AUT ACC SportSmart-9 Review Project:

Nutrition and hydration as a function of health for injury and acute illness prevention during sport and exercise participation: A narrative review.

A technical report to ACC

30th September 2020

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SportSmart-9 Review 2020 Nutrition Fact Sheet

Focus of the scoping review

To determine how nutrient and fluid intake may minimise the risk of injury and illness and promote physical health through sport and exercise participation in recreational and elite athletes. We hypothesised that appropriate nutritional status would help to minimise the risk of acute and chronic injury and illness.

What we did

- Conducted a search strategy in two phases: 1) Understanding of the current position through a review of consensus and position statements and relevant review articles; 2) Specific insight into key themes identified in phase 1 through a narrative review of peer-reviewed research articles.
- Narrative review themes were identified through appraisal of relevant nutrition and hydration-focused review articles which led to the identification of six key themes: Skeletal injuries; Muscular injuries; Upper respiratory tract infection/illness; Gastrointestinal issues; Heat illness; and Hyponatremia.

What we found

- Nutrition and hydration status should be a key consideration in preventing injuries and acute illnesses, however, intake should be tailored to the needs of the athlete, baseline nutrition and hydration status, the environment and the demands of the sport.
- A balanced diet should be followed in accordance with the Ministry of Health guidelines which advocates eating a variety of nutritious food every day (https://www.health.govt.nz/our-work/eating-and-activity-guidelines).
- Whole, relatively unprocessed foods are nutrient-dense and contain a variety of micronutrients not available in a single nutrient supplement. Dietary supplementation is only recommended if particular needs have been identified, e.g. restricted diet due to food allergy and should only be taken under the guidance of a dietician.
- Disordered eating (dietary restraint leading to low energy availability) is a risk factor for skeletal injury development, particularly those injuries which last more than 22 days. Focus should be put onto developing healthy eating attitudes in attempt to avoid disordered eating behaviours.
- Endurance and aesthetic sports associated with leanness, and recreational exercise with the goal of changing body composition, have a greater prevalence disordered eating and risk for low energy availability.
- UV exposure and intake has minimal effect at maintaining vitamin D levels over winter months; supplementation should be undertaken if exposure is limited.
- Low energy availability has been associated with GI symptoms, however, higher race-morning energy, carbohydrates and caffeine intake may lead to GI distress. Pre- and during-race fuelling balance should be practiced in training to improve gut efficiency in absorbing nutrients.
- To prevent heat-related illness during prolonged exercise, athletes are advised to drink according to thirst, rather than drinking for fluid replacement of body mass loss
- When participating in long-lasting exercise, efforts should be taken to monitor fluid intake both during and following the event, particularly for females with low body mass.

What we concluded

The review findings informed the acceptance of our hypothesis that appropriate nutritional status helps to minimise the risk of acute and chronic injury and illness within the specified population.

What we suggest happens next

Initiatives to educate athletes of the associations between nutrition and hydration, injury risk and physical capability need to be developed, piloted, and then implemented nationally. We recommend that National Sporting organisations integrate specific guidelines into their coach education programmes. ACC Sport Collaboration Group to discuss how nutrition and hydration information can be included in revised ACC SportSmart programmes and supporting resources.

Title: Nutrition and hydration as a function of health for injury and acute illness prevention during sport and exercise participation

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Abstract

Background

National sports benefit from easily implemented and cost-effective injury prevention countermeasures that are effective at reducing injury rate and severity. Nutrition and hydration influence injury and illness risk.

Objective

To determine how nutrient and fluid intake can minimise the risk of injury and illness and promote physical health through sport and exercise participation. We hypothesised that appropriate nutritional status would help to minimise the risk of acute and chronic injury and illness.

Methods

Phase 1) a review of consensus, position statements and review articles; *phase 2*) key themes identified in phase 1 (injury themes n=2, acute illness themes *n*=4) informed a narrative review of research articles. An electronic search for literature published before July 2020 from five databases was conducted for each theme.

Results and Discussion

Fifty-three articles informed phase 1 and 44 articles informed phase 2. Empirical research (phase 2) offered limited practical advice for nutritious whole-food diet and placed greater focus on dietary supplements. Practical diet advice with increased scientific grounding is required for athletes and exercisers. Nutrition and hydration intake should be tailored to the needs of the athlete, baseline nutrition and hydration status, the environment and the demands of the sport. Whole, relatively unprocessed foods are nutrient-dense and contain a variety of micronutrients not available in a single nutrient supplement. Dietary supplementation is only recommended if particular needs have been identified, e.g. restricted diet due to food allergy and should only be taken under medical supervision.

1. Introduction

Participation in sport and recreational fitness activities is advocated for benefits to health and well-being. Regular physical activity is a critical part of the solution to growing public health challenges associated with increasingly sedentary lifestyles and rising obesity. Although sport and exercise participation are largely beneficial, engagement in such activities inevitably exposes the individual to some degree of risk of sustaining an injury or developing an acute illness. In New Zealand (NZ) in 2019, $571 million was paid out through the Accident Compensation Corporation (ACC) for sport and recreation related injuries, up from $540 million in 2016. Claims for gym and fitness related injuries have increased by the greatest volume. Susceptibility is not only a concern during engagement of sport and exercise, but additionally, individuals must consider their preparation and recovery to avoid injury and acute illness. One of the major considerations in this respect is around nutrition and hydration.

A key objective of nutrition and hydration intake by athletes (including regular gym goers or those that might not consider themselves "athletes") is for protection against the risk of injury and acute illness associated with participating in training and competition. Many athletes may not know that nutrition and hydration (or lack of) can impact on injury; many just think it is for fuelling their activity. It is not always clear to athletes which nutritional and hydration advice should be followed, however, baseline guidance is provided by the Ministry of Health mantra which puts diet first and recommends eating a variety of nutritious food every day (https://www.health.govt.nz/our-work/eating-and-activity-guidelines). Extending the Ministry of Health recommendations to focus on specific injury and acute illness prevention guidelines for those who partake in sport and exercise, the ACC SportSmart framework will be used.

