muscular injuries has ever been reported. More importantly, there is no information on the popularity of grading systems, nor a description of their similarities, differences, applicability, or link to prognosis. Such knowledge would facilitate a more comprehensive understanding of the classifications currently in use and could serve to identify limitations and flaws, which could serve as a foundation for further research.

In this context, we conducted a scoping review of the recent literature to identify classifications currently used for acute non-contact muscle injuries in sporting adults, with a focus on how these injuries were categorized and how their severity grading related to prognosis, particularly in terms of TTRTP.

2. Method

Our scoping review complies with the Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) statement.²¹

2.1. Search strategy

A search strategy was collaboratively developed by the authors and underwent review by a librarian using the Peer Review of Electronic Search Strategies (PRESS) Checklist.^{22,23} Modern classifications and consensus have been published in the last decade. As these were all based on previously published work on the topic, we assumed that a systematic literature search starting in 2010 would be able to capture all relevant classifications, whether they had been developed after or before 2010. As a result, Medline and SPORTDiscus electronic databases were systematically searched from 2010, January 1st to 2022, April 19th through the platforms Pubmed and EBSCOhost respectively.

Search terms consisted of subject headings specific to each database (e.g. MeSH in Medline) and free text words relevant to striated muscle or fascia; injuries; and classifications (Appendix A).

2.2. Studies selection

To be included in the scoping review, studies had to fulfill the following inclusion criteria:

- 1) English language
- 2) published in a peer-reviewed journal
- 3) study population including sporting adults (18 years of age or older) with acute muscular or tendon injury (non-contact pathology)
- 4) include a classification of severity (grading) applicable to prognosis (timeline, return to play, re-injury, muscle physiology and healing)
- 5) if studies included a mixed population with individuals < 18 years of age, results must be stratified for adults 18 years of age and older

Studies fulfilling any of the following criteria were excluded: 1) publication types including: letters, editorials, commentaries, unpublished manuscripts, dissertations, government reports, books and book chapters, conference proceedings, meeting abstracts, lectures and addresses; 2) study designs including: case studies; 3) cadaveric or animal studies; 4) non-sporting adults; and 5) contact injuries with extrinsic mechanism such as contusions, laceration, subacute or chronic tendinopathy.

2.3. Definition of muscle injury

Muscle injury is defined as a loss of function caused by a damage of the anatomical structure that generates (muscle) and transmits (tendon) force.¹⁵ This review focused on non-contact myo-connective injuries (which are myo-aponeurotic or myo-conjunctive injuries, cf. Appendix A for all synonyms) directly related to the intrinsic mechanism of muscle contraction.^{12–14,16–18} A non-contact myo-connective injury is defined as a macroscopic junctional tear, occurring during an indirect mechanism, which can gradually and functionally degrade the myo-connective structures within the central and peripheral area. Conversely, a direct injury is defined as a direct muscular trauma caused by a blunt external force that results in damage at the point of contact.^{17,18}

2.4. Screening of titles and abstracts

All citations identified by the search strategy were exported into EndNote for reference management and tracking of the screening process. Random pairs of independent reviewers (RM, SdSO, MSC, MT, MP, SH, AM, MH, GV, VF, NL) screened articles in two phases. The first phase involved screening of titles and abstracts for relevant and possibly relevant citations based on the outlined inclusion and exclusion criteria. Possibly relevant citations from the first phase were reviewed in the second phase using the full text article. Any disagreement between reviewers was resolved by discussion between the paired reviewers to reach consensus. If a consensus could not be reached, a third reviewer (NL, VF or AB) independently screened the citation and discussed with the other two reviewers to reach a consensus.

2.5. Charting data and synthesis

One reviewer (VF) extracted data from selected studies to build evidence tables. Data extraction was verified by a second reviewer (NL). A qualitative synthesis of findings from the studies was performed to develop evidence statements according to principles of best evidence synthesis.²⁴ Specifically, the authors used evidence tables to outline the best evidence on each topic, identify consistencies and inconsistencies in this evidence and formulated summary statements to describe the body of evidence.

Extracted data included: 1) first author, year and country; 2) study design; 3) objective(s) of the study; 4) inclusion and exclusion criteria for reviews or study sample as well as sample sizes for original articles; 5) muscle of interest; 6) definition of the muscle injury reported; 7) name of the classification; 8) anatomical criteria and grade definition of the classification; 9) anatomical measurements (time of the assessment relative to the injury, if reported); 10) clinical examination criteria (time of the assessment relative to the injury, if reported); and 11) outcomes and/or link with RTP.

The full extraction table is available from the contact author upon reasonable request.

2.6. Overlap between included studies

Overlap of included secondary studies was assessed using the corrected covered area (CCA) index.²⁵ A citation matrix was constructed with each row representing an original study and each column representing a secondary study. If an original study was included in a secondary study, it was marked in the corresponding cell as “1” (i.e. included),

otherwise as “0” (i.e. not included). The citation matrix allowed to examine and describe overlaps in the inclusion of original and secondary studies and to calculate the CCA for secondary studies.

The CCA was also used to categorize the overlap between secondary studies into non-overlapping and overlapping studies. This categorization was made to override the effect of overlap on specific outcomes. CCA was calculated between each pair of secondary studies to identify pairs with high overlap (CCA > 15 %). In the case of high overlap, only the most recent study was considered non-overlapping. Therefore, non-overlapping secondary studies with low overlap or the most recent overlapping secondary studies were considered non-overlapping.

