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Sports Nutrition Science: an essential overview

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Summary

The topic of sports nutrition has received considerable attention over the past few decades, and it is likely to get even more attention, given that nutrition plays such an important and sometimes crucial role in an athlete's performance. Indeed, nutrition influences nearly every process in the body involved in energy production and recovery from exercise. To understand and apply the principles of sport nutrition, some basic understanding of nutrition, exercise physiology and sport science are necessary. The nutritional approach for training and competition is one of the most important concerns of sport nutrition science. Exercise produces several molecular, biochemical and physiological responses and the aim of a well designed diet is to guarantee a correct intake of energy, carbohydrates, proteins, fats, vitamins, minerals and water in order to support basic nutrition requirements as well as pre-, during and post-exercise specific nutrition phases. A very interesting subject of sport nutrition is the use of supplements and their effects on human performance and health. The number of supplements introduced to the market is huge, however, only few products are apparently effective and scientifically proven by a solid core of reference. For many other supplements normally used by athletes, the data are anecdotic or based on only a few studies and thus their use cannot be universally recommended. A key item in sport nutrition is the manipulation of body mass and body composition. Reducing fat mass is desirable in many sports with weight categories and increasing muscle mass can be an advantage in sports that require strength and power. Finally, nutritional requirements can be different for women, young and elderly athletes. These categories have different age and sex-related physiological needs and specific nutrition strategies must be planned to guarantee adequate exercise adaptation and maintain overall health.

Riassunto

La nutrizione applicata allo sport ha ricevuto una considerevole attenzione negli ultimi 10 anni; un'attenzione destinata ad aumentare in quanto l'alimentazione gioca un ruolo chiave, talvolta determinante nelle prestazioni di un atleta. In effetti, l'alimentazione incide su quasi tutti i processi fisiologici coinvolti nella produzione di energia e nel recupero muscolare. Per com-

prendere e applicare i principi della nutrizione sportiva, sono necessarie conoscenze di base della nutrizione, fisiologia dell'esercizio e scienza dello sport. L'approccio nutrizionale per l'allenamento e la competizione è uno dei target più importanti di cui si occupa la scienza della nutrizione dello sport. L'esercizio fisico produce diverse risposte molecolari, biochimiche e fisiologiche e l'obiettivo di una dieta ben programmata è quello di garantire un corretto apporto di energia, carboidrati, proteine, grassi, vitamine, minerali e acqua, al fine di soddisfare le specifiche richieste nutrizionali delle fasi pre-, durante e post-attività fisica. Un argomento molto interessante trattato dalla nutrizione dello sport è l'uso di supplementi e la comprensione dei loro effetti sulle prestazioni fisiche e sulla salute umana. Il numero di supplementi introdotti sul mercato è enorme, tuttavia, solo pochi prodotti sono stati scientificamente testati mostrando una certa efficacia. Per molti altri prodotti, normalmente utilizzati dagli atleti, i dati sono aneddotici o ricavati da pochi studi, e quindi il loro uso non può essere raccomandato. La nutrizione sportiva si occupa, inoltre, di studiare le variazioni di massa e composizione corporea negli atleti. La riduzione della massa grassa è auspicabile in molti sport che contemplano categorie di peso, mentre un aumento di massa muscolare può essere un vantaggio negli sport che richiedono forza e potenza. Infine, le richieste nutrizionali possono essere diverse per donne, atleti giovani ed anziani. Queste categorie hanno diverse esigenze fisiologiche legate a sesso ed età per cui specifiche strategie nutrizionali devono essere pianificate per garantire sia i meccanismi di adattamento all'esercizio fisico, sia il mantenimento dello stato di salute.

Energy and nutrients for physical activity

Although the human body has some energy reserves, most of its energy must be obtained through nutrition. During exercise, energy requirements increase and energy provision can become critical. In athletes, energy provision can be crucial and energy depletion (particularly carbohydrate depletion) is one of the most common causes of fatigue. Different types of exercise and different sports have different energy requirements. Therefore, athletes must adjust their food intake accordingly (1).

Energy is stored in the body as fat, glycogen, phosphocreatine (PCr), and adenosine triphosphate (ATP). ATP is the essential energy source used by the muscle for performing work or producing force. The breakdown of ATP to adenosine diphosphate (ADP) and inorganic phosphate (Pi) by a specific muscle enzyme (myosin ATPase) provides the energy for muscle contraction. Three mechanisms are involved in the resynthesis of ATP for muscle force generation: 1) PCr hydrolysis, 2) glycolysis, which involves metabolism of glucose-6-phosphate, derived from muscle glycogen or blood-borne glucose, and produces ATP by substrate-level phosphorylation reactions, and 3) the products of carbohydrate, fat and protein metabolism enter the tricarboxylic acid (TCA) cycle in the mitochondria and are oxidized to carbon dioxide and water; this process is known as oxidative phosphorylation and yields energy for the synthesis of ATP (1).

Energy balance

The energy balance is usually calculated over longer periods of time, days or weeks, and represents the difference between energy intake and energy expenditure. When energy intake exceeds energy expenditure, the energy balance is "positive" and will result in weight gain. When energy intake is below energy expenditure, the energy balance is "negative" and weight loss will result. Over the long term, energy balance is maintained in weight-stable individuals even though on a day-to-day basis this balance may be either positive and or negative (1).

Energy balance in different activities
Some physical activities have higher energy outputs than others, as shown in table 1. Tennis, for example, has relatively low energy expenditure if played recreationally and could be classified as a light-to-moderate activity. Although during a game, the exercise can sometimes be very intense and energy expenditure during that short burst of intense exercise can be very high. However, because this high intensity is typically followed by a longer period of relatively low intensity, walking or even standing, the average energy expenditure for this activity is relatively low. Tennis played at a high level will have shorter periods of rest and the average intensity is much higher.
In continuous sports such as cycling and running, in which there is usually little or no recovery during the activity, energy expenditures can be relatively high.
The energy requirements of an individual are influenced by factors such as body size, body composi-

Tabella 1 - Estimated energy cost in some physical activities (mean values in Kcal/min).

	Body weight				
Activity	50 Kg (110 lb)	60 Kg (132 lb)	70 Kg (154 lb)	80 Kg (176 lb)	90 Kg (198 lb)
Basketball	7.2	8.8	10	11.5	13
Circuit training	5.5	6.5	7.5	8.5	10
Cycling					
9 Km/h	3.3	4	4.5	5.3	6
15 Km/h	5.3	7	8	8.3	9.5
racing	8.8	10.5	12.3	14	15.8
Football	7	8.3	9.8	11	12.5
Gymnastics	3.5	4	4.8	5.5	6.3
Hockey	4.5	5	6	7.3	8.3
Judo	10.3	12.3	14.3	16.3	18.3
Tennis					
recreational	3.8	4.3	5	5.8	6.5
competitive	9.3	11	12.5	14.5	16.3
Volleyball	2.5	3	3.6	4.3	4.8

tion, movement efficiency, goals and the energy cost of training (1, 2).

Food and nutrients

Nutrients are usually divided into five different categories: carbohydrates, proteins, fats, vitamins, and minerals (1).

Carbohydrate

Carbohydrate remains a key nutrient for athletes. It provides the major fuel for exercise, especially during prolonged continuous exercise or high-intensity work. The body has a limited capacity to store carbohydrate (as glycogen in the muscles and liver) and stores must be replenished regularly to support training (2). About 300-500 g of glycogen is stored in the muscles and 75-100 g is stored in the liver. This is enough carbohydrate to run at a moderate intensity for about 20 miles (3). However, carbohydrate requirements are largely influenced by training loads (frequency, duration and intensity of training sessions) and the demands of competition. Given this, daily carbohydrate intake should reflect daily exercise levels. Low body stores of carbohydrate can result in fatigue, impairment of performance during training or competition, and negatively impact immune function.

On high activity days, carbohydrate intake needs to be increased to facilitate optimal exercise performance and promote recovery between exercise sessions. Conversely, on low activity days, carbohydrate intake (particularly from high-density sources such as pasta, sugar drinks, cakes, etc.) may need to be reduced to reflect a decreased training load. Others dietary goals required for weight management or aesthetic sports should consider a reduction of daily carbohydrate intake (table 2) (2, 3).

Protein

Protein is needed to support the repair of damaged body tissues and the building of new proteins in response to the training stimulus (1-3). Endurance athletes undertaking heavy training may require extra protein to cover a proportion of the energy costs of their training, and for repair and recovery after a workout. Strength-trained athletes look for additional protein to increase muscle size and strength in response to resistance training. Negative energy balance

Tabella 2 - Carbohydrate intake levels in sports nutrition (mean values for Kg of body weight).

Activity	Daily carbohydrate intake
Minimal physical activity Recovery after muscle injury or bed rest conditions	2 - 3 g
3-5 hr/week of training for dexterity sports (e.g. archery, bowling, golf, horse-back riding) Fat loss management Bodybuilding pre-contest diet	3 - 5 g
10 hr/week of training for power and team sports (e.g. bodybuilding off-season diet, canoeing, football, martial arts, sprinting, tennis, weight lifting)	6 - 7 g
20 hr/week of training of endurance sports (e.g. cross-country skiing, cycling, Nordic skiing, running, trekking)	7 - 10 g
Carbohydrates loading for endurance and ultra-endurance events (e.g. triathlon ironman, ultra-trail)	10 - 12 g

and inadequate carbohydrate intake during heavy training can also increase protein needs. Several experts have suggested guidelines for protein intakes for athletes that reflect these possible increases in protein requirements (table 3) (2). There is evidence to suggest that the greatest increases in protein requirements occur above all in the early stages of a new exercise program or a new level of exercise stress (for example, a change in the type, volume or intensity of training). However, once the body adapts to this stress, protein requirements may be reduced to a more modest level.

