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The use of dietary supplements by athletes

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Abstract

Many athletes use dietary supplements as part of their regular training or competition routine, including about 85% of elite track and field athletes. Supplements commonly used include vitamins, minerals, protein, creatine, and various "ergogenic" compounds. These supplements are often used without a full understanding or evaluation of the potential benefits and risks associated with their use, and without consultation with a sports nutrition professional. A few supplements may be helpful to athletes in specific circumstances, especially where food intake or food choice is restricted. Vitamin and mineral supplements should be used only when a food-based solution is not available. Sports drinks, energy bars, and protein–carbohydrate shakes may all be useful and convenient at specific times. There are well-documented roles for creatine, caffeine, and alkalinizing agents in enhancing performance in high-intensity exercise, although much of the evidence does not relate to specific athletic events. There are potential costs associated with all dietary supplements, including the risk of a positive doping result as a consequence of the presence of prohibited substances that are not declared on the label.

Keywords: *Supplements, ergogenic, creatine, caffeine, bicarbonate, drugs in sport*

Introduction

The foods that an athlete chooses will affect performance on and off the track through effects on both fitness and health. Compared with the other factors that determine performance – talent, training, motivation, resistance to injury, and so on – the place of diet is small. Good food choices do not compensate for an absence of talent or a lack of training, but they will help the talented and motivated athlete to make the most of their potential. Athletes who make poor food choices are unlikely to be as good as they could be.

An athlete's ability to sustain consistent intensive training and competition without succumbing to chronic fatigue, injury, and illness will be influenced not only by the types of foods eaten, but also by the amount and timing of food intake. Many athletes believe that a normal diet will not suffice for optimum performance and resort to the use of dietary supplements in an attempt to improve their diet or to gain a competitive edge. Pressure is also often exerted on athletes and those who advise them by supplement companies with products to sell. However, a well-chosen diet that contains a variety of foods and is eaten in amounts sufficient to meet the energy demands of training and competition should provide all the nutrients that an athlete needs. The use of supplements should not be seen as a substitute for good food choices.

The first step should be to ensure that all athletes make food choices that are appropriate to their nutritional goals. Most athletes need continuing support to help them make good food choices at home as well as at training and competition venues. Contrary to popular belief, high protein intakes and protein supplements are not essential, and a varied diet eaten in a sufficient amount to meet energy needs is likely to supply more than enough protein and adequate amounts of most of the micronutrients. A high carbohydrate diet is a priority during periods of hard training, especially when recovery time is restricted, unless the majority of the training consists of technical work, where the demand for energy and for carbohydrate may not be high. An adequate fluid intake is important, and water and electrolyte needs are increased when the training load is increased, especially in warm weather. Athletes with high salt

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losses in training should not restrict salt intake out of concerns for blood pressure. Well-formulated sports drinks, energy bars, and meal substitutes all have their place at specific times. These concerns are reviewed elsewhere in this issue.

A few supplements and sports foods may bring specific benefits for some athletes in some circumstances, but these should be used only after consultation with a qualified sports nutritionist or accredited sports dietician. Where energy intake is restricted to help reduce body fat or to prevent weight gain, a broad-spectrum, low-dose multivitamin and mineral supplement may help ensure that essential nutrient needs are met. It must also be recognized that not all athletes make good food choices. When athletes are resistant to changing dietary habits to ensure they eat a range of foods, including adequate amounts of fruit and vegetables, there may be a place for a daily multivitamin tablet. The routine use of iron supplements is not recommended, as this may do more harm than good, but a supplement may be necessary in some situations (Eichner, 2000). In general, supplements should be used only when a deficiency has been confirmed by blood analysis, and then only as a short-term solution under clinical supervision while dietary changes are being implemented.

The use of supplements for specific athletic events is covered elsewhere in this issue. This review will focus on some of the general issues relating to the use of dietary supplements and will look in detail at a few supplements that may have something to offer to some athletes. It is important to recognize at the outset, however, that of the many hundreds, even thousands, of different products that can be found on sale in a sports nutrition store or via the internet, there is good evidence on efficacy and safety for only a handful. Nonetheless, the absence of evidence of efficacy is not the same as evidence of absence of efficacy: products that have not been evaluated in a controlled manner cannot simply be dismissed as ineffective. Equally, however, the athlete must be aware that there will be no evidence of the safety of these products if there has been no evaluation of their effectiveness.