2.7. Statistical analyses

Statistical analyses were conducted on the R platform.²⁶ Inclusion ratings of the pairs of reviewers were combined for the first (titles and abstracts) and second (full-text articles) stages of screening. Ratings were considered as an ordinal variable (irrelevant, possibly relevant, relevant). For each phase, inter-rater agreement was evaluated by building a confusion matrix, an agreement plot and calculating Cohen's kappa statistic (κ). Unweighted and weighted (linear) κ and their approximate 95 % confidence intervals (CI) were computed using the *vcd* package.²⁷

3. Results

3.1. Studies selection

PRISMA-ScR flowchart of the literature through the assessment process is shown in Fig. 1. The literature search yielded 13,426 unique

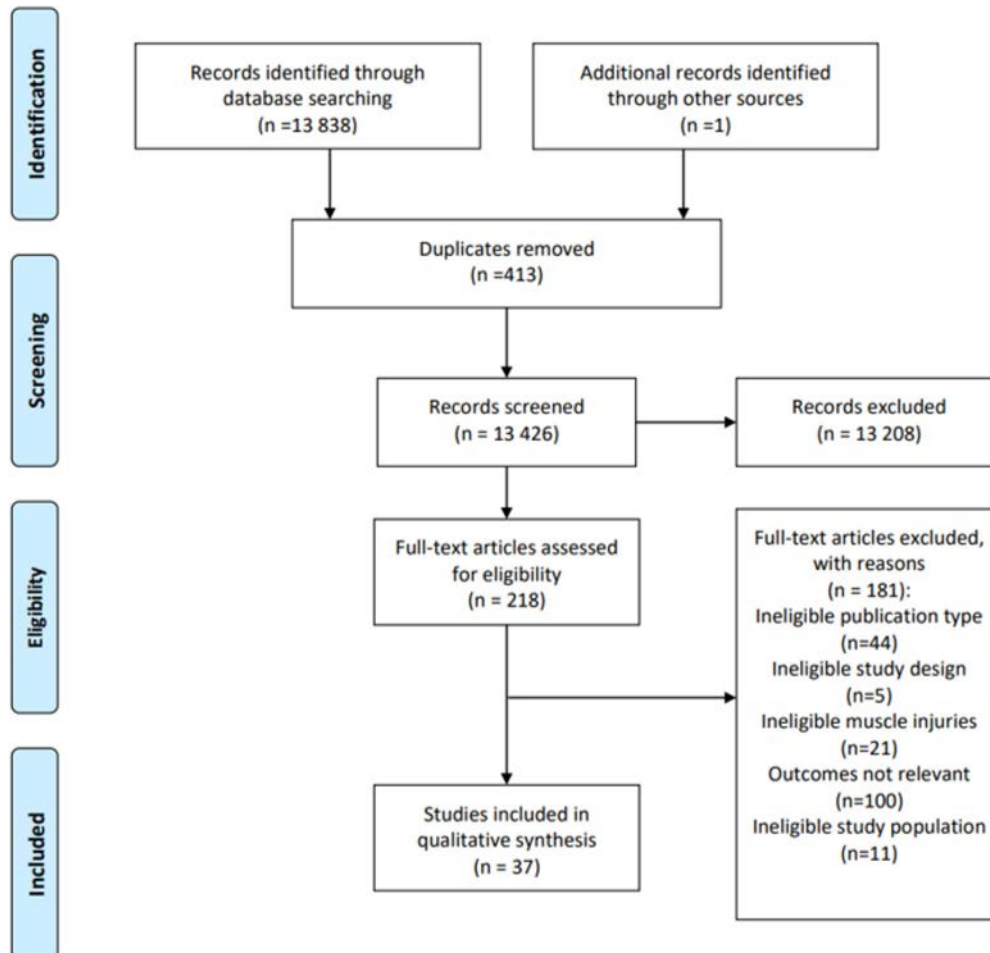


Fig. 1. Flowchart of the included studies in qualitative synthesis.

articles that were first screened with their titles and abstracts. After this, full-text articles from 218 studies were screened for further assessment. One hundred and eighty-one full-text articles were excluded for the following reasons: 1) reported/stated outcomes not relevant to prognosis (timeline, return to play, re-injury, muscle physiology and healing, $n = 100$); 2) ineligible publication type ($n = 44$); 3) ineligible muscle injury ($n = 21$); 4) ineligible study population ($n = 11$); 5) ineligible study design ($n = 5$). Finally, 37 studies were included in the qualitative synthesis.^{5–7,11,12,17–20,28–55} Initial inter-rater agreements for titles and abstracts, and full-text articles screening phases were weak ($K_{\text{weighted}} = 0.22$ [0.18–0.26] and $K_{\text{weighted}} = 0.39$ [0.27–0.51] for the two phases, respectively). All disagreements were resolved during intra-rater discussions for both phases ($K_{\text{weighted}} = 1.00$).

