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Dietary Supplements and Team-Sport Performance

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Abstract

A well designed diet is the foundation upon which optimal training and performance can be developed. However, as long as competitive sports have existed, athletes have attempted to improve their performance by ingesting a variety of substances. This practice has given rise to a multi-billion-dollar industry that aggressively markets its products as performance enhancing, often without objective, scientific evidence to support such claims. While a number of excellent reviews have evaluated the performance-enhancing effects of most dietary supplements, less attention has been paid to the performance-enhancing claims of dietary supplements in the context of team-sport performance. Dietary supplements that enhance some types of athletic performance may not necessarily enhance team-sport performance (and *vice versa*). Thus, the first aim of this review is to critically evaluate the ergogenic value of the most common dietary supplements used by team-sport athletes. The term dietary supplements will be used in this review and is defined as any product taken by the mouth, in addition to common foods, that has been proposed to have a performance-enhancing effect; this review will only discuss substances that are not currently banned by the World Anti-Doping Agency. Evidence is emerging to support the performance-enhancing claims of some, but not all, dietary supplements that have been proposed to improve team-sport-related performance. For example, there is good evidence that caffeine can improve single-sprint performance, while caffeine, creatine and sodium bicarbonate ingestion have all been demonstrated to improve multiple-sprint performance. The evidence is not so strong for the performance-enhancing benefits of β-alanine or colostrum. Current evidence does not support the ingestion of ribose, branched-chain amino acids or β-hydroxy-β-methylbutyrate, especially in well trained athletes. More research on the performance-enhancing effects of the dietary supplements highlighted in this review needs to be conducted using team-sport athletes and using team-sport-relevant testing (e.g. single- and multiple-sprint performance). It should also be considered that there is no guarantee that dietary supplements that improve isolated performance (i.e. single-sprint or jump performance) will remain effective in the context of a team-sport match. Thus, more research is also required to investigate the effects of dietary supplements on simulated or actual team-sport performance. A second aim of this review was to investigate any health issues associated with the ingestion of the more commonly promoted dietary supplements. While most of the supplements described in the review appear safe when using the recommended dose, the effects of higher doses (as often taken by athletes) on indices of health remain unknown, and further research is warranted. Finally, anecdotal reports suggest

that team-sport athletes often ingest more than one dietary supplement and very little is known about the potential adverse effects of ingesting multiple supplements. Supplements that have been demonstrated to be safe and efficacious when ingested on their own may have adverse effects when combined with other supplements. More research is required to investigate the effects of ingesting multiple supplements (both on performance and health).

1. Introduction

A well designed diet that meets the energy and nutrient intake needs and incorporates the proper timing of meals, is the foundation upon which optimal training and performance can be developed. Nevertheless, there is the common belief that, in conjunction with well designed training, the appropriate ingestion of some dietary supplements can enhance team-sport performance. This belief has given rise to a multi-billion-dollar industry that aggressively markets its products to team-sport athletes as performance enhancing, often without objective, scientific evidence to support such claims. However, while a number of excellent reviews have evaluated the performance-enhancing effects of most dietary supplements,[1-4] less attention has been paid to the performance-enhancing claims of dietary supplements in the context of team-sport performance. Such an analysis is important as fatigue has been demonstrated to be highly task specific[5-7] and, therefore, dietary supplements that enhance some types of athletic performance may not enhance team-sport performance (and *vice versa*). For example, dietary supplements that have been demonstrated to improve continuous exercise performance may not improve intermittent exercise performance.

2. Team-Sport Performance

Team sports are increasingly popular with millions of participants worldwide. However, despite the ubiquitous nature of team sports, it is difficult to define exactly what is meant by 'team-sport performance'. This is partly because the exact physical demands will differ between sports (and also between matches), but mostly because team sports are ultimately decided by points/goals scored rather than the speed, strength or endurance of individual players. Nonetheless, it is possible to identify some common physical qualities that are important for team-sport success.

Team-sport athletes are typically required to repeatedly produce maximal or near maximal efforts (e.g. 'all-out' sprints of <10 seconds) over an extended period of time (1–4 hours).[8,9] When sprints are repeated, it is useful to define two different types of exercise: intermittent-sprint and repeated-sprint exercise. Intermittent-sprint exercise can be characterized by short-duration sprints (≤10 seconds), interspersed with recovery periods long enough (60–300 seconds) to allow near complete recovery of sprint performance.[10] In comparison, repeated-sprint exercise is characterized by short-duration sprints (≤10 seconds) interspersed with brief recovery periods (usually ≤60 seconds).[11] The main difference is that during intermittent-sprint exercise there is little or no performance decrement,[12,13] whereas during repeated-sprint exercise there is a marked performance decrement.[14,15] In addition, many team sports require athletes to perform explosive jumps[16,17] or accelerations.[18] This suggests that important physical determinants of team-sport performance include speed, strength and power, repeated- and intermittent-sprint ability and aerobic endurance (to hasten the recovery between sprints).

Proposed factors responsible for performance decrements during high-intensity periods of play and towards the end of team-sport matches have previously been reviewed[19] and include limitations to energy supply (e.g. phosphocreatine [PCr] resynthesis, aerobic and anaerobic glycolysis) and metabolite accumulation (e.g. phosphate [P_i], H^+). Increasing evidence suggests that failure to fully activate the contracting muscle may also

limit repeated-sprint performance.[7,20,21] Dietary supplements that are able to lessen the influence of these limiting factors, should improve the recovery of both sprint and jump performance. Given the importance of strength and power for both jump[16] and sprint performance,[16,22-24] dietary supplements that are able to augment gains induced by resistance training may also help to improve important aspects of team-sport performance (e.g. single- and multiple-sprint performance, acceleration, jump height). In addition, dietary supplements that are able to speed the recovery of athletes following matches or training may also improve team-sport performance.

3. Dietary Supplements

As long as competitive sports have existed, athletes have attempted to improve their performance by ingesting a variety of substances. Such substances have been variously referred to as nutritional ergogenics, nutritional supplements, dietary supplements or ergogenic aids. While the term *ergogenic aid* is popular, an ergogenic aid could refer to anything that enhances performance (e.g. dietary supplements, psychological strategies or biomechanical techniques) and therefore, will not be used in this review. In addition, the terms 'nutritional supplements' and 'nutritional ergogenics' will be avoided as such terms could imply that there is some nutritional value to the discussed supplements, which may not always be the case. Instead, the term 'dietary supplements' will be used in this review and is defined as any product taken by the mouth, in addition to common foods, that has been proposed to have a performance-enhancing effect. Furthermore, this chapter will only discuss substances that are not currently banned by the World Anti-Doping Agency (WADA). While the legal implications regarding the use of dietary supplements are generally well defined, the moral/ethical implications are less clear. This review does not constitute an endorsement or recommendation of any of the dietary supplements discussed.

One factor complicating a description of the effects of dietary supplements on team-sport performance is that the vast majority of the research conducted to date has been performed on young, adult males. Therefore, while it has been suggested that there is likely to be little difference in the fatigue response of males and females during multiple-sprint exercise,[25] caution should be exercised when extrapolating the conclusions made in this review to females. Similarly, there is very little scientific information about the efficacy and safety of the use of dietary supplements by adolescents and children. In addition to the ethical questions that arise regarding the use of dietary supplements by these age groups, adolescents and children may respond to supplements differently than adults.[26] Finally, as many studies using supplements are funded by supplement companies, the conclusions from such studies need to be carefully scrutinized.