Protein comes from a variety of sources, such as beef, chicken, pork, eggs, milk, cheese, etc. Some high carbohydrate foods are also good sources of protein. Protein needs are easily taken care of when a varied diet that focuses on nutrient-rich foods is consumed. Athletes at risk of inadequate protein intake are those with restricted energy intakes and unusual dietary practices (poorly chosen vegetarian diets, extremely high carbohydrate or low-fat diets) (2).

Fat

In contrast to carbohydrate stores, fat stores are large in humans and are regarded as practically unlimited. The stores of fat are mainly located in adipose tissue but significant amounts also exists as intramuscular triacylglycerols, which can provide an important fuel during exercise (1). Carbohydrate and fat are always oxidized as a mixture, and the relative contribution of these two substrates depends on the exercise intensity and duration, the level of aerobic fitness, diet and the carbohydrate intake before and during exercise.

In absolute terms, fat oxidation increases as the exercise intensity increases from low to moderate intensities, even though the percentage contribution of fat may actually decrease.

Diet also has marked effects on fat oxidation (1). Generally a high-carbohydrate, low-fat diet reduces fat oxidation, whereas a high-fat, low-carbohydrate diet increases fat oxidation. Although the hypothesis that chronic high-fat diets may increase the capacity to oxidize fat and improve exercise performance during competition is attractive, little evidence indicates that it is true (1). The rate of carbohydrate utilization during prolonged strenuous exercise is closely related to the energy needs of the working muscle. In contrast, fat utilization during exercise is not tightly regulated. No known mechanism exists that closely matches the metabolism of fat to energy expenditure. Fat oxidation is, therefore, mainly influenced by fat availability and the rate of carbohydrate utilization (1).

Tabella 3 - Protein intake levels in sports nutrition (mean values for Kg of body weight).

Activity	Daily protein intake
Recreational exercise (adult)	1,0 - 1,4 g
Resistance/strength training	1,2 - 1,4 g
Resistance/strength training (gain muscle mass)	1,4 -1,8 g
Endurance training	1,2 - 1,4 g
Intermittent, high-intensity training (e.g. cross-training)	1,2 - 1,8 g
Ultra-endurance training Weight-restricted sports (e.g. bodybuilding, weight lifting, power lifting)	1,4 - 2,0 g
Adolescent athletes	2 g

Vitamins and minerals

Vitamins and minerals are needed in the body for several important processes, including the growth and repair of body tissues, as cofactors in enzyme catalyzed metabolic reactions, for oxygen transport and oxidative metabolism, for immune function and as antioxidants. Any sustained deficiency of an essential vitamin or mineral will cause ill health, and an unhealthy athlete is extremely unlikely to perform to the best of his or her potential (1).

Vitamins are organic compounds that are needed in very small quantities in the diet. Although physical activity may increase the requirement for some vitamins (e.g. vitamin C, riboflavin and possibly pyridoxine, vitamin A and vitamin E), this increased requirement is typically met by consuming a balanced high-carbohydrate, moderate-protein, low-fat diet. Some vitamins work as antioxidants. Evidence suggests that antioxidants provide an important defence mechanism in the body against the damaging effects of free radicals (1). Many athletes consume large doses of antioxidant vitamins (vitamins A, C and E), however excessive antioxidant ingestion may not be uniformly helpful. The controversy continues as to whether physically active individuals should consume antioxidant compounds in amounts above RDA values. At present, the data are sufficient to recommend antioxidant supplements for athletes, in particular when daily physical workload is very high or when several competitions are matched in short period of time (1).

In nutrition, the term mineral usually refers to those dietary constituents essential to life processes. Minerals are classified as *macrominerals* or *microminerals* (trace elements), based upon the extent of their occurrence in the body and the amounts that are needed in the diet (3). Appropriate dietary intake of minerals is necessary for optimal health and physical performance. Some minerals (e.g., calcium and phosphorus) are the building blocks for body tissues, including bones and teeth. A number of minerals (e.g., magnesium, copper, and zinc) are essential for the normal function of enzymes that are involved in the regulation of metabolism, and some minerals (e.g., iron and zinc) have an essential role in the functioning of immune cells. Several other minerals (e.g., sodium, potassium, and chloride) exist as ions or electrolytes dissolved in the intracellular and extracellular fluids. Like the vitamins, minerals cannot be used as a source of energy (3).

Regular exercise, particularly in a hot environment, incurs increased losses of several minerals in sweat and urine, which means that the daily requirement for most minerals is increased in athletes engaged in heavy training. However, with the exception of iron and zinc, isolated mineral deficiencies are rare (3).

Sports Supplements

Dietary supplements can play a meaningful role in helping athletes consume the proper amount of calories, carbohydrate, and protein in their diet (3). However, they should be viewed as supplements to the diet, not replacements for a good diet. While it is true that most dietary supplements available for athletes have little scientific data supporting their potential role to enhance training and/or performance, it is also true that a number of nutrients and/or dietary supplements have been shown to help improve performance and/or recovery. Supplementation with these nutrients can help augment the normal diet to help optimize performance. Sports nutrition specialists must be aware of the current data regarding nutrition, exercise, and performance and be honest about educating their clients about results of various studies (whether pro or con). Care should also be taken to make sure they do not contain any banned or prohibited nutrients and/or substances with any adverse effects. Some of the most important supplements are discussed in the following section (3, 4)

Sports foods

Sports foods such as sports drinks, bars, gels, ready to drink supplements (RTD's), and meal replacement powders (MRP's) offer practical and convenient options to help athletes meet their special nutritional needs. When used appropriately, these products are a useful addition to the nutrition program of many athletes. They are typically fortified with vitamins and minerals and differ on the amount of carbohydrate, protein, and/or fat they contain. They may also vary based on whether they are fortified with various nutrients purported to promote weight gain, enhance weight loss, and/or improve performance. Most people view these supplements as a nutrient dense snack and use them to help control caloric intake when trying to gain and/or lose weight. Sports foods can provide a convenient way for people to meet specific dietary needs and/or serve as good alternatives to fast food other foods of lower nutritional value. Use of these types of products can be particularly helpful in providing carbohydrate, protein, and other nutrients prior to and/or following exercise in an attempt to optimize nutrient intake when an athlete doesn't have time to sit down for a good meal or wants to minimize food volume. However, as mentioned previously they should be used to improve dietary availability of macronutrients – not as a replacement for a good diet (3, 4).

Sports drinks

Sports drinks are designed to deliver a balanced amount of carbohydrate and fluid to allow an athlete to simultaneously rehydrate and refuel during exercise. According to various expert position stands, to provide rapid delivery of fluid and fuel and to maximise gastric tolerance and palatability, sports drinks should be within a compositional range of 4-8% (4-8 g/100 ml) carbohydrate and 23-69 mg/100mL (10-30 mmol/L) sodium.

Sports drinks provide a convenient option for simultaneously addressing fuel, fluid and electrolyte needs before, during and after exercise. Before exercise sport drinks may be part of the pre-exercise meal or consumed immediately before exercise to top up fluid and fuel status. During exercise the major role for sport drinks is to promote hydration and refuelling. After exercise they may be part of post-exercise recovery snacks and meals to assist with rehydration (3, 4).

Sports bars

A range of sports bars is available. Differentiating characteristics include the amount and type of protein and carbohydrate. While some "high-protein" bars may contain 20-30 g of protein of high quality, other bars provide only 5-10 g of protein from varying sources and more carbohydrates. Some sports bars are fortified with micronutrients, while others may be enriched with performance or recovery enhancing ingredients, such as creatine monohydrate (CM), branched-chain amino acids (BCAA), and leucine.

Sports bars provide a low-fibre, easily consumed form of carbohydrate and protein for use in different situations: pre-event meal/snacks, where the athlete is at high risk of gastrointestinal problems during exercise; following a training session or competition to contribute to carbohydrate needs for refuelling (and if the protein content is adequate, to contribute to protein synthesis goals); and as a snack to provide energy/macronutrient intake without need to prepare or eating additional food or meals (3, 4).

Sports gels

For situations which require a high rate of carbohydrate delivery to working muscle, gels containing "multiple transportable carbohydrates" (a blend of carbohydrates such as glucose and fructose which use different intestinal transporters) may overcome the usual limitation of gut uptake. Studies show that such mixtures are effective in increasing muscle oxidation of carbohydrate consumed during exercise compared with glucose-based products. Different characteristics of gels include the volume and amount/concentration of carbohydrate, type/mixture of carbohydrates, the consistency or texture of gel, and the presence of other "active ingredients" (e.g. electrolytes and caffeine). Sports gels provide a compact and portable source of carbohydrate (each gel provides ~ 20-25 g of carbohydrates), which can easily be consumed immediately before or during exercise to assist with meeting carbohydrate intake targets. (3, 4).

