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Effects of nutrition on exercise induced muscle damage in male and female contact sports: A systematic review

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ABSTRACT

To date, how nutrition ameliorates exercise induced muscle damage (EIMD) has focused chiefly on male, contact sport athletes. The primary aim of this systematic review is to therefore determine the nutritional-related risk factors relating to EIMD in contact sports, with a secondary aim focusing on exploring potential differences by sex. The review was conducted according to the Cochrane handbook and PRISMA principles and is registered with PROSPERO (CRD42022318890). Online database searches were performed (Medline, SportDiscus, Embase, and CINHAL, as well as the search engines Web of Science and PubMed), with peer-reviewed randomised controlled trials (RCTs), longitudinal studies and cross-sectional studies within professional and recreational contact sport athletes aged between 18 and 44 years were included. Quality of evidence was assessed via the Cochrane risk of bias and critical appraisal for RCTs and cross-sectional studies, tools, respectively. Nine studies were eligible for review. Six dietary interventions positively affected EIMD through accelerated recovery with the remaining studies reporting no effect. Only one out of the nine eligible studies focused on female athletes (n = 28). Athletes complying with dietary recommendations for selected nutrients had significantly lower concentrations of creatine kinase pre-match. A range of nutritional interventions (Montecherry Tart Cherry Juice, Chocolate Milk, Raw Milk Honey, Habitual Diet, Multi Ingredient Supplement, Carbohydrate and Protein), were employed to mitigate risk of EIMD with equivocal results. Future research is recommended into how nutritional intake may affect EIMD in contact sports athletes, along with any differences by sex.

1. Introduction

Contact sports involve frequent bouts of high-intensity or maximal activity separated by periods of low-intensity work.[1] Contact sports often involve frequent bouts of eccentric exercise where the force applied to muscle can exceed the momentary force produced by the affected muscle, illustrated by actions such as sprinting, jumping, throwing and fast cutting movements and changes of direction.[2] Within contact sports the physical demands that result from collisions between players and the ground and tackling can impair muscle integrity and cause an increased risk of damage to muscle.[3,4]

Exercise induced muscle damage (EIMD) occurs after strenuous, unaccustomed exercise that results in microscopic tears, followed by inflammation.[5] As a result, EIMD can lead to disrupted muscle fibres, impairing muscle function, increasing inflammation around the muscle and decreased range of motion[6]. EIMD can occur immediately or up to 14 days post-exercise, with training periodisation used to minimise it.[6]

Activity involved in contact sports can increase the risk of EIMD due to muscle trauma sustained from repeated eccentric contractions and an overload of mechanical stress.[7,8] However, during eccentric exercise males exhibit higher absolute eccentric strength, whereas immediately

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post exercise females exhibit greater relative strength loss and lower muscle pain.[9,10]

For optimum post-exercise recovery, restoration of endogenous substrate stores such as protein and carbohydrate (CHO) are required as a fuel for recovery.[11] These substrates facilitate the muscle-damage repair process via ameliorating muscle soreness, stabilising cell membranes and restoring muscle function.[11] Increased intake of CHO, proteins and nutritional supplementation, such as creatine or polyphenols, can accelerate muscle recovery from EIMD in resistance-trained individuals and soccer athletes.[12] Conversely, inadequate protein and CHO intake can slow down tissue repair and increase loss of muscle mass and, therefore, ensuring adequate intake of CHO and protein is necessary in order to ensure adequate anabolic resistance, as well as stimulating muscle protein synthesis during the recovery period.[13,14] Post-exercise, muscle can show myofibrillar damage and extra cellular matrix disruption.[11] Creatine monohydrate (CrM) enhances recovery through increasing cell volume after exhaustive exercise, reducing cell membrane fluidity and decreasing muscle degradation.[11,12] Nutritional supplementation strategies including omega 3, tart cherries, vitamin D, beetroot juice, CrM, pomegranate juice and antioxidant vitamins have been investigated, with varying degrees of success, aimed at reducing EIMD symptoms such as muscle swelling, soreness, increased oxidative stress markers and decreased pain threshold.[11] Antioxidant vitamins C and E neutralise reactive oxygen and nitrogen species that are released in damaged muscle, owing to a build-up of calcium ions.[15] They also neutralise activity of stress hormones and pro-inflammatory cytokines that occur after a bout of exercise.[15] Similarly, polyphenols and pomegranate have been researched based on their ability to upregulate endogenous antioxidant stores, whilst Tart Cherry has been investigated for its ability to attenuate the post-exercise inflammatory response.[15] Omega 3 fatty acids can also potentially enhance recovery and reduce the effects of delayed onset muscle soreness which is a common response to EIMD and can last for 5 – 7 days post-exercise.[16]