3.2. Included studies characteristics

Fifty-four percent ($n = 20$) of the included studies were original studies,^{20,29,32,33,35,36,38,41–50,52,54,55} while the remainder were reviews (46 %, $n = 17$ ^{5–7,11,12,17–19,28,30,31,34,37,39,40,51,53}). The vast majority of original studies were cohort studies (85 %, $n = 17$ ^{20,32,33,35,36,38,41,44–50,52,54,55}), with the remainder being observational studies ($n = 2$ ^{29,42}) and case-control studies ($n = 1$ ⁴³). Secondary studies were all narrative reviews (88 %, $n = 15$ ^{5–7,11,12,17–19,28,30,31,34,39,40,53}), with the exception of one scoping³⁷ and one systematic review.⁵¹ The overall median year of publication was 2017, with the first and third quartiles (q_n) being 2014 and 2019, respectively. Median publication year of original and secondary studies were respectively 2017 ($q_1 = 2015$, $q_3 = 2019$) and 2015 ($q_1 = 2013$, $q_3 = 2018.25$).

Articles were published by 29 different research groups from Europe ($n = 24$ articles), North America ($n = 5$), Oceania ($n = 4$), Qatar ($n = 3$) and Brazil ($n = 1$). Hamstrings were the most common muscle of interest (51 %, $n = 19$). All but 3 articles^{30,37,41} (8 %) were interested in lower limb muscle injuries. The most commonly reported outcome was TTRTP (86 %, $n = 32$ ^{5–7,11,12,17,20,28,29,31–36,38–42,44–55}). The remaining reported prognosis outcomes were risk of reinjury ($n = 7$ ^{6,12,34,36,40,42,48}), muscle physiology ($n = 6$ ^{6,29,43–45,53}), surgical recommendations ($n = 3$ ^{30,31,37}), tissue healing consequences ($n = 3$ ^{29,45,53}), and, other outcomes including unconvincing prognosis or unsupported claims ($n = 11$ ^{6,12,18–20,30,31,34,46,53,55}). The definition of the injuries but also of the reported outcomes, particularly TTRTP, varied among the included studies. Definitions of injury- and outcome-related terms reported in the included studies (if any) are shown in Supplementary Table 1. Characteristics of the included studies are detailed in Table 1.

3.3. Overlap between included studies

Forty-three percent of the original studies were not included in any secondary studies. Ekstrand et al.³⁶ and Cohen et al.³² were the original studies most often included in secondary studies, being included in 63 % and 44 % of secondary studies, respectively.

On average, secondary studies included 13 % of the original studies (min: 0 %, max: 43 %). The average overlap between secondary studies as measured by the CCA was 14 % (min: 0 %, max: 25 %).

Eleven secondary studies^{5–7,18,19,28,31,34,39,53} (68.8 %) were in pairs with > 15 % CCA, reflecting high overlap. Keeping studies with < 15 % CCA or the most recent one in case of overlap resulted in 6 (37.5 %) secondary studies^{11,12,30,37,40,51} being considered with low overlap.

3.4. Muscular injury classifications

Twenty-four classifications^{9–11,17–19,32,35,37,41,45,49,50,56–65} with reported outcomes were extracted from the 37 included studies (Table 2). Eight additional classifications^{66–73} were described but not associated with a prognosis outcome. Six classifications were identified from both original and secondary studies, 7 only from original studies

Table 1
Characteristics of the included studies.

	Original studies (n = 20; 54 %)	Secondary studies (n = 17; 46 %)	All studies (n = 37)
	n (%)	n (%)	n (%)
Study design			
Cohort study	17 (85 %)		17 (46 %)
Narrative review		15 (88 %)	15 (41 %)
Observational study	2 (10 %)		2 (5 %)
Case-control study	1 (5 %)		1 (3 %)
Scoping review		1 (6 %)	1 (3 %)
Systematic review		1 (6 %)	1 (3 %)
Publication date			
2022		1 (6 %)	1 (3 %)
2021	2 (10 %)	1 (6 %)	3 (8 %)
2020	3 (15 %)	1 (6 %)	4 (11 %)
2019	1 (5 %)	1 (6 %)	2 (5 %)
2018	4 (20 %)	2 (12 %)	6 (16 %)
2017	4 (20 %)	2 (12 %)	6 (16 %)
2016			
2015	3 (15 %)	2 (12 %)	5 (14 %)
2014	0 (0 %)	2 (12 %)	2 (5 %)
2013	2 (10 %)	3 (18 %)	5 (14 %)
2012	0 (0 %)	2 (12 %)	2 (5 %)
2011	1 (5 %)		1 (3 %)
Country of principal affiliation			
United Kingdom	4 (20 %)	4 (24 %)	8 (22 %)
Spain	3 (15 %)	1 (6 %)	4 (11 %)
United States of America	1 (5 %)	3 (18 %)	4 (11 %)
Qatar	3 (15 %)		3 (8 %)
The Netherlands	1 (5 %)	2 (12 %)	3 (8 %)
Australia	2 (10 %)		2 (5 %)
Germany	1 (5 %)	1 (6 %)	2 (5 %)
Italy	2 (10 %)		2 (5 %)
New Zealand		2 (12 %)	2 (5 %)
Brazil	1 (5 %)		1 (3 %)
Canada		1 (6 %)	1 (3 %)
Finland		1 (6 %)	1 (3 %)
France	1 (5 %)		1 (3 %)
Portugal		1 (6 %)	1 (3 %)
Sweden	1 (5 %)		1 (3 %)
Switzerland		1 (6 %)	1 (3 %)
Muscle of interest			
Hamstrings	11 (55 %)	8 (47 %)	19 (51 %)
General	2 (10 %)	5 (29 %)	7 (19 %)
Thigh	2 (10 %)	1 (6 %)	3 (8 %)
Adductor longus	2 (10 %)		2 (5 %)
Calf	2 (10 %)		2 (5 %)
Gastrocnemius	2 (10 %)		2 (5 %)
Pectoralis major		2 (12 %)	2 (5 %)
Lumbrical muscles	1 (5 %)		1 (3 %)
Rectus femoris	1 (5 %)		1 (3 %)
Soleus	1 (5 %)		1 (3 %)
Not specified		1 (6 %)	1 (3 %)
Outcome reported			
TTRTP ^a	19 (95 %)	13 (76 %)	32 (86 %)
Other	3 (15 %)	8 (47 %)	11 (30 %)
Reinjury	3 (15 %)	4 (24 %)	7 (19 %)
Muscle physiology	4 (20 %)	2 (12 %)	6 (16 %)
Healing consequences	2 (10 %)	1 (6 %)	3 (8 %)
Surgical recommendations		3 (18 %)	3 (8 %)