In order to obtain the necessary articles for this review, several databases were searched, including SportDiscus®, PubMed, Web of Science, MEDLINE and Google Scholar. Key search terms used included 'ergogenic aids', 'supplements', 'ribose', 'caffeine', 'creatine', 'branched-chain amino acids', 'sodium bicarbonate', 'β-alanine', 'bovine colostrum', 'HMB', 'repeated sprint ability', 'repeated-sprint exercise', 'multiple sprints' and 'team sports'. Manual searches were also made using the reference lists from recovered articles.

3.1 Ribose

3.1.1 Classification and Usage

Ribose is a five-carbon sugar (D-ribose) which is synthesized by the body, but is also available in small amounts in the diet via ripe fruits and vegetables and as a relatively new, and increasingly popular, dietary supplement. It appears that 88–100% of an oral dose (up to 200 mg • kg^{-1} • h^{-1}) is rapidly and efficiently absorbed from the small intestine and distributed to various tissues including skeletal muscle.[27,28] Researchers have only recently begun to investigate the effects of ribose supplementation and, as a result, more research is required to determine the optimal dose or duration of supplementation to increase muscle ribose levels. However, to date, researchers have used doses of 3–60 g • d^{-1} for 1 day to 4 weeks.[29-32]

Doses of 6–12 g • d^{-1} are commonly marketed as ergogenic in athletes, such as team-sport athletes, involved in high-intensity exercise training.

3.1.2 Possible Mechanisms

The restoration of the immediate muscle energy stores (i.e. the muscle adenine nucleotides: adenosine triphosphate [ATP], adenosine diphosphate and adenosine monophosphate) following intense exercise appears to occur mainly via *de novo* synthesis (i.e. the production of new nucleotides), with possibly a small contribution from the salvage of intracellular purines.[33,34] The limiting step in nucleotide synthesis has been proposed to depend on the availability of 5-phosphoribosyl-1-pyrophosphate (PRPP),[35] which can in turn be formed from ribose in the muscle (figure 1). This is supported by the results of both animal[36] and human[33] studies, which have demonstrated ribose supplementation to enhance the rate of nucleotide synthesis. It has therefore been proposed that ribose supplementation may improve team-sport performance by increasing the rate of ATP resynthesis and the speed of recovery following high-intensity training sessions.

3.1.3 Effects on Team-Sport Performance

Despite a solid scientific rationale for its use, there is little published evidence to suggest that ribose supplementation can improve the recovery of performance following high-intensity exercise. Two studies have reported no effects of either acute (3 g + 25 minutes of rest) or chronic (10 g • d^{-1} for 5 days) ribose supplementation on repeated, all-out, 30-second cycle performance separated by 3 minutes of passive recovery.[30,31] These results were most likely expected as ribose supplementation does not appear to significantly increase ATP resynthesis until at least 24 hours after exercise.[29,33] However, Op't Eijnde et al.[29] also reported that ribose supplementation (16 g • d^{-1} for 6 days) during training (two sessions per day of intermittent knee extensions) did not significantly affect power output when performing two bouts of maximal, intermittent, knee extensions (15 sets of 12 maximal contractions separated by 15 seconds of recovery), 24 hours following the final training session. Similarly, Hellsten et al.[33] reported that, while ribose supplementation (3 × 200 mg • kg^{-1} • h^{-} for 3 days) increased the rate of ATP resynthesis, it did not improve repeated-sprint

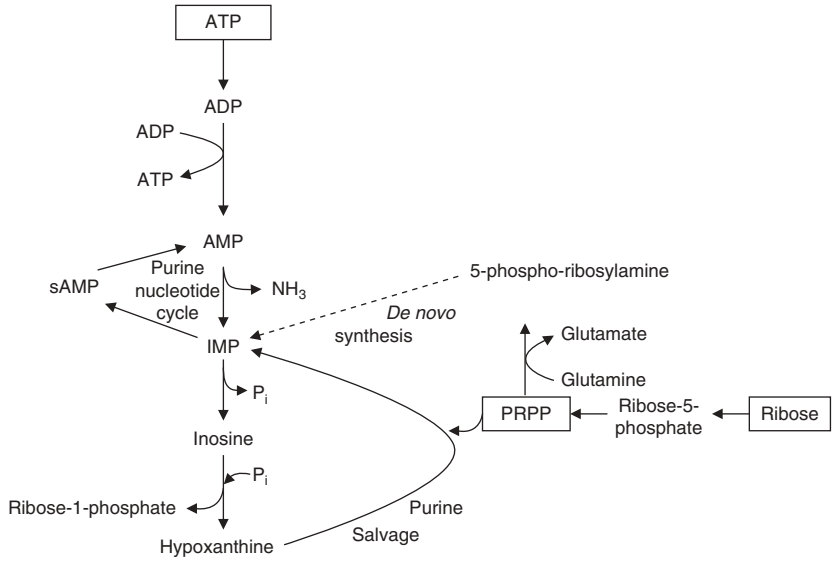

Fig. 1. Major pathways for the degradation and synthesis of muscle adenine nucleotides in human skeletal muscle. **ADP** = adenosine diphosphate; **AMP** = adenosine monophosphate; **ATP** = adenosine triphosphate; **IMP** = inosine 5′-monophosphate; **PRPP** = 5-phosphoribosyl-1-pyrophosphate; **sAMP** = succinyl AMP.

performance (15 × 10-second sprints every 60 seconds) 72 hours following the final training session. However, one study has reported a trend for a ribose-supplemented group (32 g in 36 hours) to have greater repeated-sprint performance (6 × 10-second sprints separated by 60 seconds of recovery) than a placebo-supplemented group, 36 hours after two repeats of the same repeated-sprint task; there was a significantly greater power in sprint two for the ribose-supplemented group.[32]

Ribose supplementation ($10\ g \bullet d^{-1}$), during 4 weeks of resistance training has also been reported to result in greater improvements in 1-repetition maximum bench press strength and total work performed during repeated sets of bench press.[37] These results, however, are difficult to interpret as there were large differences in baseline strength between the placebo- and ribose-supplemented groups and, in the last training session, the timing of the post-exercise testing was not specified. Thus, while further research is warranted, especially with elite team-sport athletes and with other performance measures relevant to team-sport athletes, there is not currently any good evidence to suggest that ribose supplementation can enhance recovery from high-intensity training and/or matches.

3.1.4 Adverse Effects

Ribose is currently a legal substance that appears to be well tolerated, even with doses that far exceed the recommended dose (i.e. $>100\ g \bullet d^{-1}$)[28] or when taken during exercise.[27] To date, no studies have reported adverse effects (i.e. medical problems, diarrhoea, gastrointestinal distress, muscle cramping) to ribose supplementation.[30-32,37]

3.2 Caffeine

3.2.1 Classification and Usage

Caffeine (1,3,7-trimethylxanthine) is the most commonly consumed drug in the world and is found in coffee, tea, cola, chocolate and various 'energy' drinks (table I). The actions of caffeine throughout the body correlate positively with plasma caffeine levels, which are governed by absorption, metabolism and excretion.[38] Almost 100% of orally-administered caffeine is absorbed and it begins to appear in the blood within 5 minutes of ingestion.[39] Typical experimental doses of caffeine ($4–6\ mg \bullet kg^{-1}$ of body mass) will produce peak plasma concentrations of $6–8\ \mu g \bullet mL^{-1}$ ($30–49\ \mu mol \bullet L^{-1}$) within 40–60 minutes after ingestion; plasma half-life ranges from 3 to 10 hours.[40] This suggests that if caffeine is ingested during the pre-match warm up, plasma caffeine levels will be maintained for the entire match.[41,42] While it remains unclear what the effective minimal or maximal doses are, it appears that ingestion of $2–3\ mg \bullet kg^{-1}$ of caffeine is sufficient to produce an ergogenic effect in most individuals.[43,44] Ingestion of doses $>6\ mg \bullet kg^{-1}$ do not seem to provide a further enhancement of performance.[45] It needs to be remembered, however, that caffeine uptake can vary greatly among individuals, depending on the degree of habituation,[46] and individual trialling of the appropriate dose for individual athletes is recommended. It has also been suggested that caffeine in the form of coffee may yield smaller effects than a similar dose of pure caffeine,[47] possibly due to antagonistic actions from other compounds in caffeine.

