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Healthy Athlete's Nutrition

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Abstract. Nutritional science is increasingly seen in sports practice as an instrument capable of influencing the performance, recovery and gene expression of the athlete. Vice versa, the performance itself is able to modify human metabolism and the use of substrates for energy purposes. Since even small changes are important for the athlete, nutritional science must be considered a precision medicine in which standardized protocols apply to the needs of the individual athlete (based on the type of sport, the frequency of training and its intensity, the goals in terms of weight and muscle mass) in order to minimize measurement errors. The study of the baseline composition of the athlete's body is essential to build up a nutritional plan that follows the athlete before, during and after competition, with the aim of optimizing performance and preventing the onset of fatigue. The purpose of this review is to sum up the most recent guidelines, underlining the key points of the current state of art on the best strategies to achieve specific goals in terms of changes or maintenance of body weight, preparing adequately the athlete for competition and encouraging recovery, with a brief mention to the psycho-behavioural dimension that nutrition acquires in sports practice.
Key words: *athletes, body composition, completion, recovery.*

Introduction

Nutrition significantly influences athletic performance. A specific nutritional strategy should be adopted by the athlete before, during and after training and competition to maximise mental and physical performance. This goal can be achieved only under the guidance of qualified professionals who can develop sport-specific nutritional strategies for training, competition and recovery, protecting the athletes from the risk of dangerous practices.
Aim of this review is to sum up all the guidelines and recommendation present in literature in order to provide an easily consultable paper to sport physicians which can help with the management of the topic in clinical practice. A comprehensive literature review has been employed to identify relevant articles on this topic using PubMed as the main database.

Critical role of nutrition in athletes

Type of nutrition influences performance. A primary role of nutrition in the athlete's diet is to support consistent, intensive training by promoting recovery between training sessions. While it is undoubtedly true that recovery is an important element, there is a growing recognition that nutrition has a key role in promoting the adaptations that take place in muscle and other tissues in response to each training session (1).
The increased ability of fat burning that muscles gain thanks to training can be reversed to some extent by feeding a high-CHO diet (2). This may be beneficial when the availability of CHO is limited but is of questionable value in other situations as it will lead to an increased energy cost of exercise.
The pattern of substrate used by the muscle is dictated by the exercise intensity and it changes over time, being modulated by a number of factors including prior diet and exercise, fitness level and environmental conditions (3).

Performance influences nutrition indeed
Increasing aerobic fitness levels as a result of endurance training has a number of cardiovascular and metabolic effects but one of the key adaptations is to increase oxidative capacity of the muscle, in particular oxidation of fatty acids (4). This leads to a shift in the pattern of substrate use in favour of fat oxidation but this means that there will be an increased oxygen requirement at any given power output. If the oxygen supply is limited, it is important to make effective use of the available oxygen and in this sense CHO is a better fuel than fat (5). These are only a few of the various options open to the muscle for providing energy, and they do not operate independently but they are fully integrated. The relative contributions of anaerobic and aerobic energy supply in races differ relative to the duration of exercise.
Nutrition and performance influence body composition and gene expression
The response of protein coding genes to the exercise performed is modulated by the nutrient, metabolic and hormonal environment, and this can be modified by food intake before, during and after training (6). They can modify gene expression and ultimately phenotype via mechanisms that don't involve changes in the fundamental gene sequence (DNA methylation (7), histone modifications (8) and interactions with microRNAs (9)). There is good evidence that feeding a small amount of protein or essential amino acids after a training session can stimulate protein synthesis for up to 24 hours after training (10).
Nutrition in Athletes is a precision medicine
Only small changes have relevance for athletes and standardized protocols to minimize measurements errors are needed (11). Physical assessment and determination in body composition are important tools for sport science practitioner or sports dietician. It's important to use standardized protocols to minimize measurement errors and to consider smallest worthwhile changes that has clinical or practical relevance to an athlete (12). Anthropometric measures include weight, height, body mass index, skin folds, mid-arm muscle circumference, girth and frame size (13). Contributions come also from some instrumental techniques as dual-energy X-ray absorptiometry (DXA) (14), echography, computed axial tomography (CAT), nuclear magnetic resonance (NMR), bioimpedentiometry (15).

Nutrition assessment of individual athlete
The nutritional assessment of an individual athlete, as well as a medical check-up, a musculoskeletal assessment and a psychological assessment, is now routine in many sport organizations (11). Athletes' nutrition needs and goals are not static, but they can change from day to day, within the various components of a macro-cycle, over the season, and over their career. Periodization of training is a key element in the preparation of the modern athlete, and should be reflected in a per iodized approach to nutrition (16). The overall nutritional assessment is subdivided into the dietary assessment, biochemical tests, anthropometric measurements and nutrition-focused physical examination findings. An assessment of dietary intake is not simply an evaluation of what a person eats and drinks. The process may include the collection of social, medical and psychological influences on food choice. The outcomes of nutrition assessment are to identify nutrition-related problems and their probable causes, identifying athletes who require support to restore and maintain nutritional status and monitoring the progress and efficacy of dietary intervention and effects on performance. For individual athlete, this forms the foundation for specific strategies for nutrition intervention that enhance performance and training capacity.
Nutrition focused examination has the purpose to uncover any medical condition or physiological factors that can interfere with food intake, digestion and metabolism such as chronic illness or recent ones, anxiety, depression and some drugs which interfere with absorption of nutrients and thus affect nutritional status.
Biochemical tests are useful to quantify dietary biomarkers which are increasingly used as measures of dietary intake, although they are not always diagnostic of nutrient depletion or deficiency (17). Low blood levels of some micronutrients may reflect low dietary intake, defective absorption, increased utilization or excretion. It must be underlined that population based ranges for biomarkers, although still utilized in many of athlete's evaluations, are inapplicable in strenuous training with high turnover or losses of some nutrients, and need some adjustment. Moreover, a single test is always inadequate in describing a clinical condition and integration with other tests and biomarkers is imperative.
In a contest of cultural and population based evaluation, dietary assessment involves collecting data on food and beverage intakes and then evaluating nutrient, energy or food group intakes against population or athlete reference measures that are age-, gender- and country-specific for the general population.