However, female athletes utilise substrates at varying rates, depending on which phase of the menstrual cycle they are in; for example, protein oxidation decreases during the follicular and increases during the luteal phase.[17] These variances will affect muscle strength and hypertrophy changes.[17] Female hormones also play a role in EIMD, with estrogen alleviating the inflammatory response, suppressing the infiltration of monocytes and macrophages as well as stabilising cell membrane structures.[18] Supplementation with CrM has shown that females may exhibit lower post exercise edema than males suggesting a sex-specific response, however, this research was only on healthy participants and not contact sport specific.[18]

To date, there has not been a systematic review that assesses the influences of nutrition to EIMD in male and female contact sports athletes. Therefore, the primary aim of this work is to systematically examine the influence of nutritional factors on EIMD in male and female professional and recreational contact sports. The second purpose is to explore potential differences by sex.

2. Materials and methods

The methodology and reporting of this systematic review were conducted according to the guidelines in The Cochrane Handbook.[19] and Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).[20] The papers included were longitudinal studies, cross-sectional analyses, cohorts, and randomised control trials (RCTs) involving recreational and professional contact sports athletes between 18 and 44 years. This review identified rugby union, football/soccer, American football, ice hockey and field hockey as contact sports.[21] Papers investigating any nutritional change applied through the diet that may impact EIMD either by additional supplementation or via education and reporting EIMD were included. Papers excluded from this review were articles not peer-reviewed, non-human studies, studies not in English, letters/case reports, articles about non-contact sports cohorts, review papers, conference papers, and articles not reporting primary outcome data of interest, and studies relating to cohorts under 18 and over 44 years old. Where a study included both a youth (under 18) and/or senior (over 44) cohort but reported adult and/or youth or senior results separately, the adult cohort was included in the review. This review is registered in PROSPERO (CRD42022318890).

A comprehensive search strategy was developed to identify all relevant studies. The following key topics (MeSH) were included and combined using the operators “AND”, “OR”: (“Nutrition” OR “Nutrition Invention” AND “Injury” AND “Contact”) AND (“Risk” OR “Injury Dynamics” OR “Low Energy Availability” (“LEA”) OR “Menstrual”). The full search strategy, terms, and search strings can be found in Supplementary Table 1. Papers were sought between November 2021 and February 2022, with search alerts re-run to identify further eligible papers up to September 2025. The following databases/search engines were searched: Medline, SportDiscus, CINHAL (via EBSCO), and Embase (via OVID), PubMed and Web of Science. Publication dates of the retrieved studies ranged between January 1970 and November 2024.

All recorded articles found from electronic or manual searches of relevant papers were entered into EndNote software for screening (EndNote X21, Thomson Reuters, New York). Two members of the authorship team assessed potential studies independently, excluding irrelevant studies based on the article title. Studies were initially included or excluded based on a review of the abstracts and finally included after examining the full report (Fig. 1). Studies were also reviewed during full-text screening to confirm study populations. Reference lists of included articles were screened to identify any potentially relevant missing articles. Disagreements were resolved via discussion by the same two authors (F.L., & C. A-M. G.). Any disagreements not resolved by discussion were resolved by a third member of the authorship team. Study selection and assessment resulted in no disagreements between the two authors.

A custom-developed spreadsheet (Microsoft Excel; Microsoft Corp USA, Microsoft Office Professional Plus 2019) was used to extract the following information for all studies: demographics, EIMD measurement, nutritional intervention and administration method of the intervention. Baseline measures and, where available, post-intervention measures (e.g., immediately post, post 24 h, and post 48 h) were extracted and presented as mean ± standard deviation (mean ± SD) unless otherwise stated. Research papers were extracted and reviewed following the PRISMA guidelines for identifying studies via database.[20] Studies will be discussed per EIMD biomarker (e.g. muscle glycogen concentration, creatine kinase (CK) levels), levels of dietary intake (e.g., CHO values).