RTD's and MRP's
Differentiating characteristics include the amount/type of key macronutrients protein and carbohydrate, fat and fibre content, flavors, fortification with vitamins and minerals and the presence of other "active ingredients". RTD's can be used very quickly before or soon after the exercise session while MRP's can be mixed with milk or water in order to obtain a meal shake. When used to achieve sports nutrition goals, both RTD's and MRP's may enhance training adaptations or competition outcomes. Following a training sessions (resistance training or prolonged/high intensity training) or strenuous competition events they provide a practical form of energy and blend of macronutrients, to provide targeted amounts of protein and carbohydrate to simultaneously promote repair/adaptation and refuelling. RTD's and MRP's can also be used in situations requiring energy/macronutrient intake without need to prepare or eating additional food or meals (program to increase lean body mass, heavy training loads, growth spurts, appetite suppression). RTD's and MRP's can often be overused, leading to inappropriate replacement of whole foods and over-reliance on an expensive alternative. Food sources should always be considered as the first option for meals and snacks (3, 4).

Multivitamins and minerals

Regular, prolonged strenuous exercise may result in an increased dietary requirement for certain vitamins and minerals. If the daily energy intake is high and a nutrient-dense diet is consumed, generally a supplementation with vitamins and/or minerals is not necessary. There is no evidence that supplementation with vitamins and minerals enhance performance except in cases where a preexisting deficiency exists. However, supplementation with different combinations of vitamins and minerals may be justified when there is an unavoidable reduction in energy intake or the nutrient density of dietary intake (e.g. a prolonged period of travel, particularly to countries with an inadequate or otherwise limited food supply; a prolonged period of energy restriction or weight loss, or weight maintenance; restricted dietary intake in fussy eaters or athletes with significant food intolerances who are unable/unwilling to increase food range; heavy competition schedule, involving disruption to normal eating patterns and reliance on a narrow range of foods and sports foods) (3, 4).

Protein supplements

As previously described, research has indicated that people undergoing intense training may need additional protein in their diet to meet protein needs (i.e., 1.4 – 2.0 grams/kg bodyweight/day) (3). People who do not ingest enough protein in their diet may exhibit slower recovery and training adaptations. Protein supplements offer a convenient way to ensure that athletes consume quality protein in the diet and meet their protein needs. However, ingesting additional protein beyond that necessary to meet protein needs does not appear to promote additional gains in strength and muscle mass (3, 4). The research focus over recent years has been to determine whether different types of protein (e.g., whey, casein, soy, milk proteins, colostrum, etc) have varying effects on the physiological, hormonal, and/or immunological responses to training. In addition, a significant amount of research has examined whether timing of protein intake and/or provision of specific amino acids may play a role in promoting net protein accretion (i.e. lean mass) and/or training adaptations, although most of this has been conducted in untrained populations (4). Although more research is necessary in this area, evidence clearly indicates that protein needs of individuals engaged in intense training are elevated, different types of protein have varying effects on anabolism and catabolism, that different types of protein subtypes and peptides have unique physiological effects, and timing of protein intake may play an important role in optimizing training adaptations following exercise (4). According to the current literature we know that the addition of protein (about 20 g) before and/or after resistance training can increase protein synthesis and gains in lean mass beyond normal adaptation (3, 4).

Essential Amino Acids (EAA) and Branched Chain Amino Acids (BCAA).

Recent studies have indicated that ingesting 3 to 6 g of EAA prior to and/or following exercise stimulates net protein synthesis (3). Theoretically, this may enhance gains in muscle mass during training. To support this theory, studies found that ingesting EAA with carbohydrate immediately following resistance exercise promoted significantly greater training adaptations in elderly, untrained men, as compared to waiting until 2-hours after exercise to consume the supplement. Although more data is needed, there appears to be strong theoretical rationale and some supportive evidence that EAA supplementation may enhance protein synthesis and training adaptations (5). Because EAA include BCAA, it is probable that positive effects on protein synthesis from EAA ingestion are likely due to the BCAA content. BCAA, and leucine in particular, are the key amino acids that stimulate protein synthesis (6). The International Society of Sports Nutrition (ISSN) Position Stand on protein concluded that EAA and BCAA have been shown to acutely stimulate protein synthesis, aid in glycogen resynthesis, delaying the onset of fatigue, and help maintain mental function in aerobic-based exercise (4). Aside from protein supplements, consuming EAA (in addition to carbohydrates) before and/or following exercise is another choice for athletes to stimulate protein synthesis and muscle recovery (3).

Creatine monohydrate (CM).

Without question, the most effective nutritional supplement available to athletes to increase high intensity exercise capacity and muscle mass during training is CM (3, 4). Numerous studies have indicated that CM supplementation increases body mass and/or muscle mass during training. Gains are typically 2 – 5 pounds greater than controls during 4 – 12 weeks of training (4). The gains in muscle mass appear to be a result of an improved ability to perform high intensity exercise enabling an athlete to train harder and thereby promote greater training adaptations and muscle hypertrophy. The only clinically significant side effect occasionally reported from CM supplementation has been the potential for weight gain (3, 4). Although concerns have been raised about the safety and possible side effects of creatine supplementation, recent long-term safety studies have reported no apparent side effects and/or that CM may lessen the incidence of injury during training. Additionally a recent review was published which addresses some of the concerns and myths surrounding CM supplementation (4). Consequently, supplementing the diet with CM and/or CM containing formulations seems to be a safe and effective method to promote high-intensity exercise performance and increase muscle mass. The quickest method of increasing muscle creatine stores appears to be to consume ~0.3 grams/kg/day of CM for at least 3 days followed by 3–5 g/d thereafter to maintain elevated stores. Ingesting smaller amounts of CM (e.g., 2– 3 g/d) will increase muscle creatine stores over a 3–4 week period, however, the performance effects of this method of supplementation are less supported (3, 4).

Caffeine.

Caffeine is a naturally derived stimulant found in many nutritional supplements typically as gaurana, bissey nut, or kola. Caffeine can also be found in coffee, tea, soft drinks, energy drinks, and chocolate. Caffeine can have a positive effect on energy expenditure, weight and body fat loss. Caffeine has also been shown to be an effective ergogenic aid. Researches investigating the effects of caffeine in trained cyclist found that caffeine improved speed, and power capacity (3, 4). Studies indicate that ingestion of caffeine (e.g., 3-9 mg/kg taken 30 – 90 minutes before exercise) can spare carbohydrate use during exercise and thereby improve endurance exercise capacity. In addition to the apparent positive effects on endurance performance, caffeine has also been shown to improve repeated sprint performance benefiting the anaerobic athlete (4).

Due to attenuation of its effects, people who drink caffeinated drinks regularly (habitual users) appear to experience less ergogenic benefits from caffeine than who consume caffeine sporadically.

Some concern has been expressed that ingestion of caffeine prior to exercise may contribute to dehydration although recent studies have not supported this concern (4).

The typical caffeine dosage in sport is from 3 to 6 mg/Kg/body weight. Over 9 mg/Kg/body weight several adverse effects can occur (e.g. palpitations, headache, insomnia) and this dosage is not recommended (3, 4).

Weight management.

Body weight management is an important determinant of performance for many athletes and is one of the key issues in sports nutrition (1, 3). Some athletes try to achieve weight loss, and others try to achieve weight gain. In some weight-bearing activities, such as running and jumping, extra weight may be a disadvantage and reducing body fat is important, though in some contact sports, such as American football and rugby, extra weight may be an advantage and increasing muscular mass is a common goal. For other sports, such as dancing and gymnastics, leanness is important mainly for aesthetic reasons. The desire to lose or gain weight is not limited to competitive athletes but is also common among recreational athletes and sedentary individuals who wish to change their physical appearance (1, 3).

Body composition

By measuring body composition one can quantify the most important structural components of the body: muscle, bone, and fat. A variety of techniques have been developed to measure body composition (table 4) (1). The traditional weight-height tables to measure body mass index (BMI) have strong limitations when applied to an athletic population. For instance, a bodybuilder (180 cm, 100 Kg [6 ft, 220 lb]) may have very low body fat but could be classified as overweight according to BMI tables. Clearly the "extra" weight is muscle and not body fat, which would lead to erroneous classification and possibly mistaken advice (1, 3).

Weight loss

In most cases, a sustained moderate energy deficit is required to avoid any performance impairment caused by an inadequate food intake. Unfortunately, athletes of many sports (bodybuilding, cheerleading, dancing, distance running, cross-country skiing, diving, figure skating, gymnastics, martial arts, rowing, swimming, weight-class football, and wrestling) often resort to unhealthy weight-control practices, which can potentially be harmful to their performance and/or their health (1,7,8). These unhealthy weight control practices include food restriction, vomiting, over exercising, diet-pill use, inappropriate use of prescribed stimulants, nicotine use and voluntary dehydration. They end up with suboptimal performances because of impaired strength and muscle mass, reaction time, endurance, electrolyte imbalance and acidosis. Mental skills can also be negatively affected such as concentration, alertness, mood, cognitive state, and learning ability (7). In severe cases, extreme weight loss can result in medical complications including delayed physical maturation in young athletes, oligomenorrhea and amenorrhea in female athletes, development of eating disorders, potential permanent growth impairment, increased incidence of infectious diseases, changes in cardiovascular, endocrine, gastrointestinal, renal and thermoregulatory systems and depression. Athletes should be counseled on the harmful effects of unhealthy weight-loss practices and informed that body weight is not an accurate indicator of body fat or lean muscle mass (8). For these athletes systematic body composition measurements can be very helpful and are recommended.

