IOC consensus statement: dietary supplements and the high-performance athlete

Ronald J Maughan,1 Louise M Burke,2,3 Jiri Dvorak,4 D Enette Larson-Meyer,5 Peter Peeling,6,7 Stuart M Phillips,8 Eric S Rawson,9 Neil P Walsh,10 Ina Garthe,11 Hans Geyer,12 Romain Meeusen,13 Lucas J C van Loon,14,15 Susan M Shirreffs,1 Pedro Peeling,6,7 Stuart M Phillips,8 Eric S Rawson,9 Neil P Walsh,10 Ina Garthe,11 Hans Geyer,12 Romain Meeusen,13 Lucas J C van Loon,14,15 Susan M Shirreffs,1

Abstract

Nutrition usually makes a small but potentially valuable contribution to successful performance in elite athletes, and dietary supplements can make a minor contribution to this nutrition programme. Nonetheless, supplement use is widespread at all levels of sport. Products described as supplements target different issues, including (1) the management of micronutrient deficiencies, (2) supply of convenient forms of energy and macronutrients, and (3) provision of direct benefits to performance or (4) indirect benefits such as supporting intense training regimens. The appropriate use of some supplements can benefit the athlete, but others may harm the athlete’s health, performance, and/or livelihood and reputation (if an antidoping rule violation results). A complete nutritional assessment should be undertaken before decisions regarding supplement use are made. Supplements claimed to directly or indirectly enhance performance are typically the largest group of products marketed to athletes, but only a few (including caffeine, creatine, specific buffering agents and nitrate) have good evidence of benefits. However, responses are affected by the scenario of use and may vary widely between individuals because of factors that include genetics, the microbiome and habitual diet. Supplements intended to enhance performance should be thoroughly trialled in training or simulated competition before being used in competition. Inadvertent ingestion of substances prohibited under the antidoping codes that govern elite sport is a known risk of taking some supplements. Protection of the athlete’s health and awareness of the potential for harm must be paramount; expert professional opinion and assistance is strongly advised before an athlete embarks on supplement use.

Introduction

Dietary supplements are used by athletes at all levels of sport, reflecting the prevalence of their use in the wider society. About half of the adult US population uses some form of dietary supplements,1 and although there are regional, cultural and economic differences, a similar prevalence is likely in many other countries. Athletes describe a range of different reasons for their supplement choices,2 and products that fit the description of ‘supplement’ can target various roles within the athlete’s performance plan. These include the maintenance of good health by contributing to the required intake of specific nutrients, the management of micronutrient deficiencies, and the provision of energy and macronutrient needs that might be difficult to achieve through food intake alone. Other specific uses of supplements reported by athletes include direct performance enhancement or the indirect benefits that arise from the provision of support for hard training, the manipulation of physique, the alleviation of musculoskeletal pain, rapid recovery from injury and enhancement of mood.

Some sporting bodies now support the pragmatic use of supplements that have passed a risk-versus-benefit analysis of being effective, safe and permitted for use, while also being appropriate to the athlete’s age and maturation in their sport. This review summarises the issues faced by high-performance athletes and their support team (coach, trainer, nutritionist, physician) when considering the use of supplements, with the goal of providing information to assist them to make informed decisions.

What is a supplement?

There is no single definition, either legal or within nutritional science, of what constitutes a dietary supplement. The US Congress, for example, in framing the 1994 Dietary Supplement Health and Education Act (DSHEA; https://ods.od.nih.gov/About/DSHEA_Wording.aspx), described a dietary supplement as:

‘…a product, other than tobacco, which is used in conjunction with a healthy diet and contains one or more of the following dietary ingredients: a vitamin, mineral, herb or other botanical, an amino acid, a dietary substance for use by man to supplement the diet by increasing the total daily intake, or a concentrate, metabolite, constituent, extract, or combinations of these ingredients’.

This definition is unsatisfactory, as it depends on whether or not a ‘healthy diet’ is consumed. For the purposes of this overview, we define a dietary supplement as the following:

A food, food component, nutrient, or non-food compound that is purposefully ingested in addition to the habitually consumed diet with the aim of achieving a specific health and/or performance benefit.
Furthermore, we recognise that dietary supplements come in many forms, including the following:

1. functional foods, foods enriched with additional nutrients or components outside their typical nutrient composition (eg, mineral-fortified and vitamin-fortified, as well as nutrient-enriched foods)
2. formulated foods and sports foods, products providing energy and nutrients in a more convenient form than normal foods for general nutrition support (eg, liquid meal replacements) or for targeted use around exercise (eg, sports drinks, gels, bars)
3. single nutrients and other components of foods or herbal products provided in isolated or concentrated forms
4. multi-ingredient products containing various combinations of those products described above that target similar outcomes.

PREVALENCE OF, AND RATIONALE FOR, USE BY ATHLETES

With such widespread use of supplements in the general population and with the specific focus of athletes on achieving peak performance, it is not surprising that a high prevalence of supplement use is reported in most surveys of athletes. Comparisons between surveys are confounded by numerous factors: these include differences in the definition of what constitutes a dietary supplement; ability to capture irregular use; inappropriate sample selection; and the use of non-validated and non-standardised survey instruments. Nevertheless, surveys generally suggest that supplement use:

1. varies across different sports and activities
2. increases with level of training/performance
3. increases with age
4. is higher in men than in women
5. is strongly influenced by perceived cultural norms (both sporting and non-sporting).

Although athletes often consume supplements to take advantage of intended/claimed effects or benefits, a range of motives underpin supplement use. For example, athletes use supplements:

1. to correct or prevent nutrient deficiencies that may impair health or performance
2. for convenient provision of energy and nutrients around an exercise session
3. to achieve a specific and direct performance benefit in competition
4. to gain a performance improvement indirectly accrued from outcomes such as allowing more effective training (ie, higher intensity, greater volume), better recovery from training sessions, optimising mass and body composition, or reducing risks of injury and illness
5. for financial gain (sponsorship) or because products are provided free of charge
6. as a ‘just in case’ insurance policy
7. because they know or believe that other athletes/competitors are using the supplement(s).

Some supplements may be used for multiple functions. Zinc, for example, may be taken with the aim of promoting wound healing and tissue repair, or reducing the severity and duration of the symptoms of an upper respiratory tract infection. Carbohydrate supplements are used to enhance performance in many events via the provision of fuel substrate, to support the immune system or to improve bioavailability of other supplements, for example, creatine. Similarly, creatine supplementation may directly enhance performance in strength and power events, and can assist in training harder, gaining lean body mass or maintaining lean mass during periods of immobilisation after injury. Decisions on supplement use therefore need to consider both the context of use and the specific protocol employed.

ASSESSING THE EVIDENCE BASE FOR SUPPLEMENT USE

Supplements target a range of scenarios of use, so different approaches are needed to assess their effectiveness. Supplements aimed at correcting nutrient deficiencies need to be judged on their ability to prevent or treat suboptimal nutrient status, with the benefit accruing from the removal of the associated impairment of health, training capacity or performance. The effectiveness of sports foods might be hard to isolate when they are used within the general diet to meet everyday energy needs and nutrient targets. However, benefits may be more easily detected when they are specifically consumed before, during or after an event or training session to provide nutrients that are limiting for performance (eg, to provide fuel for the muscle or brain) or to defend homeostasis (eg, by replacing water and salt losses). Performance-enhancing supplements, which are claimed to achieve direct or indirect benefits, pose a greater challenge in terms of a sound evidence base. With only a few exceptions, there is a scarcity of research, and many of the available studies are not of sufficient quality to warrant their application to elite athletes.