It is also now increasingly recognized that individual athletes will respond differently to some products. This is well illustrated in the case of vitamin or mineral supplements: the athlete who suffers from a deficiency is likely to show a benefit in response to a period of supplementation, but the well-nourished athlete is unlikely to see an improvement in health or performance when taking the same supplement. We need to recognize, too, that laboratory studies of treadmill running, cycle ergometer performance, and isometric strength may have little relevance to the world of competitive athletics. Apart from their lack of relevance to sport, most of these tests lack the sensitivity that is necessary to detect performance effects that are meaningful to the elite athlete (Jeukendrup, Saris, Brouns, & Kester, 1996).

Information on the efficacy and safety of many of the products used by athletes is limited. In many cases, evidence is entirely lacking, while other "evidence" relates to information from studies of isolated tissues exposed to unphysiological amounts of supplements. The recognition, too, that any study population may include both "responders" and "non-responders" means that the scientific approach to identification of statistically significant effects may ignore effects that are meaningful to some athletes. It is also true that new information emerges that changes our understanding. Evidence of the efficacy of carnitine supplements, for example, is inconclusive, but Stephens and colleagues (Stephens, Constantin-Teodosiu, & Greenhaff, 2007) recently pointed out that the bioavailability of carnitine in humans is increased when circulating insulin concentrations are elevated. When muscle carnitine content is increased by carnitine infusion in the presence of hyperinsulinaemia, clear effects on carbohydrate and fat metabolism are observed (Stephens, Constantin-Teodosiu, Laithwaite, Simpson, & Greenhaff, 2006). The failure of some, but perhaps not all, previous studies to ensure that carnitine administration was effective in achieving an increase in muscle carnitine concentration may account for conflicting evidence in the literature.

What are dietary supplements?

There is not a single definition, either legal or within nutritional science, of what constitutes a dietary supplement, although various attempts have been made. Supplements are often understood to include sports drinks, energy bars, and meal replacements, as well as the more exotic products that are on sale to athletes. Where definitions are attempted, they are not always helpful. The US Congress, for example, in framing the 1994 Dietary Supplements Health and Education Act (DSHEA), defined dietary supplements as follows:

> 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 is clearly absurd: a product is a supplement if consumed by an athlete who is eating "a healthy diet'', but the same product is not classified as a supplement if it is eaten by an athlete who makes unhealthy food choices.

In most countries, products regulated under food law must not claim to treat or cure an illness or condition since such claims are permitted only for pharmaceuticals. A manufacturer may seek pharmaceutical status for a product if permission to make a medical claim is sought and if there are data to support such a claim. Such a product would then become a pharmaceutical, and not strictly a ''food supplement''. This does not prevent similar products being marketed both as food supplements and pharmaceuticals, as long as they meet the conditions of each regulatory framework. Products regulated in Canada as natural health products are allowed to make a full range of claims (structure/function, risk reduction, treatment, prevention) where supported by scientific evidence, and there are also many other regional variations in what is permitted. This can be confusing for athletes who travel between countries to train and compete.

Table I illustrates some of the categories of supplements used by athletes according to their target functions. It is important to note that some supplements may be used for different functions. Zinc, for example, may be taken to promote would healing and tissue repair or to reduce the severity and duration of the symptoms of an upper respiratory tract infection.

The scale and scope of supplement use in track and field athletes

Many published surveys have reported the prevalence of supplement use by athletes, together with comparative data from other sports and in the non-athletic population. As reviewed by Maughan and colleagues (Maughan, King, & Lea, 2004), however, sample sizes have been small and the level of performance of the cohort studied is not always well defined. In athletics in particular, there are few available data on the knowledge and habits of supplement use among elite athlete; only limited data exist on young international track and field athletes in England (Nieper, 2005) and participants in the masters world championships (Striegel, Simon, Wurster, & Ulrich, 2006).

The medical and anti-doping commission of the IAAF conducted a survey at international championships from 2005 to 2007 to assess reasons for and prevalence of supplement use (F. Depiesse and F. Pillard, unpublished results). The questionnaire asked about sports participation, supplements used, reasons for their use, perceived effects, and areas of interest about supplements. Participants in the survey were elite athletes (54% full-time athletes and the remainder students or workers). A total of 310 questionnaires were collected and analysed (157 males, 153 females), of which 46% were from Western Europe, 31% from Asia, 11% from Eastern Europe, 4% from North America, 4% from Africa, 1% from South America, 1% from Oceania, and 1% from the Caribbean. The mean age of the respondents was 26 years ($s = 5$).