All full-text articles that were eligible for data extraction were reviewed for quality by two members of the authorship team using Cochrane collaboration’s risk-of-bias tool (RoB 2) for RCT[19]. For non-randomised controlled trials (NRCT), the Cochrane collaboration’s risk of bias in non-randomized studies of interventions (ROBINS-I) tool was used (Supplementary Table 2).[22] The critical appraisal tool to assess the quality of cross-sectional studies (AXIS) was utilised for crossover studies because it allowed for a critiqued appraisal of cross-sectional studies.[23] In contrast, RoB 2 and ROBINS-II focus on RCTs and NRCTS.

3. Results

The initial search results yielded 1583 articles for review. After removing duplicates, citation searching, and searches from alerts, nine research papers (n = 133) were eligible for review. The process for reviewing and selecting the final papers included in this systematic review is shown in Fig. 1.[20] The demographics of the included papers are shown in Table 1.

No studies were excluded because of quality assessment (Supplementary Table 2). Within the seven RCTs assessed, five were deemed low risk for bias, and two were rated as having some concerns because muscle soreness was assessed using a visual analogue scale.

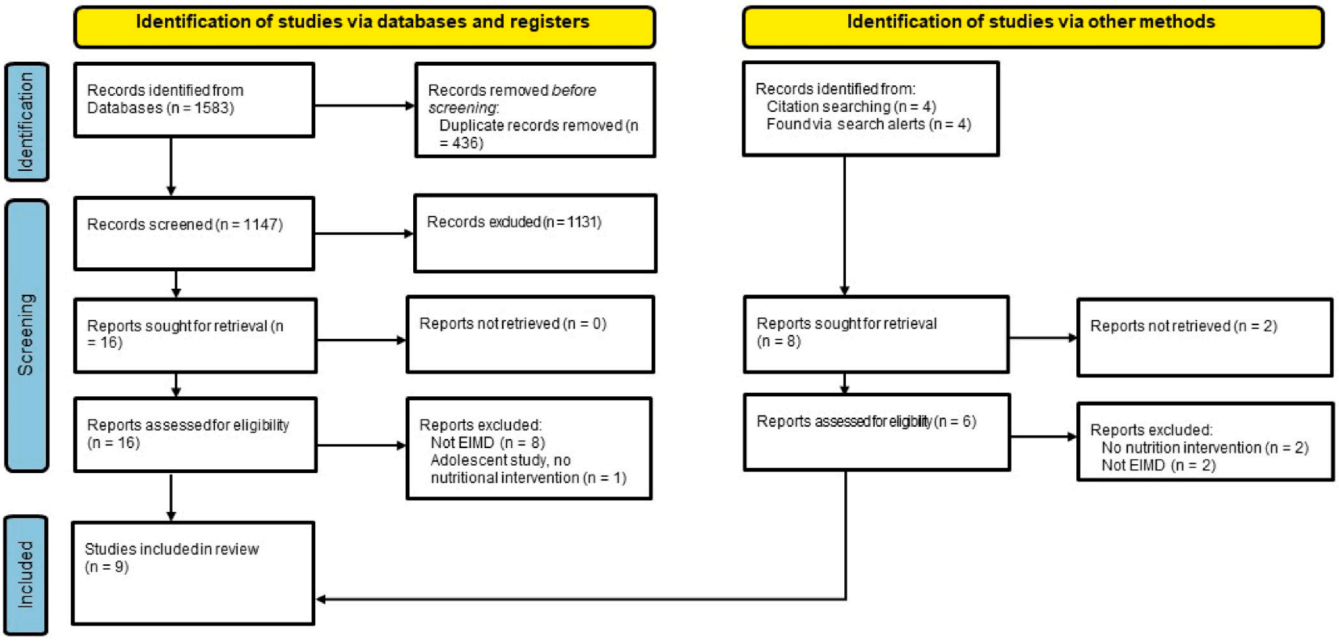


Fig. 1. PRISMA flow diagram for the identification, screening, eligibility, and inclusion of studies for the effect of nutrition on musculoskeletal injury in contact sports.

Hatchett *et al.*[28] was evaluated as having some concerns due to participants being retrospectively allocated to groups after the completion of data collection and no specific details on how the training load was given (Supplementary Table 3). Kupusarevic *et al.*[31] were evaluated as having some concerns due to using a 100 mm visual analogue scale with no additional measurement to assess muscle soreness/damage. Again, using a visual analogue scale is a validated measure of muscle soreness; therefore, the study was not excluded.[33] The one non-RCT was deemed to have a low risk of bias.[27]

For the cross-sectional study, 'Questions which related to non-responders, response rate and selection bias in the AXIS risk assessment did not apply to the relevant study and the cohort included in this review.[23] The cross-sectional study was given a good rating and thus, was not excluded (Supplementary Table 4).[29]

Of the nine studies included in this review (n = 133) a range of nutritional interventions were employed to assess impact on EIMD (Table 1).[24–32] Only one study had a female cohort[27], and the remaining had male cohorts[24–26,28–32], no studies included both sexes.