Table I. Typical caffeine content in common substances

Substance	Caffeine (mg)
1 can of cola drink	40
1 cup of tea	50
1 can of Red Bull (250 mL)	80
1 cup of brewed coffee	100
1 'No Doz' caffeine tablet	100
Guarana (100 mg)	100

3.2.2 Possible Mechanisms

The ergogenic effects of caffeine have been attributed to a number of possible mechanisms, including the blocking of adenosine receptors,[48] central nervous system facilitation,[49] increased Na^+/K^+ATPase activity,[50] mobilization of intracellular calcium[51] and increased plasma catecholamine concentration.[52] It now seems likely that adenosine receptor antagonism is the primary mechanism of action and that this contributes to improved performance via increases in neurotransmitter release, motor unit firing rates and dopominergic transmission.[53] However, there is

some evidence to support each of these mechanisms and it is probable that they all contribute to the wide range of physiological responses to caffeine that make it ergogenic. A more detailed discussion on the possible mechanisms underlying the ergogenic effects of caffeine can be found elsewhere.[53,54]

3.2.3 Effects on Team-Sport Performance

While many studies have demonstrated that caffeine is ergogenic for the performance of prolonged endurance exercise,[53-55] there is limited research that has investigated the effects of caffeine on single-sprint, multiple-sprint or team-sport performance. Following caffeine ingestion, an ~7% increase in total work has been reported during a single 4-second[42] or 6-second[56] sprint on a cycle ergometer; this improvement has a tendency to be smaller when running sprints are performed (e.g. a 1.4% reduction in 30-m sprint time following caffeine ingestion[57]). This ergogenic effect appears to be maintained when sprints are repeated. For example, Schneiker et al.[42] reported a similar 7% increase in mean power when ten male team-sport athletes (peak oxygen uptake [$\dot{V}O_{2peak}$] $56.5 \pm 8.0\ mL \bullet kg^{-1} \bullet min^{-1}$) performed an intermittent-sprint cycle test consisting of $2\times$ 36-minute 'halves', each half comprising $18\times$ 4-second sprints with 2 minutes of active recovery at 35% $\dot{V}O_{2peak}$ between each sprint. These results were supported by another study that reported caffeine ingestion to enhance simulated, high-intensity, team-sport performance in competitive male rugby players.[58] In contrast, two other studies have reported a negligible effect of caffeine ingestion when repeated running sprints ($10–12\times 20$- to 30-m) were separated by short rest periods (10–35 seconds).[57,59] All four of the above studies used a caffeine dose of 5–6 $mg \bullet kg^{-1}$ of body mass.

As a result of the improvements in initial sprint performance,[56] there is the risk that caffeine ingestion may be ergolytic as fatigue develops, possibly due to an increase in the by-products of anaerobic metabolism.[60] Indeed, in a study by Greer et al.,[61] examining the effects of a 6 $mg \bullet kg^{-1}$ dose of caffeine on peak and mean power during four 30-second Wingate tests, each separated by 4 minutes, there was a non-significant trend toward enhanced performance of the first Wingate test and a significantly reduced performance by the fourth bout. However, contrary to the results of the study by Greer et al.,[61] Schneiker et al.[42] reported that although caffeine was able to significantly enhance the performance of intermittent sprints, resulting in increased plasma lactate concentrations, this did not affect the ability of participants to maintain work efforts in the latter stages of the exercise protocol. Thus, while further research is certainly warranted, these results suggest that caffeine ingestion (6 $mg \bullet kg^{-1}$) is likely to improve intermittent, but not repeated, sprint performance. Furthermore, there is no apparent increase in the rate of fatigue development attributable to initial improvements in work and power achieved during intermittent-sprint tests as a consequence of caffeine ingestion.

In another review article, it has also been suggested that ergogenic doses of caffeine (2–6 $mg \bullet kg^{-1}$ of body mass) may negatively affect reaction time and alertness, which may, in turn, counteract the beneficial effects of caffeine on team-sport performance.[62] However, this view is inconsistent with the published research as significant increases in choice reaction time, measured before, during and after a prolonged intermittent-sprint test, have been reported following caffeine ingestion (5–6 $mg \bullet kg^{-1}$) [figure 2;[63,64]]. In addition, caffeine ingestion (6 $mg \bullet kg^{-1}$) has also been reported

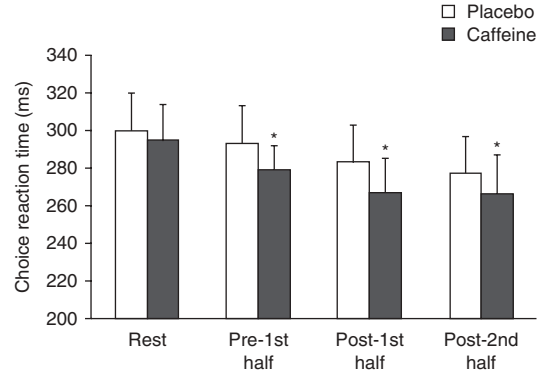

Fig. 2. Effects of caffeine ingestion (6 $mg \bullet kg^{-1}$) on choice reaction time measured before, during and after the prolonged intermittent-sprint test described by Schneiker et al.[42,63] * indicates significant difference between conditions.

to improve the ability to pass balls accurately while being pressured to pass rapidly (i.e. simulating a rugby game).[58]

3.2.4 Adverse Effects

The common social use of caffeine suggests that low-dose caffeine intake can be considered safe. However, high-dose caffeine intake is widely thought to be associated with adverse health effects.[40] In particular, caffeine is known to increase heart rate and blood pressure.[65] Other common adverse effects of caffeine include insomnia, tremors, headaches, anxiety, dependency, withdrawal and occasional gastrointestinal distress when drinking strong coffee.[40,66] Caffeine ingestion has also been reported to eliminate the ergogenic effects of creatine (Cr) supplementation.[67] While initial concerns were raised about the possible diuretic effects of caffeine on the performance and health of team-sport athletes, these concerns appear unfounded.[63] Indeed, we have found no effect of caffeine intake on urine specific gravity following the prolonged, intermittent-sprint test described by Schneiker et al.[42] The effects of caffeine on glucose transport are unclear with one study reporting that caffeine ingestion ($5\,mg \bullet kg^{-1}$) impairs insulin-stimulated glucose uptake in resting and exercised human skeletal muscle,[68] while another study reported that co-ingestion of large amounts of caffeine ($8\,mg \bullet kg^{-1}$) with carbohydrate had an additive effect on rates of post-exercise muscle glycogen accumulation compared with consumption of carbohydrate alone.[69]

