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Evaluation of nutritional status and energy expenditure in athletes

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Summary

Continuous physical exercise leads the athlete to maintain an unstable balance between dietary intake, energy expenditure and the additional demands of a high amount of physical activity. Thus, an accurate assessment of nutritional status is essential to optimize the performance, since it affects health, body composition, and the recovery of the athlete. Specific aspects like the type of sport, specialty or playing position, training schedule and competition calendar, category, specific objectives, which differ from the general population, must be considered. A biochemical assessment can give us a general idea of the nutritional status, lipid profile, liver or kidney function, if diet is too high in proteins or fats, as well as possible nutritional deficiencies and the need for supplementation. Sport kinanthropometry has great utility that enables the assessment of body mass, height, length, diameter, perimeter and skinfolds, where information is processed by applying different equations, obtaining information on somatotype, body composition, and the proportionality of different parts of the body. To give proper nutritional counselling, energy needs of the athlete must be known. If objective measurement is not possible, there are tables including theoretically established energy requirements of different sports. Dietary assessment should include information about food consumption and nutrient intake to establish the relationship between diet, health status and athlete's performance. On the other hand, an adequate hydration status in athletes is essential to maintain adequate performance. Hence, the knowledge of fluid intake by the athlete is a matter of the utmost importance. Dehydration can cause harmful effects on athletes' health. As there is no gold standard, urine gravidity and urine colour are the most extended methods for analyzing hydration status. There is consensus that due to complexity, the combination of different methods assures an effective data collection which will be useful to proceed in dietary and nutritional intervention..

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VALORACIÓN DEL ESTADO NUTRICIONAL Y DEL GASTO ENERGÉTICO EN DEPORTISTAS

Resumen

El ejercicio físico continuo conduce al atleta a mantener un equilibrio inestable entre la ingesta dietética, el gasto de energía y las exigencias adicionales de un alto grado de actividad física. Por lo tanto, una evaluación precisa del estado nutricional es esencial para optimizar el rendimiento, ya que afecta a la salud, la composición corporal, y la recuperación del atleta. Aspectos específicos como tipo de deporte, especialidad o posición de juego, programa de entrenamiento y calendario de competiciones, la categoría, objetivos específicos, que difieran de la población en general, deben ser tenidos en cuenta. La evaluación bioquímica nos puede dar una idea general del estado nutricional, del perfil lipídico, del funcionamiento de hígado o riñón, de si la dieta es demasiado alta en proteínas o grasas, así como las posibles deficiencias nutricionales y la necesidad de suplementación. La cineantropometría deportiva tiene gran utilidad ya que permite la evaluación de la masa corporal, altura, longitud, diámetro, perímetro y pliegues cutáneos, donde la información se procesa mediante la aplicación de diferentes ecuaciones, obteniendo información sobre el somatotipo, la composición corporal y la proporcionalidad de las distintas partes del cuerpo. Para poder dar una orientación nutricional adecuada, las necesidades de energía de los atletas deben ser conocidas. Si la medición objetiva no es posible, existen tablas que incluyen los requerimientos de energía teóricamente establecidos para diferentes deportes. La evaluación dietética debe incluir información sobre el consumo de alimentos y nutrientes para establecer la relación entre la dieta, el estado de salud y el rendimiento del atleta. Por otro lado, un estado adecuado de hidratación en los atletas es esencial para mantener un rendimiento óptimo. Se debe valorar específicamente la ingesta de líquidos por parte del deportista. La deshidratación puede causar efectos nocivos en la salud de los atletas. Como no existe un método "gold standard", la gravedad y el color de la orina son los métodos más extendidos para analizar el estado de hidratación. Hay consenso en que la combinación de diferentes métodos asegura una captura efectiva de datos para la valoración nutricional del deportista que permitirá proceder a la intervención dietética y nutricional.

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Palabras clave: *Antioxidantes. Cineantropometría. Hidratación. Dieta. Deporte.*

Abbreviations

BIA: Bioelectrical impedance analysis.
EE: Energy expenditure.
ISAK: The International Society of Advancement of Kinanthropometry.
MET: Metabolic equivalent.
RDAs: Recommended Dietary Allowances.
RMR: Resting metabolic rate.
USG Urine specific gravity.

Background

Physical exercise carried out on a continuous basis and at certain intensity leads the athlete to maintain an unstable balance between dietary intake (energy, macro and micro nutrients), daily life energy expenditure and the additional demands of a high amount of physical activity. Thus, an accurate assessment of nutritional status is essential to optimize the performance of the athlete, since it affects health, body composition, and the recovery of the athlete^{1,2}.