^a TTRTP, time to return to play.

and 12 only from secondary studies. The median number of reported classifications in included studies was 1 ($q_1 = 1$, $q_3 = 3$), with original and secondary studies respectively reporting a median of 1 ($q_1 = 1$, $q_3 = 2$) and 2.5 ($q_1 = 1$, $q_3 = 3$) classifications.

The 6 most cited classifications accounted for 70 % of the reports (BAMIC,¹⁹ modified Peetrans,¹⁰ Munich,¹⁸ Cohen,³² Chan,¹¹ and MLG-R¹⁷), with BAMIC (22 %, $n = 15$) and modified Peetrans (16 %, $n = 11$) being the most popular, especially when considering original studies only. Classifications were mostly developed after 2012 (MD = 2012), with half of them developed between 2009 and 2017 ($q_1 = 2009$, $q_3 = 2017$). The most reported classification in the early 2010s was the historical 3-grade and Cohen classifications, the modified

Table 2
Number of citations of identified classifications.

Classification	Original ^{17,20,29,32,33,35,36,38,41–50,52,54}	Low-overlap secondary studies ^{11,12,30,37,40,51}	All studies
BAMIC ¹⁹	8 (29 %)	1 (10 %)	15 (22 %)
Modified Peetrans ¹⁰	7 (25 %)	1 (10 %)	11 (16 %)
Munich ¹⁸	3 (11 %)	0 (0 %)	8 (12 %)
Cohen ³²	2 (7 %)	1 (10 %)	6 (9 %)
Chan ¹¹	1 (4 %)	1 (10 %)	4 (6 %)
MLG-R ¹⁷	0 (0 %)	0 (0 %)	4 (6 %)
3 grades (misc)	0 (0 %)	2 (20 %)	2 (3 %)
Shelly ⁶³	1 (4 %)	0 (0 %)	2 (3 %)
Tietjen ⁵⁷	0 (0 %)	2 (20 %)	2 (3 %)
American Medical Association ⁵⁶	0 (0 %)	0 (0 %)	1 (1 %)
Classification from Zarins and Ciullo 1983 ⁵⁸ and Clanton and Coupe 1998 ⁵⁹	0 (0 %)	0 (0 %)	1 (1 %)
Eggleston ³⁵	1 (4 %)	0 (0 %)	1 (1 %)
ElMaraghy and Devereaux ³⁷	0 (0 %)	1 (10 %)	1 (1 %)
INSEP ⁵⁰	1 (4 %)	0 (0 %)	1 (1 %)
ISMuLT ⁶⁰	0 (0 %)	0 (0 %)	1 (1 %)
Lutter ⁴¹	1 (4 %)	0 (0 %)	1 (1 %)
Modified Peetrans from Crema ^{10,61}	0 (0 %)	0 (0 %)	1 (1 %)
Unnamed classification reported in Nescolarde et al. ⁴⁴	1 (4 %)	0 (0 %)	1 (1 %)
Pedret ⁴⁵	1 (4 %)	0 (0 %)	1 (1 %)
Peetrans ⁹	0 (0 %)	0 (0 %)	1 (1 %)
Modified Peetrans for MRI from Davis 2008 ^{9,62}	0 (0 %)	1 (10 %)	1 (1 %)
Prakash ⁴⁹	1 (4 %)	0 (0 %)	1 (1 %)
Thigh muscle injury classification ⁶⁴	0 (0 %)	0 (0 %)	1 (1 %)
Wood ⁶⁵	0 (0 %)	0 (0 %)	1 (1 %)

Peetrans became the most reported between 2015 and 2018, finally the BAMIC became the most reported from 2018 until the end of our study period.

3.5. Characteristics of identified classifications

Detailed characteristics of the most frequently reported classifications are described in Table 3. Identified classifications were almost exclusively developed for or derived from hamstring injuries.

Extent of injury was a grading criterion in each classification. Extent was defined as the amount of fiber disruption and could be determined as a percentage of the damaged area (most commonly the cross-sectional area, CSA^{10,17,19,32,35}) and/or as a length.^{11,18,37,45,50,56} Extent was most commonly identified as an ordinal numerical value ranging from less severe to most severe injury, typically from 1 to 3. Such grading was first proposed in the 3-grade classification.⁵⁶ The grading of more recent classifications has been largely derived and adapted from the 3-grade classification in order to integrate imaging modalities^{9–11,17–19,32,35,37,41,45,50,60,62} (ultrasonography, US or magnetic resonance imaging, MRI). These classifications added a grade 0 for negative imaging findings and defined such injuries as functional injuries.^{9–11,17–19,35,44,49,50,61–63}

Among the most commonly reported classifications,^{11,17,19,32} all but the modified Peetrans¹⁰ and the Munich¹⁸ classifications defined topographic criteria. These criteria combined the description of the location and/or type of injured tissue. It was typically reported as a letter used in combination with the numerical grading of the extent of injury.

