Sport nutrition: A review of the latest guidelines for exercise and sport nutrition from the American College of Sport Nutrition, the International Olympic Committee and the International Society for Sports Nutrition

Potgieter S, BScDietetics, MNutrition
Lecturer, Therapeutic Nutrition, Division of Human Nutrition, Faculty of Health Sciences, Stellenbosch University
Correspondence to: Sunita Potgieter, e-mail: sunita@sun.ac.za
Keywords: sport nutrition, guidelines, International Olympic Committee, International Society for Sports Nutrition

Abstract

Evidence-based sport nutrition guidelines which explore the connection between nutrition, exercise and well-being form a crucial part of any athlete's competitive and training programme. Guidelines that are based on sound scientific evidence about the quantity, structure and timing of food intake are important to ensure that athletes train more effectively to reduce the risk of injury and illness. Appropriate nutrition complements training and recovery and can induce metabolic adaptations to training. Adequate energy should derive from a variety of foods that provide carbohydrates, proteins, fat and micronutrients. Maintenance of the energy balance in individuals with increased requirements because of physical activity is important. Challenges may arise in the case of larger athletes and those who partake in high-volume intense training. Habitual carbohydrate intake is essential for physically active individuals and should be timed according to training sessions to ensure optimal pre-, during, and post-workout nutrition. Dietary protein requirements are slightly elevated in the case of strength, speed and endurance training. Consideration of the quality and timing of protein intake is important. The fat requirements of athletes are similar or somewhat higher, so consumption of adequate amounts of fat is essential for optimal health, maintenance of energy balance, optimal intake of essential fatty acids and fat-soluble vitamins. Vitamins and minerals are needed to provide a health benefit, although the ergogenic effect of most micronutrients is still unclear and warrants further research. Supplements and sports foods are used extensively and although the use of some supplements may be ergogenic, the risk to benefit ratio needs to be carefully considered before embarking on the widespread use of supplements.

Ⓟ **Peer reviewed. (Submitted: 2012-10-02. Accepted: 2013-01-27.) © SAJCN** **S Afr J Clin Nutr 2013;26(1):6-16**

Introduction

Sport nutrition has been well documented as being an invaluable tool to be used in any athlete's training and competition programme. It is the single most complementary factor to any physically active individual or elite athlete. The task of reviewing sport nutrition guidelines has been simplified by the recent publication of a wide variety of consensus statements and reviews on sport nutrition, individual nutrients, nutrient timing, and supplements and sports foods. The *Journal of Sport Science* has published a series of papers, following several International Olympic Committee (IOC) conferences, on nutrition in sport. The first dates back to 1991. In 2003, a further consensus conference was held to update the guidelines from 1991, and more recently, the 2010 IOC consensus on sport nutrition papers was published in a special edition of the *Journal of Sport Science* in 2011. These documents set out to provide evidence-based guidelines and "a complete review of scientific evidence of the relationship between nutrition, performance and health in sport".[1]

The International Society for Sport Nutrition (ISSN) also published two consensus documents; one in 2008 that focused on nutrient timing,[2] and another in 2010 that reviewed research on and recommendations for exercise and sport nutrition.[3] The American Dietetic Association (ADA), the Dietitians of Canada and the American College of Sports Medicine (ACSM) teamed up in 2000 and 2009 to publish their position stand on nutrition and athletic performance.[4,5] These consensus documents are complemented by a variety of reviews and position stands on fluid and physical activity,[6] individual nutrients and sport supplements.[7,8]

Last year, the South African Institute of Drug Free Sport produced a position statement on sport supplements in order to provide an evidence-based guideline for use by professionals who work in the field of sport nutrition within the South African context.[9]

The main aim of this review was to summarise, critically appraise and compare key concepts, elements and guidelines from the abovementioned consensus documents. This is important in order to provide healthcare professionals with guidelines that are based on a background of sound scientific evidence of the quantity, structure and timing of food intake. Guidelines are of vital importance to ensure that physically active individuals and athletes train more effectively, thereby reducing the risk of injury and illness and improving exercise performance.[10]

General nutritional needs for physical activity

Good nutrition assists in the ability to train intensely, as well as in muscle recovery and metabolic adaptations to endurance exercise. Adequate energy should derive from a wide variety of available foods that provide carbohydrates, proteins, fat and micronutrients.

Energy and energy availability

In most instances, a well-balanced diet should be sufficient in energy in order to maintain the energy balance in individuals with increased energy requirements because of physical activity.[3] However, it might be challenging to meet the energy needs of athletes with a high body weight and height, i.e. larger athletes and athletes who partake in high-volume intense training.[3] A negative energy balance is common in endurance athletes, such as runners, cyclists, swimmers and triathletes, as well as in sports in which dietary restriction is part of the strategy to modify body composition and size, such as gymnastics, skating, dancing, wrestling and boxing.[3,11] These athletes sometimes attempt to lose weight too quickly and in mismanaged ways.[3,11] Historically, female athletes are more prone to eating disorders, which lead to a disturbed energy balance.[3] A negative energy balance in female athletes can lead to the development of the female athlete triad, which includes disturbed eating patterns, menstrual disorders and low bone mineral density.[11] It is possible for a female athlete to become energy deficient without having a clinically diagnosed eating disorder.[11] Apart from this, high intensity training can decrease appetite and change hunger patterns. Some athletes may be uncomfortable eating meals before exercise because of gastrointestinal discomfort.[3,11] Travel and training also influence food availability and safety, and careful planning around travel schedules is of vital importance.[3] Insufficient energy intake can result in weight loss, especially of muscle mass; injury, illness, increased prevalence of overtraining syndrome and ultimately decreased exercise performance.[3] To overcome this, athletes should focus on maintaining an energy balance to suit their energy expenditure and have 4-6 meals per day, including nutrient-dense food. The use of low-risk supplements, such as liquid meal replacements and multivitamin and mineral preparations, can also be considered.[3]

The ACSM recommends that "athletes need to consume adequate energy during periods of high intensity and/or long duration training to maintain body weight and health and to maximise training effects".[5] The ACSM recommends that energy requirements are calculated using either the dietary reference intakes (DRIs) or prediction equations, such as the Cunningham or Harris-Benedict equations, where the basal or resting metabolic rate is calculated using a physical activity factor (1.8-2.3) depending on the type, duration and intensity of exercise. Energy expenditure can also be calculated by means of metabolic equivalents.[5]

The ISSN recommends that energy requirements are calculated according to level of physical activity and body weight, as summarised in Table I.[3]

The 2003 and 2010 IOC consensus documents emphasise determining and calculating estimated energy availability ($_{est}$EA), in addition to calculating total energy requirements. $_{est}$EA is defined as "dietary energy intake minus energy expended in exercise (EA = EI-EEE)" and is expressed in kcal/kg fat-free mass (FFM)/day. The reasoning behind calculating $_{est}$EA is that some physiological processes are negatively affected by severely low $_{est}$EA. Only determining total energy or resting energy expenditure can underestimate a long-term undernourished, physically active individual's requirements. Energy balance cannot provide reliable information about energy requirements and is not considered to be useful when calculating an athlete's requirements.[11] Disruption of a female athlete's menstrual cycle and diminished bone health have been found when the $_{est}$EA is less than 30 kcal/kg FFM. Therefore, ingesting sufficient energy and nutrients is important to support the skeletal, reproductive and immune systems, particularly in immune-compromised athletes.[11]