Substantiating the claims made about performance supplements and sports foods is difficult. To various audiences, ‘proof’ comes in different forms. Figure 1 provides a proposed hierarchical model of the relative strength of the evidence provided by different information sources. However, most of the information around supplement efficacy in sport comes from models with the lowest rigour: anecdotes/observations from athletes; and scientific or mechanistic hypotheses that explain how a supplement might target a critical/limiting factor in performance, but with little to no evidence. Systematic reviews and meta-analyses, which synthesise the outputs of many studies to yield a conclusive statement of efficacy in a broad sense, are at the top of the evidence hierarchy. While these summaries help to provide information about the general use of performance supplements, scientific trials that are properly controlled and well-conducted provide the basis for these reviews as well as an opportunity to address more specific questions about supplement applications. Thus, meta-analyses are a reflection only of the quality and quantity of the studies that are available for review, and may also be influenced by the inclusion and exclusion criteria applied to the available data.

The ‘gold standard’ for investigating the effects of supplements on sports performance is the prospective, randomised, controlled scientific trial, in which subjects are randomly allocated to receive either an experimental or placebo treatment (ideally in a double-blind manner) or crossed over to receive both treatments in counterbalanced order, under standardised conditions. Practical issues may cause some variations to ideal design, but sports scientists are encouraged, if they wish their results to be applicable to athletes in competition, to ensure that their studies include the following:

1. an adequate sample size and appropriate participant characteristics (eg, event, training status, calibre) to allow the results to have statistical power and to be applicable to high-performance athletes
2. mimicking, as far as possible, the conditions (eg, environment, nutrition preparation, event strategies) that exist in real-life competition

3. standardisation, to the extent that is possible, of variables that might influence the results (eg, pretial exercise and diet, environmental conditions, external encouragement or distraction)—it is recognised that this conflicts to some extent with (2) above, and will limit the situations in which the results can be applied
4. use of a protocol of supplement use (eg, specific product, dose and timing of intake) that is likely to optimise any effects
5. an independent verification of the contents of the supplement under investigation to ensure that the product is truly unadulterated, both to ensure the integrity of the study and to avoid inadvertent doping positives if the subjects are athletes
6. verification that the supplement was taken and induced a biological response (eg, via muscle, blood, urine or saliva sampling)
7. a performance protocol that is valid and sufficiently reliable to detect small but potentially meaningful changes/differences in performance outcomes
8. interpretation of results in light of the limitations of the study design and the change that would be meaningful to real-life sport.

Given the specificity of the information that is required by some athletes and their support staff to assess the effectiveness of a supplement (eg, related to a targeted event and its conditions, the specific individual, the combination with other performance strategies), it is unreasonable to expect that definitive evidence will always be available. Issues that are particularly under-researched and should be considered of high priority include measurement of performance in the field or under ‘real-life’ conditions, investigation of the combined use of a number of supplements, and the repeated use of supplements as might occur in multiday competition or when heats and finals occur close together. Scenarios that fall outside the scope of the available literature or practical research design may need to be interrogated by individual or small group case studies. Recommended methodologies for these studies include repeated baseline performances before the introduction of the supplement, or an alternating series of presentation and absence of the supplement.13

For the purposes of this overview, we rely primarily on studies of healthy adults that are relevant to athletes. We recognise that data from studies of elite athletes are almost entirely absent. We also recognise that mechanistic studies on animal and cell culture models are useful in identifying mechanisms, but a mechanism is not necessary to demonstrate an effect that may be meaningful to an athlete: what we think today to be the mechanism by which enhancement of performance or health occurs might be proved wrong by later studies. It must also be recognised that an individual’s habitual diet can affect gene expression and their microbiota, and these in turn can affect response to supplementation. While the variation in the genome between individuals is less than 0.01%, the variation in microbiota is significant (80%–90%), and emerging data suggest that both these factors could affect athletic performance.16 17 The following sections present an overview of the use of supplements to address different roles in sports nutrition, first by identifying the principles of use and then by examining some of the specific products that have a good or emerging evidence base to support this situation-specific use by athletes.

Supplements used to prevent or treat nutrient deficiencies
Many micronutrients play an important role in the regulation of processes that underpin sports performance, ranging from energy production to the manufacture of new cells and proteins. A frank deficiency of one or more of these nutrients may lead to a measurable impairment of performance—either directly or by reducing the athlete’s ability to train effectively (eg, iron deficiency anaemia) or to stay free from illness or injury (eg, impact of vitamin D deficiency on bone health). Athletes are not immune to the inadequate eating practices or the increased nutrient loss/requirements found in some members of the general population and may even be at greater risk of deficiencies because of increased nutrient turnover or increased losses. A further challenge is the occurrence of subclinical deficiencies that may be both hard to assess (ie, they lack a clear metric or universal threshold of what is ‘adequate’) as well as being subject to debate about whether there is an ‘optimal’ level for performance that differs from the usual classification systems of nutrient status (deficiency/subclinical deficiency/normal). When suboptimal nutritional status is diagnosed, the use of a nutrient supplement to reverse
Table 1 Examples of micronutrients often requiring supplementation in athletes (see Larson-Meyer et al. for additional information)

<table>
<thead>
<tr>
<th>Micronutrient</th>
<th>Overview</th>
<th>Diagnosis and outcomes of insufficiency</th>
<th>Protocols and outcomes of supplementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vitamin D</td>
<td>It is important in the regulation of gene transcription in most tissues, so insufficiency/deficiency affects many body systems. Many athletes are at risk of insufficiency at various times throughout the year.</td>
<td>No consensus over the serum 25-hydroxyvitamin D concentration (the marker of vitamin D status) that defines deficiency, insufficiency, sufficiency and a tolerable upper limit. The need to supplement depends on UVB exposure and skin type.</td>
<td>Supplementation of between 800 IU and 1000–2000 IU/day is recommended to maintain status for the general population. Supplementation guidelines are not yet established in athletes. Short-term, high-dose supplementation which includes 50 000 IU/week for 8–16 weeks or 10 000 IU/day for several weeks may be appropriate for restoring status in deficient athletes. Careful monitoring is necessary to avoid toxicity.</td>
</tr>
<tr>
<td>Iron</td>
<td>Suboptimal iron status may result from limited iron intake, poor bioavailability and/or inadequate energy intake, or excess iron need due to rapid growth, high-altitude training, menstrual blood loss, foot-strike haemolysis, or excess losses in sweat, urine or faeces.</td>
<td>Several measures performed simultaneously provide the best assessment and determine the stage of deficiency. Recommended measures: serum ferritin, transferrin saturation, serum iron, transferrin receptor, zinc protoporphyrin, haemoglobin, haematocrit and mean corpuscular volume.</td>
<td>Athletes who do not maintain adequate iron status may need supplemental iron at doses greater than their RDA (ie, &gt;18 mg/day for women and &gt;6 mg/day for men). Athletes with iron deficiency require clinical follow-up, which may include supplementation with larger doses of oral iron supplementation along with improved dietary iron intake. Numerous oral iron preparations are available and most are equally effective as long as they are taken. High-dose iron supplements, however, should not be taken unless iron deficiency is present.</td>
</tr>
<tr>
<td>Calcium</td>
<td>Avoidance of dairy products and other calcium-rich foods, restricted energy intake and/or disordered eating increases risk of suboptimal calcium status.</td>
<td>There is no appropriate indicator of calcium status. Bone mineral density scan may be indicative of chronic low calcium intake, but other factors including suboptimal vitamin D status and disordered eating are also important.</td>
<td>Calcium intakes of 1500 mg/day and 1500–2000 IU vitamin D are recommended to optimise bone health in athletes with low energy availability or menstrual dysfunction.</td>
</tr>
</tbody>
</table>

Note: Indiscriminate supplementation with any of the above nutrients is not recommended. Deficiencies should first be identified through nutritional assessment, which includes dietary intake and the appropriate blood or urinary marker, if available.