3.3 Creatine

3.3.1 Classification and Usage

Cr is a naturally occurring, non-essential, guanidine compound. Cr can be obtained in the diet (from animal-based foods such as fresh fish and meat and various synthetic Cr supplements) or synthesized from the amino acids glycine, arginine and methionine (primarily in the liver, pancreas and kidneys). Cr exists in free and phosphorylated forms (i.e. PCr), and approximately 95% of the body's Cr is stored in skeletal muscle. Total Cr concentrations in skeletal muscle (i.e. Cr + PCr) average around $mmol \bullet kg$ dry weight $(dw)^{-1}$, with a higher capacity for storage in fast-twitch muscle fibres. Following a Cr loading phase (typically ~$0.3\,g \bullet kg^{-1} \bullet d^{-1}$ or $20\,g \bullet d^{-1}$ for 4–7 days), muscle Cr levels increase on average by approximately 25% to what appears to be a maximum of about $160\,mmol \bullet kg\ dw^{-1}$.[70,71] Thus, team-sport athletes can begin matches with greater levels of muscle Cr available for energy production. There is, however, considerable variability concerning muscle Cr increases following supplementation; some individuals are 'non-responders' (little or no increase in muscle Cr), whereas others, particularly athletes with low initial muscle Cr content, are 'high responders' (>30% increase in muscle Cr).[70] As the body breaks down about 1–2 g of Cr per day, it is normally recommended to follow the Cr loading phase with a maintenance phase of $3–5\,g \bullet d^{-1}$. Maintenance doses of $2\,g \bullet d^{-1}$ have been reported to be insufficient to maintain elevated muscle Cr levels.[72] Ingesting Cr prior to team-sport training sessions may augment muscle Cr uptake, as exercise is known to promote the uptake of ingested Cr by muscle.[70] An additional strategy to potentiate Cr accumulation in muscle is to consume Cr with carbohydrates (~100 g) or carbohydrate plus protein (~50 g of each).[73] Furthermore, wash-out periods of at least 2–4 weeks (every 6–8 weeks of Cr supplementation) seem prudent based on data that indicate that the effects of Cr supplementation may diminish after 2 months.[74]

3.3.2 Possible Mechanisms

It is well established that Cr supplementation can increase both total and PCr concentrations in the muscle.[70,75,76] As single and multiple sprints produce a severe reduction in intramuscular PCr concentration (figure 3), it has been proposed that increasing muscle PCr stores may improve multiple-sprint performance via a reduced ATP degradation and a faster resynthesis of PCr between sprints.[79] In addition to increasing the contribution of PCr to ATP resynthesis, this could potentially decrease the reliance on anaerobic glycolysis during team sports and thus reduce the accumulation of H^+.[80] There is also some evidence that increased muscle Cr levels may enhance oxygen uptake during high-intensity

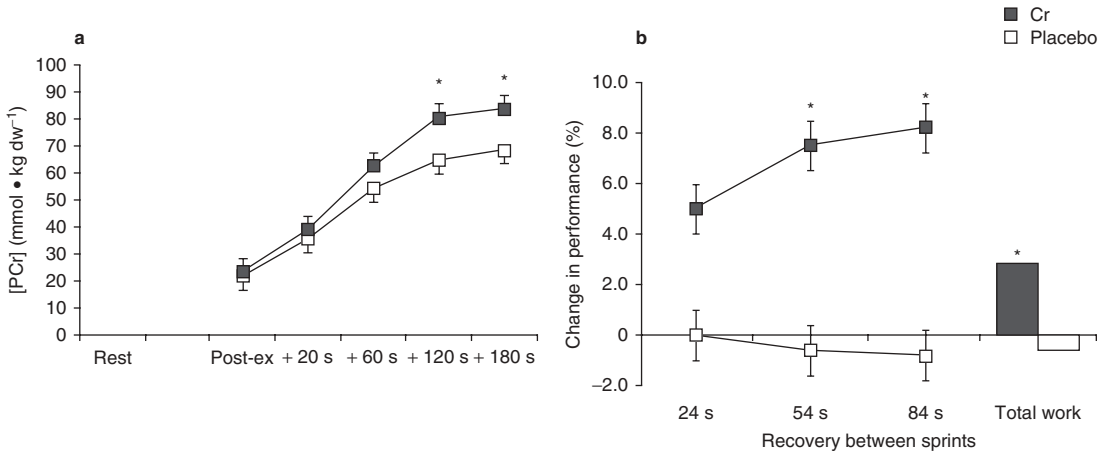

Fig. 3. Changes in phosphocreatine (PCr) resynthesis rate and repeated-sprint performance following short-term creatine (Cr) supplementation (20 g • d^{-1} for 5 days); * $p < 0.05$.[77,78] **dw** = dry weight.

exercise,[81] possibly via increased shuttling of high-energy phosphates between the cytosol and the mitochondria (i.e. the creatine-phosphate shuttle). While this could potentially contribute to a smaller performance decrement during team sports, this hypothesis remains to be tested. Finally, as Cr supplementation has been reported to increase glycogen storage,[82] this could provide an additional ergogenic effect of Cr supplementation for team-sport athletes.

3.3.3 Effects on Team-Sport Performance

Cr supplementation (typically ~20 g • d^{-1} for 5–7 days) has been reported to improve[72,77,83-86] or have no effect[76,87-92] on multiple-sprint performance. Despite these conflicting results, closer inspection of these studies reveals a general trend whereby Cr supplementation does not improve performance when the recovery between sprints is ~30 seconds or less,[76,87,89-91] but is ergogenic when the recovery between sprints ranges from 50 to 120 seconds.[72,77,83,86] For example, Cr supplementation (~20 g • d^{-1} for 5 days) has been reported to improve the performance of repeated 10-second cycle sprints interspersed with 60 seconds of recovery,[86] but not 30 seconds of recovery.[89] Moreover, within one study, Cr supplementation was reported to improve the performance of 6-second cycle sprints interspersed with recovery intervals of 54 or 84 seconds, but not 24 seconds.[77] Thus, it appears that the recovery between sprints may determine whether or not Cr supplementation improves multiple-sprint performance.

A possible explanation for the conflicting findings mentioned above is that it has been proposed that Cr supplementation may improve multiple-sprint performance via a faster resynthesis of PCr between sprints.[79] Indeed, improved multiple-sprint performance has been associated with an improved PCr replenishment rate.[77] However, as Cr supplementation has been reported to increase PCr resynthesis after 60 and 120 seconds, but not 20 seconds[78] (figure 3), this may explain why Cr supplementation does not generally improve the performance of multiple sprints interspersed with recovery periods of ~30 seconds or less.