A variety of primary outcome measures were recorded (Table 1) with equivocal results. Secondary outcome measures (Table 1) included muscle soreness[26], creatine kinase measurements,[25] lactate dehydrogenase (LDH),[27,30] tumour necrosis factor-alpha (TNF-α), high-sensitivity C-reactive protein (hsCRP), and IL −1-β, 6, 8 & 10 measurements,[24,32] and urea and warburg effect measurements.[29]

Significant differences ($p < 0.05$) were noted in all primary outcome measures of interest when CHO intake was assessed or supplemented in the studies assessing muscle damage.[25,29] Bradley *et al.*[25] found that muscle recovered faster when 90 g of CHO was consumed immediately following a rugby league match simulation protocol (51 ± 47%) when compared to a 2 h delayed refeeding of CHO protocol (24 ± 49%). Hudson *et al.*[29] found significant differences in the glucose-alanine cycle, associated with amino acid degradation, at game day (GD) −1 vs GD ($p = 0.002$), GD vs. GD + 1 ($p = 0.002$) and GD vs. GD + 2 ($p = 0.003$).

Comparison of CK measurements with dietary intake demonstrated that participants who complied with the daily recommended intake of certain macronutrients and micronutrients had lower baseline concentrations of CK, but significant differences were found only in pre-match (146 ± 68 vs.116 ± 22 U/l, $p < 0.01$; 148 ± 67 vs. 112 ± 24 U/l, $p < 0.01$; 235 ± 85 vs. 135 ± 57 U/l, $p < 0.001$; and 191 ± 86 vs. 131 ± 52 U/l, $p < 0.05$ for CHO, fibre, vitamin B1, and chromium, respectively).[27] Participants who consumed a multi-ingredient supplement (MIS) comprising of turmeric, chicken meat and apple extracts and ancient peat saw CK measurements return to baseline at 24 h post rugby match, whereas participants consuming a placebo saw CK measurements still elevated (180 U/l vs. 310 U/l, $p = 0.009$).[30]

Conversely, Bell *et al.*[24] reported that post-training muscle damage was similar between the group receiving Montmorency tart cherry juice (MC) and the placebo group and also, both groups showed changes in CK levels post-training ($p = 0.004$), with neither group or interaction effects revealed. Similarly Gilson et al.[26] showed that whilst CK increased in both CM and PLB groups between baseline and follow up no differences were noted between treatment groups (24 h follow up: 450 U/l vs 550 U/l).

In the studies assessing muscle soreness, Morehen *et al.*[32] failed to demonstrate any effect on muscle soreness with MC vs. a placebo pre-match to 48 h post-match: 3.4 ± 0.4 pre-match vs. 3.2 ± 0.9 arbitrary units (AU) at 48 h post-match, $p = 0.900$ for the MC group vs. 3.3 ± 0.7 pre-match vs. 3.0 ± 0.8 AU at 48 h post-match, $p = 0.25$ for the control group. Similar results with muscle soreness were reported with sour tart cherry juice vs a placebo ($p = 0.807$).[31] Hatchett *et al.*[28] found that whilst unpasteurised milk with added honey (RMH) reduced muscle soreness post-exercise when compared to pasteurised chocolate milk (CM), the between-group differences in muscle soreness, measured by a 6-point face pain scale, showed no effect and large variations in standard deviations were noted (baseline 0.1 ± 1.35; 24 h post-exercise 0.1 ± 1.69; 48 h post-exercise 0.8 ± 2.55). Kupusarevic et al.[31] demonstrated that whilst muscle soreness increased between baseline and follow up there was no differences between MC and PLB groups ($p = 0.807$).

4. Discussion

The primary aim of this systematic review was to examine the influences of nutritional factors on EIMD in professional and recreational contact sports. Of the nine studies reviewed, only one study had female participants.[27] Macronutrient-based nutritional interventions (CHO

Table 1
Demographics characteristics and main outcomes of included studies investigating the effect of nutrition and genetics on musculoskeletal injury in contact sports.