Consensus statement

Supplements that directly improve sports performance

A few performance-enhancing supplements might, at the present time, be considered to have an adequate level of support to suggest that marginal performance gains may be possible. These supplements include caffeine, creatine (in the form of creatine monohydrate), nitrate, sodium bicarbonate and possibly also Beta-alanine. The mechanisms of action, typical dose, potential performance benefits and known side effects of each of these supplements are summarised in Table 2. Performance-enhancing supplements should be considered only where a strong evidence base supports their use as safe, legal and effective, and ideally after adequacy of sports nutrition dietary practices is ensured. Whenever possible, supplements should be trialled thoroughly by the athlete in training to mimic the competition milieu as closely as possible before committing to use in a competition setting. Athletes should do a careful risk analysis to see if the marginal gains would outweigh the risk of inadvertent doping due to contamination.

Supplements that improve performance indirectly

Many dietary supplements claim to enhance performance indirectly—by supporting the athlete’s health, body composition, and their ability to train hard, recover quickly, adapt optimally, avoid or recover from injury, and tolerate pain or soreness. Illness is a major problem for athletes if it interrupts training or occurs at a critical time, such as during a selection event or a major competition. Susceptibility to illness is increased in situations where athletes are involved in a high volume of training or competition, and either intentionally or unintentionally experience deficits in energy intake (eg, weight loss diets), macronutrient intake (eg, train-low or sleep-low-carbohydrate) and micronutrient status (eg, vitamin D insufficiency in the winter). Athletes might benefit from nutritional supplements to support...
Summary of common sports foods and functional foods used by athletes.

<table>
<thead>
<tr>
<th>Sports food</th>
<th>Form</th>
<th>Typical composition</th>
<th>Common sports-related use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sports drink</td>
<td>Powder or ready to drink liquid</td>
<td>5%–8% CHO, 10–35 mmol/L sodium, 3–5 mmol/L potassium</td>
<td>Simultaneous delivery of fluid + CHO during exercise</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Post-exercise rehydration and refuelling</td>
</tr>
<tr>
<td>Energy drink</td>
<td>Ready-to-drink liquid or concentrated shot</td>
<td>Carbohydrate, especially in typical ready-to-drink varieties, caffeine. Note: may contain taurine, B vitamins and other ingredients with variable supporting evidence and some level of concern</td>
<td>Pre-exercise caffeine supplement</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Carbohydrate and caffeine intake during exercise</td>
</tr>
<tr>
<td>Sports gel or sports confectionery</td>
<td>Gel: 30–40 g sachets confectionery: jelly-type confectionery (generally in pouch of ~40–50 g)</td>
<td>~25 g CHO per sachet or ~5 g CHO per confectionery piece, Some contain caffeine or electrolytes</td>
<td>Carbohydrate intake during exercise</td>
</tr>
<tr>
<td>Electrolyte replacement supplements</td>
<td>Powder sachets or tablets</td>
<td>Powder sachets or tablets: 50–60 mmol/L sodium, 10–20 mmol/L potassium, Typically, low carbohydrate (2–4 g/100 mL)</td>
<td>Rapid rehydration following dehydration undertaken for weight-making</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Replacement of large sodium losses during ultra-endurance activities</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rapid post-exercise rehydration following moderate to large fluid and sodium deficits</td>
</tr>
<tr>
<td>Protein supplement</td>
<td>Powder (mix with water or milk) or ready-to-drink liquid Protein-rich bar, usually low in CHO</td>
<td>Provides 20–50 g protein in a single serve from high-quality types of animal (whey, casein, milk, egg) or vegetable (e.g., soy) origin, Note: may contain other ingredients, some of which are not evidence-based and may increase the risk of contamination</td>
<td>Post-exercise recovery following key training sessions or events where adaptation requiring protein synthesis is desired</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Achievement of increase in lean mass during growth or response to resistance training</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Portable nutrition for busy schedule or travel</td>
</tr>
<tr>
<td>Liquid meal supplement</td>
<td>Powder (mix with water or milk) or ready-to-drink liquid</td>
<td>1–1.5 kcal/mL, 15%–20% protein and 50%–70% CHO, Low to moderate fat Vitamins/minerals: 500–1000 mL supplies RDI/RDAs</td>
<td>Supplement high-energy diet (especially during heavy training/competition or weight gain)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Low-bulk meal replacement (especially pre-event meal)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Post-exercise recovery (CHO and protein)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Portable nutrition for busy schedule or travel</td>
</tr>
<tr>
<td>Sports bar</td>
<td>Bar</td>
<td>40–50 g CHO, 5–10 g protein, Usually low in fat and fibre Vitamins/minerals: 50%–100% of RDA/RDIs, Note: may contain other ingredients, some of which are not evidence-based and may increase the risk of contamination</td>
<td>CHO source during exercise</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Post-exercise recovery—provides CHO, protein and micronutrients</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Portable nutrition for busy schedule or travel</td>
</tr>
<tr>
<td>Protein-enhanced food</td>
<td>Milk, yoghurt, ice cream, cereal bars and other food forms</td>
<td>Increased protein content from normal food variety achieved by adding protein sources or filtration of water from product, Typically allows normal portion to provide ~20 g protein to meet sports nutrition target</td>
<td>Value-added food able to achieve protein target for post-exercise use or to improve protein content of other meals and snacks in an athlete’s diet</td>
</tr>
</tbody>
</table>

**CHO**, carbohydrate.
Table 3: Supplements with good to strong evidence of achieving benefits to performance when used in specific scenarios

**Beta-Alanine**

**Overview**
Caffeine is a stimulant that possesses well-established benefits for athletic performance across endurance-based situations, and short-term, supramaximal and/or repeated sprint tasks.

**Mechanism**
Adenosine receptor antagonism; increased endorphin release; improved neuromuscular function; improved vigilance and alertness; reduced the perception of exertion during exercise.14 48

**Protocol of use**

| Loading phase: ~20 g/day (divided into four equal daily doses), for 5–7 days.85 |
| Loading phase: ~3–5 g/day (single dose) for the duration of the supplementation period.6 |

**Performance Impact**
Enhanced endurance performance resulting from increased/improved protein synthesis, glycogen storage and thermoregulation.64 65

Less common: enhanced endurance performance resulting from increased/improved protein synthesis, glycogen storage and thermoregulation.64 65

**Further considerations and potential side effects**
Larger caffeine doses (~9 mg/kg BM) do not appear to increase the performance benefit,66 and are more likely to increase the risk of negative side effects, including nausea, anxiety, insomnia and restlessness.26

Lower caffeine doses, variations in the timing of intake before and/or during exercise, and the need for (or lack thereof) a caffeine withdrawal period should be trialled in training prior to competition use.