Weight loss may be beneficial when it is achieved by healthy means and involves losing excess fat without reducing lean muscle mass or causing dehydration. In general, body fat percentage should not be lower than 5% for male athletes and 12-14% for women, but there are some exceptions. For example, in swimmers a reasonable amount of fat mass helps buoyancy and is the main reason why women and men in this sport have similar performance at high levels (at least in distance-based events) (8). Weight loss, when necessary, should be gradual and should not exceed 1.5% of the total body weight, each week.

Tabella 4 - Some of the most utilized techniques to measure body composition.

Skinfold thickness	Measurement of subcutaneous fat with a calliper that gives an estimation of fat mass
Hydrostatic weighing	Underwater weighing based on Archimedes' principle to estimate lean-body mass and fat mass
Air plethysmography (BOB POD)	Measurement of air displacement to estimate lean-body mass
Bioelectrical impedance analysis (BIA)	Measurement of resistance to an electrical current to estimate total-body water, lean-body mass, and fat mass
Duel energy x-ray absorptiometry (DEXA)	X-ray scan at two intensities to measure total-body water, lean-body mass, fat mass, and bone-mineral density

In contrast, when weight is lost too rapidly or by a drastic reduction in energy intake, lean muscle mass will also be lost, and this can negatively affect performance (8). Athletes involved in sports that require mandatory weight categories should be encouraged to compete at a weight that is appropriate for their age, height, physique, and stage of growth and development. Reasonable and individualized weight and body composition goals should be identified by appropriately trained health care personnel (i.e., athletic trainers, sports dietitians, physicians) (8).

Which diet works best?

Given the known individual differences in biochemistry and metabolism, a 'one diet fits all' approach typically does not work (2). In general though, the basic approach for weight loss is to decrease total energy intake by 2000–4000 kilojoules per day (approximately 500–1000 calories), while maintaining adequate intakes of protein, carbohydrate, essential fats and other nutrients. Consideration needs to be given to the demands of the sport, the intensity, frequency and duration of training and an individual's physical size. It can often be challenging to find the balance between reducing energy intake and providing the nutritional needs of training (2). Menu patterns must also attempt to address the athlete's appetite, and the social and enjoyment aspects of eating should not be overlooked. Meal frequency also may have an important role in body composition regulation. Although recent studies have questioned this approach, most nutrition experts recommend eating frequent meals habitually (e.g., ~4-6 meals per day) because of the beneficial effects on plasma insulin as well as the regulation of appetite during the day. The input of a sports dietitian can help the athlete to understand their individual requirements and set realistic goals (2).

Maintain adequate carbohydrate intake during fat loss

Muscle stores of carbohydrate, refilled from dietary carbohydrate intake, provide an important source of fuel for training, particularly quality workouts. Even when total energy intake is reduced, daily carbohydrate intake needs to be aligned to the training load. At present there is no simple method of monitoring glycogen stores, other than expensive or invasive laboratory procedures such as muscle biopsies. Adjusting carbohydrate intake based on daily training requirements must therefore be done by 'trial and error'. General guidelines can be provided as a starting point, particularly for athletes who must undertake prolonged sessions of moderate and high-intensity activity. Such athletes are encouraged to maintain a carbohydrate intake of approximately 4-6 grams per kilogram body mass to minimise the impact on training quality. Nevertheless, all athletes should monitor training performances and recovery and adjust carbohydrate intake when their success at daily refuelling appears to be compromised (2).

Maintain adequate protein intake

A reduced-energy diet still needs to provide an adequate amount of protein, spread across meals and snacks over the day. Ensuring that protein requirements are met is important to help minimise muscle wasting and loss of strength during periods of weight loss (2, 3). Protein added to a meal or snack can increase the satiety value of the food choice, helping with appetite control. Finally, many lean protein-rich foods also provide other key nutrients to the menu, such as iron, calcium and B-vitamins. The daily protein intake for fat loss is not easy to establish and it is very variable; a range from 1,5 g to 2 g of protein daily per kilogram of body weight could be adequate for many athletes, but not for others. Strength athletes and bodybuilders often need more protein during targeted fat loss programs, because their carbohydrate restriction can be very large and more protein is required to preserve muscle mass and power output. Regarding the claim that "high protein" diets may have deleterious effects on the body, this has no basis in fact. Protein intakes up to 2,8 g daily per kilogram of body weight do not impair renal or other physiological functions in well-trained athletes (2-4).

Target high fat foods

Energy reductions can be achieved most easily by removing surplus amounts of fat from the diet. Strategies to meet this goal include choosing lower-fat versions of everyday foods and using low-fat cooking methods where possible (2). Learning to read food labels is another asset that can help the athlete to address the quantity and quality of their food choices. The commonly held consensus is that 20% to 25% of total caloric intake should come from fats. To maximize performance, athletes should take in no less than 15% of total caloric intake from dietary fats. Based on current recommendations (4), fat intake should minimize partially hydrogenated, unsaturated (trans) fats and saturated fats and promote the ingestion ofo mono- and polyunsaturated fats (particularly omega-3 fats from marine sources).

Increasing muscle mass

Sports such as football, rugby, basketball, power lifting, and bodybuilding often motivate athletes to gain weight. As with weight loss, weight gain has to be reached properly: it has to be gradual, because a gain in excess of 1.5% of body weight per week may result in unwanted fat gain (2, 3). Often, athletes use supplements (which may be of unproven value and potentially harmful) or anabolic compounds (which are harmful to athletes' health) to gain weight instead of evaluating their nutritional and training programs. Before trying to change body composition, athletes must understand potential genetic limitations. Athletes with a solid body build (mesomorphy) can expect to gain more weight than athletes with a slender body build (ectomorphy). Inadequate energy intake is often the limiting factor for athletes trying to increase muscle mass. To increase body mass and gain lean tissue, an athlete needs to follow a well-structured resistance training program and to consume a diet that provides an energy intake that is greater than daily energy expenditure (that is, achieve positive energy balance). Total energy intake should be increased by 2000–4000 kilojoules per day (approximately 500–1000 calories), with approximately 55%-60% of calories in the form of carbohydrates, 30% from fat and an extra portion of protein-rich food sources (2, 3). A pattern of frequent meals and snacks is helpful in achieving additional energy requirements and in promoting the outcomes of training by providing key nutrients at important times.

Protein needs for increasing muscle mass

Most athletes easily meet their protein requirements. Simply increasing total energy intake from a well-chosen eating plan will allow most athletes to achieve or exceed protein intake goals. However, research suggests that an appropriate timing of protein intake may be more effective in optimising gains in lean muscle tissue rather than simply eating large amounts of protein. There is strong scientific evidence that consuming protein supplements and/or amino acids (in particular the EAA) soon after the resistance training can profoundly affect skeletal muscle protein synthesis and enhance muscle mass (3, 4). The daily diet for a strength/hypertrophy athlete should contain ~1.8-2.0 g of protein per kilogram of body mass (3). Of this total amount, approximately 20 g of protein should be taken as soon as possible after the exercise session. In young and middle aged athletes, more protein is not required but in older subjects up to 40 g may be necessary to maximise protein kinetics (9).

The quality of the protein source is an important factor for increasing muscle mass and this is determined by its essential amino acid content. Some foods contain all of the essential amino acids and in amount sufficient to stimulate protein synthesis (e.g., dairy products, eggs, meat and fish), whereas others are lacking in one or more amino acids (grains, vegetables, fruits) and for this reason are less effective in promoting muscle growth. Clearly, daily diet should contain a proper combination of food sources in order to have the best protein plan strategy.

Protein supplements
Protein supplements offer a quick and convenient way to take protein with appropriate timing (3, 4). The best sources of high quality protein found in supplements are reported to be whey, casein, milk, and egg proteins. Whey protein, especially whey protein isolate and hydrolyzed whey peptides, is widely promoted to strength athletes as being perhaps the best protein, based on its high digestibility and bioavailability and its content of several critical amino acids (i.e., glutamine, leucine, isoleucine, and valine) (4). Casein is the major component of protein found in diary products and, like whey, it is a complete protein. Research has shown that dietary amino acids absorption is faster with whey protein than with casein and this can differently modulate muscle amino acid deposition, protein synthesis and breakdown after the exercise session (3, 4). Normally, after a weight training session the athletes prefer to consume a whey protein supplement; the addition of casein in a protein blend (i.e. whey + casein) is a valid solution when a solid meal cannot be consumed within 1-2 hours.

Nutritional strategies for training and competition

A key priority for athletes is to establish a well-chosen training diet that can be easily manipulated when special situations emerge (e.g., changes to training load, changing body composition goals, or special competition needs). A good base diet will provide adequate nutrients and energy to enhance adaptations from training, support optimal recovery and avoid excessive exercise-related stress. Heavy training and competition increase the need for nutrients, particularly carbohydrate, protein, water and electrolytes in sport-specific manner. The next section focuses on the nutritional strategies adopted by athletes before, during, and after exercise, in relation to the type of activity.

Nutrition before, during, and after exercise for the endurance and team sport

The causes of fatigue during prolonged, aerobic exercise will vary according to the type of exercise and the environmental conditions in which the exercise is performed (3). Depletion of carbohydrate is now considered one of the primary causes of fatigue during exercise that is sustained for long periods of time. The fatigue is directly related to muscle glycogen depletion because muscle glucose uptake is too slow to support the carbohydrate needs of the exercising muscles even when blood glucose levels are normal (3). Although depletion of muscle glycogen is normally associated with fatigue during continuous aerobic exercises such as marathon running, it is important to recognize its impact for team and skill sports that require bursts of speed or powerful movements. Without adequate muscle glycogen it becomes impossible for the basketball player to continually sprint up and down the court or the tennis player to move quickly to and from the net. Adequate muscle glycogen stores are critical for top athletic performance (3).