Table I: Energy requirements for physical activity[3]

Physical activity level	kcal/kg/day	kcal/day
General physical activity 30-40 minutes/day, 3 times a week	Normal diet, 25-35	1 800-2 400[a]
Moderate levels of intense training 2-3 hours/day, 5-6 times a week[b]	50-80	2 500-8 000[c]
High-volume intense training 3-6 hours/day, 1-2 sessions/day, 5-6 times a week[b]	50-80	2 500-8 000[c]
Elite athletes[d]	150-200	Up to 12 000[e]
Large athletes[d]	60-80	6 000-12 000[f]

a: Values estimated for a 50-80 kg individual
b: Moderate levels of intense training use lower level of range, high-volume intense training uses upper level of range
c: Values estimated for a 50-100 kg individual
d: Depending on training periodisation, and the volume and intensity of training
e: Values estimated for a 60-80 kg athlete
f: Values estimated for a 100-150 kg athlete

The recommendations of the IOC in the 2010 consensus statement on managing $_{est}$EA is for athletes to eat specified amounts of food at planned times during the day and not to wait for hunger, to eliminate harmful weight-loss strategies and practices, to ensure periodisation of diet according to periodisation of training, and to follow diet and exercise regimes which provide an $_{est}$EA of 30-45 kcal/kg FFM/day, while exercising to reduce body size and fatness.[11]

When an athlete is able to reach his or her daily macronutrient requirements, it is most likely that total energy intake will be sufficient. The guidelines that are presented by the ACSM are based on the DRIs, which have been well researched and based on equations that were developed according to the gold standard method used to assess free-living energy expenditure: doubly labelled water. They also include various activity levels, from slight to very active.[5] Although not researched to the same extent as the ACSM guidelines and thereby complicating critical appraisal of the ISSN guidelines, these recommendations can still be used to obtain a quick calculation of an athlete's energy requirements according to their physical activity level.

In addition to calculating total energy requirements, the IOC suggests that $_{est}$EA should be determined to assess whether or not the athlete is reaching his or her energy goals matched for energy expenditure, and to thereby reduce the risk of impaired skeletal, reproductive and immune functioning.

Macronutrient requirements

Carbohydrate requirements

Habitual or daily carbohydrate intake is essential in physically active individuals, and should be timed according to training sessions in order to ensure optimal pre-workout nutrition, as well as to encourage recovery post workout. If this is not possible during the day, the intake should be tailored according to individual preference and tolerance, provided that the total daily requirements are met.[12]

The field of sport nutrition has departed from calculating carbohydrate requirements as a percentage of the total energy requirement to instead focus on determining requirements expressed as grams per kilogram (g/kg) body weight (BW). When the macronutrient intake is sufficient, total energy requirements will be met. The g/kg BW requirement ensures that adequate macronutrients are provided in respect of total energy intake and that there is some flexibility when it is necessary to individualise nutrition plans according to specific training regimes.[12] Athletes require more energy and macronutrients in proportion to their body weight, expressed in kilograms, compared to sedentary individuals. Therefore, according to the ACSM and ADA, "expressing energy and macronutrient needs in terms of grams per kilogram body weight is a practical method to document these needs".[5]

Daily carbohydrate requirements

Muscle glycogen and blood glucose are the primary sources of energy for contracting muscles. An optimal dietary carbohydrate intake enhances recovery and optimises glycogen stores for the next training session. The habitual dietary requirement for carbohydrates differs according to the amount and intensity of training and should focus on including more complex carbohydrates of low-moderate glycaemic index.[3] However, concentrated, nutrient-dense sources of carbohydrates can be included during difficult and intense training and when it is a challenge to reach high carbohydrate requirements because of the high bulk and fibre content of complex carbohydrates. Low-risk supplements can also be included to achieve the daily requirements if required (Table II).[2,3,12]

The glycaemic index is a tool designed to rank carbohydrate-containing foods according to the blood-glucose response that is elicited after consumption of these foods, relative to that of glucose or white bread.[12] There is controversy about the use of the glycaemic index in sport nutrition. Currently, there are no clear recommendations for athletes. It has been reported that there is improved metabolism and substrate utilisation during exercise when low glycaemic index carbohydrate-containing food is ingested with the pre-exercise meal.[12] However, these studies have not shown improved exercise performance. It is also known that when carbohydrates are ingested during exercise, the effect of the glycaemic index on the pre-event meal is diminished.[12] Therefore, ingesting a low glycaemic index meal pre-exercise might be useful when limited carbohydrate intake during exercise is possible. However, further research is needed to confirm this.[12] Currently, the most important aspects of carbohydrate intake thought to be important are obtaining daily carbohydrate requirements and ensuring gastrointestinal comfort, since attaining the high carbohydrate intake that is required for endurance exercise can lead to abdominal bloating, cramping and diarrhoea.[12]

The timing of carbohydrate intake in relation to exercise is important. Apart from the recommendations for before, during and after exercise (discussed below), a new concept with regard to the role of periodisation of carbohydrate intake has emerged. This idea is known as "training low and competing high".[12] When an acute bout of endurance exercise is completed in a state of low muscle glycogen, it appears that there is increased transcriptional activation of enzymes involved in carbohydrate metabolism and improvement in the adaptive responses that favour fat metabolism.[12] Thus, the athlete should train in a depleted muscle glycogen state to elicit a greater training response, and then switch to a high carbohydrate intake when competing to ensure optimal exercise performance.[12] However, there are a couple of misconceptions concerning this theory and further research is warranted before any clear recommendations can be made.

The first of these misconceptions is that all training low methods necessitate chronic adherence to a low-carbohydrate, high-fat diet. Although such a diet can improve the body's ability to oxidise fat and spare muscle glycogen, it may also impair carbohydrate metabolism, and therefore the ability to perform at a high intensity.[12] Thus, the emphasis is more on the timing of training sessions, rather than following a deliberate low-carbohydrate diet in order to achieve depleted glycogen levels for selected training sessions, i.e. training after an overnight fast, drinking only water during prolonged workouts, not ingesting carbohydrates during recovery, and taking in less carbohydrates than those required by the training low.