Methods and reference standards for evaluating food or nutrient intake may need modified when applying to an athlete population (18). Although athlete may have similar eating habits of non-athletes, their requirements for some nutrients and the volume of food consumed is often higher.

The purpose of measuring dietary intakes is determining nutritional status, assessing the links with performance, diet and health status, evaluating nutrition education and intervention, assessing the effect of different dietary regimens on performance measures or metabolic responses, assessing the effect of different training periods or intensities on dietary intake.

Methods for measuring dietary intake are categorized into two main types: current dietary intakes and past dietary intakes. The classical interview-based methods have been modified by innovative technologies into self-reported formats using either interactive computer-based technologies or mobile telephones and devices (19).

For monitoring diet intake in the present, we use household measures, which are suitable for small samples. Digital food record and image-based food record apps are modern technologies which provide a real-time recording, reducing respondent burden of written recording (20). To monitor diet intake in the past the most used tools are 24-hour recall, the food frequency questionnaire (FFQ) and the diet history (21).

Energy requirements of athletes

Athletes of any age must consume enough energy to cover the energy costs of daily living, the energy cost of their sport and the energy costs associated with building and repairing muscle tissue. Females of reproductive age must also cover the costs of menstruation (22), whereas younger athletes must cover the additional costs of growth.

The maintenance of body mass and body composition requires that energy intake equals energy expended and that intakes of protein, carbohydrate (CHO) and fat equal their oxidation rates. (23) Changes in type and amount of macronutrients consumed and the oxidation of these macronutrients within the body must be considered when examining long-term weight maintenance. Increase intakes of non-fat nutrients stimulate their oxidation rates proportionally. Conversely, an increase in dietary fat intake does not immediately stimulate fat oxidation, thus increasing the probability that excess dietary fat will be stored as adipose tissue.

Breakfast must cover 25-30% of the total caloric requirement, lunch 40% of total calories and dinner 25-30% of the total caloric intake (24). Two snacks covering 5% of caloric demand should be included after breakfast and lunch. Considering the total amount of calories requested for a sedentary adult (2000-2800 kcal/day), 55-60% should derive from CHO, 25-30% from fat, 15-20% from protein (24).

Energy balance is the result of energy intake from diet and from stored energy and energy expended. The component of total energy expenditure is divided into basal energy expenditure (or basal metabolic rate, BMR), thermic effect of food (TEF), TEA (a combination of energy expended in planned activity and non-exercise activity thermogenesis) (25).

In athletes, a serious physical injury, the stress associated with an upcoming event, going to a higher altitude, performance or training in extreme environmental temperatures, or the use of certain medications may all increase resting metabolic rate (RMR) above normal levels (26).

Since fat-free mass (FFM), especially organ tissue, is very metabolically active, any change in FFM can dramatically influence RMR. There are number of ways that exercise might indirectly or directly change RMR (27). First, exercise may increase RMR indirectly by increasing an individual's FFM, which is strong determinant of RMR (28).

It is well documented that active individuals, especially elite athletes, are leaner (lower percentage body fat) and have greater FFM than their sedentary counterparts. For a given body mass, an athlete with a lower percentage of body fat and higher percentage of FFM will have higher RMR.

It has also been hypothesised that exercise training influences RMR, depending on level of fitness, type of exercise training program, methods used to measure RMR, and level of energy flux (29). Strenuous exercise may cause muscle tissue damage that requires building and repair after exercise is over, thus indirectly causing an increase in RMR. RMR is increased for a period of time (minutes or hours) after strenuous exercise, determining a phenomenon called excess post-exercise oxygen consumption (EPOC). If the exercise intensity is high and/or the duration of exercise is long enough, EPOC appears to be elevated for hours after exercise (30).

The purpose of measuring energy expenditure in the athlete is to estimate energy requirements, average daily energy expenditure (EE), assess variation in total daily EE between training, competition and rest/recovery,

modify body composition, determine energy cost of specific activities, assess sleep patterns (31). The method of assessment it must be sport-specific and feasible (predictive equations, metabolic cart in a laboratory for a cyclist completing a time trial, portable indirect calorimetry systems, heart rate monitors, accelerometers, global position systems, motion sensor technology) (32).
Suggested daily requirements of CHO for adult athletes are 6-10g/kg weight (50-50% of the total caloric demand) (24). The amount of CHO depends on the type of physical activity performed (endurance athletes need higher amount of CHO when compared to individuals who enjoy resistance training), daily expenditure, gender, environmental condition. Glucose represents the most chosen fuel source when compared with fructose and galactose. Maltodextrin, however, should be preferred as they provide a better and more continuative fuel of energy thanks to their longer absorption time.
The optimal protein intake, defined as one that maximally stimulates muscle protein synthesis yet minimally increases amino acid oxidation, is currently at 20-25 g in average weight athletes (or the equivalent of 0,25 g/kg), a level not so different from what is required in rested skeletal muscle (33).
Lipid intake should not exceed 30% of the energy value of the food. For athletes, lipid requirements are sport related, ranging between 1.5g / kg / 24hours and 2,3 g/kg/24hours for athletes who practice activities that take place in an environment with a low temperature (24).
Endurance strenuous training or athletes with a large BMI need higher intakes of micronutrients than suggested by population EAR values. A slight increase in some micronutrient is required for athletes involved in strenuous endurance training, to compensate for high nutrient turnover and increases in free radical formation induced by exercise. Evidence for slightly higher macronutrient requirements (protein and CHO) for endurance athletes compared to non-athletes is well documented (34). However, athletes involved in less rigorous training programs or those involved in intermittent training, such as in team sports, are unlikely to need the upper limit of recommended nutrient values for CHO, protein and iron.