Diet strategy before exercise: Carbohydrate loading
Carbohydrate loading strategies have evolved significantly over the last 30 years (2). In endurance-based events, starting the competition with elevated muscle glycogen stores can help postpone such fatigue. Carbohydrate loading increases muscle glycogen significantly (50-100 per cent) above normal resting values. This potentially results in a 20 per cent enhancement of endurance, or in fixed distance events, an improved

race time of 2-3 per cent. It may also improve movement patterns and maintain skill at the end of prolonged team games (2).

The most recent evidence suggests that optimal muscle glycogen levels can be achieved in well-trained athletes by combining an exercise taper with a high carbohydrate intake (7-12 g per kilogram body mass). In most cases, 24-72 hours will be required to fully carbohydrate-load, but there is also a 1-day CHO loading study (10).

Foods and fluids consumed in the four hours prior to competition complete an athlete's nutritional preparation. The pre-event meal adds to muscle glycogen stores if they have not been fully restored since the last exercise session. It also restores liver glycogen for early morning events, ensures the athlete is hydrated and prevents hunger. Food choice also impacts on gastrointestinal comfort and the athlete's psychological outlook.

Timing and amount of carbohydrate intake

Individual tolerance and competition schedule dictate the ideal timing for the pre-event meal. General guidelines suggest a meal or series of snacks should be consumed 1–4 hours before exercise (2). The longer time frame allows carbohydrate intake to contribute to liver and muscle glycogen stores. However, early morning events often mean a shorter time frame is more practical. A small proportion of athletes respond negatively when carbohydrate is consumed close (within one hour) to exercise. An exaggerated carbohydrate oxidation and subsequent decrease in blood glucose concentration at the start of exercise can cause symptoms of hypoglycaemia, including fatigue (2).

The exact cause is unknown but useful strategies for these athletes may be to allow longer time frame between eating and exercise, consume a substantial amount of carbohydrate in the pre-event snack (more than 1g per kilogram body mass or ~ 70g for the typical athlete) and include low glycaemic index (GI) foods in the pre-event meal (2). Athletes who experience gastrointestinal problems during exercise may also benefit from allowing a longer period of time between eating and exercise. Research suggests that endurance performance is improved when athletes consume a substantial amount of carbohydrate (200–300g) in the 2–4 hours before exercise. This is achievable when events are held later in the day but is not always practical before early morning events. In many situations athletes must settle for a smaller meal or snack before the event, then make up for lower than recommended carbohydrate intakes by consuming carbohydrate during the event (2).

Suggestions for pre-event food and fluid intake

2–4 hours prior to exercise:

- Pasta/rice with low fat pasta sauce
- Fruit salad with low fat yoghurt Baked potato served with baked beans
- Toast with jam and sports drink
- Crumpets or English muffins with jam/honey + fruit smoothie
- Breakfast cereal with low fat milk plus tinned fruit
- Lean meat, veggies and rice
- RTD's alone or + fruit

60 minutes prior to exercise:

- Sports drink or gels
- Cereal/muesli bars + banana + water
- juice and fruit + yogurt

Quality of carbohydrates: type of food

The carbohydrate foods most suited to pre-exercise meals are choices that are low-fat, low-fibre and low-moderate in protein; these are less likely to cause gastrointestinal upset.

Consuming low GI foods has been proposed as a clever pre-event strategy for endurance events (2). GI is a measure of the blood glucose response following ingestion of carbohydrate-containing foods. Foods with a high GI are digested and absorbed more rapidly by the body, delivering glucose quickly into the bloodstream. Foods with a low-GI are digested and absorbed more slowly, resulting in a gradual release of glucose. It is thought that low-GI foods might reduce the sudden increase in blood glucose levels prior to an event, and prevent the subsequent drop in blood glucose once exercise is commenced. In addition, a low-GI pre-event meal might provide a continued supply of carbohydrate during the exercise session (2). In general, studies have failed to show a universal benefit to performance from consuming low-GI foods prior to exercise. When carbohydrate is consumed during exercise according to sports nutrition guidelines, any effect of consuming low-GI foods in the pre-event meal is negated. When fuel cannot be consumed during a prolonged exercise session, some athletes may derive benefits by consuming a low-GI pre-event meal. However, for most occasions, the athlete can choose the foods consumed in their pre-event meal based on personal preference, availability and gastrointestinal comfort (2).

Examples of low-GI foods (GI value <55):

- Pasta served with a mixed bean pasta sauce
- Vegetable curry made with vegetables and lentils
- Fresh fruit, such as apples and oranges
- Full-cream or low-fat yoghurt
- Fruit smoothie made with milk and/or yoghurt
- Wholegrain sandwich made with Soy and Linseed bread
- Breakfast cereal plus low fat milk

Nutrition during Exercise

Many studies have shown that consumption of carbohydrates during prolonged exercise (>60-90 minutes) enhances endurance and performance (2). More recently, carbohydrate intake has also been shown to benefit performance during shorter (60 minutes) events and 'stop and go' intermittent sports such as tennis and soccer (2). The performance benefit may occur due to sparing of muscle glycogen stores, the prevention of low blood-glucose levels (hypoglycaemia) or effects on the central nervous system that are not well explained as of yet. The benefits can translate into faster race times, a delay in the onset of fatigue towards the end of the event, ability to cover more ground at faster speeds in the last half or quarter of game, and better maintenance of skills and concentration right to the final siren. Also, carbohydrate supplementation during exercise has a protective effect on the immune system post exercise, while also maintaining an adequate supply of energy substrate for the immune system during exercise (11).

The optimal rate of carbohydrate ingestion during exercise is unknown. However, in events lasting longer than 60 minutes, athletes are encouraged to consume carbohydrate at a rate of 30–60g per hour (2, 3). Experimentation in training or less important events may allow the athlete to fine tune this plan for their specific needs and opportunities. It makes sense for refuelling during the event to start well before fatigue is experienced and before a fluid deficit can build to a level where gastric emptying is reduced. The effects of consuming fluid and carbohydrate during exercise are additive. A variety of options exist for carbohydrate intake, however sports drinks offer a convenient strategy for meeting fluid and carbohydrate needs simultaneously. If other carbohydrate choices are used, care should be taken to consume adequate amounts of fluid.

Nutrition for recovery

Post-exercise recovery is an important challenge for many athletes (1-3). Optimal recovery can enhance adaptations to training and help prepare for the next workout. In competitions involving a series of games or races, recovery is important for good performances in the subsequent and final bouts. Recovery nutrition incorporates a range of nutrition-related processes, including:

- refuelling/restoring muscle and liver glycogen stores

• repair, regeneration and adaptation of muscle tissue following the damage caused by exercise
• rehydration and replacement of fluid and electrolytes lost in sweat.

A number of factors can interfere with recovery strategies in both the training and competition phases. These include fatigue, loss of appetite, poor access to foods, post-exercise commitments such as team debriefings and injury treatments, and traditional post-exercise celebratory activities. A planned approach ensures recovery needs are taken care of, despite this array of distractions.

Refueling post-exercise

It may take up to 24 hours for restoration of muscle glycogen levels when stores are fully depleted (2, 3). Several strategies have been investigated to speed up the replenishment of glycogen stores. These include altering the frequency of carbohydrate ingestion, manipulating the type of carbohydrate consumed and combining carbohydrate with other nutrients. While these factors can fine tune the rate of glycogen storage, the most important factor in the process is the amount of carbohydrate consumed. Special tactics are needed if there is less than eight hours between exercise sessions (for example, when the athlete trains more than once each day or where a tournament is played over a single day). This is especially important following glycogen-depleting exercise such as a prolonged session of endurance training or intermittent work such as in team sports. Aggressive refuelling should be undertaken so that carbohydrate stores are adequate for the subsequent exercise session. Current research suggests that optimal refuelling occurs when 1–1.5g of carbohydrate per kilogram body mass is consumed every hour in the early stages of recovery, contributing to a total carbohydrate intake of 6–10g per kilogram body mass over 24 hours. This can be challenging for smaller athletes and/or those with a poor appetite (2).

These guidelines are based on achieving maximal glycogen storage during a passive recovery period. Athletes with extremely high workloads may require additional carbohydrate. Athletes who do not fully deplete glycogen stores in their daily training will require less. Athletes with smaller energy budgets will need to incorporate recovery eating into their normal meal pattern in order to avoid over-consumption of kilojoules. When the recovery period is longer than eight hours, aggressive refuelling is not necessary and athletes can consume their carbohydrate intake targets within their usual meal schedule (2).

Addition of protein to a carbohydrate supplement

Several studies have also documented that the addition of protein to a carbohydrate supplement will enhance the rate of muscle glycogen synthesis (3). These results have important implications for athletes who wish to limit their carbohydrate intake in an effort to control body weight and for those athletes who participate in sports that have very short recovery periods during competition such as basketball, ice hockey, and soccer (3). The ingestion of protein with carbohydrate also has the added benefit of stimulating muscle protein synthesis and tissue repair (3). In fact, during prolonged strenuous exercise there is generally damage to the active muscles and this damage can continue long after exercise because of an acceleration in protein degradation. For complete recovery, it is important to initiate protein synthesis and limit protein degradation as quickly as possible. Similar to glycogen storage, muscle protein synthesis and degradation are affected by the type, amount and timing of nutrient supplementation. Appropriate protein supplementation post-exercise has been found to limit muscle damage, increase protein synthesis and increase training adaptation. This can be obtained from 10-20 g of high quality protein (whey, milk, or egg) or from 6-8 g of essential amino acids (3).