The second misconception is that research in this field is not always appropriate. Completed research on untrained individuals, as well as research on exercise metabolism and exercise science, cannot always be extrapolated to apply to well-trained individuals, or directly translate into improved sport and exercise performance enhancement.[12] Currently, there is insufficient research to confirm whether "training low and competing high" can improve exercise performance. However, there is consistent evidence that although this type of periodisation can lead to the inability to train at high intensities, especially during sessions that require high intensity or specific technique and skill, there may be some benefit in undertaking some training sessions in a glycogen-depleted state, such as low-intensity or conditioning sessions that are undertaken at the start of the training season.[12]

Carbohydrates before exercise

The limited glycogen stores in the body will only last for approximately 90 minutes to three hours during moderate- to high-intensity exercise.[2] Carbohydrate loading is a strategy that involves changes to training and nutrition which can maximise muscle glycogen stores prior to endurance exercise lasting longer than 90 minutes. This strategy elevates muscle glycogen stores and has been found to increase endurance and exercise performance.[12] This is also important to maintain muscle tissue stores which can be decreased

Table II: Carbohydrate requirements for physical activity[2,3,5,12]

Physical activity level	g/kg BW/day	Comments
Daily or habitual carbohydrate requirements		
ACSM		
Athletes	6-10 g/kg BW/day	Depends on the athlete's total daily energy expenditure, type of sport, gender and environmental conditions.
ISSN		
General physical activity, 30-60 minutes/day, 3-4 times a week	3-5 g/kg BW/day	Complex carbohydrates. Low to moderate GI. Concentrated carbohydrates.
Moderate- to high-intensity volume, 2-3 hours/day, 5-6 times a week	5-8 g/kg BW/day	
High-volume, intense exercise, 3-6 hours/day, 1-2 sessions, 5-6 time a week	8-10 g/kg BW/day	
IOC		
Low-intensity or skill-based activities	3-5 g/kg BW/day	Include pre-, during and post-training intake. Individual tolerance and preference. Nutrient-dense choices.
Moderate exercise programme, ~ 1 hour/day	5-7 g/kg BW/day	
Endurance programme, moderate to high intensity, 1-3 hours/day	6-10 g/kg BW/day	
Strength-trained athletes	4-7 g/kg BW/day	
Extreme commitment, moderate to high intensity, > 4-5 hours/day	8-12 g/kg BW/day	
Pre-event/training carbohydrate requirements		
ACSM		
Pre-event meal	200-300 g, 3-4 hours prior	Low in fat and fibre. High carbohydrates, moderate protein.
ISSN		
Carbohydrate loading	8-10 g/kg BW/day for 1-3 days prior to event	High GI carbohydrate diet.
Pre-event meal	1-2 g/kg BW carbohydrates 3-4 hours prior to event	
IOC		
General fuelling up for events > 90 minutes	7-12 g/kg BW per 24 hours	Low in fibre or residue. Individual tolerance. Avoid high-fat protein and fibre (especially if there are gastrointestinal complaints). Low GI if no carbohydrates during exercise.
Carbohydrate-loading preparation for events > 60 minutes sustained or intermittent exercise	36-48 hours of 10-12 g/kg BW per 24 hours	
Pre-event fuelling before exercise > 60 minutes	1-4 g/kg BW consumed 1-4 hours prior to exercise	
During event or training carbohydrate requirements		
ACSM		
During exercise > 60 minutes	0.7 g/kg BW/hour or 30-60 g/hour	This is especially important when no pre-event meal has been consumed or in the case of exercise in heat or humidity. 6-8% carbohydrate solution. Primarily glucose. Fructose alone is not as effective and can cause diarrhoea. Mixtures of glucose and fructose, other simple sugars and maltodextrins seem effective. If the same total amount of carbohydrates are provided, the form of carbohydrates do not appear to matter (sports drink, gel or a snack).
ISSN		
During events > 60 minutes	30-60 g/hour	Body oxidises 1-1.1 g/carbohydrates/minute or 60 g/hour 6-8% carbohydrate solution. Start drinking early and continue drinking small amounts every 15-20 minutes. Combination carbohydrates increase oxidation (up to 1.2-1.75 g carbohydrates/minute) (glucose, fructose, sucrose and maltodextrin recommended, not large amounts of fructose because of gastrointestinal discomfort).

Table II: Carbohydrate requirements for physical activity[2,3,5,12]

Physical activity level	g/kg BW/day	Comments
IOC		
During brief exercise < 45 minutes	Not needed	Practice plan before event. Higher carbohydrate intakes associated with increased exercise performance. Multiple transportable carbohydrates should be included (glucose and fructose mixtures) to increase carbohydrate oxidation.
During sustained high-intensity exercise lasting 45-75 minutes	Small amounts including mouth rinse	
During endurance exercise including "stop and start" sports lasting 1-2.5 hours	30-60 g/hour	
During ultra-endurance exercise lasting > 2.5-3 hours	Up to 90 g/hour	
Post-event or training carbohydrate requirements		
ACSM		
After exercise	1.0-1.5 g/kg BW during first 30 minutes, and again every 2 hours for 4-6 hours	Adequate fluid, electrolytes, energy and carbohydrates.
ISSN		
Post-exercise carbohydrate ingestion	1.5 g/kg BW or 0.6-1.0 g/kg BW during the first 30 minutes, and again every 2 hours for 4-6 hours	Within 30 minutes post-exercise.
IOC		
Speedy refuelling, < 8 hours recovery between two fuel-demanding sessions	1-1.2 g/kg BW/hour for first 4 hours, then resume daily fuel needs	Small, regular snacks. Compact carbohydrate-rich foods.

ACSM: American College of Sport Nutrition, BW: body weight, GI: glycaemic index, IOC: International Olympics Committee, ISSN: International Society for Sports Nutrition

with low glycogen levels.[2] The carbohydrate-loading regime is complemented with the consumption of sufficient carbohydrates before, during and after the endurance event (Table II).[2,12]

Carbohydrates during exercise

Common complaints during endurance events include muscle fatigue and hypoglycaemia, often as a result of low muscle glycogen stores. Therefore, an increase in liver and muscle glycogen stores, as well as optimal fluid intake, is needed for peak performance to be achieved. Symptoms of suboptimal carbohydrate intake include low levels of energy, heavy legs, fatigue or "hitting the wall", a slow rate of recovery, loss of concentration, dizziness, irritability and fainting. Ingestion of carbohydrates is recommended during exercise (Table II). The type, amount and timing of carbohydrate intake during exercise is important, and should be tailored to individual preference.

Carbohydrates after exercise

Carbohydrate intake is mainly responsible for increasing glycogen stores. Available evidence indicates that ideal levels of carbohydrate intake optimise muscle glycogen resynthesis (Table II). Speedy refuelling is particularly important when there is less than eight hours of recovery time between events or training sessions.[12]

The practical application of the abovementioned carbohydrate intake guidelines is complicated by the variety of intake ranges that are presented by the three different bodies.

Recommendations for the daily carbohydrate requirements differ between the three bodies. The ACSM provides a very broad guideline,[5] while the ISSN[2,3] and IOC[12] suggest carbohydrate requirements according to different groupings, depending on the duration and intensity of the exercise programmes. The IOC provides the most detailed breakdown in terms of recommended daily carbohydrate requirements.[12] This is important as these requirements can be used to individualise training programmes to a greater extent than the ACSM's broad guideline.[5] The IOC recommendations also distinguish between strength and endurance training, which further facilitates a more individualised approach.[12]

Carbohydrate-loading requirement recommendations are provided by the ISSN[2,3] and the IOC.[12] The ISSN suggests a lower range (8-10 g/kg BW) ingested for 1-3 days prior to an endurance event,[2,3] while the IOC advocates the ingestion of 7-12 g/kg BW for 24 hours, or 10-12 g/kg BW for 36-48 hours, prior to the endurance event.[12] The traditional approach of carbohydrate loading for three days prior to an event was based on physically active, rather than well-trained athletes.[12] The IOC recommendations are founded on more recent evidence that suggests that supercompensation of glycogen stores in well-trained individuals can be achieved by increasing carbohydrate intake 24-36 hours prior to an event, combined with training tapering and rest.[12] This is an important practical application as increasing carbohydrate intake for days leading up to an event can cause gastrointestinal discomfort. Also, because of the nature of carbohydrate loading, not all athletes, such as females, will be able to ingest such a large amount of carbohydrates for three days leading up to an event. Therefore, the most suited strategy to the individual should be used.