Other criteria with less influence on the grading were reported. They were more variables between identified classifications and included pain, range of motion, palpation test, etiology, neuromuscular involvement, functional tests, age of the patient, number of muscles involved and history of injury.^{17,18,32,64}

3.6. Prognostic outcomes and link with TTRTP reported for identified classifications

The reported outcomes for each classification were mostly TTRTP, with the exception of ElMaraghy³⁷ and Wood⁶⁵ classifications, for which surgical recommendations were most often reported.

The predictive value for TTRTP was reported for 11 classifications. No information on TTRTP was reported for 13 classifications.^{9,10,17,37,44,56–62,64,65}

TTRTP was reported in two or more original studies for four classifications (BAMIC,¹⁹ modified Peetrans,¹⁰ Munich,¹⁸ and Cohen³²). Reports from original studies indicated that higher grades were associated with longer TTRTP for most classifications, whereas differences between grades were unclear. Table 4 provides a comprehensive summary of the prognostic value of identified classification for TTRTP extracted from original studies.

4. Discussion

Our systematic literature search identified 24 classifications from the 37 included studies. Included studies had low-evidence study designs. There was inconsistency not only in the definition of muscle injuries but also in the reported outcomes, particularly in relation to RTP and TTRTP. The six most cited classifications accounted for 70 % of the reports (BAMIC, modified Peetrans, Munich, Cohen, Chan and MLG-R). The majority (57 %) of the classifications were published after 2009 and were largely developed for hamstring or other lower limb injuries. The extent of the injury was a grading criterion in each classification. Gradings were largely derived from the historical 3-grade classification from the 1960s and adapted to integrate imaging modalities. TTRTP was the most reported outcome (86 % of studies) and was reported at least once for most classifications (79 % of classifications). However, reporting was sparse, making it difficult to draw conclusions, as only 4 classifications had TTRTP reported in at least 2 original studies. Yet, significant relationships between grading and TTRTP (higher grade, longer TTRTP) were reported for the BAMIC (n = 12), modified Peetrans (n = 6), Munich (n = 6) and Cohen (n = 5) classifications. Reports for other classifications or other outcomes were inconclusive.

Generalizability, applicability, and prognostic value of classifications, including modern classifications, remained a concern. Inconsistencies in definitions and terminology as well as the overall low evidence study designs, contributed to these discrepancies.

4.1. A growing body of work, but still lacking high-level evidence studies as well as inconsistencies in terminology and definitions

Our systematic literature search confirmed the increasing number of publications on muscle injury classification during the last decade. This era and the underlying classifications were considered “modern” because they added imaging modalities to existing classifications from

Table 3
Detailed characteristics of the most frequently reported classifications.