Nutrition before, during, and after exercise for the strength/power athletes

Several studies have documented that strength/power athletes can improve their training sessions and performance with a combination of both proper everyday nutrition and supplementation (3). Proper nutrition can prepare the athlete for intense exercise, provide the energy for muscular contractions, help reduce post-exercise muscle damage, and enhance recovery in anticipation of the next workout. The effectiveness of these processes is largely based on the types of macronutrients selected and the timing of their ingestion. It has been well established that there are preferred types of macronutrients that aid this process based on their quality and speed of digestion (3). Creatine phosphate (CP) and muscle glycogen are the primary sources used for rapid repletion of ATP during an intense resistance-training workout. CP levels within the muscle are also limited and can be depleted after 10-15 seconds of maximal intensity effort. The rapid restoration of ATP and CP involves the anaerobic breakdown of muscle glycogen known as glycolysis. Most strength/power athletes do not realize how much muscle glycogen is used during a typical training session. One set of 10 biceps curls can result in a 12% loss of muscle glycogen, 3 sets can result in 35% depletion, and 6 sets can result in 40% depletion (3). Resistance training is not without its damaging effects. Intense resistance training, especially the eccentric phase, essentially causes microscopic tears in muscle fibres leading to muscle damage (3). Delayed onset muscle soreness can set in at least 24 hours after a workout because of the subsequent inflammatory response to the intense training bout. The body responds to the training by making bigger and stronger muscle fibers in order to sustain future demands. In addition to the microscopic tears, the catabolic hormone cortisol is released from the adrenal cortex during high-intensity exercise such as resistance training (3). Cortisol is the most potent glucocorticoid produced by the adrenal cortex and is major stress hormone that acts to supply the exercising muscles with fuel through gluconeogenesis, lipolysis, and even proteolysis (3). The breakdown of body protein can also contribute to muscle damage and eventual muscle soreness. To combat the damaging and depleting effects of intense resistance training and further help the body respond to training, a well-planned diet that meets energy-intake needs and incorporates proper timing of essential nutrients is vital (3). Athletes that do not consume enough calories and/or do not consume enough of the right type of macronutrients may hinder training adaptations and subsequent performance (3). Furthermore, maintaining a diet that is deficient of the essential macronutrients over time may lead to a loss of body mass, muscle mass, an increased susceptibility to illness, and an increase in the symptoms associated with overtraining. Otherwise, athletes who consume a well-planned diet strategy can help the body adapt to training and will likely notice improved performance (3).

Pre-exercise nutrition

Pre-exercise nutrition should consist largely of moderate to low GI foods/supplements that provide a slow, sustained release of carbohydrates and protein necessary to fuel a workout. It generally takes about 4 hours for dietary carbohydrate to be digested and begin to be stored as muscle and liver glycogen. Thus, pre-exercise meals should be consumed about 4-6 hours before exercise. Putting this into an average everyday scenario means that if an athlete trains in the afternoon, breakfast is the most important meal to top off muscle and liver glycogen levels. If the athlete trains first thing in the morning, the meal the evening before is vital. The choice of foods/supplements selected is largely up to the individual athlete and their personal preferences. It is recommended that the strength/power athlete consume something familiar on the day of competition as opposed to experimenting with a new food/supplement. Recent researches have indicated that ingesting a light carbohydrate and protein snack 30-60 minutes before exercise (e.g. 50 g of carbohydrate and 5-10 g of protein) serves to further increase carbohydrate availability toward the end of an intense exercise bout because of the slight increase in glucose and insulin levels (3). This can serve to increase the availability of amino acids and decrease exercise-induced protein catabolism. Insulin inhibits protein degradation and apparently offsets the catabolic effects of other hormones (i.e., cortisol and catecholamines). Anabolic actions of insulin seem to be related to its nitrogen- sparing effects and promotion of nitrogen retention (3). In addition, resistance training in combination with immediate post-exercise amino acid administration has been shown to augment net protein synthesis acutely. One would thus expect more pronounced muscle hypertrophy over a prolonged period (3).

Nutrition during exercise

Nutrition during an intense resistance-training session can aid in the quality of the workout, especially if the workout exceeds 60-90 minutes. Nutrition during exercise for the strength/power athlete usually centers on supplements more so than pre and post exercise nutrition if for no other reason than the convenience supplements provide. Convenience supplements include meal replacement powders, ready to drink supplements, energy bars, energy gels and fitness waters. They are typically fortified with differing amounts of vitamins and minerals and differ on the amount of carbohydrate, protein and fat they contain. The beneficial effects of solid and liquid carbohydrate/protein supplements are similar when thermal stress is not a factor. Liquid supplements do provide the added benefits of aiding rehydration and tend to digest easier for most athletes while exercising. Rapid nutrient availability is especially important during a workout in order to maintain energy levels and training intensity. Thus high GI sources should make up the majority of supplements ingested during a strength/power workout. The athlete should experiment with different formulations to find the one that works best for them before competition. Recent research has also shown that the addition of protein can have added benefits to a supplement ingested during exercise by reducing muscle protein degradation and speeding post exercise recovery (3). Carbohydrate and protein intake significantly alters circulating metabolites and the hormonal milieu (i.e. insulin, testosterone, growth hormone and cortisol) as well as the response of muscle protein and glycogen balance (3). For the strength/power athlete, the addition of protein to a carbohydrate supplement will also enhance performance gains. Whey is the preferred protein to ingest during exercise because of its rapid absorption rates and the fact that it contains all of the essential amino acids as well as a high percentage of leucine and glutamine, which are two amino acids that the body uses during sustained exercise. High GI carbohydrates (glucose, sucrose and maltodextrin) should be combined with the protein in a 4:1 ratio to provide optimal benefits (3).

Nutrition for recovery

Post-exercise nutrition for the strength/power athlete is vital to restore muscle glycogen stores, enhance skeletal muscle fiber repair and growth and maintain overall heath and wellness. This is especially important for those athletes engaging in prolonged training or competition sessions on the same or successive days. An example could be a bodybuilder working one muscle group in the morning and an opposing muscle group that evening. In addition, athletes involved with team sports (e.g. football, basketball and soccer) that hold a strength/power training session throughout the day and week are especially susceptible to nutrient deficiencies and performance decrements if proper post exercise nutrition is not followed (12). Whereas the majority of the everyday diet for the strength/power athlete should be a low to moderate GI diet, the post exercise diet should be centered on moderate to high GI sources. This nutritional approach has been found to accelerate glycogen resynthesis as well as promote a more anabolic hormonal state that may speed recovery. The increased protein and glycogen synthesis is believed to be the result of insulin secretion from the pancreas combined with an increase in muscle insulin sensitivity. A strength/power exercise session can have a profound effect on muscle growth only if muscle protein synthesis exceeds muscle protein breakdown. In addition to carbohydrate the amino acid availability is an important regulator of muscle protein metabolism. The interaction of post exercise metabolic processes and increased amino acid availability maximize the stimulation of muscle protein synthesis and results in even greater muscle anabolism than when dietary amino acids are not present. A carbohydrate/protein combination was 38% more effective in stimulating protein synthesis than a protein supplement and more than twice as effective as a carbohydrate supplement. Thus athletes should consume carbohydrate and protein foods/supplements (e.g. ~1g/kg of carbohydrate and 0,5g/kg of protein) within 30 minutes after exercise (3).

Water and electrolyte balance

Being well hydrated is an important consideration for optimal exercise performance. Dehydration (loss of »2% body weight) increases the risk of potentially life-threatening heat injury such as heat stroke, and beyond compromise aerobic exercise and cognitive performance (1, 13).

Daily water balance depends on the net difference between water gain and water loss. Water gain occurs from water intake (liquids and food) and body production (metabolic water), while water losses occur from respiratory, gastrointestinal, renal, and sweat losses. In normal conditions, the volume of metabolic water produced during cellular metabolism is approximately equal to respiratory water losses and gastrointestinal tract losses (1). Kidneys regulate water balance by adjusting urine output (20 to 1000 mL/h). During exercise and heat stress, both glomerular filtration and renal blood flow are markedly reduced, resulting in decreased urine output. Therefore, sweating provides the primary avenue of water loss during exercise-heat stress allowing heat dissipation and the reduction of body temperature (thermoregulation) increased by the physiologic adaptations to muscle contraction. Thermoregulatory mechanisms prevent excessive rises in body temperature. Increased muscular activity during exercise causes an increase in heat production in the body because of the inefficiency of the metabolic reactions that provide energy for muscle force development (13, 14).

Sweat losses are influenced by the duration and intensity of exercise, the environmental conditions, the type of clothing/equipment worn and by many individual characteristics such as body weight, genetic predisposition, heat acclimatization state, and metabolic efficiency. As a result, there is a large range in sweat rates and total sweat losses among individuals and within activities, and in some cases even in the same event on a given day (15).