Although there appears to be similarities between the nature of the pre-event meal, such as being low in fat, fibre and protein, and high in carbohydrates, the actual guidelines between the three bodies differ. The ACSM (200-300g, 3-4 hours prior),[5] the ISSN (1-2 g/kg BW, 3-4 hours prior)[2,3] and the IOC (1-4 g/kg BW, 1-4 hours prior),[12] all agree that ingestion of a pre-event meal is important for events that last longer than 60-90 minutes. Providing a guideline in g/kg BW allows for some flexibility when individualising nutrition plans and should be a preferred guideline when working with athletes. Although the carbohydrate intake range provided by the ISSN and IOC overlaps, the IOC provides a wider range of carbohydrate intake, as well as a broader time. This is extremely important in terms of the practical application of these guidelines. If an athlete has sufficient time (3-4 hours) before an event, a bigger meal, containing more carbohydrates (3-4 g/kg BW) can be ingested. This allows for enough time to ensure gastrointestinal comfort before the event. However, if there is not enough time before the event (generally the case in South Africa where running races start at 06h00, for example), the athlete can consume 1-2 g/kg BW carbohydrates, 1-2 hours prior to the event.

The three bodies advocate the same requirement in terms of the amount of carbohydrates to be ingested during events that last > 60 minutes (30-60 g/hour). [2,3,5,12] Although the ACSM provides a further individual guideline (0.7 g/kg BW/hour), it has been proved that exogenous carbohydrate oxidation is approximately 1g per minute.[13,14] The IOC also stipulates additional guidelines for sustained high-intensity exercise that lasts for 45-75 minutes, as well as guidelines for ultra-endurance exercise that persists for > 2.5-3 hours.[12] All three bodies acknowledge that the combination of glucose and fructose (as a 6-8% carbohydrate solution) is effective in optimising exogenous carbohydrate oxidation during exercise, and that fructose should not be ingested at very high rates during exercise because of the possible detrimental effect on gastrointestinal comfort.[2,3,5,12] The ISSN further provides evidence[15-21] of combining simple sugars such as glucose, fructose and sucrose with maltodextrin in order to increase exogenous carbohydrate oxidation (1.2-1.75 g/minute), and decrease the reliance on liver and muscle glycogen. These studies[15-21] were conducted by the same research group and are acknowledged in the ACSM position paper.

The post-exercise carbohydrate ranges suggested by the three bodies to increase recovery from exercise are between 1.0-1.5 g/kg BW.[2,3,5,12] All three bodies agree that carbohydrates should be ingested within 30 minutes after exercise in order to achieve higher glycogen levels. If an athlete rests for 1-2 days between exercise sessions or events, specific nutrient-timing strategies are not as important, provided that enough carbohydrates are consumed over a 24-hour period and that daily carbohydrate requirements are met according to the activity level.[5] However, in the case of limited time between exercise sessions, e.g. training more than once per day or events that comprise multiple-stage races, nutrient timing and recovery are of critical importance.[2,3,5,12] In these instances, the ACSM, ISSN and IOC recommend that carbohydrates should be ingested within 30 minutes after exercise and repeated again every two hours for 4-6 hours.[2,3 5 12]

Protein requirements

Dietary protein requirements are elevated with strength, speed or endurance training. Energy intake, exercise intensity and duration, ambient temperature, and gender and age also influence protein requirements.[3,22]

There are increased requirements in the case of strength or resistance training because protein supports muscle protein synthesis, reduces muscle protein breakdown and repairs muscle damage.[22] Endurance exercise increases leucine oxidation. Therefore, endurance athletes may have slightly higher protein requirements than their sedentary counterparts.[22]

Dietary protein intake should consist of high quality protein. Protein quality can be measured by the Protein Digestibility-Corrected Amino Acid Score (PDCAAS),[22] where a score of close or equal to 1 indicates protein of high quality. Dietary protein sources with a similar score include, but are not limited to, milk (casein and whey), egg and meat products. Isolated soy protein, when all the anti-nutrient components have been removed, also has a PDCAAS score of 1.[22] Milk protein, compared to isolated soy protein (with equivalent protein and macronutrient energy) has been shown to increase muscle protein synthesis after resistance exercise and leads to greater muscle hypertrophy.[22] In general, the benefit of whey and milk proteins was clear in studies that compared whey, casein and soy, particularly because of the high leucine content of milk protein.[3,22]

The optimal timing of protein intake should also be considered when determining and prescribing protein requirements, as this can lead to faster recovery times and improved adaptation after training.[22]

Daily protein requirements

According to the DRIs, and more specifically, the recommended dietary allowance (RDA), the general protein requirement for a sedentary person is 0.8 g/kg BW/day.[5,22,23] Incidentally, this requirement suffices for general fitness and can be slightly elevated to 1.0 g/kg body weight/day.[22]

The ACSM recommends daily protein requirements for strength and endurance athletes of 1.2-1.7 g/kg body weight. It is recommended that these requirements are reached through diet alone. Additional supplementation is not necessary, especially when the energy intake is optimal.[5]

The daily protein requirements for physical activity, as recommended by the ISSN, are summarised in Table III.[3]

IOC general protein guidelines for athletes are 1.3-1.8 g/kg BW and 1.6-1.7 g/kg BW/day for strength-training athletes.[24] Because of the high energy intake of these athletes, these requirements may be met easily.[24] According to the IOC, protein intake above these guidelines does not have any additional benefit and can promote amino-acid catabolism and protein oxidation.[24] The IOC recommends optimising body composition in favour of losing fat and gaining muscle mass by decreasing daily carbohydrate intake (3-4 g/kg BW/day) and increasing daily protein intake (1.8-2.7 g/kg BW/day), while following a hypo-energetic diet and specified training programme.[22]

Protein before exercise

The ACSM recommends that a moderate amount of protein is added to the pre-event meal. No specific guideline on ingestion of protein before exercise is included in the consensus document.[5]

Table III: Daily protein requirements for physical activity[3]

Daily or habitual protein requirements		
Physical activity level	**g/kg BW/day**	**Comments**
ISSN		
General fitness	0.8-1.0 g/kg BW	Focus on protein quality. Amino-acid content. Whole foods. Safe, convenient supplements where needed.
Older individuals	1.0-1.2 g/kg BW	
Moderate amount of intense training	1.0-1.5 g/kg BW	
High volume of intense training	1.5-2.0 g/kg BW	

The ISSN recommends that, depending on the individual's exercise duration and fitness level, protein should be included with carbohydrates in the pre-event meal before resistance exercise or when a desired change in body composition is required.[2] This can be achieved by including 0.15-0.25 g/kg BW protein with the recommended 1-2 g/kg BW carbohydrates in the pre-event meal 3-4 hours before training or competition.[2]