ACC SportSmart

ACC SportSmart is a scientifically grounded framework accessible to all those involved recreation in sport and active recreation. Developed in 1999 as a resource to help inform organisations, teams, and individuals on how best to reduce the risk of sports injury, and reviewed in 2015 [1] and 2017 [2], one of the nine components of the SportSmart framework is 'Food and Fluid'. Within the SportSmart-9 food and fluid fact sheet [3], key considerations include:

1. Player nutrition needs to be multifactorial and include foods and fluids.
2. Nutrition should meet the nutritional needs for any training or game. A nutrition (diet and hydration) programme should be planned based on the level of the athlete and the stage of training.
3. The nutrition programme should be monitored to assess its effectiveness in improving performance and reducing injury risk.
4. Sports drinks are not recommended except in very hot, humid environments with high physical activity where electrolyte loss and carbohydrate use may be increased.

Knowledge and recommendations for practice evolve over time and therefore there is need for continual update and dissemination of recommendations [4]. Further, there has been an increase in the volume of nutrition and hydration content shared on social media that is not from credible sources. It is important to advance the current SportSmart content on nutrition and hydration, and make evidence informed guidance widely accessible. Therefore, the purpose of this review was to use empirical research findings to examine the effectiveness of nutrition and hydration interventions in reducing the incidence and severity of athletic injuries and illnesses associated with participating in various sports and activities.

Objective

To determine how nutrient and fluid intake can promote physical health through sport and exercise participation via examination of the effects of nutritional status on injuries and acute illnesses in sporting and exercising cohorts. We hypothesised that appropriate nutritional status would help to minimise the risk of injury and acute illness.

2. Methods

To inform the review article, the search strategy was undertaken in two phases: *Phase 1*) understanding of the current position through a review of consensus and position statements and relevant review articles; *Phase 2*) specific insight into key themes identified in phase 1 through a narrative review of peer-reviewed research articles.

Literature Search Methodology

Phase 1: Nutrition and hydration consensus and position statements which related to injuries and acute illnesses of sport and exercising cohorts were gathered from experts in the field. In addition, a search for meta-analysis, review and systematic review articles published up to May 2020 was conducted using two databases: Pubmed and SPORTDiscus. The search was undertaken using the key words sport, exercise, injury, acute illness, nutrition, hydration.

Phase 2: Informed by themes drawn from Phase 1, a comprehensive search of literature published up to July 2020 was conducted using electronic databases: PubMed, SPORTDiscus and Medline via EBSCO. The search focused on keywords nutrition, hydration, injury prevention, skelet*, bone, musc*, acute illness, respiratory tract, gastrointestinal, heat, hyponatremia. Relevant studies suggested by experts in the field were additionally added to the literature for review.

Search Parameters and Criteria

Phase 1: The following criteria were used to select articles for inclusion in phase 1 of the current review: (i) position or consensus statements, narrative review, systematic reviews or meta-analyses; and (ii) written in English. Articles were excluded if they had no full text available.

Phase 2: The following criteria were used to select articles for inclusion in phase 2 of the current review: (i) original articles; and (ii) written in English. Articles were excluded if they had no full text available or focused on a specific sub-population e.g. spinal cord injuries, pregnancy, wheelchair-based sport.

Data Extraction

Phase 1: Experts in the field of nutrition and hydration identified nine relevant position and consensus statement articles. The narrative review, systematic review and meta-analysis article search identified a total of 345 articles, of which 292 were excluded from further analysis as they did not meet the inclusion criteria or were duplicates. A total of 53 relevant articles were selected to inform phase 1 of the current review. Thematic analysis of statements and review articles informed the identification of six relevant themes related to injury and acute illness prevention: Skeletal injuries (10 articles); Muscular injuries (16); Upper respiratory tract infection/illness (6); Gastrointestinal issues (5); Heat illness (15); and Hyponatremia (1 article).

Phase 2: Using relevant key words related to each theme, a computerized electronic search for literature published before July 2020 from five databases (PubMed, SPORTDiscus, Medline via EBSCO, Web of Science, and Scopus) was conducted. Inclusion criteria were original research studies published in English. A total of 2,302 original research articles were identified across all databases. The removal of duplicates left 343 articles, of which 159 were excluded from further analysis as they did not meet the inclusion criteria. After screening by title and elimination based on exclusion criteria, a total of 184 articles were read in their entirety. Relevant data from 39 original journal articles informed the review and a total of 5 papers were added by experts throughout the review writing process. Subsequently, a total of 44 journal articles informed phase 2 of the current review (Figure 1).