There are different methods to assess the nutritional status of an individual. It is often useful to combine several of them to get a more complete and accurate assessment. The isolated assessment of any of its components should not be understood as an outcome of diagnosis, but as a complementary method to the total nutritional assessment¹.

There are several methods used for a proper nutritional evaluation. This review will get deeper into selected biochemical markers, some specific anthropometrical aspects, and evaluation of dietetic – nutritional and hydration status. Data obtained from these methods must be interpreted according to the competitive phase of the athlete^{1,2}. The complexity of information gathered both individually and in nutritional studies requires validated tools and trained researchers and professionals to facilitate the analysis of the collected information.

Some issues that should be familiar in the nutritional assessment of athletes and that differ from the population in general are¹:

- The type of sport (strength, endurance, speed or team (acyclic) or even aesthetics (rhythmic gymnastics) and specialty or playing position.
- The days, schedules and time spent in trainings and competitions.
- Category in which the athletes are competing (amateur or professional).
- What is the main objective at a specific moment (get fit, a particular competition,..). It is important to prioritize actions.

Likewise, it is also important to know the training planning, focusing on the microcycles and daily workouts^{1,2}.

Interest

Nutritional assessment in the field of sport is necessary and beneficial for both health and performance. One of the aims is making a proper diet-nutrition intervention, which should include, among others¹:

- Evaluation of energy balance (caloric intake - energy expenditure), verified by maintaining a stable body weight, a good health status and an optimal physical performance.
- Compliance with nutrient recommendations according to sport, type of training and season.
- Organizing meal schedules, adapted to training and competition. In this way, the athlete will be able to optimize training, having maximum performance and ensuring a correct post-exercise recovery.
- Evaluating and correcting excesses and deficiencies of nutrients as well as errors related to hydration.
- Continuous nutrition education to achieve understanding and compliance.

Controversy

There is no doubt that an adequate diet will contribute to support consistent intensive training while limiting the risks of illness or injury. It is essential to get the right amount of energy and nutrients to stay healthy and to perform well. But there is no simple formula to predict how much energy an athlete needs and there is no consensus if regular training increases nutrient requirements. In the same way, the use of one or the other method in the evaluation of dietary intake can provide different data of dietary assessment. Energy (and nutrient) demands will fluctuate throughout the season and even between training sessions. Monitoring body weight can be misleading as it is not a reliable indicator of energy balance in athletes. While an increase of fat mass negatively affects athletic performance and increases energy demands, an increase in musculoskeletal mass is seen as a positive indicator of sports performance, by contributing to increased power production during exercise as well as greater size and strength with high dynamic and static loads. Therefore, measuring skinfold thickness across the season can provide more useful information to know athletes body composition. Formula developed for the general population can bias results on body composition and energy expenditure in athletes. There is also controversy around how much dehydration can be acceptable without compromising performance. Health-related aspects are often forgotten in elite sports.

Limitations

Every athlete is different. They have different requirements for energy and nutrients depending on multiple factors like body size, sports discipline, training load, number of training days, etc. This makes nutritional assessment quite difficult, as numerous confounding variables have to be taken into account. In addition, they have individual genetic, physiological, biochemical and biomechanical characteristics which determine their nutrient needs². Comparison with recommended dietary intakes and reference ranges for the general population will be misleading. Each athlete, man or woman, must identify his/her nutritional goals in terms of requirements of energy, carbohydrate, protein, fat, vitamins, minerals and water in order to be healthy and to have an optimum performance. Comparability of results among athletes is limited. They should monitor body composition and biochemical markers throughout the season to have their own registry.

Current state and perspective

Biochemical assessment

A biochemical assessment of the nutritional status in athletes is essential². Biochemical markers are obtained from clinical analyses, well through blood or urine samples. These parameters can give us a general idea of the nutritional status, lipid profile, liver or kidney function, if diet is too high in proteins or fats, as well as possible nutritional deficiencies. A sustained interest has developed around vitamins and trace element nutrition and metabolism, as it relates to athletic performance⁴. Concretely, vitamin and minerals are necessary for a number of metabolic processes in the body including numerous reactions related to exercise and physical activity, such as energy, carbohydrate, fat and protein metabolism, oxygen transfer and delivery, and tissue repair. Therefore, it is important to examine if exercise affects the function of these elements or not⁴.