Supplements were used by 85% of the respondents (males: 83%; females: 89%). The prevalence of use by event varied from 76% for short sprints to 91% for distance running events (3000 m to Marathon; Table II). Supplement users were older than non-users ($P < 0.0001$). Reasons given for using supplements were to aid in recovery from training (71%), to improve health (52%), to improve performance (46%), to prevent or treat an illness (40%), and because the respondent believed they didn't have a balanced diet (29%). The substances used most

Table I. There are many different ways of categorizing supplements, but most athletes think of them according to their intended use of target function. This table lists some of those categories and gives a few examples from the enormous number of different products on sale.

Athlete's objectives	Examples
Muscle growth and repair	Protein powder; protein hydrolysate; amino acids, essential amino acids; HMB
Fat reduction	Pyruvate; caffeine; carnitine; ma huang
Exercise metabolism	Carbohydrate, caffeine; bicarbonate; creatine
Promoting recovery	Whole protein powders; protein isolates and hydrolysates; protein–carbohydrate bars and drinks; ginseng
Joint health	Glucosamine; chondroitin sulphate
General health	Vitamins; minerals; evening primrose oil
Immune function	*Echinacea*; anti-oxidants; zinc; glutamine; lycopenes; pycnogenol
CNS stimulation	Taurine; caffeine; guarana
Meal/replacement	Liquid meals, sports bars; carbohydrate gels
Fluid and electrolytes	Sports drinks, electrolyte supplements

Table II. Prevalence of dietary supplement use among elite track and filed athletes (unpublished data from an IAAF study conducted by F. Depiesse).

Event	*n*	Use of supplements (%)
Sprints (100 m, 200 m, hurdles)	51	77
Sprints (400 m, 400-m hurdles)	34	82
Throws	26	85
Jumps	35	89
Middle distance	39	87
Long distance	88	88
Race walking	18	89
Multi-events	16	88
Total	307	86

commonly were vitamins and antioxidants (84%), minerals (73%), protein and creatine supplements (53%), and ergogenic supplements, including coenzyme Q10, caffeine, ginseng, and ephedrine (52%).

Health professionals (53% medical doctors and 30% nutritionists and dieticians), coaches (28%), and personal research (22%) were the most reported information sources. Only a few athletes (4%) used the internet to buy products. In many previous studies, a high proportion of participants indicated knowing little about supplements and wanted to learn more. In the IAAF study of elite track and field athletes, however, 65% thought they were sufficiently educated about the risks of using supplements (72% of users), and 63% (73% of users) thought they knew sufficient about the benefits of not using supplements.

Supplements that may have something to offer the athlete

Some of the supplements used by athletes are supported by good evidence of efficacy and safety. Even then, though, athletes may use them in an inappropriate way, by using them when there is unlikely to be any benefit, by taking too high or too low a dose, or by taking them at the wrong time. For example, athletes must recognize that although sodium bicarbonate may improve performance in events from 400 m to 5000 m, there is no reason to suspect that there will be any benefit to jumpers or throwers. Similarly, the question of whether the use of bicarbonate in training may allow more effective training, or whether it will reduce the adaptation that normally takes place, is at present unresolved.

The following sub-sections briefly review some of the supplements that may be of benefit to some athletes.

Protein and amino acids

The use of high-protein diets has a long history in sport and such diets were reportedly popular with athletes in the Olympics of Ancient Greece. Protein requirements are increased by hard training and it is often recommended that the protein intake of strength athletes should be 50 – 100% greater than that of their sedentary counterparts (Tarnopolsky, 2007). Athletes often insist that much higher amounts of protein are necessary to increase muscle mass, but the literature does not support this supposition. This apparent inconsistency may be explained in part by Millward's adaptive metabolic demand model, which proposes that the body adapts to either high or low levels of intake, and that this adjustment to changes in intake occurs only very slowly (Millward, 2001). With high protein intakes, there is an up-regulation of protein degradation and amino acid oxidation. The athlete consuming a high protein diet who acutely reduces protein intake will experience a loss of lean tissue until a new equilibrium has been achieved.