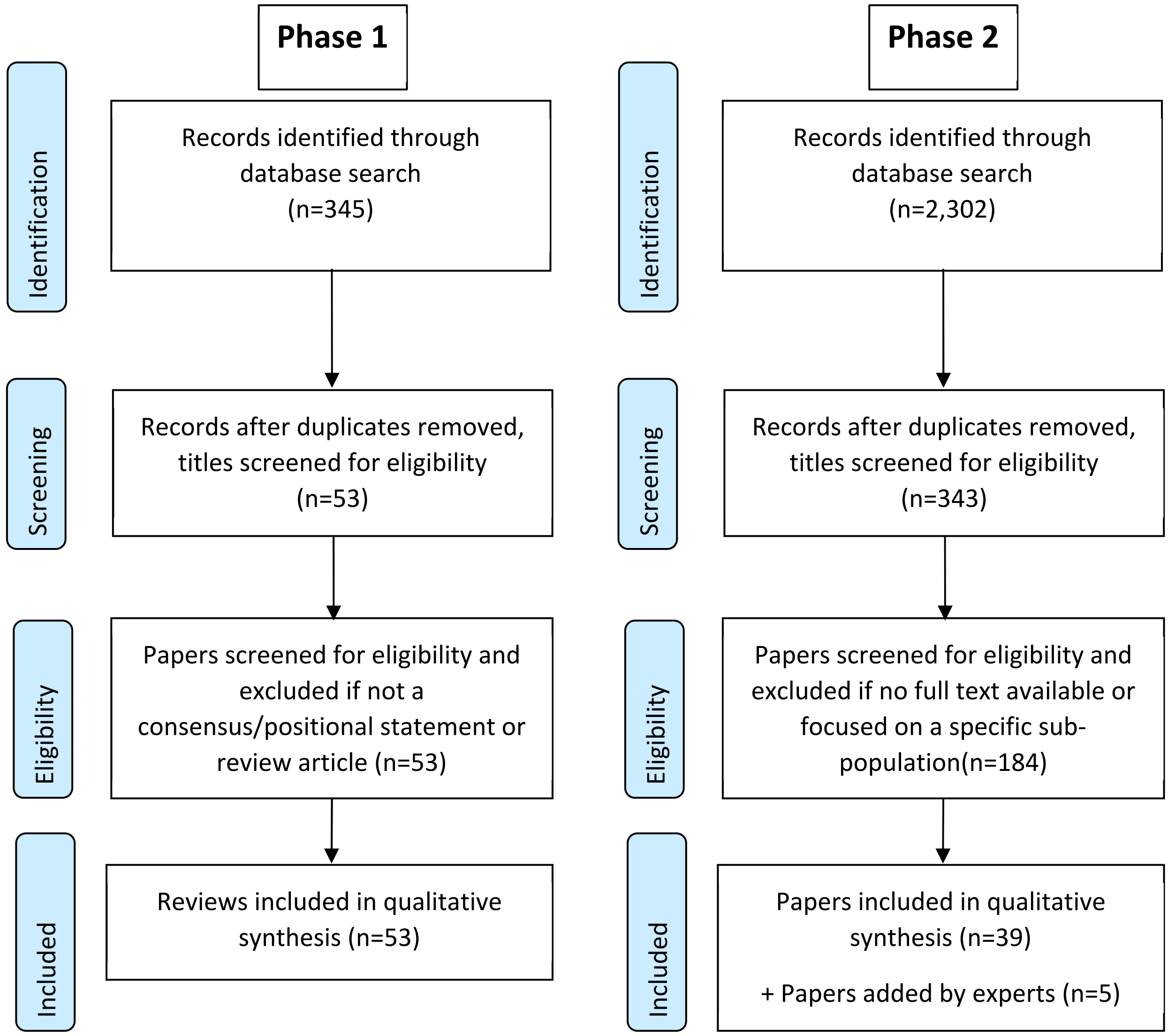

Figure 1. Flow of information through the article review process for phases 1 and 2.

3. Results and Discussion

The review provided papers on injury/illness and the association with nutrition/hydration and underpinning factors (e.g. energy availability).

Study Characteristics

The key characteristics of the studies are displayed in Tables presented at the forefront of each section.

Participants

The investigations identified in the search included a wide range of study participants, from recreationally active to amateur and professional male and female athletes.

Injury prevention

Skeletal injuries

Relevant information was extracted from 10 articles to inform nutrition and hydration guidelines in relation to musculoskeletal injuries in sport and exercising populations (Table 1). The informing research ranged from cross-sectional to 6-month double-blind, randomized, placebo-controlled trial studies. The total 15,618 participants informed the outcomes for this topic of skeletal injuries, although the vast majority were introduced by a single study [5]. A range of cohorts were included in the studies, from adolescent to older adults and across multiple sports and activities. Nutrition has been found to play an important role in the development of skeletal injuries when combined with physical activity. From our review, the main nutrition-based factors which influenced skeletal injury risk were dietary restriction, dairy consumption, calcium and vitamin D.

Table 1. Studies of nutrition, hydration and skeletal injuries

Reference	**Date**	**Sample (*n*)**	**Population characteristics**	**Objective**	**Study design**
Beals and Manore [6]	2002	425	Female collegiate athletes from 7 universities across the United States	To examine the prevalence of and relationship between the disorders of the female athlete triad in collegiate athletes participating in aesthetic, endurance, or team/anaerobic sports	Cross-sectional study
Warrington *et al.* [7]	2009	27	Elite male jockeys	To evaluate the impact of weight restrictions on physiological function and bone health in a group of horse racing jockeys	Cross-sectional study
Rauh *et al.* [8]	2010	163	Female athletes competing in 8 interscholastic sports	To examine the relationship among disordered eating, menstrual dysfunction, and low bone mineral density (BMD) and musculoskeletal injury among girls in high school sports	Prospective cohort study
Nieves *et al.* [9]	2010	125	Female competitive distance runners aged 18-26 years	To identify nutrients, foods, and dietary patterns associated with stress fracture risk and changes in bone density among young female distance runners	2-year prospective cohort study
Wentz *et al.* [10]	2012	59	Female runners with stress-fracture history (*n*=27) + controls (*n*=32)	To compare female runners with and without a history of stress fractures to determine possible predictors of such fractures	Cross-sectional study
Bauer [11]	2013	1	62-year-old healthy woman who exercises regularly	To provide a case vignette highlighting a common clinical problem	Clinical case study
Lewis *et al.* [12]	2013	45	Male and female collegiate swimmers and divers	To determine the effect of season-long vitamin D supplementation on changes in vitamin D status, which is measured as 25(OH) D, body composition, inflammation, and frequency of illness and injury	6-month double-blind, randomized, placebo-controlled trial

Maroon *et al.* [13]	2015	80	Professional football league players	To assess vitamin D levels, including the prevalence of vitamin D deficiency/insufficiency, in professional American football players and to evaluate the association of vitamin D levels with race, fracture history, and the ability to obtain a contract position, which may be a marker for athletic performance	Cohort study
Julian *et al.* [5]	2016	14,624	Male and females aged 42-82 years	To assess the associations between physical activity, age and 25hydroxyvitamin D (25(OH)D) status separately and in combination with the incidence of fracture risk in the EPIC-Norfolk cohort study	Cohort study
Slater *et al.* [14]	2016	109	Female recreational exercisers	To describe the estimated prevalence of New Zealand recreational exercisers at risk for low energy availability	Cross-sectional survey study
Barrack *et al.* [15]	2017	69	Male adolescent athletes aged 13-19 years (n=51 endurance runners, n=18 non-runner athletes)	To evaluate the proportion of athletes with low bone mineral density and related single and multivariable risk factors previously associated with low bone mineral mass among a sample of male adolescent runner and non-runner athletes	Cross-sectional study

Dietary restriction is relatively common practice among individuals who partake in sport and exercise. Matching dietary energy intake to exercise energy expenditure is required to maintain optimal energy availability for athletes. An operational definition of energy availability, as outlined by the International Olympic Committee 2018 consensus statement on relative energy deficiency in sport [16]:

$$Energy\ availability = energy\ intake\ (kcal) - energy\ expendature\ (kcal)/fat\ free\ mass\ (FFM)\ (kg)$$

Nutritional strategies to reduce energy intake, resulting in low energy availability are most common for those competing in sports that emphasise leanness [6], such as weight category sports, gymnastics, and ballet. Low energy availability risk extends beyond sporting cohorts and has been found to be highly prevalent in recreational exercisers. Slater *et al.* [14] classified 45% of females who took part in an online low energy availability questionnaire (n = 109) to be at risk of low energy availability. The research further revealed concerning trends whereby significantly more individual than team sport participants were classified as having low energy availability, and all who reported previous stress fracture injuries to be in the "at risk" grouping. Low energy availability has been demonstrated to have detrimental short-term effects on markers of bone health, specifically an exercise-associated negative energy balance was associated with a decrease in the synthesis or serum concentration of IGF-1 and a decrease in bone collagen formation in male distance runners [17]. Therefore, the populations who employ a restricted energy intake strategy should be closely monitored for bone injury risk.