			EIMD Measurement				Post-intervention measure[c]		
Study	**Demographics**[a]	**Sport**	**Primary**	**Secondary**	**Nutritional intervention**	**Administration method**[b]	**Baseline measure**	**Immediate**	**Follow up**
Bell et al.[24]	N = 16 males; Age: 25 ± 4 years Body Mass: 81.9 ± 6.6 kg Height: 180.8 ± 7.4 cm	Recreational Football	Muscle CK measurement	TNF-α, hsCRP, Cytokine, IL-1-β, IL-6, IL-8, IL-10	MC	2 × 30 ml MC in 2 × 100 ml water vs commercially available fruit cordial.	CK MC: 293 ± 228 $U.L^{-1}$ PLB: 197 ± 143 $U.L^{-1}$	CK MC$^{\beta}$: 691 ± 365 $U.L^{-1}$ PLB$^{\beta}$: 310 ± 535 $U.L^{-1}$	CK 24 h$^{\beta}$ MC: 1551 ± 1473 $U.L^{-1}$ PLB: 1096 ± 652 $U.L^{-1}$
Bradley et al.[25]	N = 15 males; Age: 20.9 ± 2.9 years Body Mass: 87.3 ± 14.1 kg Height: 177.4 ± 6.0 cm	Recreational Rugby	Muscle Glycogen concentration	CK measurement	Immediate vs delayed refeed (2 h post-exercise) protocol	Rapid refeed group: 90 g CHO and 30 g PRO beverage immediately after exercise. Delayed refeed group: 30 g Protein beverage immediately after exercise protocol.	Immediate Refeed Group: 337 mmol / kg dry weight. Delayed Refeed Group: 376 mmol / kg dry weight	Immediate*: decreased by 25 ± 14% (ES: ± 90% CI: −1.38 ± 0.90). Delayed$^{\beta}$: decreased by 24 ± 12% (-1.38 ± 0.92)	48 h* Immediate: increased by 51 ± 47% (0.88 ± 0.66). Delayed: increased by 24 ± 49% (0.7 ± 1.23).
Gilson, et al.[26]	N = 13 males; Age: 19 years Body Mass: 79.4 ± 2.6 kg, Height: 184.0 ± 0.02 cm	Recreational Football	CK measurement	Muscle soreness via VAS	Chocolate Milk vs Placebo	672 ml beverage either chocolate milk or placebo	PLB: 220 $U.L^{-1}$ Chocolate Milk: 210 $U.L^{-1}$	-	24 h$^{\beta}$ PLB: 550 $U.L^{-1}$ Chocolate Milk: 450 $U.L^{-1}$
Gravina, et al.[27]	N = 28 females; Age: 21 ± 6 years Body Mass: 61 ± 8.4 kg, No height given	Professional & Recreational Football	Muscle DRV compliance		Macro/ micronutrient intake	8 day weighed food, drink & supplements intake (inc. match day).	Compliant: CHO**: 116 ± 22 $U.L^{-1}$ VB1**: 135 ± 57 $U.L^{-1}$ Fibre**: 112 ± 24 $U.L^{-1}$ Chr**: 131 ± 52 $U.L^{-1}$ Non-Compliant: CHO: 146 ± 68 $U.L^{-1}$ VB1: 245 ± 85 $U.L^{-1}$ Fibre: 148 ± 67 $U.L^{-1}$ Chr: 191 ± 86 $U.L^{-1}$	Compliant: CHO3: 200 ± 50 $U.L^{-1}$ VB1: 200 ± 160 $U.L^{-1}$ Fibre: 190 ± 50 $U.L^{-1}$ Chr: 200 ± 160 $U.L^{-1}$ Non Complaint: CHO: 220 ± 120 $U.L^{-1}$ VB1: 400 ± 200 $U.L^{-1}$ Fibre: 230 ± 130 $U.L^{-1}$ Chr: 240 ± 70 $U.L^{-1}$	18 h Compliant: CHO: 290 ± 110 $U.L^{-1}$ VB1: 285 ± 115 $U.L^{-1}$ Fibre: 220 ± 135 $U.L^{-1}$ Chr: 255 ± 295 $U.L^{-1}$ Non-Compliant: CHO: 250 ± 290 $U.L^{-1}$ VB1: 550 ± 50 $U.L^{-1}$ Fibre: 290 ± 250 $U.L^{-1}$ Chr: 340 ± 260 $U.L^{-1}$
Hatchett et al.[28]	N = 20 males, Age: 20 years, Body Mass: 79.78 kg, Height: 174.70 cm	Recreational Sprint Football	Muscle soreness via VAS	-	Chocolate Milk vs. Raw Milk Honey	240 ML beverage, either Chocolate Milk or Raw Milk Honey solution.	Chocolate Milk: 1.5 Raw Milk Honey: 0.6	Chocolate Milk: 3.2 Raw Milk Honey: 4.5	24 h Chocolate Milk: 3.3 Raw Milk Honey: 3.2
Hudson et al.[29]	N = 7 males; Age: 22.0 ± 2.7 years Body Mass: 102.5 ± 13.7 kg, No height given	Professional Rugby	Muscle CHO Intake	Urea Cycle and Warburg-effect measurements	Habitual Diet	Habitual diet	-	CHO intake**: GD-1: 4.32 ± 0.89 GD: 5.62 ± 0.85 GD + 1: 2.93 ± 0.64 GD + 2: 2.11 ± 0.42 Glucose-Alanine cycle**: GD-1 v GD: p = 0.0019 GD v GD + 1: p = 0.0019 GD v GD + 2: p = 0.0025	-
Hsueh et al.[30]	N = 13 males; Body Mass: 86.0 ± 22.8 kg Height 176.0 cm ± 0.08 m	Recreational Rugby	Muscle CK measurement	LDH	MIS	2 x tablets daily vs 2 x placebo tablets daily dissolved in 300 ml water.	MIS and Placebo: 180 U/l	MIS & Placebo**: 340U/l	MIS: 180 U/L Placebo$^{\beta}$: 310 U/l
Kupusarevic et al.[31]	N = 10 males; Age: 28 ± 4 years Body Mass: 106.8 ± 7.6 kg, Height: 188.0 ± 0.64 cm	Professional Rugby	Muscle soreness via VAS	-	MC vs placebo	2 * 30 ml servings or MC or placebo	MC: 34 ± 25 mm PLB: 39 ± 30 mm	-	24 h$^{\beta}$ MC: 101 ± 35 mm PLB: 125 ± 30 mm
Morehen et al.[32]	N = 11 males; Age: 18 ± 1 years Body Mass: 92.2 ± 8.6 kg, Height: 182 ± 0.04 cm	Professional Rugby	Muscle soreness via VAS	TNF-α, hsCRP, Cytokine, IL-1-β, IL-6, IL-8, IL-10	MC vs PLB	2 × 30 ml Montmorency tart cherry juice in 2 × 100 ml water vs. commercially available fruit cordial with water matched for energy and CHO content.	PLB: 3.3 ± 0.7 AU MC: 3.4 ± 0.4 AU	-	24 h PLB$^{\beta}$: 2.6 ± 0.8 AU MC: 2.6 ± 0.5 AU