Caffeine consumption during activity should be considered concurrent with carbohydrate (CHO) intake for improved efficacy.52

**Creatine**
Overview: 
Creatine loading can acutely enhance the performance of sports involving repeated high-intensity exercise (eg, team sports), as well as the chronic outcomes of training programmes based on these characteristics (eg, resistance or interval training), leading to greater gains in lean mass and muscular strength and power.58 59

Mechanism:
Supplementation increases muscle creatine stores, augmenting the rate of PCr resynthesis, thereby enhancing short-term, high-intensity exercise capacity.60 67

**Protocol of use**

| Loading phase: ~20 g/kg BM, ~200 mg, provided both before and during exercise; consumed with a CHO source.68 |
| Loading phase: ~3–6 mg/kg BM of caffeine taken 50–60 min before exercise results in performance gains of >3% for task completion time, mean power output and peak power output during anaerobic activities of 1–2 min in duration;52 and of 1%–8% for total work output and repeat sprint performances during intermittent team game activity.44 51

**Performance Impact**
Enhanced maximum isometric strength.63 and the acute performance of single and repeated bouts of high-intensity exercise (<150 s duration); most pronounced effects evident during tasks <30 s.64 65

Chronic training adaptations include lean mass gains and improvements to muscular strength and power.38 39

Less common: enhanced endurance performance resulting from increased/improved protein synthesis, glycogen storage and thermoregulation.64 65

Potential anti-inflammatory and antioxidant effects are noted.66

Further considerations and potential side effects
No negative health effects are noted with long-term use (up to 4 years) when appropriate loading protocols are followed.67

A potential 1–2 kg BM increase after creatine loading (primarily as a result of water retention) may be detrimental for endurance performance or in events where the BMI must be moved against gravity (eg, high jump, pole vault) or where athletes must achieve a specific BM target.

**Nitrate**
Overview: 
Dietary nitrate (NO3−) is a popular supplement that has been commonly investigated to assess any benefits for prolonged submaximal exercise.9 10 11 12 and high-intensity, intermittent, short-duration efforts.70 71

Mechanism:
Enhances nitric oxide (NO) bioavailability via the NO−-nitrite-NO pathway, playing an important role in the modulation of skeletal muscle function.52

Nitrate augments exercise performance via an enhanced function of type II muscle fibres;75 a reduced ATP cost of muscle force production; an increased efficiency of mitochondrial respiration; an increased blood flow to the muscle; and a decrease in blood flow to VO2 heterogeneities.74

Protocol of use:
High nitrate-containing foods include leafy green and root vegetables, including spinach, rocket salad, celery and beetroot.

Acute performance benefits are generally seen within 2–3 hours following an NO− bolus of 5–9 mmol (310–560 mg).75

Prolonged periods of NO− intake (>3 days) also appear beneficial to performance.90 91 and may be a positive strategy for highly trained athletes, where performance gains from NO− supplementation appear harder to obtain.92

Performance impact: 
Supplementation has been associated with improvements of 4%–25% in exercise time to exhaustion and of 1%–3% in sport-specific TT performances lasting <40 min in duration.73 76

Supplementation is proposed to enhance type II muscle fibre function, resulting in the improvement (3%–5%) of high-intensity, intermittent, team-sport exercise of 12–40 min in duration.70 71

Evidence is equivocal for any benefit to exercise tasks lasting <12 min.76 79

Further considerations and potential side effects: 
The available evidence suggests there appear to be few side effects or limitations to nitrate supplementation.

There may exist the potential for GI upset in susceptible athletes, and should therefore be thoroughly trialled in training.

There appears to be an upper limit to the benefits of consumption (ie, no greater benefit from 16.8 mmol (1041 mg) vs 8.4 mmol (521 mg)).80

Performance gains appear harder to obtain in highly trained athletes.77

**Beta-alanine**
Overview:
Beta-alanine augments intracellular buffering capacity, having potential beneficial effects on sustained high-intensity exercise performance.

Mechanism:
A rate-limiting precursor to the endogenous intracellular (muscle) buffer, carnosine; the immediate defence against proton accumulation in the contracting musculature during exercise.84

Chronic, daily supplementation of Beta-alanine increases skeletal muscle carnosine content.82

**Consensus statement**

---


Continued
ADVERSE EFFECTS

Adverse effects from the use of supplements may arise from a number of factors, including the safety and composition of the product per se and inappropriate patterns of use by athletes. Poor practices by athletes include the indiscriminate mixing and matching of many products without regard to total doses of some ingredients or problematic interactions between ingredients. Even commonly used products may have negative side effects, especially when used outside the optimal protocol. For example, iron supplementation in those with already adequate iron stores especially when used outside the optimal protocol. F

Further considerations and potential side effects

Further considerations and potential side effects include skin rashes and/or transient paraesthesia.

Sodium bicarbonate

Overview

Sodium bicarbonate augments extracellular buffering capacity, having potential beneficial effects on sustained high-intensity exercise performance.

Mechanism

Acts as an extracellular (blood) buffer, aiding intracellular pH regulation by raising the extracellular pH, and HCO₃⁻ concentrations.

Protocol of use

Single acute NaHCO₃ dose of 0.2–0.4 g/kg BM, consumed 60–150 min prior to exercise. Alternative strategies include the following:

- Split doses (ie, several smaller doses giving the same total intake) taken over a time period of 30–180 mins
- Serial loading with 3–4 smaller doses per day for 2–4 consecutive days prior to an event

Performance impact

Enhanced performance (~2%) of short-term, high-intensity sprints lasting ~60 s in duration, with a reduced efficacy as the effort duration exceeds 10 min.

Further considerations and potential side effects

Well-established GI distress may be associated with this supplement. Strategies to minimise GI upset include the following:

- Concoction with a small, carbohydrate-rich meal (~1.5 g/kg BM carbohydrates)
- Use of sodium citrate as an alternative
- Split dose or stacking strategies

Given the high potential for GI distress, thorough investigation into the best individualised strategy is recommended prior to use in a competition setting.

Table 3 Continued

Beta-Alanine

Coffeine

Protocol of use

Daily consumption of ~65 mg/kg BM, ingested via a split-dose regimen (ie, 0.8–1.6 g every 3–4 hours) over an extended supplement time frame of 10–12 weeks.

Performance impact

Small, but potentially meaningful performance benefits (~0.2%–3%) during both continuous and intermittent exercise tasks of 30 s to 10 min in duration.

Further considerations and potential side effects

A positive correlation between the magnitude of muscle carnosine change and performance benefit remains to be established. Large interindividual variations in muscle carnosine synthesis have been reported. The supplement effectiveness appears harder to realise in well-trained athletes. There is a need for further investigation to establish the practical use in various sport-specific situations. Possible negative side effects include skin rashes and/or transient paraesthesia.

Sodium bicarbonate

Overview

Sodium bicarbonate augments extracellular buffering capacity, having potential beneficial effects on sustained high-intensity exercise performance.