In female athletes, the link between dietary restraint and skeletal injury development is well established, with athletes who display disordered eating behaviours found to sustain more bone injuries, in addition to reporting a greater frequency of menstrual irregularities [6]. The negative impact of dietary restrictions on bone health is not reserved for female athletes only, low bone mineral density and high levels of dehydration were found to be prevalent in elite male jockeys who endured sport related injuries [7]. Warrington *et al.* [7] has additionally suggested causal links between skeletal injuries and weight-making practices through energy, nutritional and hydration restrictions. When assessed across a broad range of collegiate sports, Rauh *et al.* [8] reported a significant association between elevated dietary restraint and injuries lasting more than 22 days. Athletes should be aware of the notion that inadequate energy intake relative to expenditure, in addition to macro- and micro-nutrient deficiencies, may have important implications for athletes' skeletal injury risk. In accordance with recommendations provided by Papageorgiou *et al.* [18] athletes should avoid training and competing in a low energy state, identified as <30 kcal kgLBM−1 day−1. The IOC consensus statement on relative energy deficiency in sport [16] for healthy physiological function in females is 45 kcal/kg FFM/day (188kJ/ kg FFM/day). The outline cut-off may be used as a guideline, however, it should be noted that standardising across cohorts in applied research introduces errors; a cut-off of 30 Kcal/kg/FFM has been seen in tightly controlled lab studies, but this cut-off is not as clear in field research due to limitations in assessing energy availability. Individual differences such as body size and age, will additionally impact optimal energy intake. Importantly, significant drops in dietary energy intake should be avoided; the change in energy intake (reduction) maybe just as important as the chronic intake. Such unhealthy eating attitudes and behaviours have been found to be more apparent among athletes who develop injury [8].

From the empirical evidence, the food grouping with the greatest relation to skeletal injury risk has been reported to be dairy, likely due to its calcium content. The (low) calcium intake of female runners was found to be one of the five variables (lower dietary calcium intake, history of menstrual irregularity, lower bone mineral density, longer history of running, and running predominantly on hard ground) which contributed to the predicted risk of stress fractures with 75% success [10]. Those with history of stress fracture had a daily calcium intake from their diet of 904 ± 330 mg compared to the control group who consumed 1,111 ± 491 mg calcium through their diet alone. Interestingly, Wentz *et al.* [10] found total calcium intake from supplements + diet did not predict stress fracture risk in women as well as calcium from diet alone, suggesting the use of calcium supplementation may be an effective approach to disrupting the relationship between diet and stress fracture risk. Although seemingly suitable to supplement dietary intake, if calcium intake is mainly via supplement use, individuals should be aware of the increases in risk of nephrolithiasis and potential increased risk of cardiovascular events [11]. Further support for the notion that adolescent calcium intake has a significant influence on bone development was provided by Nieves *et al.* [9], who reported each additional cup of skim milk consumed per day to be associated with a 62% reduction in stress fracture incidence in female runners. A general dietary pattern trend of high dairy and low fat intake was further associated with a 68% reduction in stress fracture incidence [9]. Consumption of less than one serving of calcium-rich food per day has been reported as a risk factor for low bone mineral density in a male adolescent distance running cohort [15]. The long-term effects of calcium intake during childhood and adolescence have been highlighted by Wentz *et al.* [10] who found retrospective estimates of weekly servings of milk during middle school (one serving is 8 fluid oz) to significantly predict bone mineral density at four sites in a cohort of 18-40 year old female runners. However, the empirical evidence should be considered with some caution introduced by studies such as the meta-analysis undertaken by Tai and colleagues [19] who concluded increased calcium intake from diet or supplements has small effects on bone mineral density which are unlikely to lead to significant reductions in fracture risk.

Empirical evidence has additionally supported an association between vitamin D and stress fracture rates; however, the associations have not been consistent across age groups. Julian *et al.*[5] reported an inverse relationship between vitamin D status and fractures in middle aged adults and a J-shaped relationship for older adults. The contributions of vitamin D to decreased bone mineral density and increased fracture prevalence is pertinent to athletic populations, with groups such as professional football players revealed to be at greater risk of bone fracture with vitamin D deficiency [13]. Although not found to be directly related to injury, Lewis *et al.*[12] reported 77% of injuries during their study to coincide with decreases in 25-hydroxy vitamin D. If challenged to maintain a sufficient level through dietary intake or due to low UV exposure to the skin, 4,000 IU vitamin D supplementation has been recommended as an inexpensive intervention that effectively increased 25-hydroxy vitamin D [12], with likely positive effects on bone mineral density and skeletal injury risk. A review by Bouillon [20] reported daily sunlight exposure guidelines of 7–30 minutes (depending on latitude, skin colour and season) for hands, arms and the face to generate sufficient vitamin D and maintain serum levels of 25OHD above the minimal threshold required to maintain normal bone health. It should additionally be noted that in New Zealand, from May to October the sun is too low for the ultraviolet wavelength to penetrate the skin to help vitamin D, therefore supplements should be considered during this time.

Muscular injuries

Nutritional intake has been found to influence muscle damage, oxidative stress, immunity and inflammation markers [21]. Although these markers can be considered important insight for muscular injury, they also have associations with positive, adaptive responses, leading to muscle development. The current review synthesised the relevant information which may contribute to muscular injuries; however, the reader is advised that distinction between detrimental muscle damage, oxidative stress, inflammation markers and positive effects of recovery and adaptation processes are challenging to decipher [22]. Of the 16 informing studies, seven involved randomized, placebo-controlled designs, three were randomized, non-controlled by placebo studies, two were cross-sectional, two were repeated-measures crossover designs, one was a cohort design and one was a randomized controlled intervention (Table 2). It should be noted that no studies were identified which published placebo-controlled, randomised trials on nutrition for the prevention or treatment of "true" muscle injury during sport or exercise activity. Furthermore, literature within the area of muscular injury risk related to nutrition and hydration has tended to focus on the influence of the ingestion of specific nutrients in isolation, rather than whole foods or food groups, with a dominant focus on supplements. Challenges in whole food consumption are introduced as whole foods provide a range of antioxidant and matrix combinations not available in a single antioxidant nutrient supplement.