Weight changes in athletes
As in the general population, even in athletes, the distribution and amount of fat mass is influenced by genetic and environmental factors as well as the training schedule, the sport and any attempt at weight control or reduction (35, 36). Genetic factors influence not only body fatness and body composition in a proportion between 50 and 90% but also dietary intake and food preferences (37).
Body weight tends to remain stable in many people for a long time, despite varying food intake and energy expenditure, a situation also known as the set point theory: body weight seems to be regulated by a series of set points for an individual during his life.
Reductions and increases in weight away from the current baseline or set point result in metabolic alterations that resist the maintenance of a new weight and promote weight loss or gain towards the set point (38). This can explain why is more difficult for an underweight person to maintain gain loss and for an overweight one to maintain weight loss (39).
Athletes are, to some extent, protected from excess gains in fat mass because of high energy expenditure and gains in lean body mass (LBM) that result from resistance training programs (40). Aerobic exercise causes an increase in LBM and mitochondrial density (41) which leads to increase in metabolic rate and energy metabolism to hence energy expenditure (42). Despite these adaptations, some athletes still gain an inappropriate amount of body weight and fat mass and need to limit energy intake to reach desired levels of leanness. Regardless of the approach used, an energy deficit is still required for body weight or fat to be lost (43). Nevertheless, a caloric restricted diet needs to meet nutrient requirements and provide enough energy to recover for the next training session: it is fundamental to ensure an appropriate level of restriction which does not compromise LBM or cause the disruption of endocrine and immune function (18). Proteins, rather than CHO, seem to be the most critical macronutrient to provide dietary fat mass loss (44).
In fact, human body requires mainly protein and seams that fat and CHO consumption is driven by the need of minimal amount of protein (the *protein-leverage effect*) (45). It is theoretically possible that the increased protein requirements of elite athletes further influence this over-consumption behaviour (this can explain why some athletes and the general population often overeat).
As many of the most accessible snack are build up in order to be a small resource of high density energy foods and are enriched in CHO and have low fat content, the convenience of these foods promotes regular possibly over-consumption, which may result in excess energy intake and a positive energy balance (46).
It has been recorded that some athletes eat too much food to reward themselves or compensate particularly after a hard exercise session. The energy content of food consumed (usually CHO-rich foods) after exercise

results in partial, complete and even overcompensation of the energy expended before, which helps to promote weight gain (47). Women seem to be more susceptible to this behaviour probably thanks also to the baseline body fat levels and potential hormones influences on basal metabolic rate. Cold environments of training stimulate more intake of food after exercise then warm or hot ones (48).

There are a number of possible explanations for an athlete's ability to maintain body mass despite the discrepancy between reported energy intake and energy expenditure (the so called energy efficiency). This discrepancy may be due to inaccuracies in reported estimates of energy expenditure or energy intakes, particularly due to athlete's under-reporting or under-consuming their usual intake during the period of monitoring (49). Moreover, active individuals become more sedentary during non-exercising portions of the day, thus expending less energy than estimated (50). These differences may be due to increased metabolic efficiency, which, if present, causes actual energy requirements of these athletes lower than those estimated by traditional means and would partially explain their ability to maintain body weight despite a seemingly low energy intake. Thus they may expend less energy at rest, while performing various daily tasks and during exercise than those whose energy intake appears adequate.

The amount of energy expended during exercise depends on characteristics of the individual athlete and the type of exercise performed (51). A large body mass expends more energy to perform weight-bearing activities than a small body mass. However, a trained athlete, particularly in skill-based sports and to a lesser extent in weight-based sports, uses less energy because of improved efficiency.

Exercise intensity in particular affects the magnitude of the post exercise elevation in metabolic rate: post exercise energy expenditure may be significantly elevated in athletes who perform high-intensity, long-duration exercise, even though this component of expenditure is considered to be trivial for most non-athletes (52). (53).

Eating behaviour are important determinants in the maintenance of desired body weight and in many athletes who tend to have regimented lifestyle that revolve around training and competition schedules, food is often used as reward. For some athletes, pressure to perform or achieve a particular body mass results in a rebellion against a dietary regimen designed to control body composition; in other ones, obsession with weight loss may result in disordered eating behaviours, which can lead to eating disorders.

In the "female athlete triad" (which describes a condition in which clinical, metabolic and behavioural conditions all together are associated in women who practice high-level sports), energy deficiency impairs reproductive system and skeletal health (54). The particular type of energy deficiency in the triad is low energy availability; the particular type of reproductive disorder is functional hypothalamic menstrual disorders; and the particular type of skeletal impairment is the uncoupling of bone turnover, with an increased rate of bone resorption and a reduced rate of bone formation. In a minor proportion, this condition can also involve men, with gender specific clinical expression.

Tapered training to facilitate physical recovery and restoration of fuel reserves may result in a substantial reduction in energy expenditure and increase the risk for loss of LBM and an increase in fat mass (55). Gaining weight during tapering are reported in different groups of athlete, of course with a consistent part of genetic predisposition to regulate this phenomenon (56).

Body composition assessment using skinfold measurements (13), validation of euhydration with urine specific gravity (57) and diet records (21) can be part of the assessment used by professionals to develop a goal weight and strategy for change. Regular monitoring of health and performance of the athlete will help in making decisions to adjust the weight-loss plan.

Weight loss in athletes is generally motivated by a desire either to achieve a pre-designated weight to compete in a specific weight class or category or a specific body composition to improve performance by optimizing power to weight ratio. Moreover, in some sports, such as synchronized swimming, ice-skating, dance, floor gymnastic, the aesthetic aspect is very important. Adding to these performance issues, current social trends encourage the pursuit of leanness for both men and women (36).

In a society where physical attractiveness is used for promotion or advertising, the preoccupation with body weight and fat levels is increasing, although there is limited evidence of the effect of body composition on performance. In addition, the reduction of fat mass to extremely low levels may not actually benefit performance per se. In fact, when energy availability falls below 30 kcal/kg of fat free mass/d during a too much restrictive diet scheme, several adverse effects occur, at least in women (58).