Body water content and sweat losses

Total body water (TBW) averages ~60% of body mass, with a range from approximately 45 to 75% (1). These differences are primarily due to body composition: fat-free mass is ~70 to 80% water, while adipose tissue is ~10% water (1). Trained athletes have relatively high TBW values by virtue of having a high muscle mass. When assessing an individual's hydration status, there is no one TBW that represents euhydration (normally hydration), and determinations need to be made of body water fluctuations beyond a range that have functional consequences. The use of first morning body weight measurement after voiding, in combination with a measure of urine concentration should allow sufficient sensitivity (low false negative) to detect deviations in fluid balance. Urine specific gravity (USG) of <1.020 is indicative of being euhydrated. For well-hydrated persons the first morning (after urinating) nude body weight will be stable and fluctuate by ~1% (15)

Acute changes in body weight during exercise can be used to calculate sweating rates and perturbations in hydration status. This approach assumes that 1 mL of sweat loss represents a 1g loss in body weight (i.e., specific gravity of sweat is 1.0 g/mL). Sweat rates can range from as little as 0.3 to as much as 2.4 L/h, demonstrating the difficulties in providing a "one size fits all" recommendation. Following the end of exercise, over a protracted period (e.g., 8–24 h), if adequate fluid and electrolytes are consumed, the water losses will usually be fully replaced to reestablish the "normal" TBW (15).

Electrolytes content in sweat

Besides containing water, sweat contains "lost" electrolytes (1). Sweat electrolyte losses depend on the total sweat losses and sweat electrolyte concentrations. Sweat sodium concentration averages ~35 mEq/L and varies depending upon genetic predisposition, diet, sweating rate, and heat acclimatization state. Sweat concentrations of potassium averages 5 mEq/L, calcium 1 mEq/L, magnesium 0.8 mEq/L and chloride 30 mEq/L. Dehydration can increase sweat concentrations of sodium and chloride. Sweat glands reabsorb sodium and chloride, but the ability to reabsorb these electrolytes does not increase proportionally with the sweating rate. As a result, the concentration of sweat sodium and chloride increases as a function of sweating rate. Heat acclimatized individuals usually have lower sweat sodium concentrations for any given sweating rate (15).

Hydration and exercise

Considering the importance of being well hydrated to avoid health risks and optimize athletic performance and the numerous variables which affect sweating rate and composition, for correct recommendations we referred to the American College of Sports Medicine (ACSM) position stand, though considering as best practice for the athletes to learn to assess their hydration needs and develop a personalized hydration strategy (13).

Hydration before exercise

Because even mild dehydration has debilitating effects on exercise performance, some athletes attempt hyperhydration (greater than normal body water content) by drinking large amounts of fluid (approximately 5–7 mL/kg body weight of water or a sport beverage) immediately before exercise in the hopes of improving thermoregulation by expanding blood volume and thereby improving heat dissipation and exercise performance. However, several findings on this strategy provide no clear physiologic or performance advantage over euhydration and we therefore discourage this practice. Instead, drink the same volume of fluid about 4 h before exercise. This will allow enough time to optimize hydration status and for excretion of any excess fluid as urine (13).

Hydration during exercise

Athletes dissipate heat produced during physical activity by radiation, conduction, convection, and vaporization of water (1). In hot, dry environments, evaporation accounts for more than 80% of metabolic heat loss. The intent of drinking during exercise is to avert a water deficit in excess of 2% of body weight. The amount and rate of fluid replacement is dependent on the individual athlete's sweat rate, exercise duration, and opportunities to drink should not depend on thirst to prompt them to drink because people do not typically get thirsty until they have lost a significant amount of fluid through sweat. Consumption of beverages containing electrolytes and carbohydrates can help sustain fluid and electrolyte balance and improve endurance exercise performance (14). Fluids containing sodium and potassium help replace sweat electrolyte losses, whereas sodium stimulates thirst and fluid retention and carbohydrates provide energy. Fluid balance during exercise is not always possible because maximal sweat rates exceed maximal gastric emptying rates that in turn limit fluid absorption, and most often, rates of fluid ingestion by athletes during exercise fall short of amounts that can be emptied from the stomach and absorbed by the gut (14). Commercially available sports drink with 4-8% of carbohydrates and 10-25 mEq/L promote effective rehydration during exercise (especially for events lasting longer than 1 h) and simultaneously deliver an additional source of fuel for muscle and brain (2, 13). The optimal rate of fluid ingestion during exercise is unknown; authors suggest 400-1000 ml per hour, however this should be individualized through monitoring and practice (2, 13).

Effect of fluid and electrolytes loss

Exercise-induced dehydration develops because of fluid losses that exceed fluid intake. Although some individuals begin exercise euhydrated and dehydrate over an extended duration, athletes in some sports might start training or competing in a semi-dehydrated state because the interval between exercise sessions is inadequate for full rehydration. Another factor that may predispose an athlete to dehydration is "making weight" as a prerequisite for a specific sport or event (8, 13).

The risk for dehydration and heat injury increases dramatically in hot, humid environments. When the ambient temperature exceeds body temperature, heat cannot be dissipated by radiation. Moreover, the potential to dissipate heat by evaporation of sweat is substantially reduced when the relative humidity is high. There is a very high risk of heat illness when temperature and humidity are both high. If competitive events (especially for endurance athletes) occur under these conditions, it is necessary to take every precaution to ensure that athletes are well hydrated, have ample access to fluids, and are monitored for heat-related illness.

It is possible for dehydration to occur in cool or cold weather. Factors contributing to dehydration in cold environments include respiratory fluid losses and sweat losses that occur when insulated clothing is worn during intense exercise. Dehydration can also occur because of low rates of fluid ingestion. If an athlete is chilled and available fluids are cold, the incentive to drink may be reduced. Finally, removal of multiple layers of clothing to urinate may be inconvenient and difficult for some athletes, especially women, and they may voluntarily limit fluid intake. Respiratory water losses may be as high as 1900 mL/d in men and 850 mL/d in women (1, 3). Total fluid intake at high altitude approaches 3–4 L/d to promote optimal kidney function and maintain urine output of 1.4 L in adults (1, 3).

Exercise-induced dehydration with an electrolyte deficit is associated with skeletal muscle cramps and muscle fatigue and are more common in profuse sweaters who experience large sweat sodium losses.
Hypohydration, a practice of some athletes competing in weight-class sports (i.e., wrestling, boxing, lightweight crew, martial arts, etc.), can occur when athletes dehydrate themselves before beginning a competitive event. Hypohydration can develop by fluid restriction, certain exercise practices, diuretic use, or sauna exposure before an event. In addition, fluid deficits may span workouts for athletes who participate in multiple or prolonged daily sessions of exercise in the heat (13).
Hyponatremia (serum sodium concentration less than 130 mmol/L) can result from prolonged, heavy sweating with failure to replace sodium, or excessive water intake. Hyponatremia is not common but can occur in novice marathoners who run slowly, sweat less, or consume excessive sodium-free water before, during, or after an event. Hyponatremia is associated with symptoms such as confusion, headaches, fatigue and coma (13).

Hydration after exercise
Because many athletes do not consume enough fluids during exercise to balance fluid losses, they complete their exercise session dehydrated to some extent. Given adequate time, intake of normal meals and beverages will restore hydration status by replacing fluids and electrolytes lost during exercise. Rapid and complete recovery from excessive dehydration can be accomplished by drinking at least 450–675 mL of fluid for every pound (0.5 kg) of body weight lost during exercise. Consuming rehydration beverages and salty foods at meals/snacks will help replace fluid and electrolyte losses (1, 13).

Practical messages
Some of the methods outlined above require equipment or expertise that are not available to all athletes. However, there are several simple steps that they can take themselves to identify whether their current hydration practice is appropriate to their needs.
1. Athletes should get into the habit of weighing themselves before and after training sessions of different durations and intensities and in different weather conditions to estimate their sweat losses. Weight loss should generally not exceed about 1–2% of body mass. If more than this has been lost, then they should drink more next time. If body mass loss was less than this, fluid intake was probably greater than was necessary for hydration purposes.
2. If urine volume is small and urine color is darker than usual, fluid intake should be increased.
3. "Salty sweaters" may need drinks with more salt and may need more salt in food when sweat losses are high. Self-assessment of salt losses can be done by wearing a black T-shirt and looking for salt stains on the chest and under the armpits where the sweat has evaporated. High salt losses are a contributing factor in some cases of muscle cramps.

Women, young and elderly athletes

Although general sports nutrition guidelines regarding macronutrient composition, meal timing, and recovery nutrition are applicable to all athletes, there are special needs for subgroups of athletes including youth, women, and the elderly.

Women

Some female athletes have unique nutritional needs because of food influences on their hormonal functions (3). In fact inadequate energy intake, low body fat content and strict training program can cause menstrual irregularities which could result in inadequate bone growth and fracture proneness.
There is enormous pressure on many women to achieve an unre-

alistic body weight and body fat level. This can compromise both short term athletic performance and long term health. Any athlete with menstrual irregularities should treat these as a possible warning sign, and seek professional advice. If there is a need to reduce body fat, this should be done sensibly.

Female triad

The existing interrelationship between nutritional, menstrual and bone disorders is known as the female athlete triad. Menstrual dysfunctions include subclinical ovulatory disorders such as luteal phase deficiency and anovulation, in addition to clinical disorders such as oligomenorrhea and amenorrhea. Bone disorders range from the inability to reach the peak bone mass, a reduction in bone mineral density (osteopenia), and the pathological manifestation known as osteoporosis (3).