In the whole table, data shown is mean ± standard deviation, * significant at $p < 0.05$ and **significant at $p < 0.01$ between treatment groups, $^{\beta}$ significant at $p < 0.05$ from baseline values
AU = arbitrary units, CK = Creatine Kinase, CHO = Carbohydrate, Chr = Chromium, CRP = C-Reactive Protein, DRVs - Daily recommended values, GD = Game day, GD-1 = Day before game day, GD+ 1 = Day after game day, GD+ 2 = 2 days after game day, HMB-FA = β-Hydroxy-β-Methyl butyrate Free Acid, hsCRP = high sensitivity C-reactive protein, IL-1-β = Interleukin 1 Beta, IL-6 = Interleukin 6, IL-8 = Interleukin 8, IL-10 = Interleukin 10, LDH = Lactate dehydrogenase, MC = Montmorency tart cherry juice, PLB = Placebo, TNF-α = Tumour necrosis factor - alpha, $U.L^{-1}$ = units per litre, VB1 = Vitamin B1.

[a] Demographic information collected via pre-screening questionnaires, anthropometric measurement collection and medical examinations.

[b] Beverages consumed are shown in millimetres (ML), and supplements consumed are shown in grams per day(g/day). Consumption of macronutrients is shown in grams per kilogram of body mass per day (g.kg.day).