Table 2. Studies of nutrition, hydration, and muscular injuries

Reference	**Date**	**Sample (*n*)**	**Population characteristics**	**Objective**	**Study design**
Wojcik *et al.* [23]	2001	27	Untrained males	To examine the effects of carbohydrate, milk-based carbohydrate protein, or placebo beverages on glycogen resynthesis, muscle damage, inflammation, and muscle function following eccentric resistance exercise	Randomized, placebo-controlled study
Beaton *et al.* [24]	2002	18	Young, healthy, but currently inactive males	To determine the effect of vitamin E supplementation on indices of exercise-induced muscle damage and the post-exercise inflammatory response after performance of repeated eccentric muscle contractions	Randomized, double-blind, placebo-controlled study
Bloomer *et al.* [25]	2005	20	Resistance trained men	To determine the effects of astaxanthin supplementation on various indirect markers of muscle injury following eccentric exercise in trained men, with emphasis on muscle performance measures	Randomized, double-blind, placebo-controlled study
Beck *et al.* [26]	2007	20	Males untrained in resistance exercise	To examine the effects of a protease enzyme supplement on muscular strength and selected markers of muscle damage and DOMS after high-intensity eccentric muscle actions of the forearm flexors	Double-blinded, placebo-controlled, crossover design
Luden *et al.* [27]	2007	23	Male and female college cross-country runners	To compare the effects of 6 days of post-exercise carbohydrate and carbohydrate-protein-antioxidant beverage consumption on muscle damage, soreness, and subsequent performance in college cross-country runners	Repeated-measures crossover design

Koikawa *et al.* [28]	2009	30	Well-trained college runners	To investigate the pattern of delayed-onset muscle injury in well-trained athletes after a competitive half-marathon and the effects of post-race intake of wheat gluten hydrolysate	Randomized, non-controlled by placebo study
Betts *et al.* [29]	2009	17	Healthy young men	To examine systemic indices of muscle damage, inflammation, and recovery of muscle function, following strenuous exercise, with ingestion of either carbohydrate alone or a carbohydrate–protein mixture	Repeated-measures crossover design
Cooke *et al.* [30]	2010	17	Untrained males	To examine the effects of short-term consumption of whey protein isolate on muscle proteins and force recovery after eccentrically induced muscle damage in healthy individuals	Randomized, double-blind placebo-controlled
Gravina *et al.* [21]	2012	28	Females from 2 soccer teams of the same professional soccer club	To determine the effect of macro/micronutrient intake on markers of oxidative stress, muscle damage, inflammatory and immune response in female soccer players	Cross-sectional study
Hansen *et al.* [31]	2015	18	Elite male and female orienteers	To examine the effect of intake of whey protein hydrolysate plus carbohydrate compared with intake of isocaloric carbohydrate beverages before and after each running session during a training camp for elite orienteering runners with a very high training load	Randomized controlled intervention
Jakeman *et al.* [32]	2017	27	Physically active males	To assess whether an acute dose of omega-3 fish oil immediately following strenuous, eccentrically biased exercise would moderate symptoms of exercise-induced muscle damage	Randomized, double-blind, placebo-controlled study
Brown *et al.* [33]	2018	20	Physically active females from a University dance team	To examine the efficacy of whey protein hydrolysate gel supplementation on physiological and functional recovery following a bout of exercise designed to cause temporary muscle damage in females	Randomized, double-blind design
Pilpott *et al.* [34]	2018	30	Competitive male soccer players	To investigate the impact of adding fish oil–derived n-3PUFA to a whey protein, leucine, and carbohydrate containing supplement over a six-week period on acute recovery from eccentric muscle damage in competitive soccer players	Cohort design
Black *et al.* [35]	2018	20	Professional rugby union players	To assess the impact of a twice daily supplement of omega-3 polyunsaturated fatty acid (n-3 PUFA) combined with protein on muscle recovery in professional Rugby Union players during a 5-week training camp	Double-blind, placebo-controlled study

Miyamoto-Mikami *et al.* [36]	2019	1559	Japanese athletes	To test the hypothesis that the COL5A1 rs12722 polymorphism influences joint flexibility via passive muscle stiffness, and is accordingly associated with the incidence of muscle injury	Cross-sectional study
Córdova *et al.* [37]	2019	18	Elite male cyclists	To evaluate the effects of supplementation with 80 mg/day of iron on haematological parameters, serum cortisol and biochemical muscle indicators on elite male cyclists during the 3-week stage race the Vuelta a España	Randomized, non-controlled by placebo study

The influence of nutrient supplementation on muscle injury potential and recovery has produced conflicting results. Overall research has not provided overarching support for the use of supplements in relation to muscle injury prevention and recovery, with the ingestion of carbohydrate beverage [23], COL5A1 rs12722 polymorphism [36], astaxanthin supplement [25] and vitamin E [24] found to have no influence on inflammation, muscle function or injury. However, there has been some support for positive influence of omega-3 fish oil [32, 34, 35], iron [37], wheat gluten hydrolysate [28], protease enzyme [26] and carbohydrate-protein-anti-oxidant [27]. The positive findings have been reported across a range of cohorts and sports, rendering direct comparisons across studies a challenge. To better inform recommendations of the respective supplements, investigation of their effects on markers of muscle injury across multiple sports should be undertaken.

Unsurprisingly, given the crucial role of dietary protein in muscle protein turnover, one of the most widely studied supplements is whey protein. Inconsistent findings have been reported on the potential benefits of whey protein and as stated previously, caution should be taken with drawing direct associations between muscle damage and injury. Brown *et al.* [33] reported supplementation of whey protein hydrolysate (2 doses of 70 ml) across four days to be beneficial for the reduction of exercise-induced muscle damage symptoms and to be related to improved recovery of muscle function in physically active females. Following repeated sprint exercise, the authors demonstrated that compared to isocaloric carbohydrate supplementation, whey protein hydrolysate reduced the circulation of creatine kinase activity, attenuated the decline in relative strength index and accelerated recovery of hamstring flexibility [33]. Supplements of isolated whey protein have additionally been reported to contribute to small improvements in the maintenance of muscle strength in the days following eccentric muscle damage [30], along with reduced markers of muscle damage during strenuous training in elite orienteers [31]. Although benefits have been reported, the addition of whey protein to a dietary carbohydrate supplement following strenuous exercise has additionally been found to have a limited influence on muscle damage attenuation, inflammation or restore of muscle function compared to carbohydrate ingestion alone [29]. Furthermore, the timing of intake has been found to be an important feature of protein intake [38], current evidence advises for an even distribution of protein intake across the day, with appropriate protein boluses rather than a focus on total daily protein intake. Given the equivocal evidence to support the role of protein in muscle injury prevention, it may be the case that if sufficient protein intake is gained through dietary intake, by an athlete, additional intake through supplementation may not be of great benefit for muscle injury prevention. However, it should be noted that, with the exception of orienteering, the studies into whey protein effects on muscle damage have focused on exercise only. Further research into the influence of whey protein and muscle injury potential during sport activities is warranted to support recommendations for sporting populations.