Reduction in metabolic rate, lowered sex hormone levels (in both men and women), compromised immune function and bone health, decreased protein synthesis and possible electrolyte imbalance as well as

depression and disordered eating are possible outcomes, some of them not reversible when energy intake is normalised.
Nevertheless, many coaches are persuaded that the trained eye component influences the score attributed by the judges.
Guidelines for a safe rate of weight loss are around 0,5-1kg/week, not only in general population but also for most of the athletes (59). This goal can be reached through a 500 to 1000kcal/d energy deficit, which can be achieved by diet, exercise or both (60). Moderate energy restriction without compromising CHO or nutrient intake is optimal and best achieved with a diet low in fat (15-25% of energy), with adequate CHO intake to support daily training or competition requirements. Protein intake should be approximately 1,5-2 g / kg body mass/d with the upper level recommended if energy restriction is substantial (61). Foods high in fibres and / or low glycaemic index may assist with appetite control. Calcium intake at or above the RDA/RDI, ideally from dairy foods, may also assist with weight control. Higher intensity exercise maintained for a reasonable duration (30-60 min/d), in addition to an athlete's standard training, are useful and the best approach for well-trained individuals.
Exercise prescription however should be tailored to the athlete's individual needs. There are many diet schemes and regimen recommended to weight and fat loss targeted at the general population (usually obese). Some of them can be suitable and effective also for the athlete who wants to reach a desired lean body composition.
Ad libitum low fat diet produces a satisfactory result in athletes who have long-term, modest weight or fat-reduction goals. Bearing in mind optimization of nutrient intake and prevention of low energy availability (with all of its consequences), it is recommended a restriction of maximum 500 kcal from theoretical requirements or, to obtain a sudden energy deficit, gradual energy reduction of 10% to 20% of total energy requirements (62).
Low energy-density nutrient-rich foods diet is an approach based on the use of compacter low volume food, which might be perceived as not satisfactory, leading to over consumption effect (46).
Intermittent fasting is a scheme developed to face the challenging experience of a chronic energy restriction, too often perceived as difficult to maintain by many individuals (63). It involves normal eating and fasting from 1 to several days. The normal eating day is termed as feed day, where usual food choices can be consumed ad libitum for a prescribed period, followed by 1 to 4 days of fasting, where food intake is either completely or partially reduced. Some studied showed lower losses of LBM from intermittent energy restriction than from chronic one, which is a potential positive finding. In athletes, although it has not been studied, theoretically, this approach in counterproductive to maintaining adequate glycogen reserves for the type of training programs undertaken. Studies on Muslim athletes fasting during a 1-month period of Ramadan however, even with complaint for fatigue, show minimal adverse physiological or performance effects (64).
The zone diet is a reduced-carbohydrate diet based on a specific macronutrient distribution of 40% of energy from CHO, 30% from protein, 30% from fat from each meal and snack. In practice most meals and snack foods do not comply with this ratio of macronutrients, which is moreover quiet different to the ideal diet recommended for training. The popularity of this diet, although thanks to the energy restriction lead the followers to lose weight, has diminished (65).
The Atkins diet is a rigorous low CHO diet not energy restricted, providing only 30g CHO/d and unlimited quantities of high-protein/high-fat foods (66). It induces ketosis which is considered critical to promote weight loss and to assist with appetite control. The higher rate of short-term weight loss on a low-CHO diet has been related to high satiety, increased thermogenesis and hence slightly increased energy expenditure. A reduction in glycaemic load may also contribute. Practically, it is more the compliance to the diet than ketosis the most effective element of the weight loss trough this diet. Because it is known that restricting CHO leads to catabolization of endogenous proteins to maintain glucose homeostasis, this would be counterproductive in athletes, causing the reduction of LBM resulting in a potential loss of power and strength. It has been demonstrated that, if a low CHO-diet is compensated with a high intake of protein, retention of LBM is enhanced (typically for the athletes none low CHO diet reach the level of CHO reduction of the Atkins one). In athletes, low-CHO, high-protein, Atkins-like diets are effective for short-term weight loss but in chronic cause glycogen depletion and fatigue, delayed recovery and possibly a LMB reduction with impaired immune function. For this reason, it is not recommended.
The Paleo diet for athletes, not energy restricted, recommends avoidance of grains, dairy foods, and legumes in favour of lean meats, fish, non-starchy fruits and vegetables with a macronutrient ratio of 35-45% of

energy from CHO, 19-35% from protein and the remaining energy from fat, particularly saturated and mono-saturated fatty acids. For athletes it is recommended the addition of more CHO foods before, during and after exercise, and limited consumption of bread, pasta, rice, starchy vegetables and dried fruit (67). During exercise, intake of high glycaemic index foods (including sports drinks) and electrolyte replacement is included. The high satiety value of the large meat serve of this diet helps followers lose weight by minimising hunger, and consequentially eating less foods and calories but if the athlete does not compensate with extra amounts of CHO-rich foods, the loss of weight may be excessive and too rapid to support energy requirements of training and conserve LBM.

For athletes who need chronically to restrict energy intake to maintain a low body mass for their sports and for hungry ones, low-glycaemic index diets are recommended thanks to the positive effect on satiety, although the effects on weight loss are small. Moreover, they do not have the negative health effects of CHO restriction. More studies must be performed to understand effect on glycogen storeging and performance in athletes (68).

High calcium intake, as in high diary diets, seems to be inversely related to BMI, body fat and obesity although no changes in body composition have been reported.

Adjunctive agents for weight and fat loss are dietary supplements and pharmacological agents/drugs (developed to alter weight for short-term, medium-term and long-term use; most of them are not permitted by the World Anti-Doping Agency and should be used only in the appropriate situation under medical supervision) (69).