Mechanism

Acts as an extracellular (blood) buffer, aiding intracellular pH regulation by raising the extracellular pH, and HCO₃⁻ concentrations.

Protocol of use

Single acute NaHCO₃ dose of 0.2–0.4 g/kg BM, consumed 60–150 min prior to exercise. Alternative strategies include the following:

- Split doses (ie, several smaller doses giving the same total intake) taken over a time period of 30–180 mins
- Serial loading with 3–4 smaller doses per day for 2–4 consecutive days prior to an event

Performance impact

Enhanced performance (~2%) of short-term, high-intensity sprints lasting ~60 s in duration, with a reduced efficacy as the effort duration exceeds 10 min.

Further considerations and potential side effects

Well-established GI distress may be associated with this supplement. Strategies to minimise GI upset include the following:

- Concoction with a small, carbohydrate-rich meal (~1.5 g/kg BM carbohydrates)
- Use of sodium citrate as an alternative
- Split dose or stacking strategies

Given the high potential for GI distress, thorough investigation into the best individualised strategy is recommended prior to use in a competition setting.


Consensus statement
## Table 4  Nutritional supplements for immune health in athletes: proposed mechanism of action and evidence for efficacy

<table>
<thead>
<tr>
<th>Supplement</th>
<th>Proposed mechanism of action</th>
<th>Evidence for efficacy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vitamin D</td>
<td>This is an essential fat-soluble vitamin known to influence several aspects of immunity, particularly innate immunity (eg, expression of antimicrobial proteins). Skin exposure to sunlight accounts for 90% of the source of vitamin D.</td>
<td>Moderate support Evidence for deficiency in some athletes and soldiers, particularly in the winter (decreased skin sunlight exposure) Deficiency has been associated with increased URS. Recommend 1000 IU/day D₃, autumn-spring to maintain sufficiency Further support required</td>
</tr>
<tr>
<td>Probiotics</td>
<td>Probiotics are live micro-organisms that when administered orally for several weeks can increase the numbers of beneficial bacteria in the gut. These have been associated with a range of potential benefits to gut health, as well as modulation of immune function.</td>
<td>Moderate support in athletes with daily dose of −10¹⁵ live bacteria Cochrane review of 12 studies (n=3720) shows −50% decrease in URS incidence and −2 day shortening of URS; minor side effects. More evidence is required supporting efficacy to reduce gastrointestinal distress and infection, for example, in a travelling athlete. Further support required</td>
</tr>
<tr>
<td>Vitamin C</td>
<td>This is an essential water-soluble antioxidant vitamin that quenches ROS and augments immunity. It reduces interleukin-6 and cortisol responses to exercise in humans.</td>
<td>Moderate support for ‘preventing URS’ Cochrane review of 5 studies in heavy exercisers (n=598) shows −50% decrease in URS taking vitamin C (0.25–1.0 g/day). Further support required Unclear if antioxidants blunt adaptation in well-trained athletes Relatively small effects on cortisol compared with carbohydrate; immune measures no different from placebo. No support for ‘treating URS’. Cochrane reviews show no benefit of initiating vitamin C supplementation (&gt;200 mg/day) after onset of URS</td>
</tr>
<tr>
<td>Carbohydrate (drinks, gels)</td>
<td>It maintains blood glucose during exercise, lowers stress hormones, and thus counters immune dysfunction.</td>
<td>Low-moderate support Ingestion of carbohydrate (30–60 g/hour) attenuates stress hormone and some, but not all, immune perturbations during exercise. Very limited evidence that this modifies infection risk in athletes. Further support required</td>
</tr>
<tr>
<td>Bovine colostrum</td>
<td>First milk of the cow that contains antibodies, growth factors and cytokines Claimed to improve mucosal immunity and increase resistance to infection.</td>
<td>Low-moderate support that bovine colostrum blunts the decrease in saliva antimicrobial proteins after hard exercise. Some evidence in small numbers of participants that bovine colostrum decreases URS. Further support required</td>
</tr>
<tr>
<td>Polyphenols, for example, Quercetin</td>
<td>These are plant flavonoids. In vitro studies show strong anti-inflammatory, antioxidant and antipathogenic effects. Animal data indicate an increase in mitochondrial biogenesis and endurance performance.</td>
<td>Low-moderate support Human studies show some reduction in URS during short periods of intensified training and mild stress. Some support for modulation of mitochondrial biogenesis and endurance performance, although in small numbers of untrained subjects. Limited influence on markers of immune function Putative antiviral effect for Quercetin Further support required</td>
</tr>
<tr>
<td>Zinc</td>
<td>This is an essential mineral that is claimed to reduce incidence and duration of colds. Zinc is required for DNA synthesis and as an enzyme cofactor for immune cells. Zinc deficiency results in impaired immunity (eg, lymphoid atrophy) and zinc deficiency is not uncommon in athletes.</td>
<td>No support for ‘preventing URS’. High doses of zinc can decrease immune function and should be avoided. Moderate support for ‘treating URS’. Cochrane review shows benefit of zinc acetate lozenges (75 mg) to decrease duration of URS; however, zinc must be taken &lt;24 hours after onset of URS for duration of cold only. Side effects include bad taste and nausea.</td>
</tr>
<tr>
<td>Glutamine</td>
<td>This is a non-essential amino acid that is an important energy substrate for immune cells, particularly lymphocytes. Circulating glutamine is lowered after prolonged exercise and very heavy training.</td>
<td>Limited support Supplementation before and after exercise does not alter immune perturbations. Some evidence of a reduction in URS after endurance events in competitors receiving glutamine supplementation (2×5 g) Relatively small effects on cortisol and some, but not all, immune perturbations during exercise. Unclear if antioxidants blunt adaptation in well-trained athletes Further support required</td>
</tr>
<tr>
<td>Caffeine</td>
<td>This is a stimulant found in a variety of foods and drinks (eg, coffee and sports drinks). Caffeine is an adenosine receptor antagonist and immune cells express adenosine receptors.</td>
<td>Limited support Evidence that caffeine supplementation activates lymphocytes and attenuates the fall in neutrophil function after exercise. Efficacy for altering URS in athletes remains unknown.</td>
</tr>
<tr>
<td>Echinacea</td>
<td>This is a herbal extract claimed to enhance immunity via stimulatory effects on macrophages. There is some in vitro evidence for this.</td>
<td>Limited support Early human studies indicated possible beneficial effects, but more recent, larger scale and better controlled studies indicate no effect of Echinacea on infection incidence or cold symptom severity.</td>
</tr>
<tr>
<td>Omega-3 PUFAs</td>
<td>Found in fish oil May influence immune function by acting as a fuel, in their role as membrane constituents or by regulating eicosanoid formation, for example, prostaglandin Prostaglandin is immunosuppressive Claimed to exert anti-inflammatory effects postexercise</td>
<td>Limited support for blunting inflammation and functional changes after muscle-damaging eccentric exercise in humans and no evidence of reducing URS in athletes</td>
</tr>
<tr>
<td>Vitamin E</td>
<td>An essential fat-soluble antioxidant vitamin that quenches exercise-induced ROS and augments immunity</td>
<td>No support Immune-enhancing effects in the frail elderly but no benefit in young, healthy humans One study actually showed that vitamin E supplementation increased URS in those under heavy exertion. High doses may be pro-oxidative.</td>
</tr>
</tbody>
</table>

**Consensus statement**

Nutritional supplements are likely to provide modest benefits for acute and chronic URS in well-trained athletes, mainly through a combination of antioxidant, anti-inflammatory and anti-proapoptotic effects, and direct modulation of immunity. Further work is required to validate efficacy in larger, controlled clinical trials. Prospective work is needed to develop protocols for optimal dosing, frequency and time to onset of action with specific supplements, while also considering potential adverse effects.