Acute illness prevention

Upper respiratory tract infection/illness

All of the six studies which informed the review findings related to upper respiratory tract infection/illness (URI) were randomised placebo-control trials (Table 3. **Studies of dietary supplements, hydration and upper respiratory tract infections or illnesses**). Each of the studies considered the effects of a specified supplementation on a variety of aspects of URIs across populations including elite athletes, high school students and adolescent competitive swimmers.

Table 3. Studies of dietary supplements, hydration and upper respiratory tract infections or illnesses

Reference	**Date**	**Sample (*n*)**	**Population characteristics**	**Objective**	**Study design**
Haywood *et al.* [39]	2014	30	Elite rugby union players	To determine the effectiveness of probiotics on the number, duration and severity of infections amongst elite union rugby players	Randomized control trial with two arms; placebo and probiotic
West *et al.* [40]	2014	465	Physically active males and females	To examine the effect of daily supplementation with a single strain (Bifidobacterium lactis subsp lactis Bl-04) probiotic and double strain (Lactobacillus acidophilus NCFM and Bifidobacterium animalis subsp. Lactis Bi-07) on respiratory and gastrointestinal illness in healthy active individuals	Double-blind, placebo-controlled trial
Jones *et al.* [41]	2014	57	Regularly exercising males	To determine the effects of Bovine colostrum on innate and mucosal markers of immunity and the subsequent incidence of URI in regularly exercising males	Randomized, placebo-controlled study
Dubnov-Raz *et al.* [42]	2015	82	Adolescent competitive swimmers aged 12-21 years	To examine if vitamin D3 supplementation reduces URI burden in vitamin D-insufficient swimmers	Randomized, placebo-controlled study
Michalickova *et al.* [43]	2016	39	Elite athletes	To evaluate if Lactobacillus helveticus Lafti L10 (Lallemand Health Solutions, Montreal, Que., Canada) supplementation during 14 weeks in winter can influence the duration, severity, and incidence of upper respiratory tract illness, as well as to monitor different immune parameters in the population of elite athletes	Randomized, double-blind, placebo-controlled study
Somerville *et al.* [44]	2019	32	High school students who play sport for the elite team at their school	To determine the effect of olive leaf extract supplementation on URI incidence and duration in high school athletes	Randomized, double-blind, placebo-controlled trial

There is a current lack of evidence on the influence of whole food and food groups on URI, however, positive effects of supplement intake on URI have been reported in various athletic populations. A statement by the International Society of Sports Nutrition (ISSN) has shown beneficial effects of probiotic supplements on upper respiratory tract infections [45]. Supplementation of Lactobacillus Helveticus Lafti L10 (Lallemand Health Solutions, Montreal, Que., Canada) 2 × 10^{10} Colony Forming Units (CFU) daily for 14 weeks had a positive influence on the duration of URI during winter for an elite athletic population. However, the severity and incidence of URI was not influenced by the supplement [43]. Beneficial effects have also been seen in the reduction of URI duration and incidence in elite rugby players but again severity was not affected by probiotic supplementation [39]. A 27% reduction in URI risk was found as consequent to the consumption of probiotics, specifically, Bifidobacterium animalis subsp. lactis Bl-04 (one sachet daily of either 2.0 x 10^9 CFU per day of Bifidobacterium animalis subsp. lactis Bl-04 or L. acidophilus NCFM and Bifidobacterium animalis subsp. lactis Bi-07 1.0 x 10^{10} CFU per day (5.0 x 10^9 CFU of each strain) in a 1 g sucrose base or placebo powder (sucrose base without the probiotic bacteria) dissolved in a cold non-alcoholic beverage during the intervention period of 150 days) [40]. The probiotic supplement, along with others tested (Lactobacillus acidophilus NCFM and Bifidobacterium animalis subsp. lactis Bi-07), was associated with a delay in the time of URI. The findings by West *et al.* [40] may be of particular interest to those involved in competitive sport. However, results in females appear to be less conclusive, see ISSN review for full details on probiotics.

A study by Somerville *et al.* [44] found a reduction in URI duration through olive leaf extract supplementation, although URI incidence did not reduce in the high school athletic population studied. In regularly exercising males, bovine colostrum supplementation was found to limit microbial changes in the oral cavity during the winter months [41]. Compared to the isoenergetic/isomacronutrient placebo group, Jones *et al.* found the bovine colostrum group had a significantly lower number of URI episodes over a 12-week period; however, the supplement had no effect on severity or duration of URI episodes. Administering vitamin D_3 (2,000IU·d^{-1}) to adolescent swimmers with vitamin D insufficiency during winter showed some positive trends in the elevation of mean serum vitamin D concentrations, although the frequency, severity and duration of URI symptoms were not reduced by the intervention [42].

A new paradigm for exercise immunology has been presented by Walsh [46] which focuses on 'tolerance' (the ability to endure microbes and dampen defence activity) in an effort to progress from the contemporary focus on 'resistance' (the strength of the immune weaponry). The paradigm helps to further understanding of the potential for nutritional supplements with tolerogenic effects (probiotics and vitamins C and D) to reduce the infection burden in athletes. In addition to probiotics and vitamin D, there has been strong support for preventing URIs in athletes with no reported side effects. A review of five studies of heavy exercisers (n = 598) showed an ~50% decrease in URI incidence when taking 0.25-1.0 g/day of vitamin C [47]. However, it remains unclear if antioxidants blunt adaptation in well trained athletes.

Gastrointestinal issues

Five studies with a primary focus on running and cycling cohorts have investigated the contribution of nutrition and hydration factors to gastrointestinal issues (GI) (Table 4. **Studies of nutrition, hydration and gastrointestinal issues.**). Two studies focused on endurance athletes, one considering dietary factors associated with GI during a 70.3-mile triathlon [48] and the other during a 161-km ultramarathon [49].