As team-sport athletes are often required to perform multiple sprints, interspersed with recovery periods ranging from 40 to 120 seconds,[93] it appears that Cr supplementation is likely to improve some aspects of team-sport performance. This is supported by the results of Cox et al.[84] who reported that Cr supplementation resulted in small improvements in some 20-m sprints and agility tasks during an exercise protocol designed to simulate match play in female soccer (association football) players; Cr supplementation had no effect on ball-kicking accuracy. Although not always explicitly reported, the improved

multiple-sprint performance appears to be due to an attenuation of fatigue as Cr supplementation has been reported to have limited effects on single-sprint performance.[87,94] It also needs to be considered that, when used in conjunction with training, Cr supplementation can potentiate gains in fat-free mass, muscle force and power output.[95-98] This augmented training response may be associated with an ability to perform more training when supplementing with Cr.[97]

3.3.4 Adverse Effects

At conventional doses, Cr supplementation in healthy adults has generally been found to be safe.[99] Throughout the years, however, some concerns have been raised, especially with respect to individuals who exceed the recommended loading and maintenance doses.[2] Cr loading is often accompanied by a rapid increase in body mass (1–2 kg in the first 2 weeks), which probably results mainly from intracellular water and/or glycogen accumulation driven by muscle Cr uptake.[62] While increases in body mass may be advantageous for contact team sports (e.g. rugby, American football), some have suggested that this may be disadvantageous for other team sports that involve considerable running.[3] The increase in muscle water content may also increase intramuscular pressure, which, in some individuals, has been reported to increase the risk of compartment syndrome.[100] While there were also initial concerns with regard to the potential adverse effects of Cr on renal function, subsequent studies have reported intact renal function after acute and prolonged dietary Cr intake.[101,102] There have been some rare reports of gastrointestinal distress,[84] which may be related to the timing of Cr ingestion or to co-ingestion with other substances.[103]

3.4 Branched-Chain Amino Acids

3.4.1 Classification and Usage

Amino acids are the building blocks of proteins. There are 20 common amino acids, of which nine are considered essential, i.e. they cannot be produced in sufficient amounts by the body and must be supplied by the diet. Branched-chain amino acids (BCAAs; leucine, isoleucine, valine) are essential amino acids that can be oxidized by skeletal muscle. Supplementation studies have typically involved doses of 5–20 $g \bullet d^{-1}$.[104-107] However, some researchers have recommended doses of 7–10 $g \bullet d^{-1}$ (100 mg • kg body mass),[105] as such doses are less likely to increase plasma ammonia which can readily cross the blood-brain barrier and may contribute to central fatigue.

3.4.2 Possible Mechanisms

During prolonged exercise, there is increased oxidation of BCAA in the muscle and a rise in free fatty acids in the blood. As free fatty acids compete with tryptophan for binding sites on plasma albumin,[108] an increase in free fatty acids will lead to the displacement of tryptophan from its binding sites and an increase in free (unbound) tryptophan levels (figure 4). Thus, both an increase in free tryptophan and a decrease in BCAAs will act together to increase the free tryptophan : BCAA ratio. As both tryptophan and BCAAs compete for the same transporters in the brain, a decrease in this ratio will facilitate the transport of tryptophan (5-hydroxytryptamin: 5-HT) across the blood-brain barrier resulting in increased levels of brain serotonin. The 'central fatigue hypothesis' proposes that an increase in brain serotonin levels may limit both mental and physical performance.[109] It has therefore been hypothesized that BCAA supplementation will prevent the drop in plasma BCAA concentration, decrease the rise in free tryptophan : BCAA ratio, attenuate the increase in brain serotonin and reduce both mental[110] and physical fatigue during team sports.[107] In addition to this potential acute effect on performance, it has also been reported that BCAA supplementation before and after exercise has beneficial effects for decreasing exercise-induced muscle damage and promoting muscle-protein synthesis.[111,112] This may improve muscle recovery following hard training and matches.

3.4.3 Effects on Team-Sport Performance

While BCAA ingestion has been reported to increase the plasma BCAA concentration and to attenuate the rise in the free tryptophan : BCAA ratio,[113] most studies indicate that BCAAs do

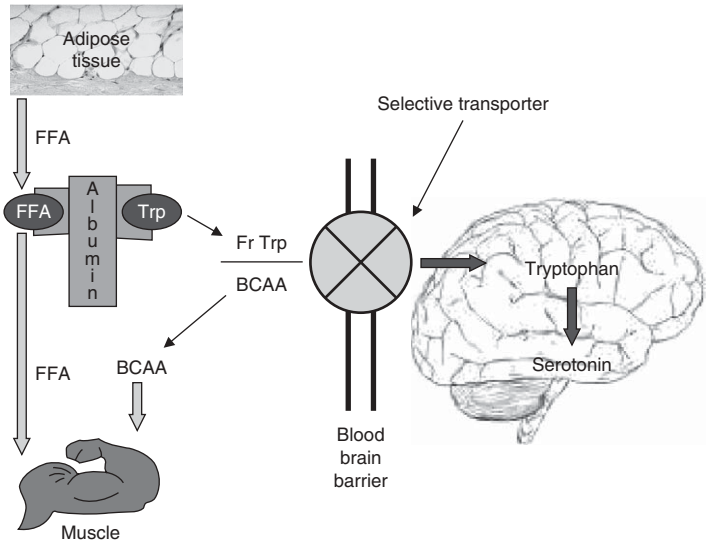

Fig. 4. Proposed relationship between plasma branched-chain amino acid (BCAA) levels, plasma free fatty acid (FFA) levels, plasma tryptophan levels (Fr Trp) and increased serotonin levels in the brain.

not improve endurance performance.[110] Researchers have been unable to demonstrate any ergogenic effects of BCAA supplementation on time to fatigue during prolonged, fixed-intensity exercise[106,114-116] or incremental exercise.[117] Furthermore, in the only study to date, BCAA ingestion did not benefit time to fatigue during an intermittent shuttle test (walking, sprinting and running) designed to simulate the physiological demands of football.[107] Thus, despite a good rationale for its use, there is no evidence to suggest that the intermittent-sprint performance of team-sport athletes will be improved by BCAA ingestion. However, further research is required to investigate the effects of BCAA supplementation on other types of team-sport-related performance (e.g. repeated-sprint ability and jump performance when fatigued). As team sports require the precise execution of skills and tactics, especially late in a match when athletes are fatigued, further investigation into the effects of BCAA ingestion on the maintenance of cognitive function is also warranted.

3.4.4 Adverse Effects

BCAAs are considered relatively safe with only mild concern that high doses may cause gastrointestinal distress or interfere with the absorption of other amino acids.[4]

3.5 Alkalizing Agents

3.5.1 Classification and Usage

The bicarbonate system is present in both the intracellular and extracellular fluids and operates to resist changes in H^+ concentration when a strong acid or base is added (figure 5). When a strong acid is added to the fluid, the bicarbonate ions (HCO_3^-) act as weak bases to tie up the H^+ released by the stronger acid, and forms carbonic acid (H_2CO_3).

The $[HCO_3^-]$ in the extracellular fluid is normally around 25 mmol • L^{-1} at rest and this has been reported to increase by an average of 5.3 mmol • L^{-1} after the ingestion 0.3 g • kg^{-1} of body mass of sodium bicarbonate ($NaHCO_3$).[118] While further

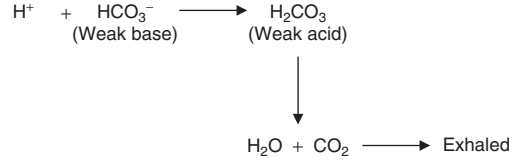

Fig. 5. The bicarbonate buffer system.

research is required, 0.3 g of $NaHCO_3$ per kg of body mass appears close to an optimal dose as it is generally accepted that 0.18 g • kg^{-1} is the threshold for induced alkalosis,[119,120] and that dosages higher than 0.3 g • kg^{-1} are likely to cause gastrointestinal discomfort in many subjects.[121] The most effective time to ingest $NaHCO_3$ has not been accurately determined, however, most authors agree that it should occur between 60 and 90 minutes before exercise.[122-124] In addition, it has been suggested that chronic, lower doses of $NaHCO_3$ administration over 5 days may be more applicable to athletes as they are less likely to have gastrointestinal irritation, especially on the day of performance.[125] $NaHCO_3$ may be administered via the ingestion of capsules, in solution or through intravenous injections. While future research is needed, the literature suggests that the optimal ingestion protocol would involve 0.2–0.3 g • kg^{-1} of $NaHCO_3$ taken 60–120 minutes prior to exercise. Instead of the more commonly used $NaHCO_3$, sodium citrate has also been used as the alkalizing substance in some studies.