	BAMIC ¹⁹	Modified Peetrons ¹⁰	Munich ¹⁸	Cohen ³²	Chan ¹¹	MLG-R ¹⁷
Year	2014	2012	2013	2011	2012	2017
Muscle	Hamstrings	Hamstrings	General	Hamstrings	General (derived from hamstrings)	Hamstrings
Imaging	MRI ^a ideally within 24–48 h	MRI ideally within 24–48 h	US ^b or MRI	MRI within 3 days	US or MRI	MRI ideally within 24–48 h
Extend	Digit	Digit	Only for indirect structural muscle injuries (types 3 and 4)	Up to 8 points from a composite score (maximum = 19 points) allocated to items describing the extent of the lesion.	Roman numeral	Digit (grading)
	<ul style="list-style-type: none"> 0: negative MRI 1: <10%CSA^c/5 cm CC^d length 2: 10 % < CSA < 50 %/5 < length < 15 cm 3: >50%CSA/15 cm CC length 4: complete 	<ul style="list-style-type: none"> 0: negative MRI 1: edema but no architectural distortion 2: architectural disruption indicating partial tear 3: total muscle or tendon rupture 	<ul style="list-style-type: none"> 3A: diameter < muscle fascicle/bundle 3B: diameter > muscle fascicle/bundle 4: (sub)total muscle fascicle/bundle 	<ul style="list-style-type: none"> Up to 3 points allocated to CSA: 0: CSA < 25 % 1: 25 < CSA < 50 % 2: 50 < CSA < 75 % 3: CSA ≥ 75 % Up to 3 points allocated to the craniocaudal sagittal length of abnormal hyperintense T2 signal (long axis length): 0: 0 cm 1: 1 < length < 5 cm 2: 6 < length < 10 cm 3: length > 10 cm Up to 2 points allocated to the tendon or muscle retraction length: 0: none 1: length < 2 cm 2: length ≥ 2 cm Up to 5 points from a composite score (maximum = 19 points) allocated to items describing the location of the lesion. Up to 3 points allocated to the location of the abnormality: 1: Proximal 2: Middle 3: Distal Up to 2 points allocated to the involvement of the insertion: 0: No 2: Yes 	<ul style="list-style-type: none"> 1: Minor (<5 %) fiber disruption; edema but no architectural distortion 2: Partial (5 % < x < 100 %) fiber disruption. Fibers are discontinuous, disorganized, and thin; edema and hemorrhage. 3: Complete discontinuity of muscle fibers, hematoma and retraction of the muscle ends 	<ul style="list-style-type: none"> 0: negative MRI 1: fiber disruption; edema but no architectural distortion 2: Fiber disruption with minor architectural. No quantifiable gap between fibers. 3: Any quantifiable gap between fibers in craniocaudal or axial planes with partial retraction of muscle fibers.
Location and/or type of injured tissue	Letter: a: myofascial (extending to the periphery); b: within the muscle/MTJ ^e ; c: intratendinous	No	No for indirect structural muscle injuries	Up to 5 points from a composite score (maximum = 19 points) allocated to items describing the location of the lesion.	Digit Location:	Uppercase letter to describe the location relative to the muscle belly:
				<ul style="list-style-type: none"> 1: Proximal involving the MTJ 2: Muscle 3: Distal involving the MTJ 	<ul style="list-style-type: none"> If muscle (2), an uppercase letter describes the location relative to the MTJs: A: Proximal B: Middle C: Distal 	<ul style="list-style-type: none"> P: proximal third M: middle third D: distal third
				<ul style="list-style-type: none"> Up to 2 points allocated to the involvement of the insertion: 0: No 2: Yes 	<ul style="list-style-type: none"> In any cases, a lowercase letter describes the type of tissue involved: a: intramuscular b: myofascial c: myofascial/perifascial d: myotendinous e: combined 	<ul style="list-style-type: none"> Lowercase letter to describe the location relative to the MTJ: p: proximal d: distal Injuries affecting the tendon with disruption/retraction or loss of tension are precise with a superscript (r)
Clinical	Pain, ROM, ^f palpation	No	Pain, ROM, palpation, functional test, hematoma	No	No	Yes
Other	No	No	Etiology, neuromuscular involvement, functional properties	Age, number of muscles involved	No	Yes (history, mechanism)
Reliability	Interrater: kappa = 0.80–1.00 ^{46,55,78,79} Intrarater: kappa = 0.65–0.80 ^{78,79}	Interrater: kappa = 0.95 ⁷⁹ Cronbach's α = 1.0 ⁸⁰ Intrarater: kappa = 0.89 ⁷⁹ Cronbach's α = 0.96 ⁸⁰	Interrater: kappa = 0.82–1.00 ^{46,55}	No	Interrater: kappa = 0.85 ⁷⁹ Intrarater: kappa = 0.85 ⁷⁹	No

^a MRI: magnetic resonance imaging.

^b US: ultrasound.

^c CSA: cross-sectional area.

^d CC: craniocaudal

^e MTJ: myotendinous junction

^f ROM: range of motion.

Table 4

Comprehensive summary of the prognostic value of identified classification for TTRTP extracted from original studies.

Classification	Overall properties	Between grades differences
BAMIC	<ul style="list-style-type: none"> Higher the grade, longer the TTRTP^{29,42,46,48,55} $r = [0.77-0.96]$, $\rho = 0.64$ Change between post-injury and post-RTP BAMIC scores²⁹ ($Z = -2.088$, $p = 0.037$) Grade 3 ($p < 0.001$) and intratendinous (c) site ($p = 0.008$) were associated with an increase in the TTRTP⁴⁸ 	Extend: <ul style="list-style-type: none"> Shorter TTRTP for grade 0 injuries with respect to every other grade^{47,48} Shorter TTRTP for grade 1 vs grade 3^{20,47} Unclear difference between grades 1 and 2: no difference reported in 2 studies^{20,48} difference reported in 1 study⁴⁷ No difference between grades 2 and 3^{20,47} Location and/or tissue type: <ul style="list-style-type: none"> Unclear difference between sites a and b: no difference reported in 3 studies,^{20,47,48} difference reported in 1 study⁴² Unclear difference between sites a and c: no difference reported in 1 study,²⁰ differences reported in 2 studies^{42,47} Difference between sites b and c^{20,47} No differences between injuries with and without tendon involvement (1a & 1b, or 2b & 2c)⁴²
Modified Peetrans	<ul style="list-style-type: none"> Conflicting evidence for an increase of TTRTP with higher grades, relationship in two studies^{20,54} (grade 0 as reference, grade 1 $\beta = 3.6$, grade 2 $\beta = 8.1$); no correlation ($\rho = 0.40$; $p = 0.18$) in one study²⁹ Change between post-injury and post-RTP modified Peetrans scores ($Z = -2.530$, $p = 0.011$)²⁹ 	<ul style="list-style-type: none"> Grade 2 lengthened TTRTP compared to grade 1 ($\beta = -0.215$, $p = 0.026$)²⁹
Munich	<ul style="list-style-type: none"> Higher the grade, longer the TTRTP for the subgroups of structural injuries ($r = [0.97-0.98]$), median TTRTP of 13, 32, and 60 days respectively for minor partial muscle tears, moderate partial muscle tears, and subtotal/complete muscle injury/tendinous avulsion^{36,46,55} No significant association between injury classification and re-injury rate³⁶ 	
Cohen	<ul style="list-style-type: none"> Conflicting evidence for an increase of TTRTP with higher scores, weak correlation ($r = 0.21$) of continuous score. Ranked scores correlated in one study but not in another^{32,38} ($\rho = [0.18-0.58]$) TTRTP in those with a Cohen's score of 10 or more took 9.8 days longer than a score of less than 10³⁸ (effect size: 0.85, $p < 0.01$) 	Extend: <ul style="list-style-type: none"> the number of muscles involved was found to have a significant relationship with TTRTP^{32,38} Conflicting evidence for a relationship between percentage of muscle/tendon involvement, and/or the amount of retraction and TTRTP^{32,38} Location and/or tissue type: <ul style="list-style-type: none"> The location (proximal, mid substance, or distal) did not correlate with TTRTP^{32,38} Other: <ul style="list-style-type: none"> Age did not correlate with TTRTP^{32,38}
Chan Shelly	<ul style="list-style-type: none"> No effect of grading²⁰ (1 vs 2, $p = 0.054$) Higher the grade, longer the TTRTP³² ($\rho = 0.62$) 	<ul style="list-style-type: none"> Difference between grades 1 + 2 and 3³² No difference between grades 1 and 2³²
Eggleston	<ul style="list-style-type: none"> Higher the grade, longer the TTRTP³⁵ (J-statistic = 294.00) 	<ul style="list-style-type: none"> Difference between grades 1 and 2³⁵ Difference between grades 1 and 3³⁵ Difference between grades 2 and 3³⁵
INSEP	<ul style="list-style-type: none"> Higher the grade, longer the TTRTP when considering the overall grades (1–3) or the type of injury independently⁵⁰ 	<ul style="list-style-type: none"> Longer TTRTP for type C injuries in comparison to type M injuries⁵⁰
Lutter	<ul style="list-style-type: none"> Healing period for the Grade III injuries longer than in the two other sub-groups⁴¹ 	
Pedret	<ul style="list-style-type: none"> Higher the grade, longer the TTRTP⁴⁵ 	
Prakash	<ul style="list-style-type: none"> Gradings associated with different TTRTP⁴⁹ 	