Table 4. Studies of nutrition, hydration and gastrointestinal issues.

Reference	**Date**	**Sample (*n*)**	**Population characteristics**	**Objective**	**Study design**
West *et al.* [50]	2011	99	Male and female competitive cyclists	To evaluate the effectiveness of a probiotic on faecal microbiology, self-reported illness symptoms and immunity in healthy well-trained individuals	Double-blind, randomized, placebo-controlled trial

Sugihara *et al.* [51]	2014	8	Healthy active males	To determine the sodium concentration that induces hypervolemia with a minimal risk of gastrointestinal disturbance	Randomized crossover design
Wilson [48]	2016	53	Male and female triathletes	To assess whether pre-race dietary and non-dietary factors were associated with gastrointestinal distress during the cycle and run of a 70.3-mile triathlon	Observational design
Stuempfle *et al.* [49]	2016	30	161 km ultramarathon athletes	To explore possible contributing factors to gastrointestinal distress, including endotoxemia, hyperthermia, dehydration and nutrition, during a 161-km ultramarathon	Cross-sectional study
March *et al.* [52]	2019	12	Healthy males	To determine the effect of 14 days of bovine colostrum (Col) supplementation on intestinal cell damage (plasma intestinal fatty acid-binding protein, I-FABP) and bacterial translocation (plasma bacterial DNA) following exercise in the heat	Double-blind placebo-controlled crossover design

Significant associations between diet and GI symptoms have been evidenced in the literature. Low energy availability has been associated with negative GI functions, including stool leakage and constipation compared to those considered to have adequate energy availability [53]. In addition to low energy availability associations, specific nutritional groupings have been linked to GI issues in a variety of athletic populations. For example, during the cycle and run of a 70.3-mile triathlon, morning kilocalorie and carbohydrate intakes were associated with upper GI symptoms during the cycle and morning caffeine intake was associated with lower GI symptoms during the run [48]. The findings dictate the need for athletes to consider the potential increased risk of GI distress as consequence of higher race-morning energy, carbohydrate and caffeine intake. However, this must be balanced with careful consideration of the performance benefits of the aforementioned factors. Indeed, low energy availability has been linked to increased GI symptoms suggesting additional reasons to ensure fuelling is optimal at the start of an event. To decipher best practice for on an individual level, an athlete should practice nutritional strategies in training, thereby training the gut to be more efficient at absorbing nutrients as opposed to limiting or avoiding fuelling before or at the start of a race.

Beyond dietary nutrition, supplementation has also been reported to influence GI symptoms in athletic populations. Lactobacillus fermentum supplementation was found to be useful for reducing GI symptoms at high training loads for healthy exercising males, however, this finding was not reflected in well-trained females, with some evidence of an increase in symptoms [50]. In addition, the ingestion of oral bovine colostrum supplementation over 14 days demonstrated potential for the reduction of intestinal injury following exercise in the heat through mechanisms to blunt increases in plasma I-FABP [52].

Although there has been some evidence for the positive roles played by nutrition and hydration in GI, not all study findings have supported the association. For example, during 161km ultramarathon runners, inflammatory responses indicating gastrointestinal distress was not found to be influenced by race diet, hydration level or core temperature [49]. The need to consider athlete's nutrition and hydration statuses so as to tailor nutrient and fluid intake has been emphasised. Sugihara *et al.* [51] highlighted the importance of considering whether an athlete is hypohydrated or euhydrated to inform the sodium concentration of fluids. In the study, gastrointestinal upset (e.g. diarrhoea) was reported when subjects ingested fluids with sodium concentrations in excess of 120 mmol^{-1}.

Heat illness

The 4 studies with a primary focus on heat illness conducted their research across a range of cohorts between 2010 and 2016 (Table 5).

Table 5. Characteristics of the 4 studies examining effects of nutrition and/or hydration on heat issues.

Reference	Date	Sample (*n*)	Population characteristics	Objective	Study design
Batchelder *et al.* [54]	2010	17	College ice hockey players	Measure hydration status and gastrointestinal temperature in male ice hockey players during practice sessions.	Repeated measures design
Hillman *et al.* [55]	2011	7	Male trained cyclists	Investigate the effects of exercise-induced dehydration with and without hyperthermia on oxidative stress.	Randomized experimental design
Butts *et al.* [56]	2016	14	Healthy males and females	The effects of mild hypohydration compared to euhydration on the cooling efficacy of cold-water immersion.	Repeated measures design
Valentino *et al.* [57]	2016	30	Ultramarathon runners	Assess whether a loss of >2% body mass leads to elevations in core temperature during an ultramarathon	Cross-sectional study

Besides vasodilation, evaporative heat loss through sweating is the other primary defence against heat storage in the body. The loss of body fluids through sweating leads to dehydration, threatening fluid balance and further challenging blood redistribution to the muscles and skin [58]. Physical activity increases total metabolic rate to provide energy for skeletal muscle contraction, and 70 to almost 100% of this metabolically generated heat needs to be dissipated. Depending on environmental humidity, the hotter the environment, the greater the dependence on evaporative heat loss via sweating [59]. A reduction of the central circulating blood volume due to either reduced blood volume (hypovolemia) accompanying dehydration, or the dilation of the peripheral blood vessels, results in a fall in the cardiac filling pressure and stroke volume. If left uncompensated, cardiac output will be compromised.

With sweating, a reduction of total body water occurs in particular if adequate amounts of fluid are not consumed. The initial body water loss mostly comes from the blood volume and the fluid in between the cells. However, as body water loss increases, a proportionately greater percentage of water deficit comes from within the cells themselves [60]. Water appears to be lost from the plasma at a rate one to five times that of other fluid compartments, with relatively greater plasma water loss accompanied by sodium ions lost through sweat and urine. Nose and colleagues [61] investigated the relationship between sodium [Na+] in sweat and the distribution of body water during dehydrating exercise. A linear relationship exists between the change of extracellular fluid and the change in plasma volume, indicating that it is the increase in plasma concentration that shifts fluid from the intracellular to the extracellular compartments to maintain plasma volume. The amounts of electrolytes lost in sweat are typically reduced with heat acclimation as the sodium and chloride lost with sweat are primarily from the extracellular compartment. Over the course of heat acclimation, the sweat sodium concentration decreased by ~59% despite an increase of sweat rate by 12% [62]. Hence, for a given sweat rate in heat acclimated individuals, the solute lost from the plasma was significantly reduced, allowing for a greater shift of fluid from the intracellular to the extracellular compartments, which would lessen the loss of blood volume compared to an un-acclimated individual.