The IOC states that although preliminary evidence appears to support increased muscle protein synthesis in response to resistance training when protein is given before exercise, follow-up studies have failed to confirm this finding. Therefore, the current opinion of the IOC is that protein should be ingested after exercise at a time that is associated with optimal muscle protein synthesis.[24]

Protein during exercise

The ACSM states that evidence pertaining to the benefit of the addition of protein to carbohydrate solutions during exercise is inconclusive. No recommendation is made in this regard in the consensus document.[5]

According to the ISSN, the addition of protein to carbohydrates (carbohydrates to protein ratio of 3-4:1) during exercise has shown promise in recent literature. It has been demonstrated to be favourable in terms of improving endurance performance, increasing muscle glycogen stores, reducing muscle damage and promoting better training adaptations after resistance training.[2] However, it is not known whether this addition of protein is because of the added energy that is available for substrate utilisation. Although the ISSN advocates adding protein to carbohydrate intake during endurance exercise, more research in this field is needed as there is insufficient evidence to support this unequivocally.[5,24-26]

The IOC refers to recent evidence that suggests that co-ingestion of carbohydrates and essential amino acids is beneficial before and during resistance exercise as it increases substrate availability and exercise performance, improves the anabolic hormonal environment, stimulates muscle protein synthesis and decreases muscle damage or tenderness. However, the IOC concludes that current guidelines promote the ingestion of protein at a time that is associated with maximal stimulation of muscle protein synthesis (after exercise), and do not provide any recommendations for protein intake before or during a workout.[24]

Protein after exercise

After exercise, the ACSM recommends that the primary goals of recovery should be to provide sufficient fluid, electrolytes, energy and carbohydrates to replace muscle glycogen stores and facilitate recovery.[5] The addition of proteins can provide amino acids for the maintenance and repair of muscle protein, but no specific guideline has been provided by the ACSM to include protein as part of the recovery programme after exercise.[5]

The ISSN recommendation for recovery is to add protein to carbohydrates at a carbohydrate to protein ratio of 3-4:1, or by supplementing with 0.2-0.5 g/kg BW protein. This results in increased glycogen resynthesis and ultimately improved performance.[2] The consensus document also recommends that ingestion of amino acids, especially essential amino acids (EAA), stimulates muscle protein synthesis. This can be achieved by adding 6-20 g EAA to at least 30-40 g high glycaemic carbohydrates and ingesting this immediately or within three hours post exercise. This addition of protein to carbohydrates will also result in increased strength and enhanced body composition during chronic resistance training. The document also recommends adding a small amount of creatine (0.1 g/kg BW) to the carbohydrate and protein mixture post exercise to optimise the adaptations of resistance training.[2]

Current IOC guidelines also advocate the ingestion of protein after exercise, as this is when maximal stimulation of muscle protein synthesis is required.[24] The IOC recommends that 20-25 g of high quality/or high biological value protein is included after resistance exercise.[22] The combination of carbohydrates and protein post exercise is important to restore muscle glycogen and promote protein synthesis.[24] Protein intake that exceeds this recommended amount does not promote muscle protein synthesis, but can lead to protein oxidation.[24] The dietary protein form of choice is flavoured low fat milk. It shows beneficial improvements in muscle synthesis.[22]

Although there appears to be consensus between the ACSM, ISSN and IOC that the daily protein requirements of athletes range between 1.2-2.0 g/kg BW/day, there are differences in the ranges provided. The ACSM provides a broad range (1.2-1.7 g/kg BW),[5] whereas the ISSN gives recommendations according to training volume and intensity.[3] Although these guidelines overlap, the ISSN guidelines are based on publications by the same author and do not include the entire spectrum of published papers on protein intake and exercise.

The IOC provides specific recommendations for strength-training athletes and those who wish to prevent loss of lean body mass and to promote fat loss.[22,24] It is recommended that athletes who want to increase muscle mass and reduce body fat should follow these guidelines.

Guidelines for protein intake before and during exercise are provided by the ISSN only, while the ACSM advocates a "moderate" intake of protein before exercise. Although there has been some evidence that supports the intake of protein before exercise,[27] follow-up studies have failed to unequivocally support this practice.[28,29] There is also inconclusive evidence to support the use of protein during endurance exercises.[5, 24-26]

There is consensus from the ACSM, ISSN and IOC on the beneficial effect of the ingestion of ~20 g protein with carbohydrates within 30 minutes post exercise. This recovery strategy can be achieved through dietary sources. Additional supplementation is not warranted. Although the ISSN recommends,[3] and the IOC recognises,[24] that the addition of creatine monohydrate as a supplement after exercise can increase skeletal muscle hypertrophy after resistance training, the practical application of this is questionable as currently, the sport supplement industry is not regulated in South Africa. Also, the risk of ingesting contaminated supplements is high. It is proposed that the ingestion of creatine after exercise is not necessary and can even be harmful to health. The same result can be achieved with the ingestion of sufficient carbohydrates and high biological value protein within 30 minutes after exercise. This can be achieved easily by the ingestion of a low-risk supplement which has the correct carbohydrate to protein ratio, such as a liquid meal replacement, especially if the athlete cannot consume a meal because of practical constraints, or because of the appetite-suppressing nature of exercise.

Fat requirements

The fat requirements of athletes are similar, and are slightly higher than those in non-athletes. It is important to consume adequate amounts of fat to ensure optimal health, maintenance of energy balance, optimal intake of essential fatty acids and fat-soluble vitamins, as well as to replenish intramuscular triacylglycerol stores. The amount of required fat depends largely on the training status and goals of the athletes.[3,5]

The ACSM recommends that daily fat intake for athletes should be 20-35% of total energy intake and that fat intake should not decrease below 20% of total energy intake, as the intake of fat is important for the ingestion of fat-soluble vitamins and essential fatty acids.[5] High-fat diets for athletes are not recommended.[5]

The ISSN suggests a moderate fat intake of 30% of total energy for athletes. This can increase to 50% of total energy for high-volume training,[3] i.e. elite competitor training of 40 hours/week (like the Ironman). In order to reduce body fat or lose body weight, a fat intake of 0.5-1.0 g/kg BW/day is suggested.[3] Optimisation of the type of dietary fatty acids is important. The focus should be on increasing dietary sources of unsaturated or essential fatty acids.[3]

The IOC recommends following a diet that does not contain less than 15-20% fat of total energy.[30]

It is suggested that athletes should be cautious of high-fat diets (> 30% of total energy intake). The recommendation from the ACSM regarding fat intake should suffice for any athlete. A high-fat intake can be at the expense of carbohydrate intake and may have negative effects on training and racing performance.