---

Some supplements may actually cause harm to health, but these can be difficult to identify, and products are usually withdrawn only after a significant number of adverse events have occurred. For example, a range of products containing hydroxycitric acid were withdrawn from sale, but only after they were linked with the death of one consumer and with a substantial number of other cases of liver toxicity, cardiovascular problems and seizures (https://www.fda.gov/downloads/safety/recalls/enforcementreports/ucm169089.pdf). The extent of this problem is illustrated by the fact that, in the USA in 2015, approximately 23,000 emergency department visits annually are reported to be associated with dietary supplement use. This figure can be viewed as substantial, or it can be seen as small compared with the total number of adverse responses associated with the use of medications. However, minor problems that do not require acute medical aid may still be sufficient to interrupt training or prevent participation, so this statistic probably underestimates the risk for athletes.

The biggest concern for athletes who compete under an anti-doping code (usually the World Anti-Doping Code, as published by WADA) is that supplements can contain prohibited substances that result in an antidoping rule violation (ADRV). Athletes—and their support teams—may be at risk for an ADRV if there is evidence that they have used or attempted to use products containing ingredients on the Prohibited List (www.wadaama.org). A common problem is the recording of an adverse analytical finding (AAF) of a prohibited substance in a urine sample (‘positive drug test’) as a result of supplement use. Millions of athletes may be subject to antidoping testing, although these are mostly professional-level, national-level or international-level athletes. For these athletes in particular, even if the ingestion of the prohibited substance was unintentional, the rules of strict liability within the World Anti-Doping Code mean that an AAF will be recorded, and may mean the loss of medals won or records set, and financial sanctions as well as temporary or permanent suspension from competition. It also damages the athlete’s reputation and may lead to loss of employment and income through failed sponsorship opportunities. Where there has been deliberate cheating or benefit accrued from the use of a prohibited substance, these penalties seem entirely appropriate, but it is undoubtedly true that some ADRVs can be attributed to the innocent ingestion of prohibited substances in dietary supplements, with catastrophic results for the athlete.

One cause of an AAF arising from supplement use relates to an athlete’s failure to read product labels to recognise the presence of prohibited substances. Many athletes consider supplements to be ‘natural’ or ‘regulated’ and therefore safe. Other athletes are confused by the number of chemical names for some prohibited substances and thus fail to recognise them on the product label. However, the most worrying cause of an inadvertent AAF is the use of supplements that contain prohibited substances as an undeclared ingredient or contaminant. Since the publication of the seminal study on the presence of undeclared prohibited substances in supplements,32 there have been numerous reports of supplement contamination. Recent reviews suggest that this problem remains (http://www.informed-sport.com/news/australian-supplements-survey-highlights-need-testing). It is difficult to gain a perspective of the true prevalence of supplement contamination. Although the original study reported that ~15% of more than 600 products acquired from around the world contained undeclared prohormones, this and other investigations rarely include a truly random sample of the supplements and sports foods used by athletes. Some individual products or categories of products can be considered inherently more at risk of contamination due to the country of origin, the manufacturer, the type of product and the range of declared ingredients (https://www.usada.org/substances/supplement-411). Nevertheless, it should also be recognised that common supplements, including vitamin C, multivitamins and minerals, have also been found, although rarely, to contain prohibited substances. The range of prohibited substances found as undeclared ingredients in supplements now includes products from many sections of WADA’s List of Prohibited Substances and Methods, including stimulants, anabolic agents, selective androgen receptor modulators, diuretics, anorectics and β2 agonists.

In some cases, the amount of the prohibited substance in a supplement may be high, even higher than the normal therapeutic dose. For example, Geyer et al38 reported the analysis of metandienone (commonly known as methandrostenolone or Dianabol) in high amounts in a ‘body building’ supplement from England. The recommended amount of the supplement would have supplied a dose of 10–43 mg; in comparison, the typical therapeutic dose of this drug was 2.5–5 mg/day, although its medical use has been discontinued in most countries for many years. This amount would certainly have a potent anabolic effect, but would likely produce serious side effects, including psychiatric and behavioural effects, and significant damage to a range of body systems including the liver. Unlike many of the earlier cases involving steroids related to nandrolone and testosterone, this is not a trivial level of contamination and raises the possibility of deliberate adulteration of the product with the intention of producing a measurable effect on muscle strength and muscle mass. Most reports of adverse health outcomes resulting from supplement use have focused on liver problems of varying degrees of severity, but other organs are also affected. One epidemiological case–control study39 examined the association between use of muscle-building supplements and testicular germ cell cancer (TGCC) risk, with 356 TGCC cases and 513 controls from eastern USA. The OR for the use of muscle-building supplements in relation to risk of TGCC was elevated (OR=1.65, 95% CI 1.11 to 2.46), with significantly stronger associations for early users and longer periods of use.

Ironically, supplements that are contaminated with extremely small amounts of prohibited substances—too low to have any physiological effect—may still cause a positive doping outcome. For instance, ingestion of 19-norandrostenedione, a precursor of nandrolone, will result in the appearance in the urine of the diagnostic metabolite for nandrolone. If the urinary concentration of 19-norandrosterone exceeds 2 ng/mL, an AAF is recorded. The addition of as little as

<table>
<thead>
<tr>
<th>Supplement</th>
<th>Proposed mechanism of action</th>
<th>Evidence for efficacy</th>
</tr>
</thead>
<tbody>
<tr>
<td>β-glucans</td>
<td>Polysaccharides derived from the cell walls of yeast, fungi, algae and oats that stimulate innate immunity</td>
<td>No support in humans. Effective in mice inoculated with influenza virus; however, human studies with athletes show no benefits.</td>
</tr>
</tbody>
</table>
Consensus statement