^a TTRTP: time to return to play.

the pre-imaging era.^{6,11,12,17,18,20,32,50,60} Secondary studies were more frequent in the early 2010s, while original studies increased in number during the 2010s, slightly outnumbering secondary studies. Original studies were predominately cohort studies (most of them retrospective cohort studies) and secondary studies were almost only narrative reviews. Consequently, the overall quality of evidence in the included articles was notably low.

As secondary studies tended to report more classifications, narrative review reports were particularly prevalent. Conversely, most original studies reported only one classification, making comparisons between classifications impossible. One of the only original studies which reported more than one classification also reported moderate agreement between them.²⁰ In addition to the overall low level of evidence, our search identified inconsistencies in terminology and definitions of injuries and outcomes. In particular, while TTRTP is the most commonly reported outcome, its definition and assessment varied widely from “return to daily activity” to “return to training” to “return to competition”. Inter-rater agreement during screening was initially low for both phases. Disagreements were successfully resolved during

discussion for each pair of raters. Differences in definition and terminology appeared to be the main factor contributing to initial disagreement, as indicated by verbal reports of the discussions. This highlights that even among trained readers, inconsistencies in terminology and definitions can negatively affect comprehension.

Overall, our systematic search identified and confirmed several shortcomings of the currently used classifications, which preclude their consensual use based on their prognostic value.^{6,12,17,18}

4.2. Identification of many classifications that converge on a more precise anatomical description

Our search of the recent literature yielded 37 articles describing 24 classifications and their association with a prognostic outcome. This relative abundance of classifications highlights the lack of a consensus classification.^{6,12,14,18,31,60} It is important to note that our scoping review focused on systematically identifying descriptions of classifications in the recent literature. Consequently, we did not objectively evaluate the degree of similarity between classifications. As a result, some of

the classifications we identified were extensions, modifications, or differently named versions of other identified classifications.

Nevertheless, six classifications (BAMIC,¹⁹ modified Peetrons,¹⁰ Munich,¹⁸ Chan, Cohen,³² and MLG-R¹⁷) were more frequently described. They have all been developed in the last decade and are often referred to as modern classifications. The commonality is that these classifications derived from the American Medical Association 3-grade classification,⁵⁶ in which they have refined anatomic and topographic criteria using imaging modalities. The 3-grade classification was the most popular classification prior to the introduction of imaging criteria. The introduction of Peetrons⁹ classification for ultrasound marked a turning point and was later surpassed by the modified Peetrons¹⁰ which was adapted for MRI. As of recently, BAMIC¹⁹ has become the most popular classification. This timeline reflects the increasing importance of precise topographic descriptions in grading criteria. In addition to the extent of the injury, criteria now include a precise description of the location and the type of tissue involved.

4.3. Limited generalizability of classifications

Lower extremity injuries were the focus of all but three of the retained articles. In fact, the classifications identified were largely developed for or derived from hamstring injuries. This raises the question of generalization to other muscles. While the use of refined anatomical criteria may improve prognostic value, it would likely hinder generalization due to anatomical differences between muscles.⁷⁴

Imaging studies have become the standard objective criterion for grading.^{75–77} However, it requires expensive equipment as well as skilled operators and graders. These prerequisites are even more difficult to attain in a timeframe which the examination must be performed (ideally 48 h). As a result, such grading would only be feasible under special circumstances, such as elite sports, and would not be accessible to the general population.