It should be considered that physically active and amenorrheic adolescents may not be worried about the long-term risk for osteoporosis, but may be persuaded to change their food intake and load of exercise training when warned against the risks of stress fracture and problems with hypothermia during exercise in cold climates. The first aim of a female athlete diet is to provide the adequate energy intake to allow normal body functions, to sustain training load and to ensure an optimal performance (3).

To reduce the risk of developing a bone disorder, it is advisable for female athletes to pay close attention to their calcium intake. The principal calcium-rich foods are dairy products but they are often eliminated from female diets due to their high fat content. Thus, it may be necessary to take calcium supplements to reach a total daily intake of 1500 mg of elemental calcium. The consumption of 400-800 IU per day of vitamin D may aid calcium absorption and help maintain bone health (17).

Female and iron needs

Female athletes are also at risk of iron deficiency because of increased iron requirements due to menstrual blood losses matched against a smaller intake of food. Iron is required for the formation of oxygen carrying proteins, hemoglobin and myoglobin, and for enzymes involved in energy production (3). Oxygen carrying capacity is essential for endurance exercise as well as normal function of the nervous, behavioral, and immune systems. So iron deficiency can result in a variety of deleterious symptoms, including fatigue exacerbated by exertion, dyspnea, increased lethargy/sleepiness/apathy, poor concentration, moodiness/irritability, increased susceptibility to injury, and complaints of feeling cold (3).

Female athletes should be screened periodically to assess and monitor their iron status. They should be tested not only for hemoglobin levels but also serum ferritin, a more sensitive measure of iron status. If the values are low, improving the diet is the first step in learning to resolve iron deficiency. In particular, they could consume moderate servings of red meats (well-absorbed iron) in 3-5 meals per week, choose iron-fortified cereal products such as breakfast cereals, combine plant and non-meat sources of iron (e.g. legumes, cereals, eggs, green leafy vegetables) with food factors that enhance iron absorption (vitamin C and a factor found in meat/fish/chicken). It is important to remind athletes to add iron slowly to minimize gastro intestinal distress. If an iron supplementation is necessary, the goal could be adding at least 20 additional milligrams of iron per day. Normally, the dietary reference intake for iron is 15 to 18 mg/d, but the recommendation for athletes is at least 18 mg/d for both men and women (17).

Young athletes

Athletes should be encouraged to develop good nutritional habits at an early age. Adolescence is a time marked by an increased independ-

ence in food choice and food preparation. The promise of sporting success may provide strong motivation to develop good dietary practices. Information and the example of good role models may help a young person to develop healthy eating practices in everyday (training) diets as well as the specific preparation for competition.
Young athletes have to eat a wide range of foods and normally they do not need dietary supplements. Good eating practices, involving good choices of foods and drinks, are part of the formula for sporting success, and a healthy life.

Special needs of young athletes
Although many of the sports nutrition principles identified for adults are similar to those for young athletes, there are some important physiological, metabolic, and biomechanical differences (3, 18, 19):

- the growth spurts during childhood and adolescents require additional nutritional support in terms of adequate intake of energy, protein, essential fats and minerals;
- young athletes have a higher metabolic cost of locomotion and preferential fat oxidation during exercise;
- young athletes, particularity children, are at a thermoregulatory disadvantage due to a higher surface area to weight ratio, a slower acclimatization, and lower sweating rate.

Active young people may find difficulties to meet their needs for energy and nutrients when the costs of training and growth are added. For example children's energy requirements per kilogram of body mass during walking and running can be as much as 30% higher than in adults (3).
Furthermore it has to be considered that a negative energy balance may inhibit the production of growth factors typical of normal growth and development such as growth hormone and IGF-1 (3, 18, 19). These hormonal changes could impair normal growth and development of body size. So young athletes should be correctly advised by nutrition professionals about how to reach a proper energy and protein intake, avoid an excessive intake of fat and sugar-rich foods, and ensure adequate vitamin and mineral intake to avoid growth impairments.
Subjects at a particular risk of delayed growth and maturation are athletes aiming to reduce body mass or fat content (20). It often occurs among female athletes involved in sports which esthetics, strength and weight are determining factors. It could result also in amenorrhoea and reduced bone density, with increased risk to develop osteopenia or osteoporosis in adulthood. If a reduction in body mass is required, it should be gradual and not more than 1.5% of body mass each week (19). Changes in body composition should be monitored by qualified personnel in order to assess its effects on health and performance.

Macronutrients
The macronutrient needs for active child and teenagers are higher than their sedentary counterparts mainly because of the increased energy demands of their sports. However, significant differences in calorie needs only exist for very active youth compared to their sedentary peers. In terms of protein requirements, limited data are available for young athletes. In adults, the upper level of protein requirement for athletes is about 2.0 g/kg/day, and it is expected that this amount is also adequate for children and adolescents involved in a regular program of physical activity (3).

Micronutrients
The intake of at least two minerals should be evaluated in the youth population: calcium and iron. Among the multitude of factors responsible for bone mineral accretion, adequate calcium intake, especially during childhood, is critical (3). Athletes who restrict their energy intake may be at particular risk for suboptimal calcium

intake. Although calcium is important for bone mass development in all children, for athletes inadequate calcium intake and low bone mineral content have also been associated with stress fractures. To ensure a correct daily calcium intake level, the diet has to meet energy requirement with at least three servings per day of dairy products and/or other calcium enriched food (3).

Studies show a high percentage of iron deficiency in adolescent athletes, typically in teenage girls. Iron deficiency impairs athletic performance, reducing the capacity of haemoglobin and myoglobin to carry oxygen in the blood and muscles. In order to assess iron deficiency it is important to measure haemoglobin, hematocrit and also total iron binding capacity, serum ferritin, and transferring (3). In case of iron deficiency, young athletes should encourage to increase servings of red meat or fortified iron food weekly.

Fluid intake during exercise

Finally, young athletes should monitor their fluid intake. They should be advised to monitor body mass before and after the exercise to avoid dehydration. During dehydration, young athletes have a faster increase in their internal temperature when compared to adults (3). These findings emphasize the necessity to encourage and monitor fluid intake by children and adolescents during physical exercise. For long-lasting sports activities, especially those over 90 minutes, a sport drink with adequate carbohydrate concentration (6 - 8%) and osmolarity may be used, having as advantage a more pleasant flavor than normal water. Young athletes should be encouraged to drink 150-300 mL every 15-20 minutes during physical activity (3). Bottled drinks should be readily available to facilitate ingestion and be based on individual preference.

Elderly athletes

Aging is accompanied by a progressive loss of skeletal muscle mass and strength, leading to the loss of functional capacity and an increased risk of developing chronic metabolic disease. The age-related loss of skeletal muscle mass is attributed to a disruption in the regulation of skeletal muscle protein turnover, resulting in an imbalance between muscle protein synthesis and degradation. Recent studies suggest that the muscle protein synthetic response to food intake is blunted in the elderly. In addition, glucose intolerance may also play an important role in a reduced post-prandial increase in muscle protein synthesis in elderly people.

Physical activity maintains a similar post-exercise muscle protein synthetic response in the elderly, although it is delayed compared to younger subjects. Resistance type exercise training represents an effective therapeutic strategy to increase skeletal muscle mass and improve functional performance in the elderly.

Calorie and macronutrient needs

Calorie needs are generally considered to be age-dependent with a decrease later on in life (3). Because many elderly individuals have decreases in muscle mass with aging, it is vital that they consume adequate calories, carbohydrate and protein to maintain and eventually rebuild muscle mass. There are no studies that estimate the caloric needs of the athletic elderly; for this, a weekly food recording with a monitoring of body composition could be useful to planning a correct diet strategy (3).

Calculating the energy demands of exercise during aging is another factor that should be considered. Some types of activities (i.e. endurance training) increase the caloric needs more than others (i.e. resistance training), and this has to be taken into account in order to optimize a nutrition strategy for elderly athletes (3).

There has been some controversy regarding the adequacy of the RDA for protein in elderly individuals. Recent studies suggest that the muscle protein synthesis response to the ingestion of smaller, meal-like amounts of amino acids is attenuated and delayed in the elderly compared with young controls (3). Because of this, some data suggest that elderly men and women should consume dietary protein above current recommendations (0.8 g/kg/day) to optimize muscle mass (3). Other studies demonstrate that the attenuated muscle protein synthesis response to food intake in the elderly can, at least partly, be compensated for by increasing certain amino acids content of a meal (i.e. essential amino acids, BCAA, or leucine) with foods or supplements (21, 22). However it's the interactive effects of exercise and nutrient ingestion that produce an anabolic response in muscle.

Micronutrient requirements

Besides protein usefulness to reduce the risk of muscle loss, which could worsen in sarcopenia, there are other nutrient requirements that may change with age. Recommendations for increased calcium, vitamin D, and vitamin E intakes for elderly people have been made (3). With aging a reduction in bone mineral density occurs, which could result in an increased risk of fractures and osteoporosis. Calcium and vitamin D supplements may be useful to counteract the development of these clinical events (3).

Vitamin D has also other healthy effects and its deficiency is widespread among elderly people. It seems to protect from infections, and vitamin D insufficiency is suggested to be a risk factor for chronic inflammatory and various types of autoimmune diseases (3).

Vitamin E, instead, with its antioxidant properties, could reduce free radicals levels, which negatively contribute to all the inflammatory and age related disease (3).

Finally, considering that aging is associated with an increased risk of anaemia and iron deficiency, elderly athletes should try to ingest adequate amounts of iron rich foods (3).

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