Fluid and electrolyte requirements

The 2007 and 2009 ACSM guidelines for fluid and electrolytes are summarised in Table IV.[5,6]

The ISSN exercise and sport nutrition review document states that a decrease in sport performance is evident if 2% or more of an athlete's body weight is lost through sweat. Athletes should not only rely on thirst as an accurate indicator of fluid needs. Body weight should be measured before and after exercise sessions to determine sweat loss. It is also recommended that, in order to maintain fluid balance and prevent hypohydration, fluid should be ingested at a rate of 0.5-2 l/hour. Also, there should be frequent (every 5-20 minutes) ingestion of small amounts of fluid (150-200 ml). Recommended fluid intake should be increased in hot and humid environments. Excessive techniques to reduce body weight, such as the use of diuretics, vomiting and saunas, are inappropriate and dangerous to human health.[3]

Table IV: American College of Sports Medicine guidelines on fluid and electrolyte replacement for physical activity[5,6]

Fluid and electrolyte recommendations for physical activity	
Before exercise	Pre-hydration should be initiated several hours before exercise to ensure fluid absorption and normal urine output. Beverages and sodium-containing and salted snacks can increase the sensation of thirst and retain fluids.
During exercise	Fluid programmes should be customised for each individual, based on body weight measurements before and after exercise. Athletes should aim to prevent > 2% body weight loss during exercise. Fluids should contain carbohydrates and electrolytes to maintain fluid balance and exercise performance..
After exercise	Normal meals and beverages will induce euhydration. If more rapid recovery is required, 1.5 l of fluid per kg body weight loss during exercise should be ingested. Beverages and snacks should contain sodium to help with rapid recovery, stimulation of thirst and fluid retention.

The IOC suggests that "sufficient fluid should be consumed during exercise to limit dehydration to less than approximately 2% of body mass. Sodium should be included when sweat losses are high, especially if exercise takes place for more than two hours. Athletes should not drink so much that they gain weight during exercise. During recovery from exercise, rehydration should include replacement of both water and salt lost in sweat".[31] It is also recommended that sodium should be added to fluids during exercise that lasts > 2 hours, as well as in fluids that are ingested by athletes who have lost more than 3-4 g sodium in their sweat during exercise.[31] It is recommended that following exercise that leads to loss of body weight because of sweat loss, water and sodium are consumed in amounts that are greater than those of the losses (3-4 g), in order to achieve optimum recovery of water and electrolyte balance.[31] This is especially important at times when rapid recovery is required (< 24 hours), as well as in cases where a body weight loss of > 5% body weight is recorded.[31]

Although alternative recommendations are also provided by Noakes,[32,33] the scope of this review is to summarise the recommendations by the ACSM, ISSN and the IOC. As these guidelines are similar, the suggestion is that athletes calculate their own individual fluid needs in order to prevent hyper- and hypohydration.

Micronutrient requirements

Vitamins and minerals are essential nutrients in terms of providing a health benefit, although the ergogenic effect of most micronutrients is still unclear and warrants further research.

The ACSM recommends that no additional vitamin and mineral supplementation is needed if an athlete obtains sufficient energy from a wide variety of foods.[5] The ACSM further allows for micronutrient supplementation that is unrelated to exercise performance, such as folic acid supplementation during pregnancy.[5] Supplementation may be individually prescribed by the attending healthcare professional for certain athletes, such as those restricting energy intake, vegetarians, people who are ill, recovering from injury or with specific medical conditions.[5] Vegetarians may require vitamin B_{12}, iron, calcium, vitamin D, riboflavin and zinc supplementation.

According to the ISSN, specific vitamins may exhibit some health benefit, e.g. vitamin E, niacin, folic acid and vitamin C.[3] However, few have been reported to provide direct ergogenic properties. Some vitamins may assist physically active individuals to endure heavy training and exercise, thereby improving exercise performance.[3] In particular, vitamins C and E may decrease oxidative damage caused by vigorous training schedules and may also help to support a healthy immune system. Minerals are essential nutrients too, and are important for most bodily functions. Some studies have shown mineral deficiencies in athletes. These can impact negatively on sports performance.[3] The health and ergogenic value of some minerals has been studied. These include calcium, which reduces the risk of developing premature osteoporosis, and maintains body composition; iron, particularly in the case of athletes who are prone to iron deficiency; sodium phosphate, which increases maximal oxygen uptake, anaerobic threshold and endurance capacity; sodium chloride, to maintain fluid and electrolyte balance; and zinc, which decreases exercise-induced changes in immune functioning. However, there is little evidence to link improved sporting performance to boron, chromium, magnesium or vanadium.[3]

The ISSN recommends that a normal nutrient-rich diet that contains a variety of food groups should provide sufficient amounts of micronutrients in most cases. Athletes who are susceptible to low-energy intake, or who purposefully restrict energy intake to lose or maintain body weight, might be at risk of developing micronutrient deficiencies.[3] Low doses of multivitamin and mineral combinations may be prescribed, or vitamin- and mineral-enriched liquid meal replacements taken in such cases. However, this should be carried out in consultation with the dietitian and in combination with altered eating habits.[3]

The IOC recognised and evaluated two specific micronutrients in its latest consensus statement, namely antioxidant and vitamin D supplementation. Antioxidants have been popular in literature and research studies. There are arguments for and against the use of these by athletes.[34] Arguments that support antioxidant supplementation propose that this group of micronutrients is able to decrease the reactive oxygen species that forms during exhaustive exercise.[34] Free radicals can promote muscular fatigue, and in turn, decrease exercise performance.[34] These arguments also suggest that some athletes do not consume a healthy diet that contains antioxidant food groups, such as whole grains, fruits, vegetables, nuts and seeds, and that antioxidant supplementation is not toxic or harmful to human health.[34] On the other hand, it is believed that although exercise can promote oxidative stress, there is no evidence to support the theory that this exercise-induced oxidative stress is detrimental to human health or performance, and that participation in regular exercise increases the body's own ability to produce endogenous antioxidants. If energy requirements are met, and the athlete is able to ingest all of the various dietary antioxidants, additional supplementation should not warranted and toxic levels may impair muscle functioning and reduce training adaptations to exercise.[34] In light of the above controversy in the available literature, the IOC recommends that athletes should not consume antioxidant supplements and that caution should be exercised, particularly with the use of single-nutrient, high-dose antioxidant supplements.[34]

Vitamin D supplementation is also becoming more popular, not only in the athletic arena, but also in the general population, as studies of the latter have reported vitamin D deficiencies in certain population groups.[34] In the case of athletes, there is particular concern about athletes who work out indoors, reside at higher latitudes and have dark pigmented skin. In sport, various factors hinder an athlete's exposure to sunlight, and therefore the amount of vitamin D that is synthesised by athletes. Clothing, the use of sunscreen, ageing, skin pigmentation, training times during the day, seasonal factors, cloud cover and latitude may all influence vitamin D synthesis from sunlight. Vitamin D supplementation might have an ergogenic effect in athletes who do not have adequate levels of vitamin D, but there have been limited experimental studies in this regard.[34] Some studies have found that there is a direct link between vitamin D status and jumping height, velocity, muscle tone, muscle power and hand-grip strength, while others have suggested that there is a reduction in the rate of stress fractures when vitamin D is supplemented with calcium.[34] In general, the arguments against vitamin D supplementation are that it is not supported by a strong body of evidence, and that since vitamin D is a fat-soluble vitamin, and it can accumulate in the body and cause toxic side-effects such as nausea, vomiting, poor appetite, constipation, weakness, weight loss, mental confusion, irregularities in cardiac rhythm and calcification of soft tissues, all of which would negatively impact on exercise performance and general health.[34] There are also large inter-individual differences in the way in which individuals respond to vitamin D supplementation.[34] Current guidelines are opposed to vitamin D supplementation, unless it is medically warranted. It is also recommended that athletes have at least 5-30 minutes of direct sun exposure on the arms and legs several times per week between 10h00 and 14h00. Because vitamin D and calcium metabolism are so closely linked, it is also recommended that at the very least, DRI levels of calcium (obtained from dietary sources) must be reached in athletes.[34]