Very high protein intakes can be achieved by choosing appropriate foods, but many high protein foods are also high in fat. Knowledge about the composition of foods among athletes is not generally good, which means that a restricted choice of foods is almost inevitable, and not all athletes who think they are achieving their protein intake goals will actually be doing so. Protein supplements offer athletes the possibility of achieving their desired level of protein intake without an unacceptable increase in fat intake and without major changes to their eating habits. This may be especially important when athletes wish to ingest protein either just before or just after training with the aim of promoting the adaptations that take place in response to the training stimulus (Hawley, Tipton, & Millard-Stafford, 2006). Milk-based protein shakes made using protein powders allow athletes to be sure of achieving an appropriate protein intake in a convenient form.

In the case of some of the amino acids, there are data from clinical studies involving severely stressed patients (where the stress is the result of trauma, burn injury or surgery) that supplementation may reduce the muscle wasting that normally occurs. This profoundly catabolic state, however, may not be relevant to the healthy athlete who is trying to increase muscle mass. Individual amino acids claimed to promote muscle growth include glutamine, branched-chain amino acids, leucine, lysine, arginine, and ornithine. There is little evidence to support a benefit of supplementation of any of these amino acids for athletes eating a normal diet. Very high doses of arginine, ornithine, and lysine may result in increased circulating concentrations of growth hormone and insulin, but this has not been shown to result in changes in lean body mass or in muscle function (Merimee, Rabiowitz, & Fineberg, 1969). The changes in growth hormone that result are transient and small relative to the normal fluctuations that occur and to the increases that result from even a short period of high-intensity effort.

Caffeine

Caffeine occupies an unusual position in the world of sport. It has a long history of use as a stimulant and was, at one time, used in very large doses. To counter this use, the IOC classified caffeine as a "controlled" substance. Recognizing that caffeine is present in small amounts in the diets of most people, an outright ban is not practical, so a threshold level of $12\ \mu g \cdot ml^{-1}$ was initiated. This limitation was removed by WADA in 2004, leading to increased interest in the use of caffeine by athletes.

The effects of caffeine on performance were initially ascribed to stimulation of fatty acid mobilization, leading to glycogen sparing. More recent studies suggest that the primary effect of caffeine is to reduce the perception of fatigue or to enhance central drive by binding to adenosine receptors in the brain (Davis *et al.*, 2003). A recent meta-analysis of published studies on caffeine and exercise performance (Doherty & Smith, 2005) suggested that the magnitude of the performance effect increases as the duration of exercise increases. Beneficial effects on performance can be achieved with low doses of caffeine, in the order typically of 2 – 6 mg · kg body mass^{-1} (Kovacs, Stegen, & Brouns, 1998), though effects may be seen at even lower doses (Cox *et al.*, 2002).

Cox *et al.* (2002) showed how small caffeine doses can be effective. A group of well-trained cyclists rode for 2 h and drank one of the following during the last hour:

- Coca-Cola (90 mg caffeine + carbohydrate)
- caffeine-free Cola (extra carbohydrate)
- half-strength Cola (90 mg caffeine)
- half-strength caffeine-free Cola (control)

They then rode a time-trial where they completed a fixed distance as fast as possible. On the control trial, this took 27:05 min to complete; with extra carbohydrate, time to completion was 26:55 min; with caffeine it took 26:36 min; with caffeine plus extra carbohydrate, it took 26:15 min. This is a substantial performance improvement with only a small dose (90 mg) of caffeine.

Commercially available products can provide significant amounts of caffeine (see Table III). Caffeine tablets, popular with overworked students studying for examinations, are also popular among athletes. Recent reports suggest that caffeine is absorbed into the circulation faster if it is retained in the mouth by the use of caffeine-containing chewing gum (Kamimori *et al.*, 2002). Caffeine taken in this way can improve both mental and physical performance (McLellan *et al.*, 2005).

Table III. Caffeine content of some common foods and drinks. Data are compiled from various sources, as compiled by Maughan and Griffin (2003).

Source	Caffeine content (mg) per serving*
Tea	15 – 75
Instant coffee	50 – 140
Filter Coffee	60 – 200
Hot chocolate	10 – 20
Cola	20 – 70

*Serving size is corrected to 200 ml for tea, coffee and hot chocolate, and to 330 ml for cola. Note that an American grande size serving of coffee may contain as much as 600 mg of caffeine.