3.5.2 Possible Mechanisms

The cell membrane is relatively impermeable to HCO_3^-,[126] and the ingestion of $NaHCO_3$ does not increase the resting intracellular pH or muscle buffer capacity.[123] Rather, the ingestion of alkalizing agents (e.g. $NaHCO_3$) prior to exercise increases the extracellular buffer capacity and enhances the efflux of H^+ from the muscle into the blood, maintaining muscle pH levels closer to normal during high-intensity exercise.[126,127] This should help to reduce the potential negative effects of H^+ accumulation on repeated-sprint and high-intensity running performance. While the ergogenic benefits of alkaline ingestion have been largely attributed to the enhanced extracellular buffer capacity, it has recently been demonstrated that the ingestion of alkalizing agents (either $NaHCO_3$ or sodium citrate) can also reduce the exercise-induced increase in extracellular K^+.[128,129]

3.5.3 Effects on Team-Sport Performance

While many studies have investigated the effects of alkaline ingestion on high-intensity exercise performance, there is a paucity of studies that have investigated the effects of alkaline ingestion on team-sport performance. Bishop et al.[123] reported a significant improvement in power output during sprints 3, 4 and 5 of a repeated-sprint test (5 × 6-second sprints performed every 30 seconds), following the ingestion of 0.3 g • kg^{-1} of $NaHCO_3$ (figure 6). In support of this finding, Lavender and Bird[130] also reported $NaHCO_3$ ingestion to be ergogenic for the performance of ten, 10-second cycle sprints with 50 seconds of recovery between each sprint. In contrast, $NaHCO_3$

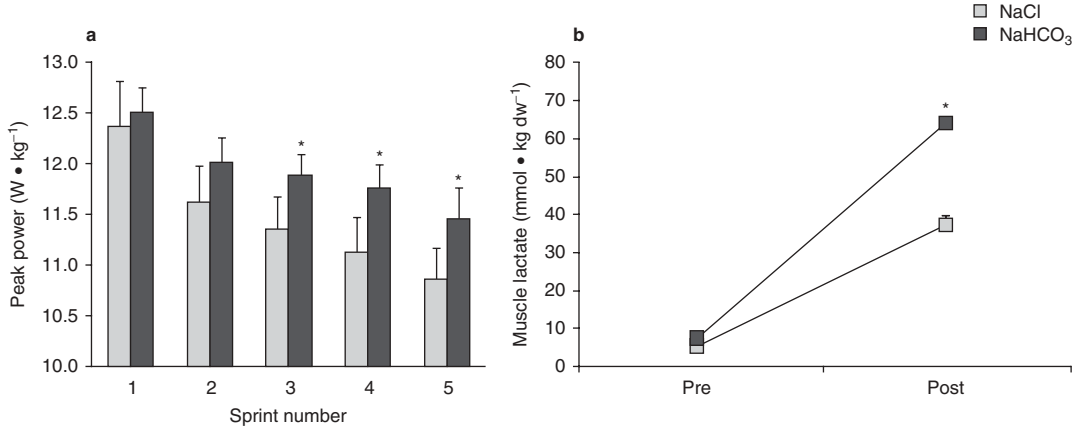

Fig. 6. (**a**) Peak power output (W • kg^{-1}) for each of the five sprints of the 5 × 6-second test of repeated-sprint ability (RSA), following the ingestion of either sodium bicarbonate ($NaHCO_3$) or a placebo (NaCl). (**b**) Muscle lactate values pre and post the RSA test. Values are mean ± standard error of the mean (n = 10). **dw** = dry weight; * indicates significantly different to placebo ($p < 0.05$).[123]

ingestion produced only a small (~2%), non-significant improvement in the performance of ten, 6-second running sprints (on a non-motorized treadmill), separated by 30-second recovery periods.[131] While it is possible that these contrasting findings are due to differing effects of $NaHCO_3$ ingestion on running and cycling repeated-sprint performance, the more likely explanation is the relatively small change in blood pH reported in the final study (7.38–7.43), possibly due to the greater time delay (150 min) between ingestion and exercise. Thus, while confirmatory research is required, it appears that alkaline ingestion leading to a large increase in pH (~0.1 of a pH unit) and $[HCO_3^-]$ (~5.0 mmol • L^{-1}) is likely to improve repeated-sprint performance. Furthermore, while improved K^+ regulation may contribute, the greater production of muscle lactate suggests that reduced inhibition of anaerobic glycolysis also plays a role (figure 6).

Alkaline ingestion may also improve intermittent-sprint performance over the duration of a match, although the results are less convincing. Price et al.[132] reported that $NaHCO_3$ ingestion significantly increased power output during a prolonged intermittent-sprint test (10 × 3-minute blocks of 90 seconds at 40% $\dot{V}O_{2peak}$, 60 seconds at 60% $\dot{V}O_{2peak}$, a 14-second maximal sprint and 16 seconds of rest). The results of this study are consistent with the findings of Bishop and Claudius[12] who investigated the effects of $NaHCO_3$ ingestion on the performance of an intermittent-sprint test involving shorter sprints (two 36-minute 'halves' of repeated ~2-minute blocks; all-out 4-second sprint, 100 second of active recovery at 35% $\dot{V}O_{2peak}$, 20-seconds rest), also performed on a cycle ergometer. It was reported that subjects performed significantly more work and achieved a higher peak power in almost half of the second-half sprints. Interestingly, the plasma $[HCO_3^-]$ peaked at 30.0 mmol • L^{-1} immediately prior to the second half of the intermittent-sprint test (approximately 90 minutes after a second ingestion of 0.2 g • kg^{-1} of $NaHCO_3$), and this may have contributed to why performance was improved in the second but not the first half of the test. The limited research to date, therefore, suggests that alkaline ingestion, leading to a large increase in $[HCO_3^-]$ (~5.0 mmol • L^{-1}), is likely to improve both the repeated- and intermittent-sprint performance of team-sport athletes.