**Table 5** Supplements that may assist with training capacity, recovery, muscle soreness and injury management

<table>
<thead>
<tr>
<th>Supplement</th>
<th>Proposed mechanism of action</th>
<th>Evidence for efficacy(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creatine monohydrate</td>
<td>Enhanced adaptive response to exercise via increased growth factor/gene expression and increased intracellular water Reduced symptoms of, or enhanced recovery from, muscle damaging exercise (eg, DOMS) Enhanced recovery from disuse or immobilisation/extreme inactivity Improved cognitive processing Decreased risk/enhanced recovery from mTBI</td>
<td>Many studies demonstrate improved training adaptations, such as increased lean mass or strength, indicating an enhanced adaptive response to exercise. (^{12,13}) Reduced symptoms of, or enhanced recovery from, muscle damaging exercise (eg, DOMS) have been reported in some, but not all studies (reviewed in ref (^{122})). Enhanced recovery from disuse or immobilisation/extreme inactivity has been reported in some, but not all studies (reviewed in ref (^{122})). Improved cognitive processing is reported in most studies, especially when volunteers were fatigued by sleep deprivation or mental/physical tasks (reviewed in refs (^{11,125–127})). The effects in athletes have not been well-characterised, and only one group attempted to translate these effects to athletic performance, although with a positive result. (^{156}) Decreased damage and enhanced recovery from mTBI are supported by open-label trials in children (^{157,158}) and using animal models. (^{159}) These data are not conclusive and more research is warranted. However, athletes at risk for concussion, who already ingest creatine supplements for performance or muscular benefits, may receive important brain benefits as well. A small increase in body mass is common with supplementation. This may be relevant for sports with weight classes/restrictions or where increased body mass may decrease performance.</td>
</tr>
<tr>
<td>Beta-hydroxy beta-methylbutyrate (HMB)</td>
<td>Beneficial effects of HMB on strength and fat-free mass are small, while the effects on muscle damage are unclear. (^{151}) Recent reports of ‘steroid like’ gains in strength, power and fat-free mass, and reductions in muscle damage from HMB-free acid supplementation, (^{132–134}) have not been reproduced and seem unlikely. (^{156}) Potential use for HMB during extreme inactivity/disuse or recovery from injury, but these effects have only been described in older adults following 10 days of bed rest. (^{156}) Benefits of HMB supplementation could most likely be obtained from normal dietary protein or whole protein supplements, (^{159}) so HMB supplements may not be more effective than adhering to the current protein intake recommendations.</td>
<td></td>
</tr>
<tr>
<td>Omega-3 fatty acids About 2 g/day</td>
<td>Improved cognitive processing Decreased risk/enhanced recovery from mTBI Increased muscle protein synthesis Reduced symptoms of, or enhanced recovery from, muscle damaging exercise (eg, DOMS)</td>
<td>Improved cognitive processing following omega-3 fatty acid supplementation shown in healthy older adult with mild or severe cognitive impairment (reviewed in ref (^{148})). It is not known if these benefits would occur in young, healthy athletes, or how this would translate to athletic performance. Animal data show that the structural damage and cognitive decline associated with mTBI are reduced/attenuated with omega-3 fatty acid supplementation when ingested either before or after the injury (reviewed in refs (^{150–146})). Two case studies support these findings, (^{141,142}) and large, double-blind, placebo-controlled trials are currently under way (ClinicalTrials.gov NCT01903525 and NCT01814527). In muscle, omega-3 fatty acid supplementation can increase muscle protein synthesis, (^{143,144}) but this may not occur when protein is ingested after exercise in recommended amounts. (^{143,144}) Anti-inflammatory effects of omega-3 fatty acid intake may reduce muscle damage or enhance recovery from intense, eccentric exercise (eg, decrease DOMS), but this is not a consistent finding. (^{145,146}) No indication that decreased omega-3 fatty acids in the body impair performance, and high-dose supplements can cause some adverse effects (reviewed in refs (^{145,148})), so the best recommendation may be to include rich sources of omega-3 fatty acids, such as fatty fish, in the diet instead of supplements. Low-risk but unclear if supplementation should be pursued by athletes, in lieu of including fatty fish in the diet as a source of omega-3 fatty acids. Fish oil or omega-3 fatty acid supplement consumption could include heavy metal contaminants, or cause bleeding, digestive problems and/or increased LDL.</td>
</tr>
</tbody>
</table>

*Continued*
2.5 µg of 19-norandrostenedione to a supplement can result in a urinary concentration of 19-norandrosterone that exceeds this threshold. These amounts are close to the limits of detection of the analytical methods currently applied to the analysis of dietary supplements, and are far below the levels of contamination deemed acceptable from a health and safety perspective.

Various efforts are being made to address the problems, including the use of third-party auditing activities to ensure the safety and efficacy of supplements.

### Table 5  Continued

<table>
<thead>
<tr>
<th>Supplement</th>
<th>Proposed mechanism of action</th>
<th>Evidence for efficacy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vitamin D</td>
<td>An essential fat-soluble vitamin</td>
<td>Data on the effects of vitamin D supplementation on muscle function and recovery are equivocal, with discrepancies likely explained by differences in baseline vitamin D concentrations prior to supplementation. Collectively, these data strongly suggest a role for adequate vitamin D in the adaptive process to stressful exercise. Low vitamin D status is associated with a 3.6× higher stress fracture risk in Finnish military recruits. US Naval recruits supplemented with 800 IU/day of vitamin D3 and 2000 mg calcium reduced stress fracture incidence by 20%. More data are needed, but it appears that vitamin D status relates to stress fracture risk, and supplementation, when warranted, may reduce this risk.</td>
</tr>
<tr>
<td>Gelatin and vitamin C/collagen</td>
<td>Enhanced adaptive response to exercise</td>
<td>Gelatin and collagen supplements appear to be of low risk. Few data available, but increased collagen production and decreased pain seem possible. Functional benefits, recovery from injury, and effects in elite athletes are not known.</td>
</tr>
<tr>
<td>Anti-inflammatory supplements</td>
<td>Anti-inflammatory effects</td>
<td>Decreases in inflammatory cytokines and/or indirect markers of muscle damage with anti-inflammatory supplements such as curcumin and tart cherry juice (reviewed in refs 159 160) have been reported. Anti-inflammatory effects may be beneficial, although benefits may be sport/training-specific. More research is needed before these compounds can be recommended to athletes.</td>
</tr>
</tbody>
</table>

DOMS, delayed-onset muscle soreness; mTBI, mild traumatic brain injury (concussion).

### Table 6  Supplements promoted to assist with physique changes: gain in lean mass and loss of body fat mass

<table>
<thead>
<tr>
<th>Supplement</th>
<th>Proposed mechanism of action</th>
<th>Evidence for efficacy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gaining LBM*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protein</td>
<td>Usually comprised isolated proteins from various sources (whey and soy most common)</td>
<td>Meta-analyses focusing on younger and older participants have shown positive effects enhancing gains in muscle mass, but effects are not large.</td>
</tr>
<tr>
<td>Recommended daily dose: 1.6 g protein/kg/day optimal (up to 2.2 g/kg/day with no adverse effects)</td>
<td>Enhances lean mass gains when ingested during programmes of resistance training due to increased provision of building blocks (amino acids) and leucine as a trigger for a rise in muscle protein synthesis and suppression of muscle protein breakdown</td>
<td></td>
</tr>
<tr>
<td>Leucine</td>
<td>Stimulates muscle protein synthesis and suppresses protein breakdown (possibly through insulin)</td>
<td>Short-term mechanistic data available, but no long-term trials showing efficacy</td>
</tr>
</tbody>
</table>

Losing fat mass†                   |                                                                                               |                       |
| Protein from increased dietary sources or supplemental isolated proteins | Enhances fat mass loss and promotes retention of lean mass | Meta-analyses confirm small but significant effects of greater dietary protein in weight loss to enhance fat mass loss and promote lean mass retention. |
| Pyruvate                            | No data                                                                                       | Small to trivial effect |
| Chromium                            | Potentiates biological actions of insulin                                                      | No effect             |
| Green tea (polyphenol catechins and caffeine) | Thermogenic agent and/or lipolytic enhancing agent                                               | Small to trivial effect |
| α-Lipoic acid                       | No clear role, but possible antioxidant                                                      | Small to trivial effect |
| Conjugated linolenic acid           | Changes membrane fluidity favouring enhanced fat oxidation                                    | Small to trivial effect |
| Konjac fibre (glucomannan)          | Water-soluble polysaccharide—dietary fibre                                                    | Small to trivial effect |
| Omega-3 polyunsaturated fatty acids | No clear role, but possible appetite suppression, improved blood flow and/or modulator of gene expression | Small to trivial effect |
| Chitosan                            | Lipid-binding agent to reduce lipid absorption                                               | Small to trivial effect |

*In combination with a progressive resistance exercise programmes.
†In combination with an exercise-induced and/or diet-induced energy deficit.
identify products that athletes may consider to be ‘low risk’ of containing prohibited substances. There can be no absolute guarantee that any product is entirely safe, but these schemes do help the athlete to manage the risk. Athletes contemplating the use of dietary supplements should consider very carefully whether the possible benefits outweigh the risks of a doping offence that might end their career.