Athletes competing in weight-category sports are highly motivated to lose weight acutely prior to weight-in to avoid disqualification that occurs if even slightly higher than category allows. However, to meet competition weight class, athletes may practice extreme weight-loss methods to achieve rapid weight loss, hoping to recover between the weigh-in and the competition, and compete with an advantage over a smaller opponent. Others may be chronically dieting throughout the season to maintain a weight close to their competitive weight class. The most popular weight loss methods among sports such as martial arts (70), wrestling, boxe and similiars (71) of losing excess weight are food restriction, fluid restriction, increased exercise, dehydration (saunas and exercising in vapour-impermeable suits), laxatives. Appetite suppressant and other drugs (diuretics, laxatives, smoking) are the methods preferred as well as extended fasting and skipping meals, chronic low-energy intakes, restrictive diets (72). This weight-cycling practices are associated with an elevated rate of bone loss and reduced bone mass (73). Moreover, many athletes tend to binge eating after races and engage in these extreme last-minute weight-loss measures (74). These methods of malnutrition increase the risk of dehydration and reduced aerobic capacity leading to impairment of performance or health.

Dehydration is one of the most popular method to rapidly lose weight before the weight –in but the risk of heat injury is high. Indeed, it can decrease plasma volume reducing the amount of fluid available for sweat loss and hence cooling. Sweating significantly increased loss of electrolytes while reduction in fluid intake does not produce the same effect, and it is even easier the rehydration after weigh-in (75).

The rate and magnitude of weight loss in the short- and long-term, the frequency of food intake and the amount of protein intake consumed while losing weight can inhibit protein synthesis and reduce LBM and potentially muscle growth (76). Useful methods which help to minimize loss of LBM are the slow loss of weight combined with strength program, higher number of meals during the day, the reduce number of weight-cycling and the doubling of RDA protein intake during energy restriction (77).

Depending on experience and the rate and magnitude of acute weight loss, athletes are at risk of experiencing adverse effects on mood and motor function and decreased capacity for performing mental tasks during periods of weight loss and potentially at competition (78). Training can be affected, which can result into poor motivation and quality of workout.

Self-determined weight loss studies reported a perception of impairment in performance after weight loss over the sportive season and a decrease in muscle strength, speed, agility and concentration. The detrimental effect of dehydration on aerobic performance is well documented (79), while effect on muscle power, strength and agility is less clear (80). Adding energy restriction to dehydration, or dieting alone, appears more consistent in causing impairment of muscle performance and the magnitude of energy restriction and rapidity of weight loss negatively impact high-intensity performance. However, athletes can apparently recover if sufficient time is provided. A high-CHO diet in wrestlers has shown the maintenance of high power-performance when compared to modest consumption of CHO diet for weight loss (81).

Many athletes are aware that weight loss has adverse effects on performance but assume that they can recover in time for competition, however the recovery time may be longer than expected. In fact, recovery of fluids lost through dehydration may take 24-48 hours (75) and the most effective way to restore fluid balance includes an intake of fluid equivalent to 125-150% of the fluid deficit, together with replacement of lost electrolytes, principally sodium; reduction of glycogen storage secondary to weight loss can be overcome with time and adequate CHO intake, however recovery may not be realistically achieved between weight-in and the start of competition. A high CHO-diet during recovery from energy restriction can prevent the impairment of performance due to loss in muscle and liver glycogen (82).

Preparation for competition

A variety of nutritional factors can reduce an athlete's ability to perform at their best during exercise. The risk and severity depends on issues including the duration and intensity of the exercise involved; environmental conditions, for example temperature and humidity; training status of the athlete; individual characteristics of the athlete; success of nutrition strategies before and during the event.

"Competition eating" is based on the principle of implementing nutrition strategies that can reduce or delay the onset of factors (such as depletion of glycogen stores in the active muscle, hypoglycaemia, other mechanisms involving neurotransmitters, dehydration, hyponatraemia, gastrointestinal discomfort and upset) that cause fatigue or performance impairment. These strategies are undertaken before, during and in the recovery from the event. Pre-competition nutritional strategies include dietary interventions that are implemented during the week prior to an event, as well as special tactics that are undertaken in the minutes or hours before the event begins. According to the characteristics of the event, strategies might aim to minimise fluid deficits, ensure fuel availability or prevent gastrointestinal discomfort. A combination of strategies seems to be superior in optimizing performance.

Pre-event fuelling

The depletion of body CHO stores is a major cause of fatigue during exercise. Optimising CHO status in the muscle and liver is a primary goal of competition preparation. In the absence of muscle damage, muscle glycogen stores can be normalised by 24 hours of rest and an adequate CHO intake: up to 7-10g/kg body mass (BM) per day (83). Such stores appear adequate for the muscle fuel needs of events less than 60-90 minutes in duration (84). The athlete should take part of a day of rest or light training before the event while continuing to follow high-CHO eating patterns. For events lasting more than 90 minutes, it is essential to take glycogen muscle stores to 150-250 mmol/kg wet weight (ww) (84). For well-trained athletes at least, CHO loading may be seen as an extension of "fuelling up" (rest and high CHO intake) over 3-4 days (85). The modified loading protocol offers a more practical strategy for competition preparation, by avoiding the fatigue and complexity of extreme diet and training requirements associated with the previous depletion phase. Super compensation of glycogen stores is beneficial for the performance of exercise of greater than 90 minutes' duration, and when tested for running or cycling it shows a postposition of fatigue and extension of duration of steady state exercise by 20%, improving performance over a set distance or workload by 2-3% (86). Shorter events do not show significant performance benefits from CHO loading. Endurance-training individuals, who already practice high-CHO eating strategies, may only need an additional day of CHO loading at 10-13g/kg/d to achieve their goals, while a novice runner may best consider a 3-day CHO load (87). The goals of the pre-event meal (1-4 hours pre-event) (88) are listed in Table 1.

Table 1. The pre-event meal goals

Goals of the pre-event meal
Continue to fuel muscle glycogen stores if they have not fully restored or loaded since the last exercise session.
Restore liver glycogen content, especially for events undertaken in the morning where liver stores are depleted from an overnight fast.
Ensure that the athlete is well hydrated
Prevent hunger, yet avoid the gastrointestinal discomfort and upset often experienced during exercise
Include foods and practices that are important to the athlete's psychology or superstitions.