Caffeine can have a number of unwanted side-effects that may limit its use in some sports or by sensitive individuals: these effects include insomnia, headache, gastrointestinal irritation and bleeding, and increased urine flow. In the very high doses that are sometimes used by athletes, noticeable muscle tremor and impairment of coordination have been noted (Spriet, 1995). The diuretic action of caffeine is often stressed, particularly where dehydration is a major issue. This is important at competitions held in hot, humid climates where the risk of dehydration is high, and is more important for endurance athletes where dehydration has a greater negative effect on performance. Athletes competing in these conditions are advised to increase their intake of fluid, but are usually also advised to avoid tea and coffee because of their diuretic effect. It seems likely, however, that this effect is small for those habituated to caffeine use (Armstrong, 2002; Maughan & Griffin, 2003) and the negative effects caused by the symptoms of caffeine withdrawal may be more damaging.

Creatine

The use of creatine by athletes has caused much controversy, with many calls for its use to be prohibited. The only justification for this seems to be that it is effective in improving performance: if this is the basis for banning it, then training should also be banned. There is a sound theoretical basis for the use of creatine supplements, but not all athletes will benefit. Creatine phosphate is an important energy source in high-intensity exercise, and is especially important in rapid recovery between multiple sprints with short recoveries. There is substantial evidence to show that creatine supplementation can increase the amount of creatine and creatine phosphate in the muscles and can improve performance in strength and power events (Hespel, Maughan, & Greenhaff, 2006). It is also sometimes, but not always, associated with a rapid gain in body weight of about 1 – 4 kg, which may be an advantage in some sports but may be a disadvantage in others. Creatine is not on the doping list and creatine intake in healthy adults has been found to be generally safe (Terjung *et al.*, 2000).

Creatine is a normal component of muscle and the main sources in the diet are therefore meat and fish. The body needs about 2 g of creatine per day to replace the amount that is broken down to creatinine and lost in the urine. Vegetarians have little dietary creatine intake, but meat eaters typically get about 1 g per day from the diet. The rest of what we need is synthesized from amino acids supplied by the diet. A typical meat-containing diet will provide about 1 g of creatine per day, but the high protein – and therefore usually high in meat and fish – diets of strength and power athletes may supply substantially more than this. It may be because of the additional creatine they supply that the high protein diets of these athletes are believed to be effective in promoting gains of muscle mass and increases in strength and power performance. The vegetarian diet provides little preformed creatine and even though synthesis from amino acids will meet the body's needs, the muscle creatine content of vegetarians is typically less than that of omnivores (Delanghe *et al.*, 1989).

The recommended creatine loading regimen typically involves an initial loading phase, of about 20 g per day, in four divided doses if taken for 4–6 days; this is then followed by a maintenance dose of 2–5 g per day (Terjung *et al.*, 2000). During the supplementation period, endogenous creatine synthesis will be suppressed, and it may be advisable for athletes to interrupt each 4–6 week period of creatine supplementation with an interval of about 4 weeks. Exercise is known to stimulate the uptake of ingested creatine into muscles, perhaps due to the greater muscle blood flow (Harris, Söderlund, & Hultman, 1992). Creatine uptake into muscle is also stimulated by insulin, and ingesting creatine supplements in combination with carbohydrate–amino acid–protein supplements can increase muscle creatine concentrations by elevating circulating insulin concentrations (Green, Hultman, Macdonald, Sewell, & Greenhaff, 1996).

Although the primary use of creatine to date has been by athletes who want to build muscle or to increase strength and power, it may have some other important uses. When taken together with a series of high carbohydrate meals after endurance exercise that has resulted in depletion of muscle glycogen, creatine has been found to stimulate glycogen synthesis (Robinson, Sewell, Hultman, & Greenhaff, 1999). While the use of creatine may not therefore be of direct benefit to the endurance athlete, this may help achieve higher muscle glycogen concentrations, especially where recovery between races is limited.