3.5.4 Adverse Effects

In general, alkaline supplementation is safe when taken in recommended doses. However, both $NaHCO_3$ and sodium citrate may cause gastrointestinal side effects (abdominal pain, nausea, cramps, diarrhoea) in some subjects.[133] Excessive doses of alkalotic substances may cause severe metabolic alkalosis with complications such as heart arrhythmias, although this is not known to have occurred in athletic situations.[134]

3.6 β-Alanine

3.6.1 Classification and Usage

β-Alanine is a non-essential amino acid that is common in many foods, especially meats.[135] β-Alanine is an important precursor of carnosine (β-alanyl-L-histidine),[136] an important muscle buffer that has been estimated to account for ~10% of the total buffering capacity in the human vastus lateralis muscle[137] (figure 7). Researchers have only recently begun to investigate the effects of β-alanine and, as a result, there is little information about the optimal dose or duration of supplementation to increase muscle carnosine levels. However, 4–6 weeks of β-alanine supplementation (4.8–6.4 g • d^{-1} divided into 6–8 equal doses throughout the day) has been reported to

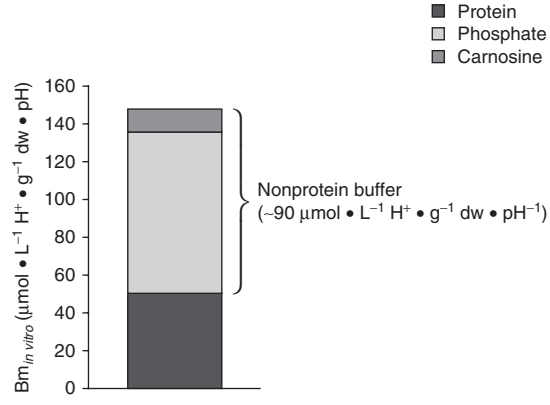

Fig. 7. Components of *in vitro* muscle buffer capacity ($Bm_{in\ vitro}$).[138-142] **dw** = dry weight.

increase muscle carnosine by ~40–60%.[137,143-146] One study has also reported that a slightly longer supplementation period (4.0–6.4 g • d^{-1} for 10 weeks) can produce greater increases in muscle carnosine levels (~80%).[137]

3.6.2 Possible Mechanisms

In theory, a 60% increase in muscle carnosine levels[137] should equate to approximately a 6.5% increase in muscle buffer capacity. As the accumulation of H^+ has been reported to affect muscle contraction,[147] and to reduce the rate of anaerobic energy production,[148-150] greater muscle buffering (via β-alanine supplementation) may translate to improvements in multiple-sprint performance. In support of this, both repeated-sprint ability[151] and prolonged, intermittent-sprint ability[152] have been correlated with muscle buffer capacity.

3.6.3 Effects on Team-Sport Performance

In the limited number of studies conducted to date, it has been reported that β-alanine supplementation results in a significant increase in total work done at 110% of the power at maximum oxygen uptake (+13%),[137] a significant increase in performance during repeated, isokinetic, leg extensions[146] and a significant increase (+2.5%)[153] or no change[154] in time to exhaustion during an incremental cycle test. It has also recently been reported that β-alanine supplementation improved mean and peak power during a 30-second, all-out isokinetic task after a 110-minute simulated cycling race.[155] However, in the only study to date, β-alanine supplementation did not improve repeated-sprint ability (2 × [5 × 5-second sprints: 45 seconds of recovery]: 2 minute recovery).[156] Further studies, using intermittent-sprint protocols or simulated match play, are required to confirm the hypothesis that β-alanine supplementation may improve the multiple-sprint performance of team-sport athletes.

3.6.4 Adverse Effects

Large, acute doses of β-alanine (>10 mg • kg^{-1} body mass) have been reported to induce temporary skin reactions (mild flushing and tingling sensations) in some subjects, which dissipate in ~2 hours.[136] It is for this reason that 6–8 servings, separated by at least 2 hours, are usually recommended to achieve a dose of 4.8–6.4 g • d^{-1}. No other studies appear to have investigated or reported possible adverse effects of β-alanine supplementation on indices of health.

3.7 Bovine Colostrum

3.7.1 Classification and Usage

Colostrum is the initial milk secreted by mammals after parturition (bovine colostrum is secreted by cows). It is a rich source of proteins, carbohydrate, fat, vitamins, minerals and biologically-active components such as antimicrobial molecules, immunoglobins and growth factors (e.g. insulin-like growth factor; IGF-1).[157] To date, relatively few studies have been conducted using bovine colostrum and it is therefore difficult to recommend an optimal dose. Most of the early studies supplemented with 60 g • d^{-1} of bovine colostrum for 8–9 weeks.[158-161] However, subsequent studies reported some positive effects on endurance performance when supplementing with 10[162] and 20 g • d^{-1}.[163] As bovine colostrum supplementation has been hypothesized to potentiate adaptations to training, there is also some limited evidence that a supplementation period of >1[164] to 4[158] weeks is required. However, as all of these studies incorporated different outcome measures, they are difficult to compare and further studies are required to establish an optimal supplementation protocol for bovine colostrum.

3.7.2 Possible Mechanisms

Colostrum is important for human development,[165] and the presence of similar active components in bovine colostrum has led to the growing use of bovine colostrum in humans.[166] Dietary colostrum has been shown to increase circulating IGF-1 concentrations in some,[164,167] but not all[158,163] studies. As IGF-1 is believed to play an important role in the development of skeletal muscle,[168] this probably contributes to the positive effects that colostrum has been reported to have on skeletal muscle protein synthesis.[167] This suggests that colostrum might improve anabolic processes during the post-training recovery and augment improvements in muscle function and athletic performance in response to a specific training stimulus. It has also been proposed

that colostrum supplementation during training may result in greater improvements in the ability to recover from intense exercise.[158] Finally, compared with a placebo, 9 weeks of bovine colostrum supplementation, in conjunction with pre-competition training, has been reported to result in a 22% greater increase in estimated,[160] but not titrated,[159] blood buffer capacity. As a higher blood buffer capacity has been associated with both improved repeated-sprint ability[123,169] and prolonged intermittent-sprint ability,[12] increases in blood buffer capacity may improve team-sport performance.

3.7.3 Effects on Team-Sport Performance

To date, there is only one published study that has investigated the effects of bovine colostrum supplementation ($60\,g \bullet d^{-1}$ for 8 weeks), in conjunction with field-hockey training, on team-sport performance.[161] Compared with a placebo, there were no significant differences for improvements in aerobic performance (shuttle test), a trend for greater improvements in vertical jump height (2.1 ± 0.7 cm vs 0.3 ± 0.8 cm; $p = 0.12$) and a significantly greater improvement in 5×10 m shuttle sprint performance (-0.64 ± 0.09 vs -0.33 ± 0.09 seconds; $p = 0.023$). While the mechanisms by which colostrum exerted its ergogenic effects were not investigated, it was hypothesized that colostrum may have potentiated improvements in those systems which were trained extensively (the training programme emphasized speed and power training). Other studies, not conducted on team-sport athletes, have produced mixed results. Bovine colostrum supplementation in conjunction with endurance training has been reported to improve the recovery from intense exercise in physically-active male runners,[158] but not elite, female rowers.[160] Colostrum has also been reported to have a 'likely benefit' (+1.9%) on improvements in 40 km time-trial performance during high-intensity training,[162] and to augment training-induced improvements in cycle time-trial performance following a 2-hour ride.[163] Thus, while more research is needed, especially on team-sport athletes and using team-sport-relevant testing, there is some evidence that bovine colostrum supplementation may augment training-induced improvements in sprint, jump and endurance performance.

3.7.4 Adverse Effects

No adverse effects of bovine colostrum supplementation have been reported in the literature. However, it should also be noted that there appear to be no studies that have specifically investigated potential adverse effects of prolonged bovine colostrum supplementation.