The meal menu should include CHO-rich foods and drinks (4g glucose/kg body weight is the suggested load pre-event), preferring low-fat, low-fibre and low-moderate protein content: if consumed 4 hours before exercise, it significantly increases the glycogen content of muscle and liver depleted by previous exercise or overnight fast (89). If the event occurs after 1 hour, it is suggested a CHO intake of 1 g /kg body weight, while if the competition starts 2 hours after the meal, the athlete can consume even 2 g/kg body weight of CHO. The issue of CHO intake prior to exercise is not straightforward. The elevation of plasma insulin concentrations following pre-exercise CHO feedings could be a potential disadvantage to exercise metabolism and performance. A rise in insulin suppresses lipolysis and fat utilisation, concomitantly accelerating CHO oxidation and causing a decline in plasma glucose concentrations at the onset of exercise. However, such metabolic perturbations do not appear detrimental to performance.

Many studies showed that pre-exercise low-GI, CHO-rich meals generally achieve a lower post-prandial blood glucose response and a more sustained metabolic response throughout exercise compared to high-GI, CHO-rich foods (90). Although there are some conflicts in showing effect on glycogen utilisation during exercise, the greatest conflicts in the pre-event menu debate refer to the effect on exercise performance. Some studies have reported that a low-GI meal before exercise enhances exercise capacity or performance compared with high-GI CHOs (91) (92). Other studies have failed to find benefits from the consumption of a low-GI pre-event meal even when metabolism was altered throughout the exercise (93) (94). A central issue that is overlooked in the debate is the overall importance of pre-exercise feedings in determining CHO availability during prolonged exercise. In endurance exercise events, a typical and effective strategy used by athletes to promote CHO availability is to ingest CHO-rich drinks or foods during the event.

Special attention is needed to ensure full restoration of fluid balance after previous exercise bouts, particularly if unusually large fluid losses have occurred, for example to “make-weight” in weight-category sports.

Pre-exercise hydration and hyperhydration. It is generally recommended that athletes consume 5-7 mL of fluid per kg of body mass about 4 hours before exercise and, if urine colour is dark, consume additional 3-5 mL of fluid per kg of body mass in the final 2 hours.

“Fluid overloading” can be a consequence of strategies applied to reduce the total fluid deficit incurred. It may have detrimental effect on performance if it causes urge to urinate immediately before or in the early stages of the event. The discomfort of the excess fluid in the gut has also shown to impair performance of moderate-high intensity exercise (95). To excess levels, it may lead to hyponatraemia. One study demonstrated that in the heat, a superior level of hydration status increases heat tolerance and enhanced duration of work in the heat, allowed achievement of maximal aerobic workload at a lower heart rate and improved performance (96). A method of hyperhydration under current study involves the consumption of a small amount of glycerol (1-1,2 g/kg BM) along with a large fluid bolus (25-35 mL/kg) in the hours prior to exercise. Within the body, glycerol is evenly distributed throughout fluid compartments and exerts an osmotic pressure. When consumed orally, it is rapidly absorbed and distributed among body fluid compartments before being slowly metabolised via the liver and kidneys. This allows a fluid expansion or retention of 600 mL above a fluid bolus alone, by reducing urinary volume (97). In some studies, this protocol has been associated with performance benefits (98). Some athletes, however, experiment nausea, gastrointestinal distress and headaches resulting from increased intracranial pressure. At the present, however, World Anti-Doping Agency (WADA), from 2010, included glycerol within its examples of banned plasma expanders, setting a threshold for urinary glycerol at 1,3 mg/mL, rendering its use not available for athletes who are competing under WADA-linked anti-doping code. Another protocol that enhance fluid status prior to exercise is the consumption of high sodium beverage.

As a general rule, most athletes can tolerate a bolus of about 5 mL/kg BM (300-400 mL) of fluid immediately before the event starts, providing a useful start to fluid intake tactics during exercise.

Nutrition for performance

When choosing foods and fluids to be consumed during competition, there is no need to take into account long-term nutritional goals: the main intentions are performance optimization and prevention of fatigue.

Although the beneficial effect of CHO ingestion on performance are well known for a range of endurance as well as intermittent activities, new areas of applications are prevention of muscular fatigue (99), maintenance