**PRACTICAL IMPLICATIONS AND DECISION TREE**

Dietary supplements are an established part of the landscape of modern sport and are likely to remain so. Athletes who take supplements often have no clear understanding of the potential effects of supplements they are using, but supplements should be used only after a careful cost-benefit analysis has been conducted. On one side of the decision tree are the rewards, the most obvious of which are correction of nutrient deficiencies, achievement of nutritional goals, or enhancement of one or another physiological/biochemical function to directly or indirectly improve performance. On the other side lie the costs, the possibility of using an ineffective supplement, the possible risks to health and the potential for an ADRV. A flow of questions that could be posed in reaching an informed decision is shown in figures 2 and 3.

In deciding whether to use a supplement, athletes should consider all aspects of their maturation in, and preparation for, their event to ensure that the supplement under consideration provides an advantage that no other strategy can address. Whether the supplement is practical to use should also be assessed: is the product available, affordable, tolerated and compatible with the athlete’s other goals? The input of the athlete’s coaching team and medical/science support network is important. Athletes who do not have regular access to such

![Flow chart to guide informed decision making and reducing risk of antidoping rule violation during nutritional supplement use. MD, medical doctors.](http://bjsm.bmj.com/)

Figure 2
Consensus statement

A network should consider decisions around supplement use as an important reason to consult an independent sports nutrition expert as well as a physician. Analysis of the evidence around the effectiveness of supplements and their safety is often difficult. A complete nutritional assessment may provide an appropriate justification for the specific use of nutritional supplements and sports foods. For a small number of sports supplements, there is good evidence of a performance effect or indirect benefit for some athletes in some specific situations with little or no risk of adverse outcomes. Professional advice is often important in ensuring that the athlete is sufficiently knowledgeable about the appropriate protocol for use of these supplements, but individual athletes may respond very differently to a given supplement, with some exhibiting a markedly beneficial effect while others experiencing no benefit or even a negative effect on performance. Furthermore, the situation in which the athlete wishes to use the supplement may differ in important ways from its substantiated use. Repeated trials may be necessary to establish whether a true effect, rather than just random variation, is seen in response to use of any novel intervention. Some trial and error may also be involved in fine-tuning the supplement protocol to suit the needs of the specific situation of use or the individual athlete.

Evidence to support the effectiveness and safety of many of the supplements targeted at athletes, however, is largely absent. There seems to be little incentive for those selling supplements to invest the substantial sums needed to undertake detailed scientific evaluation of their products. Even where some evidence does exist, it may not be relevant to the high-performance athlete because of limitations in the study design (such as the specificity of the exercise tests), the study population or the context of use. Failure to verify the composition of the supplements used may also give misleading results. It seems sensible to exercise caution when using supplements, as any compound that has the potential to enhance health or exercise performance by altering physiological function must also have the potential for adverse effects in some individuals. Athletes should see good evidence of a performance or other benefit, and should be confident that it will not be harmful to health, before accepting the financial cost and the health or performance risks associated with any supplement. Finally, the athlete should be sure, if supplements or sports foods are to be used, that they have undertaken due diligence to source products that are at low risk of containing prohibited substances.

CONCLUSION

Dietary supplements can play a small role in an athlete’s sports nutrition plan, with products that include essential
micronutrients, sports foods, performance supplements and health supplements all potentially providing benefits. Some supplements, when used appropriately, may help athletes to meet sports nutrition goals, train hard, and stay healthy and injury-free. A few supplements can directly enhance competition performance. However, it takes considerable effort and expert knowledge to identify which products are appropriate, how to integrate them into the athlete’s sports nutrition plan, and how to ensure that any benefits outweigh the possible negative side effects, including the potential for an ADRV. A strict risk-benefit analysis involving a decision tree approach to the effectiveness, safety and risks should identify the small number of products that may benefit the athlete. Such an analysis requires the input of a well-informed sports nutrition professional.

Author affiliations
1 School of Medicine, St Andrews University, St Andrews, UK
2 Sports Nutrition, Australian Institute of Sport, Canberra, Australia
3 Mary MacKillop Institute for Health Research, Melbourne, Australia
4 Department of Neurology, Schulthess Clinic, Zurich, Switzerland
5 Department of Family & Consumer Sciences (Human Nutrition), University of Wyoming, Laramie, Wyoming, USA
6 School of Human Sciences (Exercise and Sport Science), The University of Western Australia, Crawley, Western Australia, Australia
7 Western Australian Institute of Sport, Mount Claremont, Australia
8 Department of Kinesiology, McMaster University, Hamilton, Canada
9 Department of Health, Nutrition, and Exercise Science, Messiah College, Mechanicsburg, Pennsylvania, USA
10 College of Health and Behavioural Sciences, Bangor University, Bangor, UK
11 The Norwegian Olympic and Paralympic Committee and Confederation of Sport, Oslo, Norway
12 Institute of Biochemistry, Center for Preventive Doping Research, German Sport University, Cologne, Germany
13 Human Physiology Research Group, Vrije Universiteit Brussel, Brussels, Belgium
14 Department of Human Biology and Movement Sciences, NUTRIM School of Nutrition and Translational Research in Metabolism, Maastricht University Medical Centre, Maastricht, The Netherlands
15 Human Health & Nutritional Sciences, University of Guelph, Ontario, Canada
16 BMJ, London, UK
17 Department of Science and Medicine, World Anti-Doping Agency (WADA), Montreal, Canada
18 English Institute of Sport, Loughborough, UK
19 Medical and Scientific Commission, International Olympic Committee, Lausanne, Switzerland
20 Medical and Scientific Department, International Olympic Committee, Lausanne, Switzerland
21 Anti-Doping Foundation, Stockholm, Sweden
22 Human Health and Nutritional Sciences, Health and Performance, Centre University of Guelph, Guelph, Ontario, Canada
23 Medical and Scientific Commission Games Group, International Olympic Committee, Lausanne, Switzerland

Funding This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Provenance and peer review Not commissioned; externally peer reviewed.

Open Access This is an Open Access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited and the use is non-commercial. See: http://creativecommons.org/licenses/by-nc/4.0/

© Author(s) (or their employer(s) unless otherwise stated in the text of the article) 2018. All rights reserved. No commercial use is permitted unless otherwise expressly granted.

REFERENCES

Consensus statement


104 Davison G, Diment BC. Bovine colostrum supplementation attenuates the decrease of salivary lysozyme and enhances the recovery of neutrophil function after prolonged exercise. Br J Nutr 2010;103:1425–32.