Therefore, currently, there are no clear guidelines on micronutrient supplementation in athletes and which suggest that athletes should be monitored on an individual basis.[3,5,34] A healthy, balanced diet, which includes all the different food groups, as well as adequate exposure to sunlight, should provide sufficient micronutrients. The recommendation by the ACSM and the ISSN that groups who are at risk (including athletes on severe energy-restricting diets, and perhaps those following vegetarian diets), may benefit from taking a low-dose, multivitamin and mineral supplement, or from including micronutrient-fortified, liquid meal replacement supplements in their diet, after consultation with a medical doctor and dietitian, is supported.[3,5]

Sports food and supplement requirements

The ACSM has concluded that "athletes should be counselled regarding the appropriate use of ergogenic aids. Such products should only be used after careful evaluation for safety, efficacy, potency, and legality".[5]

The ISSN 2010 review notes that while some supplements might have a beneficial effect on athletic performance, no amount of supplementation will compensate for inadequate dietary intake.[3]

According to this consensus document, supplements are categorised in the following manner according to safety and efficacy:

- *Apparently effective and generally safe:* These supplements include weight-gain powders, creatine, protein, EAAs, low-calorie foods, ephedra (a banned substance), caffeine, water and carbohydrate-electrolyte solutions, sodium phosphate and bicarbonate and beta-alanine.
- *Supplements that are possibly effective:* These include β-hydroxy-β-methylbutyrate in untrained subjects, branched chain amino acids (BCAA), calcium, conjugated linoleic acid (CLA) and green tea extract.
- *Supplements whose effectiveness is too early to tell:* The list extends to α-ketoglutarate, α-ketoisocaprate, ecdysterones, growth hormone-releasing peptides and secretogues, ornithine-α-ketoglutarate, zinc-magnesium aspartate, chitosan, phosphatidl choline, betaine, Coleus Forskolin, dehydro-epiandrosterone (DHEA), psychotropic nutrients or herbs and medium-chain triglycerides.
- *Supplements which are apparently not effective or are dangerous to use:* Examples of such supplements are glutamine, smilax, isoflavones, sulphopolysaccharides, boron, chromium, CLA, gamma oryzanol, prohormones, tribulus terrestris, vanadium, calcium pyruvate, chitosan, L-carnitine, phosphates, herbal diuretics, ribose and inosine.[3]

According to the IOC, the following supplements increase exercise performance. This is strongly supported by evidence:

- Alkalinising agents (sodium bicarbonate and sodium citrate) increase anaerobic exercise performance.
- L-arginine boosts aerobic endurance. (There is little, but convincing evidence in this regard).
- Beta-alanine enhances anaerobic and aerobic exercise performance.
- Caffeine improves endurance and reaction time.
- Creatine increases performance in strength and power events.
- Nitrate advances aerobic endurance exercise.
- Carbohydrates, proteins, water, electrolytes and amino acids have ergogenic properties.[35]

The IOC strongly discourages the indiscriminate use of supplements, supplementation when nutritional needs can be met via dietary intake, the use of supplements that pose a risk of a positive doping outcome and supplement use by young athletes (< 18 years).[8,35] The IOC cautions against the widespread use of supplements, especially in terms of acute or long-term effects on health, positive doping outcomes and possible detrimental effects on exercise performance.[8,35] Current regulations that govern supplement use are more liberal compared to those by the pharmaceutical market. Often, supplements either contain little or no active ingredient or too much of certain toxic nutrients. They may also contain harmful impurities, such as lead, broken glass and animal faeces because of poor manufacturing practices.[8,35] The majority of products on the market fail to reach expected standards.[8,35] Other involved risks include inaccurate labelling, failure to declare the ingredients on the label and cross-contamination of supplements.[8,35]

Supplements and sports food are used extensively by athletes at various levels, as well as by non-athletes. Although the use of some supplements may have added benefits in terms of improving body composition, sports performance and overall health, the risk to benefit ratio needs to be carefully considered before embarking on the widespread use of supplements. Dietary supplements are poorly regulated in South Africa and other countries. Although the manufacturers of these products are not allowed to state that a supplement can prevent or treat any illness or disease without sufficient scientific evidence, monitoring is not thorough. Regulation of supplements is also further complicated by the widespread sale thereof on the Internet. This promotes the use of supplements from unidentified sources.

The product safety and purity, claimed benefits and safety of the supplement for short- and long-term, needs to be considered carefully before it is taken.[8] Poor quality control of supplements on sale in pharmacies and supermarkets can also potentially increase the likelihood of athletes obtaining negative results in doping tests.[8] Poor hygiene and lack of good manufacturing practices can result in supplements containing impurities such as lead, broken glass and animal faeces, which carries obvious health risks for athletes and other users.[8] Direct or deliberate, and indirect contamination of dietary supplements with undeclared and unlabelled anabolic steroids also places supplement users in a difficult position.[8] Some supplements may not contain the exact amount of ingredients that are listed on the label as a marketing tool. Athletes may be unaware of the potential negative effects of using these supplements.[8] Currently, the World Anti-Doping Agency (WADA) does not distinguish between deliberate cheating and inadvertent doping, and the responsibility and future athletic career of the individual rests solely with the athlete.[3,35] For further reading on banned substances in sports, readers are referred to the latest WADA code, as well as South African Institute for Drug-Free Sport (www.drugfreesport.org.za).

Conclusion

The aim of this review was to summarise and critically analyse key concepts, elements and guidelines from the ACSM, ISSN and IOC consensus documents. No single consensus document provides all the necessary guidelines and recommendations needing for consultation with an athlete with regard to sport nutrition. Therefore, a combination of these and other guidelines should be used to individualise the nutritional management of athletes. Apart from the abovementioned guidelines and recommendations, sport-specific nutritional strategies should also be implemented in training programmes to aid in exercise, sports performance and recovery.[30,36-39] A nutritionally complete, balanced diet should provide ample amounts of energy, carbohydrates and protein to ensure sustained exercise performance and optimal nutrition to support exercise performance.