[c] Visual Analogue Scale measures are mean only. Correlations are Pearson's product-moment correlation coefficient (r).

immediate vs. delayed refeed, CHO metabolism, and daily recommended values (DRV) compliance vs. non-compliance) reported significant differences in muscle glycogen concentration, CK levels and glucose-alanine cycle.[25,27,29] Supplementation with a MIS reported significant differences in CK levels after a rugby match when compared to a placebo.[30] Studies involving MC and CM reported mixed results, with no effects reported for studies involving RMH.[24,26,28,31,32] Two studies that included CHO as part of daily recommended intake values or as a refeed protocol reported that muscle glycogen stores recovered faster and serum CK levels were lower.[25,27] EIMD was also lower when DRVs for CHO, fibre, vitamin B1, and chromium were complied with[27].

The second aim of this review was to explore whether sex-related differences influenced the effect of diet on EIMD in contact sports. Only one study investigated DRVs and markers of EIMD (CK and LDH) in female football athletes.[27] In the remaining studies investigating the influence of diet or nutrition on EIMD in male athletes, various interventions were used with mixed results; therefore, no conclusions as to how sex as a confounder in the effectiveness of diet or nutrition in EIMD can be made. Gravina *et al.* assessed nutrient intake and total antioxidant status against markers of EIMD in female soccer athletes.[27] The authors noted that athletes who complied with dietary reference intakes (DRI) of CHO, vitamin B1, fibre, and chromium had lower levels of CK.[27] Damaged muscle reduces the effectiveness of glucose uptake, resulting in decreased glycogen synthesis which can be lessened by adequate or increased consumption of CHO[34]. Chromium and vitamin B1 play an important role in CHO energy metabolism with a vitamin B1 deficiency signified by muscle fatigue leading to increased muscle weakness characterised by muscle pain and a chromium deficiency signified by increased glucose intolerance.[35,36] Dietary fibre can increase the number of short chain fatty acid (SCFA) producers, with SCFA having an important role in the reduction of inflammation and preserving skeletal muscle mass.[37]

The findings of this review suggest that, post-match, athletes who did not meet the DRI for vitamin E or CHO had greater secondary markers of LDH activity. Non-compliant athletes had more EIMD, as shown by higher levels of LDH.[27] Vitamin E is an endogenous antioxidant and can prevent cell damage from inflammatory cells by scavenging free radicals; however, research in this area has also produced mixed results[38–41] but our review highlighted that adequate levels of vitamin E resulted in lower levels of LDH.[27].

Female athletes may be more vulnerable to EIMD during the early follicular phase of the menstrual cycle when sex hormone concentrations (estradiol b-17 and progesterone) are lower than in the mid-luteal phase.[42] This suggests that females may respond differently to a nutritional intervention and EIMD protocol assessment at different stages of the menstrual cycle than their male counterparts who do not experience this variation.[42] Thus, conclusions derived from studies in male athletes relating to the efficacy of nutritional interventions or the influence of nutritional risk factors on EIMD cannot be equivocally stated for their female counterparts, highlighting the requirement for further research in this area.

One explanation for mixed results when assessing EIMD is that the various nutritional interventions used in the studies work at distinct stages of the EIMD cascade. Inconsistent results were found for drinks that provide polyphenols to enhance contact sports athletes' antioxidant/anti-inflammatory mechanisms.[24,31,32] For example, polyphenols such as MC are metabolised to electrophiles, activating nuclear factor erythroid-2 related factor 2 (NrF-2), which regulates inflammation during the secondary phase of EIMD.[6] Likewise, whilst MIS supplementation reduced CK levels after rugby union match-play it didn't have any effect of inflammation and oxidative stress markers.[30] The MIS supplement contained turmeric, chicken meat and apple extracts, selected for their antioxidant properties.[30] A key component of turmeric is curcumin and like MC is a polyphenol, with anti-inflammatory properties that downregulates cycloxygenease-2 (COX-2).[43] COX-2 is a prostaglandins enzyme that contributes to swelling and pain in muscle damage post exercise and curcumin decreases the release of prostaglandins which in turn reduces muscle damage.[43] Another component of the MIS was chicken meat extract which contains carnosine, an endogenous dipeptide with antioxidant properties that activates Nrf2 and scavenges reactive oxygen species that occur within muscle after intense exercise.[44] Likewise the last components of the MIS, ancient peat and apple extract also decreases reactive oxygen species activity and can improve mitochondrial function.[45]