Hydration status plays an important role in relation to heat illness. Individuals' cooling rate may be altered as a result of hydration status changes (Butts *et al.,* 2016). The importance of fluid consumption during exercise in the heat and the ability for it to attenuate thermal and oxidative stress was demonstrated by Hillman *et al.* [55]. The study revealed exercise-induced dehydration to lead to an increase in oxidized glutathione concentration, while maintenance of euhydration attenuated these increases regardless of environmental condition [55]. In male college athletes, research has emphasised the need to implement prevention and rehydration strategies to reduce the potential for development of heat-related illness as a result of hypohydration during participation [54]. In exertionally hyperthermic individuals, mild hypohydration attenuates the rate of cooling, reducing the capacity to remove heat produced during exercise [56]. To prevent heat-related illness during prolonged exercise, Valentino *et al.* [57]

recommended athletes to use thirst as a guide for hydration management rather than fluid replacement for body mass loss.

Exercise Associated Hyponatremia (EAH)

Two studies with a primary focus on EAH and fluid consumption was identified in the literature, both with a focus on endurance events, specifically the Boston Marathon and the Western States Endurance Run (Table 6).

Table 6. Characteristics of the one study examining effects of nutrition and/or hydration on exercise-associated hyponatraemia issues.

Reference	**Date**	**Sample (*n*)**	**Population characteristics**	**Objective**	**Study design**
Almond *et al.* [58]	2005	488	2002 Boston Marathon runners	To estimate the incidence of hyponatremia and to identify the principal risk factors.	Cross-sectional study
Hoffman [59]	2018	627	Finishers of the Western States Endurance Run - 161 km, 5500m climb, 70000 m descent, 30 hour time limit	To predict the percentage of athletes at risk for exacerbation of EAH from indiscriminate hydration after an ultramarathon.	Cross-sectional study

Exercise-associated hyponatraemia (EAH) refers to a clinically relevant reduction in the serum, plasma or blood sodium concentration during or up to 24 hours after physical activity. This can be a result of solute (primarily sodium) loss and/ or excess fluid load [60]. The study of Boston marathon runners revealed the strongest predictor of EAH to be considerable weight gain, which was correlated with excessive fluid intake during the run. EAH was found to develop in more female than male runners, however, Almond *et al.*'s [58] observations suggest body size and longer racing time may account for the associations rather than sex per se. A study by Hoffman [59] further advocated caution for overhydrating during and after endurance events and found intravenous hydration following an ultramarathon to carry a notable risk for exacerbating EAH. When participating in long-lasting exercise, efforts should be taken to monitor fluid intake both during and following the event, particularly for females with low body mass.

4. Conclusions and general guidelines for practice

The myriad of intricate responses to nutrition and hydration, from cellular mechanisms to sex differences, provides a complex landscape for understanding of best practice for nutritional and fluid intake for injury and acute illness prevention during sport and exercise participation. Users are encouraged to consider recommendations for eating and drinking on an individual level, under the guidance of a qualified professional if possible, however, some general guidelines for practice have been determined from the scientific literature included in the current review.

Guidelines for Practice and Integration of Findings into SportSmart

Nutrition

- Nutrition and hydration status should be a key consideration in preventing injuries and acute illnesses, however, intake should be tailored to the needs of the athlete, baseline nutrition and hydration status and the demands of the sport.
- A balanced diet should be followed in accordance with the Ministry of Health guidelines which advocates for eating a variety of nutritious food every day (https://www.health.govt.nz/our-work/eating-and-activity-guidelines).
- Whole foods provide nutritional complexes which contain a variety of micronutrients not available in a single nutrient supplement.
- Dietary supplementation is only recommended if particular needs have been identified, e.g. restricted diet due to food allergy and should only be taken under the guidance of a dietician.

- Focus should be put onto developing healthy eating attitudes in attempt to avoid disordered eating behaviours that can lead to low energy availability, particularly in endurance and aesthetic sports and recreational exercisers with a goal of changing body composition.
- Coaches and athletes participating in aesthetic, endurance sports and recreational exercise that have an association with leanness should be aware of the increased prevalence of disordered eating and low energy availability risk.
- UV exposure and intake has minimal effect at maintaining vitamin D levels over winter months; supplementation should be undertaken if exposure is limited.
- Low energy availability has been associated with GI symptoms. However, higher race-morning energy, carbohydrates and caffeine intake may lead to GI distress. Pre-race fuelling balance should be practiced in training to train gut efficiency in absorbing nutrients.

Hydration

- To prevent heat-related illness during prolonged exercise, athletes are generally advised to drink according to thirst, rather than drinking for fluid replacement of body mass loss; however, for events longer than 90 minutes, scheduled drink reminders are advised.
- When participating in long-lasting exercise, efforts should be taken to monitor fluid intake both during and following the event, particularly for females with low body mass.

Limitations and Future Research

- Empirical research offers limited practical advice diet through nutritious foods and places greater focus on dietary supplements. Practical diet advice with increased scientific grounding is required for athletes and exercisers.
- Specific diets, e.g. vegetarian or vegan, were not a focus of the current review; consideration of their impact on injury and acute illness within sport and exercise cohorts to inform practical guidance should be undertaken within future research.
- Limited research has been undertaken to investigate eating and drinking patterns for injury and acute illness prevention.
- Although beyond the scope of the current review, the concept of personalised nutrition is one which may be considered to have notable potential to improve human health [61].
- At present, nutrition and hydration recommendations for muscular injury are generally related to markers, such as muscle damage, which have additional associations with adaptive responses leading to muscle development. Further research is required to distinguish between detrimental and beneficial nutrition and hydration for muscle injury prevention.
- The studies which have informed recommendations for calcium intake in association with skeletal injury risk have been primarily focused on runners. Further evidence from a range of sports is therefore warranted.
- Some evidence is provided for the potential benefits of whey protein on markers of muscle injury, however, further research which is inclusive of athletes across a broader span of sport activities is required.
- Future research should look towards investigating nutritional components of sustainable diets that are friendly to the planet and humans to provide sustainable dietary guidelines.

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Competing Interests Statement

The authors declare that there are no competing interests associated with the research contained within this manuscript.