Alkalinizing agents

In high-intensity exercise of short duration, the challenge to the athlete is to supply energy to the muscles at very high rates. When exercise lasts from a few seconds to a few minutes, this requires not only a high rate of aerobic metabolism, but also a high rate of anaerobic metabolism. The contribution of creatine phosphate is limited after the first 30 s or so of maximal exercise, and the contribution of anaerobic glycolysis becomes a major determinant of performance. The rapid breakdown of muscle glycogen to lactate allows high rates of ATP resynthesis, but the associated fall in pH has a number of effects within the muscle. A low intracellular pH can reduce the rate of glycolysis by inhibition at the level of phosphofructokinase, can interfere with calcium binding and hence with the contractile process itself, and will stimulate free nerve endings causing subjective discomfort. Nonetheless, the greater the capacity for lactate formation, the greater the amount of energy that can be supplied.

To maximize energy supply by anaerobic glycolysis, buffering of the hydrogen ions is achieved within the cell by local buffering agents and by removal of hydrogen ions to the extracellular space. Increasing buffering capacity should increase performance where pH is a limiting factor, and many investigations into the effects of metabolic alkalosis (usually induced by ingestion of sodium bicarbonate or sodium citrate) on the performance of high-intensity exercise have been carried out (Maughan, 1999). The results are not entirely consistent, but the evidence does tend to support beneficial effects on performance lasting about 1–15 min (Maughan *et al.*, 2004).

Wilkes and colleagues (Wilkes, Gledhill, & Smyth, 1983) simulated athletic competition by requiring trained non-elite (best 800-m time about 2 min 5 s) middle-distance runners to complete a 800-m race after ingestion of nothing, a placebo or sodium bicarbonate ($0.3\ g \cdot kg^{-1}$): after bicarbonate ingestion, participants ran almost 3 s faster than in the placebo or control trials. Another report indicated similar improvements (3–4 s) at 1500 m in runners who completed simulated races in about 4 min 15 s (Bird, Wiles, & Robbins, 1995). These effects are of considerable significance to the athlete for whom an improvement of even a fraction of a second is a major achievement.

Sodium citrate has been recommended as an alternative to sodium bicarbonate, especially for those athletes prone to the gastrointestinal disturbances that sometimes accompany the large doses necessary to produce an effect (McNaughton, 1990). Van Montfoort and colleagues (Van Montfoort, van Dieren, Hopkins, & Shearman, 2004), however, have suggested that citrate is less likely to produce a positive effect on performance than is bicarbonate.

Carnosine (β-alanyl-histidine) is an important intracellular buffer, and muscle carnosine concentrations may be increased by ingestion of carnosine or β-alanine. This in turn can improve performance in various high-intensity exercise tasks without apparent adverse effects (Hill *et al.*, 2007).

Glucosamine

Athletes who train intensively over many years may be prone to problems due to excessive wear and tear on joints. The cartilage in joints is made up of proteoglycans (protein molecules to which are bound various complex sugars) and the protein collagen. Chondroitin – one of the main glycosaminoglycans – is a long-chain molecule consisting of large numbers of molecules of two components: galactosamine and glucuronic acid. Commercial preparations are extracted from the cartilaginous tissues of animals. Glucosamine is a carbohydrate – amino compound produced from the chitin that forms the main structural element of sea shells. Both compounds are marketed with claims that they stimulate formation of components of cartilage when given orally to humans.

There is a considerable amount of information from clinical trials involving patients with osteoarthritis to show that regular (once or twice per day) long-term (about 2 – 6 months) treatment with glucosamine and chondroitin sulphate can reduce the severity of subjective symptoms and prevent progression of the disease (Fillmore, Bartoli, Bach, & Park, 1999). Braham and colleagues (Braham, Dawson, & Goodman, 2003) reported the effects of 12 weeks of supplementation in individuals with knee pain, showing similar improvements in clinical and functional tests in the treatment and placebo groups, but more members (88%) of the treatment group reported some improvement in knee pain than those in the placebo group (17%). A meta-analysis of published studies concluded that "some degree of efficacy appears probable for these preparations" but expressed cautions about the quality of available data (McAlindon, LaValley, Gulin, & Felson, 2000). More recent reviews (Reginster, Bruyere, & Neuprez, 2007; Lozada, 2007) have been equally unable to provide a firm conclusion, perhaps because of differences in study design and populations and in the products tested. The evidence for efficacy of glucosamine sulphate may be stronger than for other formulations (Reginster *et al.*, 2007).