There is a broad array of methods that record both the primary and secondary phases of EIMD and it is important to note that the response can vary widely between athletes.[12] A second explanation for the lack of consensus regarding influences on EIMD is that only Bradley *et al.*[25] used muscle biopsies to assess muscle glycogen levels as an indicator of metabolic demands and glycogen utilisation; the remaining papers used less invasive and less valid techniques, either a variety of Likert Scales to assess perceptions of muscle soreness[26,28,31,32] or blood biomarkers to assess muscle damage.[24,26,30,32] Kupusarevic *et al.*[31] used a visual analogue scale to assess perceptions of muscle soreness instead of objective measures such as blood CRP, CK and IL-6, −8 and −10. It should be noted that Likert Scales, a popular method in measuring and assessing attitudes and respondents' views of a given situation, are inherently subjective, resulting in differing reliability levels.[46]

CK was used as a measure of EIMD in four studies.[24,26,27,30] Clarkson & Hubal[47] reported that CK had been the most widely assessed marker, mainly due to the magnitude of increase post-EIMD compared to other muscle proteins and the cost of the assay is modest. However, CK levels can remain high for several days after an exercise protocol due to other concentric exercises performed, and as such is inherently unreliable.[47] The unreliability of CK measurements stems from the fact that CK levels can be influenced by a variety of measures, such as differences in body composition as well as exercise intensity and modality.[48] Studies in this systematic review covered different sports and will have employed different exercise protocols and rest intervals that could contribute to varying CK measurements.[48] Furthermore, individuals with greater muscle mass will experience higher CK levels.[49] Again, conclusions derived from studies using CK measurement on a male cohort cannot be equivocally stated for female counterparts, as they can have lower baseline CK levels with greater peaks post exercise, with hormonal fluctuations throughout the menstrual cycle modulating CK levels.[48]

However, creatine supplementation induces differentiation of skeletal muscle myoblasts and positively affects satellite cell numbers, which are vital for muscle fibre regeneration[50]. Supplementation with creatine can indeed have both an anti-inflammatory and anti-catabolic effect on muscle, decreasing measures of muscle breakdown.[50] Creatine combines with a phosphoryl group to form phosphocreatine (PCr) via an enzymatic reaction catalyzed by CK.[51] Cr and adenine triphosphate diffuse into the cytosol and assist in buffering energy requirements, acting as a direct or indirect antioxidant reducing the formation of reactive oxygen species.[51] However, the effect of creatine supplementation may be different in females. Smith-Ryan *et al.*[52] explained that whilst females may have 70–80% lower endogenous creatine stores than males, they also have been reported to have higher levels of intramuscular creatine concentrations (~10%) than their male counterparts and, as such, may respond differently to creatine supplementation strategies. Notably, of the research that has been carried out to date, creatine supplementation has been shown to be effective in females by improving their muscular strength and power[52]. Since the studies in this review that utilised creatine supplementation only focus on male participants, research into whether creatine supplementation reduces injury rates in female contact athletes is required.

This systematic review has reviewed the available literature relating to nutritional factors in relation to EIMD, however, it is not without its limitations. Nine of the studies selected were RCTs, however, none had a male and female cohort to determine sex-related differences, so no direct comparisons could be made. Furthermore, there was a lack of consistency in the nutritional interventions tested and the primary

markers assessing EIMD, signifying that specific conclusions could not be made. A further limitation is the use of the term 'contact sport'. Despite a search of studies relating to nutritional factors and the potential effects on EIMD, it must be acknowledged that additional studies may exist that were not identified by the included search terms.

5. Conclusions

In the studies investigating EIMD mixed results were noted: studies involving CHO, compliance with DRVs and MIS reduced the risk of EIMD, whilst the remaining strategies of MC, CM and RMH found no benefit or conflicting results. No research studies had a cohort of both sexes or explored the effects of genetics on the influence of nutritional strategies on EIMD; therefore, conclusions on the influence of sex and genetic-related risk factors to EIMD could not be made. Research involving female contact sport athletes and mixed-sex cohorts needs to be considered, more specifically factoring in the potential psychological and hormonal differences between male and female athletes. Additionally, this research should account for EIMD specific differences, to determine how different nutritional interventions may affect EIMD in female vs. male contact sports athletes.

Ethical approval

Ethical approval was not required for this review.

CRediT authorship contribution statement

Anne Delextrat: Writing – review & editing. **Christopher Curtis:** Writing – review & editing. **Catherine Anna-Marie Graham:** Writing – review & editing. **Rianne Costello:** Writing – review & editing. **Vasiliki Iatridi:** Writing – review & editing. **Felicity Lucas:** Writing – original draft.

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Data availability

All data relevant to the study are included in the article or uploaded as supplementary information.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.aehs.2026.03.001.

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