Although not the primary purpose of our review, we identified reliability reports for four classifications. The BAMIC,^{46,55,78,79} modified Peetrons,^{79,80} and Chan⁷⁹ classifications had good interrater ($\kappa = [0.80–1.00]$) and intrarater ($\kappa = [0.65–0.89]$) reliabilities, whereas only good interrater reliability ($\kappa = [0.82–1.00]$) was reported for the Munich classification.^{46,55} No reliability was reported for the other classifications. Validity was not reported for any of the classifications.

4.4. Equivocal relationships between grading and TTRTP

Despite heterogeneous definitions, TTRTP was by far the most commonly reported outcome reflecting prognostic value. We proposed an inventory of studies that reported an association between grading and TTRTP. This inventory showed that few classifications had multiple reports of an association with TTRTP. The number of reports was closely related to the popularity of the classifications, making it impossible to draw conclusions for less commonly used classifications. Among the most popular classifications, positive relationships between grade and TTRTP (higher grade, longer TTRTP) were frequently reported for the BAMIC, Munich, and Cohen classifications. The inventory revealed less distinct relationships for the modified Peetrons, Chan, and MLG-R classifications.

The relationships described were most often linear correlations between grade and TTRTP. Such correlations appeared to be driven by extreme grades. When finer analysis was performed, limited prognostic value was found for intermediate grades.^{11,19,20,32,36,38,42,47,48,50} Therefore, the management of muscle injuries might be limited by the limited appropriate care for such severity.⁵ This is a major shortcoming of modern grading systems. Since extreme grades are also the grades that are most easily categorized based on clinical examination,^{5,54} the added value of imaging modalities could be questioned.^{6,31,39,54} Experts agreed that imaging was important for classification and less important for diagnosis.¹² In fact, imaging could help in the classification of intermediate grades, which are the most common and have a high variability in

TTRTP.^{12,14,81,82} The relatively poor prognostic value of modern classification for these grades may be explained by the lack of specific imaging guidelines and the difficulty in using them for classification.¹²

4.5. Shall existing classifications be refined or is it (still) time for a paradigm shift?

Perhaps because of their high degree of phylogeny, classifications have converged on a more precise anatomic description based on imaging criteria. The apparent limited prognostic value of the grading derived from these criteria raises the question of their usefulness. Maybe it is time for a paradigm shift, as advocated by Hamilton and colleagues.⁶ More specifically, should the existing anatomical criteria be refined, should the modality of examination be changed, or should other criteria or non-anatomical features be added?

Some of the identified classifications already include other features^{17,18,32,64} (e.g., etiology, pain, functional characteristics, history). However, they have a relatively small influence on grading compared to anatomical criteria. Other features such as muscle bioimpedance⁸³ may be predictive of severity. In contrast to standardized imaging evaluation,⁷⁵ the assessment of these other features has yet to be standardized.

Dedicated studies with low risk of bias are needed to understand the prognostic value of already included and candidate new features. In any case, existing and future classifications should aim for an ideal balance between prognostic performance and applicability.

4.6. Strengths and limitations

To our knowledge, this is the first time that an inventory of existing muscular injury classifications has been made with a systematic search strategy. Our findings gathered knowledge and limitations on this field for new perspectives in research and clinical RTP settings.

Our scoping review has some limitations. As its design indicated, a scoping review does not include critical appraisal of the articles included and designs of included articles are mostly low evidence level. Furthermore, we only focused on classification using TTRTP or prognosis value criteria so our findings cannot be generalized to other type of muscular classifications.

5. Conclusion

There is no agreed use of muscle injury classification and no consensus on definitions and terminology. As a result, reported outcomes and their relationship to severity grading are inconsistent across studies. There is a need to improve the generalizability and applicability of existing classifications and to refine their prognostic value. High-level evidence studies are needed to resolve inconsistencies. Without this, classifications might be helpful in decision making but will not be sufficient in themselves to predict TTRTP. More original studies are needed to investigate the reliability and validity of classifications. A systematic review of evidence-based RTP criteria could help to better understand the prognostic value of classifications and serve as a framework for classification refinement.

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jsams.2024.07.016>.

Funding information

No funding or external financial support was associated with this project.

Confirmation of ethical compliance

All articles included in our review followed ethical guidelines. Because our study is a secondary study, ethical approval was not sought.

However, our study was conducted in accordance with ethical principles for biomedical research involving human subjects.

CRedit authorship contribution statement

Vincent Fontanier: Project administration, Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft, Writing – review & editing, Visualization. **Arnaud Bruchard:** Project administration, Conceptualization, Writing – review & editing, Supervision. **Mathieu Tremblay:** Investigation, Writing – review & editing. **Riaz Mohammed:** Investigation, Writing – review & editing. **Sophia da Silva-Oolup:** Investigation, Writing – review & editing. **Minisha Suri-Chilana:** Investigation, Writing – review & editing. **Mégane Pasquier:** Investigation, Writing – review & editing. **Sarah Hachem:** Investigation, Writing – review & editing. **Anne-Laure Meyer:** Investigation, Writing – review & editing. **Margaux Honoré:** Investigation, Writing – review & editing. **Grégory Vigne:** Investigation, Writing – review & editing. **Stéphane Bermon:** Conceptualization, Methodology. **Kent Murnaghan:** Methodology, Resources. **Nadège Lemeunier:** Project administration, Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing, Visualization, Supervision.

Declaration of interest statement

None declared.

Acknowledgment

None.

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