3.8 β-Hydroxy-β-Methylbutyrate

3.8.1 Classification and Usage

β-Hydroxy-β-methylbutyrate (HMB) is a naturally occurring metabolite of the essential BCAA, leucine. It is produced endogenously in small amounts (2–10% of leucine oxidation proceeds to HMB[170]) and can also be consumed through both plant (e.g. citrus fruits) and animal (e.g. catfish, breast milk) foods. As a dietary supplement, HMB is usually marketed as calcium-HMB-monohydrate. The recommended dose of HMB is $3\,g \bullet d^{-1}$ for 3–8 weeks, based on the dose-dependent manner in which it has been reported to affect resistance training-induced gains in the lean body mass of untrained subjects (figure 8). It should be noted, however, that the absence of a positive effect for doses $>3\,g \bullet d^{-1}$ is based on one study only[171] and further research is warranted, especially with well trained subjects.

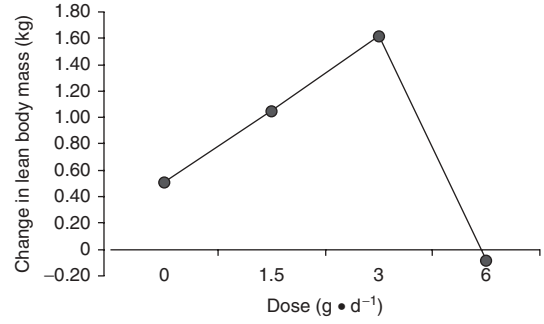

Fig. 8. Changes in lean body mass during 3–8 weeks of resistance training are related to the β-hydroxy-β-methylbutyrate dose.[171-173]

3.8.2 Possible Mechanisms

HMB has been proposed to function as an anti-catabolic agent and to decrease exercise-induced muscle damage.[172] This has been inferred from decreases in urine 3-methylhistidine and plasma enzymes following resistance training[172,174,175] and endurance exercise[176] in untrained subjects. However, decreases in training-induced markers of catabolism have not been observed following HMB supplementation in trained subjects.[177,178] This may be explained by the observation that adaptations to physical training cause subsequent exercise to be accompanied by less protein turnover and breakdown in trained athletes[2] thus rendering the proposed benefits of HMB less likely in trained athletes.[179] It has also been proposed that HMB may promote the synthesis of cholesterol needed to form and stabilize cell membranes.[180] By minimizing protein breakdown and the damage to cells that may occur during intense training, it is hypothesized that HMB may promote training-induced increases in both lean body mass and strength.

3.8.3 Effects on Team-Sport Performance

To date, only one study has specifically evaluated the effects of HMB supplementation on team-sport performance.[178] It was reported that HMB supplementation ($3\,g \bullet d^{-1}$) during winter resistance/agility training did not produce greater improvements in repeated-sprint ability ($12\times$ 6-second sprints with 30 seconds of recovery) than a placebo. Three studies have also reported no benefits of HMB supplementation during pre-season training on the anaerobic power (10- to 60-second cycle sprint) of team-sport athletes.[177,181,182] With few exceptions,[183] HMB supplementation also does not improve indices of aerobic fitness.[176,181] Due to its reported ability to promote adaptations associated with resistance training,[172,174,175,184] HMB may be of benefit to team-sport athletes who need to increase lean body mass or strength. However, as enhanced gains in lean body mass and strength have tended not to be replicated in trained athletes,[177,181,185,186] the benefits of HMB supplementation for elite, team-sport athletes remain unproven and further research is required.

3.8.4 Adverse Effects

There are no reports of adverse effects of the recommended $3\,g \bullet d^{-1}$ dose of HMB in the limited number of short-term (1–8 weeks) studies. These include no reported changes in blood pressure, lipid profile, renal function, liver enzymes, electrolytes, haematological parameters, urinalysis, testosterone, cortisol or male fertility.[171,180,187] There are currently no data on the long-term (>8 weeks) effects of HMB supplementation, or the effects of taking more than the recommended dose.

4. Risks

While most of the supplements described in this review appear safe when using the recommended dose, it needs to be remembered that athletes often work on the 'more must be better' principle, and there are studies indicating that people are consuming more than the recommended doses of some supplements. The effects of these higher doses on indices of health remain unknown, and further research is warranted. It needs also to be remembered that very little is known about the potential adverse effects of ingesting multiple supplements. Supplements that have been demonstrated to be safe when ingested on their own may have adverse effects when combined with other supplements. The use of supplements by adolescents needs to be carefully considered due to evidence suggesting that such use may lead to an increased risk for subsequent use of illegal, performance-enhancing substances.[26]

If a team-sport athlete does decide to take a supplement, they need to ensure that they are getting what they think they are getting. Studies investigating the components of various supplements have reported more than 85% to contain less product than what was labelled.[188] Of greater concern is the possibility that some supplements may contain undeclared substances, banned by WADA, which may lead to a positive drugs test.[188,189] Baume et al.[190] reported that 19 of the 103 (18%) supplements that they tested contained substances not disclosed on the label. It is important to remember that athletes who test positive for banned substances are, in most

jurisdictions, held responsible for what is found in their body, regardless of whether they knowingly ingested the banned substance.[191] For example, in 2008, a Canadian bobsled athlete was banned for 20 months based on a positive test for nandrolone, which was subsequently discovered to be an unlabelled ingredient in a supplement he was taking.

5. Conclusions and Recommendations for Future Research

A well designed diet that meets the energy and nutrient intake needs, and incorporates the proper timing of meals, is the foundation upon which optimal training and performance can be developed. Nevertheless, there is the common belief by team-sport athletes and their coaches that the appropriate ingestion of some dietary supplements, in conjunction with well designed training, can enhance team-sport performance. While more research is required, evidence is emerging to support the performance-enhancing claims of some, but not all, dietary supplements that have been proposed to improve team-sport performance. For example, there is good evidence that caffeine, Cr and $NaHCO_3$ ingestion can improve multiple-sprint performance. The evidence is not so strong for the performance-enhancing benefits of β-alanine or colostrum, although further research is warranted using more team-sport-specific performance tests. Current evidence does not support the ingestion of ribose, BCAAs or HMB, especially in well trained athletes.

While many studies have evaluated the performance-enhancing effects of most dietary supplements, more research needs to be conducted using team-sport athletes and using team-sport-relevant testing. Dietary supplements that enhance some types of athletic performance may not necessarily enhance team-sport performance (and *vice versa*). Furthermore, there is no guarantee that the effectiveness of dietary supplements, which improve isolated performance (i.e. single-sprint or jump performance), will remain in the context of a team-sport match. Anecdotal reports suggest that team-sport athletes often ingest more than one dietary supplement. More research is required to investigate the effects of ingesting multiple supplements (both on performance and health).

Notwithstanding the real need for applied research in 'real-life' settings, it is important that basic research is not neglected.[192] This should include initial research to determine the optimal dose, timing and number of days/weeks to ingest the various dietary supplements proposed to enhance team-sport performance. Without such information, researchers run the risk of obtaining negative findings not because the dietary supplement is not efficacious, but because of an inappropriate supplementation protocol. In addition, despite the need to determine the effects of supplements in the 'real world' (e.g. regular matches, limited time devoted to physical training, co-ingestion of other dietary supplements), efficacy trials are first required to test whether a supplement has a substantial positive or negative effect on actual sports performance when delivered under optimum/ideal conditions. Efficacy trials (both in the laboratory and in the field) are characterized by strong control in that a standardized intervention is delivered in a uniform and tightly controlled fashion to a specific, often narrowly defined, homogenous, motivated population. This approach should include random selection of participants, random assignment to conditions and the use of placebos (ideally double blind) or cross-over designs. Subsequent research is then required to determine if the intervention effect is large enough to make a difference in an applied setting or if it interacts positively or negatively with other training/nutrition factors.

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