References

1. Maughan RJ. Abstracts of BASES (British Association of Sport and Exercise Sciences 2011. September 5-8, 2011. Colchester, United Kingdom. J Sports Sc. 2011;29 Suppl 2:S1-S132.
2. Kerksick C, Harvey T, Stout J, et al. International Society of Sports Nutrition position stand: nutrient timing. Int J Soc Sports Nutr. 2008;5:17 [homepage on the Internet]. c2012. Available from: http://www.jissn.com/content/pdf/1550-2783-5-17.pdf
3. Kreider RB, Wilborn Cd, Taylor L, et al. ISSN exercise and sport nutrition review: research and recommendations. Int J Soc Sports Nutr. 2010;7:7 [homepage on the Internet]. c2012. Available from: http://www.biomedcentral.com/content/pdf/1550-2783-7-7.pdf
4. Position of the American Dietetic Association, Dietitians of Canada and the American College of Sport: Nutrition and athletic performance. J Am Diet Assoc. 2000;100(12):1543-1556 [homepage on the Internet]. c2012. Available from: http://download.journals.elsevierhealth.com/pdfs/journals/0002-8223/PIIS0002822300004284.pdf
5. Rodriquez NR, DiMarco NM, Langley S. Position of the American Dietetic Association, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and athletic performance. J Am Diet Assoc. 2009;109(3):509-527 [homepage on the Internet]. c2012. Available from: http://journals.lww.com/acsm-msse/Fulltext/2009/03000/Nutrition_and_Athletic_Performance.27.aspx
6. Sawka M, Burke L, Eicher R, et al. Exercise and fluid replacement. Med Sci Sports Exerc. 2007;39(2):377-390.[homepage on the Internet]. c2012. Available from: http://www.acsm-msse.org
7. Burke LM, Castell LM, Stear SJ. BJSM reviews: A-Z of supplements: dietary supplements, sports nutrition foods and ergogenic aids for health and performance Part 1. Br J Sports Med. 2009;43(10):728-729.
8. Maughan RJ, Depiesse F, Geyer H, et al. The use of dietary supplements by athletes. J Sports Sci. 2007;25 Suppl 1:S103-S113.
9. Claassen A, Meltzer S, Havemann-Nel L, et al. Position statement of the South African Institute of Drug Free Sport (SAIDS) on the use of supplements in sport in adults [homepage on the Internet]. 2011. c2012. Available from: http://www.drugfreesport.org.za/wp-content/themes/dfs/pdf/SAIDS%20Sport%20SupplementsPosition%20Statement.pdf
10. International Olympic Committee (IOC) consensus statement on sports nutrition 2010. J Sports Sci. 2011;29(SI):S3-S4.
11. Loucks AB, Kiens B, Wright HH. Energy availability in athletes. J Sports Sci. 2011;29(S1):S7-S15.
12. Burke LM, Hawley JA, Wong SH, et al. Carbohydrates for training and competition. J Sports Sci. 2011;29(S1):S17-S27.
13. Jeukendrup AE, Jentjens R. Efficacy of carbohydrate feedings during prolonged exercise: current thoughts, guidelines and directions for future research. Sports Med. 2000;29(6):407-424.
14. Tarnopolsky MA, Gibala M, Jeukendrup AE, Phillips SM. Nutritional needs of elite endurance athletes. Part I: Carbohydrate and fluid requirements. Eur J Sport Sci. 2005;5:3-14.
15. Jentjens R, Shaw C, Birtles T, et al. Oxidation of combined ingestion of glucose and sucrose during exercise. Metabolism. 2005;54(5):610-618.
16. Wallis GA, Rowlands DS, Shaw C, et al. Oxidation of combined ingestion of maltodextrins and fructose during exercise. Med Sci Sports Exerc. 2005;37(3):426-432.
17. Jentjens R, Achten J, Jeukendrup AE. High rates of exogenous carbohydrate oxidation from multiple transportable carbohydrates ingested during prolonged exercise. Med Sci Sports Exerc. 2004;36(9):1551-1558.
18. Jentjens R, Jeukendrup AE. High exogenous carbohydrate oxidation rates from a mixture of glucose and fructose ingested during prolonged cycling exercise. Br J Nutr. 2005;93(4):485-492.
19. Jentjens R, Moseley L, Waring RH, et al. Oxidation of combined ingestion of glucose and fructose during exercise. J Appl Physiol. 2004;96(4):1277-1284.
20. Jentjens R, Venables MC, Jeukendrup AE. Oxidation of exogenous glucose, sucrose, and maltose during prolonged cycling exercise. J Appl Physiol. 2004;96(4):1285-1291.
21. Currell K, Jeukendrup AE. Superior endurance performance with ingestion of multiple transportable carbohydrates. Med Sci Sport Exerc. 2008;40(2):275-281.
22. Phillips SM, Van Loon LJC. Dietary protein for athletes: from requirements to optimum adaptation. J Sport Sci. 2011;29 Suppl 1):S29-S38.
23. Nutrition Information Centre, Stellenbosch University. Dietary reference intakes. Washington: The National Academies Press; 2003.
24. Slater G, Phillips SM. Nutrition guidelines for strength sports: sprinting, weightlifting, throwing events, and bodybuilding. J Sports Sci. 2011;29(S1):S67-S77.
25. Van Essen GM. Failure of protein to improve time trial performance when added to a sports drink. Med Sci Sports Exerc. 2006;38(8):1476-1483.
26. Cermak NM, Solheim AS, Gardner MS, et al. Muscle metabolism during exercise with carbohydrate or protein-carbohydrate ingestion. Med Sci Sports Exerc. 2009;41(12):2158-2164.
27. Tipton KD, Rasmussen BB, Miller SL, et al. Timing of amino acid-carbohydrate ingestion alters anabolic response of muscle to resistance exercise. Am J Physiol Endocrinol Metab. 2001;281(2):E197-E206.
28. Fujita S, Dreyer HC, Drummond MJ, et al. Essential amino acid and carbohydrate ingestion before resistance exercise does not enhance postexercise muscle protein synthesis. 2009;106(5):1730-1739.
29. Tipton KD, Elliot TA, Cree MG, et al. Stimulation of net muscle protein synthesis by whey protein ingestion before and after exercise. Am J Physiol Endocrinol Metab. 2007;292(1):E71-E76.
30. Sundgot-Borgen J, Garthe I. Elite athletes in aesthetic and Olympic weight-class sports and the challenge of body weight and body composition. J Sports Sci. 2011;29(S1):S101-S114.
31. Shirreffs SM, Sawka MN. Fluid and electrolyte needs for training, competition, and recovery. J Sports Sci. 2011;29(S1):S39-S46.
32. Noakes TD. Fluid replacement during marathon running. Clin J Sports Med. 2003;13(5):309-318.
33. Noakes TD. Drinking guidelines for exercise: what evidence is there that athletes should drink "as much as tolerable", "to replace the weight lost during exercise" or "ad libitum"? J Sports Sci. 2007;25(7):781-796.
34. Powers S, Nelson WB, Larson-Meyer E. Antioxidant and Vitamin D supplements for athletes: sense or nonsense? J Sports Sci. 2011;29(S1):S47-S55.
35. Maughan RJ, Greenhaff PL, Hespel P. Dietary supplements for athletes: emerging trends and recurring themes. J Sports Sci. 2011;29(S1):S57-S66.
36. Holway FE, Spriet LL. Sports-specific nutrition: practical strategies for team sports. J Sports Sci. 2011;29(S1):S115-S125.
37. Meyer NL, Manore MM, Helle C. Nutrition for winter sports. J Sports Sci. 2011;29(S1):S127-S136.
38. Stellingwerff T, Maughan RJ, Burke LM. Nutrition for power sports: middle-distance running, track cycling, rowing, canoeing/kayaking, and swimming. J Sports Sci. 2011;29(S1):S79-S89.
39. Jeukendrup A. Nutrition for endurance sports: marathon, triathlon, and road cycling. J Sports Sci. 2011;29(S1):S91-S99.