of power output but also motor skills, cognition and motor output. Intakes of fluids and fuel during competition integrates with pre-competition nutritional strategies to maximise performance and delay fatigue. There are two types of fatigue: one coming entirely from the central nervous system (CNS) and the other one in which fatigue of the muscle themselves is superadded to that of the nervous system (100). In hot environments, however, fatigue occurs while substantial CHO stores remain, and performance is limited more by factors associated with thermoregulatory function and hydration status (101).
How does CHO supplementation during exercise work? During exercise of at least 2 hours, CHO feeding will prevent or delay hypoglycaemia, maintain high rate of CHO oxidation and increase endurance capacity compared with placebo ingestion (102). During shorter duration, CHO ingestion can also improve exercise performance but the mechanism behind this result is completely different (103). Thus, the contribution of CHO to energy metabolism increases with increasing exercise intensity but falls with increasing duration at a constant intensity.
The intake of CHO and fluid offers benefits to the performance of a number of sports events and exercise activities. It depends, of course, on the goals of the individual, the nature and duration of the event, the climatic conditions, the pre-event nutritional status, and the physiological and biochemical characteristics of the individual. The effects of dehydration include subtle, but often important, decrements in performance at low levels of fluid deficit to the severe health risks associated with substantial fluid losses during exercise in the heat (104).
The American College of Sports Medicine recommends that athletes take between 30 and 60 g of CHO during endurance exercise (>1 h) or 0,7 g /kg/h (105). The upper limit is determined by the observation that taking in more CHO does not result in greater use by the muscle; the lower rate is a reflection of studies that demonstrated performance benefits with lower rates of CHO intakes. It is not necessary to ingest large amounts of CHO during exercise that lasts approximately 30 minutes or less than 1 hour. For high intensity intermittent-pattern activities, the refuel should include not only liquids, minerals and CHO but also lipids which, in this situations, are catabolized in order to favour the activation of adrenaline, noradrenaline, glucagon and growth hormone (GH). During the final hours of endurance performances (after 2 hour) of longer duration, such as marathon or cross-country skiing, the inclusion of protein can be useful to avoid muscle mass catabolization and the onset of fatigue.
Of course the opportunity to eat or drink during an event and the possible subsequent gastrointestinal discomfort are strong conditioning factors for CHO and fluid intake during exercise.
It is a matter of common experience that the perception of effort is increased, and exercise capacity reduced, in hot climates. When environmental temperature is higher than the skin temperature, the only way to lose the heat surplus is by evaporation from skin surface and respiratory tract (106). However, some individuals sweat at rates that are higher than maximum evaporative capacity, which is determined by the skin. Water losses come from plasma, extracellular and intracellular water. Any decrease in plasma volume impacts negatively on thermal regulation and exercise capacity. Increases in core temperature and heart rate during prolonged exercise are graded according to the level of hypohydration achieved (107). Oral fluid intakes during exercise can improve thermoregulatory capacity, independent of increases in the circulating blood volume. Hypohydration impairs only aerobic performance in warm-hot environments, not only endurance training but also high-intensity exercise. A loss of 2% in weight leads to a reduced thermoregulation and exercise performance; a loss of 5% makes cramps appear; with 7% loss hallucinations and coma arrive; death occurs with a 20% of loss (108). The sweat loss that accompanies prolonged exercise leads not only to a loss of water but also of electrolytes (sodium and chloride are the major ones lost) (109).
As well as providing an energy substrate for the working muscles, the addition of CHO to ingested drinks will promote water absorption in the small intestine.
The amount and types of CHO present in a drink will influence its efficacy when consumed during exercise. The optimum concentration of CHO to be added to a sports drink will depend on individual circumstances. High CHO concentrations will delay gastric emptying, thus reducing the amount of fluid that is available for absorption, but will increase the rate of CHO delivery (110). If the concentration is high enough to result in a markedly hypertonic solution, net secretion of water into the intestine will result, and this will actually increase the danger of dehydration. It may also lead to gastrointestinal disturbances (111). Dilute glucose-electrolyte solutions may also be as effective, or even more effective, in improving performance in some exercise scenarios as more concentrated solutions (110), and adding as little as 90 mmol/L glucose may improve endurance performance (112).

Although most of the popular sports drinks are formulated to have an osmolality close to that of body fluids, and are promoted as isotonic drinks, there is good evidence that hypotonic solutions are more effective when rapid rehydration is desired (113). Also the temperature at which drinks are ingested impacts on performance: pre-exercise cooling by ingestion of cold or iced drinks can improve endurance performance in conditions of heat stress, by delaying the time until a critical elevation of core temperature occurs (114).
To assess pre-exercise hydration status, urine markers, especially colour and osmolality, can be used. It might be more appropriate to advise athletes to monitor their body mass losses during training or competition, and to drink sufficient to restrict body mass loss to not more than 1-2 % of the initial value (115).

Nutritional strategies for recovery

Post-exercise nutrition should be individualized and periodized within an athlete's program. The aims of recovery nutritional strategies are the restoration of body losses/changes caused by the first session to restore performance levels for the next and the promotion of adaptive responses to the stress/stimulus provided by the session to gradually make the body become better at the features of exercise that are important for performance.
While goals of restoration and adaptation often overlap, or at least the strategies used to achieve one goal often also promote the other, several new themes have emerged in sports nutrition: better adaptation to an exercise stimulus might be achieved by contradicting the practices used to promote restoration (116). A new concept is "train low", which explores the hypothesis that greater adaptation to the same training stimulus can be achieved when the physiological/biochemical environment is not optimal (117).
It is generally accepted that optimal adaptation to repeated days of heavy endurance training requires a diet that replenishes muscle glycogen reserves. However, it has been found that when exercise is undertaken with low muscle glycogen content, the transcription of a number of genes involved in training adaptations is enhanced. In fact, exercising with low muscle glycogen stores amplifies the activation of a number of signaling proteins, including the AMP-activated protein kinase (AMPK) and the p38 mitogen-activated protein kinase (MAPK). These two enzymes have direct roles in controlling the expression and activity of several transcription factors involved in mitochondrial biogenesis and other training adaptations (118). Thus, athletes who deliberately train in a glycogen-depleted state ("train low") are able to maximize physiological adaptations to endurance training. This concept not only can be applied in CHO availability, but also in other areas, such as deliberately training with a fluid deficit to accelerate the processes underpinning acclimation to exercise in hot weather.
Another scenario regards the idea that some of the "damaging" processes that occur during exercise might be important in creating cellular signals for the processes that promote adaptive remodelling; this seems to be directed to the oxidative damage or inflammatory responses to exercise. Thus, a strategy that acutely addresses this damage may assist the body to restore its original function more quickly, it may also switch off processes that promote longer term adaptations to gradually enhance original function. Antioxidant and anti-inflammatory chemicals/nutrients show benefits only when used acutely to achieve a short-term recovery need; thus, their chronic use can interfere with the optimal response to a training program, leading to a reduced adaptation and to an impairment of performance (119).
All of these strategies need to address the degree to which restoration of homeostasis or promotion of adaptation from the specific session relies on: restoration of muscle and liver glycogen stores ("refuelling"); replacement of the fluid and electrolytes lost in sweat ("rehydration"); protein synthesis for repair and adaptation ("rebuilding"); responses of other systems such as the immune, inflammatory and antioxidant systems.
Obviously, each recovery nutrition plan needs to be organised to integrate the athlete's overall nutritional goals, integrated when it takes part of a long-term nutritional outcome or, if there is a single event, without taking long-term issues into account.
The depletion of muscle glycogen provides a strong drive for its own re-synthesis (120) and its restoration precedes that of liver glycogen and, even in the absence of a dietary supply of CHO, after exercise, it occurs at a low rate- 1-2 mmol/kg ww of muscle per hour- with some of the substrate being provided through gluconeogenesis (121). High-intensity exercise that results in high post-exercise levels of lactate appears to be associated with rapid recovery of glycogen stores in the absence of additional CHO feeding (122). After

moderate-intensity exercise, muscle glycogen synthesis is dependent on the provision of exogenous CHO. The rate of glycogen restoration is affected by factors such as insulin- or exercise-stimulated translocation of GLUT4 protein transporter to the muscle membrane (123); by factors regulating glucose disposal such as the activity of glycogen synthase enzyme. Changes in these factors are responsible for a bi-phasic muscle glycogen storage pattern, or a decline in glycogen storage rate over time (124).