There is no evidence at present of a benefit for athletes with joint pain, but there have been no properly controlled trials in athletes. One study of US military special operations personnel with knee and back pain showed subjective improvements after treatment but no effect on tests of running performance (Leffler, Philippi, Keffler, Mosure, & Kim, 1999). Nonetheless, subjective relief alone has some value and this possible benefit cannot be ignored. There have been no reports of significant adverse effects of supplementation, but the widespread use of these products means that any problems should have become apparent.

CNS-acting compounds

Apart from caffeine, a number of other products are sold to athletes with claims that they can enhance performance by actions on the brain. Many herbal preparations are sold with claims of beneficial effects on various aspects of brain function: improvements in alertness, memory, mood, and various other functions are claimed. St John's Wort is perhaps one of the best known supplements in this area: it is widely used and is one of the biggest selling products worldwide. Some of the other herbal products in this area (including kava-kava) have been linked to possible adverse effects, including liver damage. In the case of kava-kava, this has led to withdrawal of the product in some countries.

The branched-chain amino acids (valine, leucine, and isoleucine) have attracted much attention due to their possible influence on the synthesis and release of serotonin (5-hydroxytryptamine, 5-HT). There is good evidence from studies that have used pharmacological interventions to manipulate serotoninergic and dopaminergic function, but the evidence that dietary manipulations thought to affect serotonin concentrations can influence exercise performance is not convincing.

Various neurotransmitter precursors are promoted for use by athletes. Tryptophan and its derivative 5-hydroxytryptophan are sometimes promoted for relief of mild depression, weight loss by appetite suppression, and pain relief, but the evidence is not strong. A combination of tyrosine and phenylalanine is currently promoted to athletes on various websites with claims that it can boost alertness and motivation. This is based on the fact that L-phenylalanine – an essential amino acid – can be converted to tyrosine, which acts as a precursor for catecholamine synthesis. D-Phenylalanine can be converted to phenylethylamine, which may produce effects on mood. There is some limited evidence of efficacy in the treatment of clinical depression, but that is hardly the same as showing a benefit in healthy individuals. There appears to be no published evidence of effects on exercise performance.

Cost – benefit analysis of supplement use

Athletes use dietary supplements in the expectation that there will be a performance benefit. Few consider that these same supplements may also result in negative consequences. Potential negative outcomes include a decrement in performance, acute or long-term harm to health, and a positive doping result.

The regulations that govern the purity of dietary supplements are very different from those relating to pharmaceutical products, and rather more liberal claims can be made as to their purity and efficacy. The enactment of the Dietary Supplements Health and Education Act (1994) by the US Congress resulted in considerable liberalization of the regulations regarding the manufacture and sale of nutritional supplements. Current regulations in many countries permit the unrestricted sale of substances closely related to testosterone and other anabolic androgenic agents. The American Food and Drugs Administration (FDA), prompted in part by a number of fatalities associated with supplement use, has introduced guidelines for the manufacture and distribution of dietary supplements (Food and Drugs Administration, 2007). Product recalls by the FDA include a folic acid product with 34% of the stated dose and products containing excessive (and potentially toxic) doses of vitamins A, D, B6, and selenium (Maughan, 2005). Some products have been shown to contain potentially harmful impurities (lead, broken glass, animal faeces, etc.) because of poor manufacturing practice. Data presented on the internet suggest widespread problems in the supplements industry, and it is reported that, for some specific supplements, the majority of the available products fail to meet the expected standards. For example, it was recently reported that seven out of nine ginkgo biloba products did not contain an adequate dose of one or more important compounds (Consumerlabs, 2003).

Dietary supplements are not currently evaluated by regulatory agencies in most countries, and inaccurate labelling of ingredients is known to be a problem. New European regulations relating to the sale of nutritional supplements will require manufacturers to provide information on the label of the product, but internet selling has effectively removed most of the national controls that might protect the consumer. Travelling athletes can purchase products that may not be available in their home countries. Problems can arise when products have the same name, but different ingredients, in different countries. Most dietary supplements are probably safe and will not cause problems for the athlete, and most of the companies that manufacture and supply these supplements are anxious to ensure the welfare of their customers. Nonetheless, there is compelling evidence that dietary supplements may be responsible for at least some of the positive doping results recorded by athletes in recent years. This is reflected in the decisions by the governing bodies of some sports to apply reduced sanctions in the cases of some athletes who have tested positive.

It has been shown that some products do not contain measurable amounts of the substances identified on the label, while others may contain up to 150% of the stated dose (Gurley, Gardner, & Hubbard, 2000; Kamber *et al.*, 2000; Parasrampuria, Schwartz, & Petesch, 1998). Where relatively expensive ingredients are involved, some products contain little or no active ingredient (Green, Catlin, & Starcevic, 2001). Of special concern to the athletes is the presence of substances that are not declared on the product label. These include stimulants, especially caffeine, ephedrines and sibutramine in over-the-counter herbal tonics (Geyer *et al.*, 2001; Koehler *et al.*, 2007; Parr, Geyer, Sigmund, Köhler, & Schänzer, 2003). While caffeine is no longer a problem, ephedrines and sibutramine are prohibited substances. Since 2000, many published studies have also reported contamination of supplements with prohibited anabolic-androgenic steroids, which can lead to unintentional positive doping tests (Baume, Mahler, Kamber, Mangin, & Saugy, 2006; Geyer, Mareck-Engelke, Reinhart, Thevis, & Schänzer, 2000; Geyer *et al.*, 2004; Gmeiner & Hofer, 2002; Van der Merwe & Grobbelaar, 2005). The fact that their presence is not declared on the label is not a defence for the athlete who tests positive after taking these products.

The first comprehensive study to evaluate the doping risk posed by dietary supplements showed that about 15% of a total of 634 supplements purchased in various countries in 2000 and 2001 contained varying levels of cross-contaminations with prohibited anabolic steroids (Geyer *et al.*, 2004). Since 2002, products have also been identified that contain high amounts of anabolic steroids, not declared on the label, such as metandienone, stanozolol, boldenone, dehydrochloro-methyltestosterone, and oxandrolone (Geyer, Bredehoft, Marek, Parr, & Schänzer, 2002; Gmeiner, 2002; Parr, Geyer, Opfermann, & Schänzer, 2004, Parr *et al.*, 2007). Products containing unlabelled new "designer" steroids (Ayotte *et al.*, 2006; Parr, Opfermann, & Schänzer, 2006; Rodchenkov *et al.*, 2006) have also been detected on the nutritional supplement market. Because the manufacturers of these contaminated products also manufacture other nutritional supplements on the same production line, the risk of cross-contaminations with such anabolic androgenic steroids is very high. A new study showed cross-contaminations of vitamin C, multivitamins, and magnesium tablets with stanozolol and metandienone (Geyer, Mareck, Köhler, Parr, & Schänzer, 2006). To protect athletes from inadvertent doping, databases of low-risk supplements, such as those prepared in the Netherlands (NZVT List: http://antidoping.nl/nzvt/zvt) and Germany (Cologne List: www.koelnerliste.com), should be introduced in other countries. In general, athletes are advised to seek assurances regarding quality control of supplement manufacture to ensure freedom from contamination with toxic or doping substances.

Summary of dietary supplement use

Consensus for:

- Athletes should ensure they have a good diet before contemplating supplement use.
- The use of supplements does not compensate for poor food choices. Where a nutrient deficiency is demonstrated, supplements may provide a short-term solution until a dietary solution can be identified and implemented.
- There is good evidence for the use of some ergogenic supplements, but athletes are cautioned against the use of these supplements without first conducting an individual and event-specific cost–benefit analysis. It is increasingly recognized, however, that responses to supplement use may differ between individuals depending on nutritional status, training status, and genotype.
- Supplements that may benefit some athletes in some circumstances include creatine, caffeine, and buffering agents.
- Supplement use requires individual assessment and advice by a qualified sports nutrition professional and medical practitioner.
- A significant number of supplements on the market contain doping agents that are not declared on the label but will cause an athlete to fail a drugs test.
- Athletes are advised to seek assurances regarding quality control of supplement manufacture to ensure freedom from contamination with toxic or prohibited components

Consensus against:

- The indiscriminate use of dietary supplements on a "just-in-case basis" is to be discouraged, and is likely to do more harm than good.
- Athletes should not use supplements where nutrient needs can be met by normal foods.
- Athletes should not use supplements where there is a risk of a positive doping outcome.
- Supplements should not be used by young athletes (aged under 18 years) except where medically indicated and where use is monitored.

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