Several factors can enhance or impair muscle glycogen storage. There is a direct and positive relationship between the amount of dietary CHO intake and post-exercise glycogen storage, at least until the muscle capacity is reached (123). Requirements for total daily CHO intake are lower for athletes whose training programs do not fully deplete glycogen stores and may be higher when the fuel requirements of continued heavy training are added to glycogen restoration needs (125). Increasing CHO intakes can be useful especially after muscle damage, which causes on its own an impairment in post exercise re-synthesis (126). 2003 and 2010 International Olympic Committee (IOC) consensus guidelines suggest that the threshold for early glycogen recovery is reached by a CHO feeding schedule providing 1g/kg body weight during the first hour after training and then 7-12 g/kg during the next 24 hours (127).

Even if meeting the total CHO requirements is more important than the pattern of intake, also the timing of CHO intake counts (128). A more frequent intake of smaller proportions helps to overcome the gastric discomfort associate with eating large amounts of high-CHO foods. When the interval between exercise session is short, the athlete should maximise the effective recovery time by beginning CHO intake as soon as possible. However, when longer recovery periods are available, the athlete can choose their preferred meal schedule as long as total CHO intake goals are achieved. The ideal patter should be 1-1,5 g/kg body weight for the first 30 minutes, then every 2 hours till 500-700g (127).

Since glycogen storage is influenced by both insulin and a rapid supply of glucose substrate, it appears logical that CHO sources with a moderate to high GI would enhance post-exercise refuelling (129).

Solid and liquid forms of CHO are equally efficient in providing muscle glycogen resynthesis; liquid or high fluid content forms are preferred when fatigue arises and appetite is suppressed (130).

Greater proportions of available CHO substrates (such as dietary CHO) are likely to be oxidised to meet immediate energy needs during energy restriction, whereas CHO consumed during a period of energy balance or surplus may be available for storage within the muscle and the liver.

It is also possible that the co-ingestion of other macronutrients, such as proteins, may influence glycogen restoration, particularly if they provide gluconeogenic substrates, as well as digestion, insulin secretion or the satiety of meal (131). Protein ingestion during recovery is essential for its effect on muscle synthesis; however, when CHO intake is below the targets for optimum glycogen storage during the first 4 hours of recovery, the co-ingestion of 20-25 g protein can enhance it while, when CHO intake is adequate, the co-ingestion of protein has no further effect (132).

In order to enhance glycogen storage from a given amount of CHO, some other strategies can be used, for example the use of high molecular weight glucose polymers, co-ingestion of large amounts of caffeine (133), prior creatine loading (134), addition of fenugreek (135). Not all of these strategies evidence benefits and are practical, so their use is limited. Table 2 and Table 3 resume 2010 IOC guidelines for CHO intake in training diet for fuel and recovery and the ideal timing of it.

Table 2. 2010 IOC guidelines for recommended CHO intake in training diet for fuel and recovery

Intensity of the activity performed	**Total CHO daily needs**
Low intensities or skill-based activities	3-5 g/kg body weight/day
Moderate exercise program (i.e. 1 hour per day)	5-7 g/kg body weight/day
Endurance program (i.e. 1-3 hours per day of moderate-high intensity exercise)	6-10 g/kg body weight/day
Extreme commitment (i.e. more than 4-5 hours per day of moderate-high intensity exercise)	8-12 g/kg body weight/day

Table 3. 2010 IOC guidelines for special timing of intake to support key training sessions

Phase of training session	Total CHO intakes and time settings
Pre-exercise	1-4 g/kg body weight consumed 1-4 hours pre-session
During exercise of 45-75 min duration	small amounts (including "mouth rinsing")
During exercise of 1-2,5 hours of duration	30-60 g/hour
During exercise of 2,5-3 hours of duration	up to 90 g/hour
Post-exercise (especially when there are less than 8 hours recovery between two fuel-demanding sessions)	1-1,2 g/kg body weight/hour in first hour

The success of post-exercise rehydration depends on the ability of the athlete to replace body fluid losses after one exercise session so that the next workout can start in fluid balance. Even though in normal people fluid balance occurs thanks to thirst and urine losses, under stress conditions, thirst can often be suppressed and there may be a considerable lag of 4-24 hours before body fluid can be restored after a moderate to severe hypo-hydration (136). Optimal rehydration requires a scheduled plan of fluid intake but a number of factors can affect it such as palatability of fluids; possible gastrointestinal fullness and discomfort that follow large volumes of fluid ingestion; amount of sodium in recovery fluids which can avoid the suppression of thirst leads by over-dilution of plasma volume (137).
Since sodium losses in sweat vary markedly, there is some argument about the optimal sodium level for post-exercise rehydration. 50 mmol/L may well be justified (138). Alternatively, additional sodium may be ingested via sodium-containing foods or salt added to meals, thanks to the enhancing effect of fluid retention. The addition of potassium (25 mmol/L) to a rehydration beverage is also effective in retaining fluids ingested during recovery from exercise-induced dehydration (139).
Caffeine-containing fluids are not ideal rehydration beverages and should be avoided in relation to exercise or other situations of dehydration, though it seems that the effect of caffeine is overstated and may be minimal in people who are habitual caffeine users (140).
Some strategies derived from guidelines for post-exercise rehydration suggest to start to consume fluids soon after the session of workout finishes and aim to consume the target volume over the next 2-4 hours. It is best for gastrointestinal comfort to spread fluid over these periods than ingest larger amounts in a shorter time (127).

Conclusion
Nowadays, it is overpowering the role that nutrition plays into the sport science field. In the right hands, it can be an instrument to enhance the performance of the athlete promoting recovery without risks.

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