Vitamin C and vitamin E

Vitamins C and E are one of the most studied biochemical compounds as they have a strong relationship with physical activity and sport performance. Following this fact, we will focus on these two vitamins.

It has been widely noted that vitamins C and E show numerous beneficial effects because of and beyond their antioxidant properties. Consequently, vitamins C and E are expected to prevent diseases related to free radical excess. In the field of sports medicine, many studies dealing with vitamins C and E have been conducted originally from the point of view of its effects

on physical performance. Although some earlier studies indicated that vitamin C and/or vitamin E supplementation could improve physical performance, differences in the study design, kind of sport and statistical analysis may explain the discrepancies appearing when comparing results from these different reports. However, some recent studies could enhance our understanding of vitamin effect on physical activities.

Vitamin C acts in humans as an electron donor (antioxidant agent) for eight enzymes of which three are involved in collagen hydroxylation and two are involved in carnitine biosynthesis. Vitamin C has been also shown to protect lipids in human plasma and low density lipoprotein. It also interacts with other nutrients, aiding in the absorption of iron and copper, maintenance of glutathione in the reduced form, and stabilization of folate. Recommended Dietary Allowances (RDAs) are set to 75 mg/day and 90 mg/day for women and men, respectively⁵. In addition to its activities as an antioxidant, vitamin E is involved in immune function, cell signaling, regulation of gene expression, and other metabolic processes. Alpha-tocopherol, the main biochemical bioactive form of vitamin E family members, inhibits the activity of protein kinase C. Vitamin allows blood vessels to be more able to resist blood-cell components adhering to their surface. Vitamin E also increases the expression of two enzymes that suppress arachidonic acid metabolism. RDAs for vitamin E are set at 15 mg/day, corresponding to 22.4 UI of α -tocopherol. Vitamin E deficiency is rare⁵, even some newly published data are indicating that vitamin E deficiency, at least at subclinical level, is may be increasing.

Paschalis et al. have shown recently that low vitamin C concentrations are associated with a poor physical performance and an increase of oxidative stress markers⁶. This situation can be reversed by using vitamin C supplementation, obtaining better exercise performance and reducing oxidative stress. For this purpose, authors have selected 10 individuals with the lowest and 10 with the highest vitamin C values from an initial group of 100 males. Using a placebo-controlled crossover design, the 20 selected subjects performed aerobic exercise until exhaustion before and after vitamin C supplementation for 30 days. Results have been obtained by using F₂-isoprostanes and protein carbonyls as oxidative stress markers.

In contrast, very high levels of vitamin C intake, with doses surpassing 1,000 mg/day seem to be detrimental to increase physical endurance as shown by Paulsen and collaborators⁷. Researchers analyzed 54 young and healthy men and women for 11 weeks. Participants were divided in two groups, the first one with an intake of 1,000 mg of vitamin C and 235 mg of vitamin E per day (consistent with the amount found in available supplements), and the second group received a placebo each day. All subjects were required to carry out an endurance training program that consisted of three to four training sessions each week, mainly involving running. They

also underwent fitness tests, muscle biopsies, and had blood samples taken at the baseline of the study and after the study ceased. Results of the study revealed that markers for the production of new muscle mitochondria only increased in the participants who received placebo. Because vitamins C and E are antioxidants, high doses of them seem to inhibit to some extent the free radicals action and to block the positive proceeding of the oxidative stress process on training, for example, in the development of muscular endurance.

Trace elements: Iron, zinc, chromium and selenium

Trace elements, like iron, zinc, selenium, and chromium are ingested in very small amounts and are fundamental to regulate whole-body metabolism, including energy utilization and work performance.

Iron is the mineral most studied in athletes due to its implication in several physiological mechanisms related to physical performance and endurance. A deficiency in the deposit can lead to an iron-deficiency anemia, state in which athletic performance can be compromised⁸. Mechanisms that cause iron deficiency anemia in athletes include hemolysis, deficiency of dietary origin due to low intake of non-hem iron coming from vegetarian diets or potential food interference, as well as by the increase of oxidative stress⁸. To avoid iron deficiency, a recommendation is to test iron status regularly. The evidence confirms that athletes must include iron-rich foods in their diet such as lean red meat and breakfast cereals fortified with iron, among others⁹. Vegetables rich in iron, such as whole-grain cereals, spinach and legumes should be combined with animal iron sources or sources of vitamin C (e.g. a glass of orange juice consumed with breakfast cereals) that improves iron absorption.

Zinc is required to serve either a catalytic or structural role in more than 200 enzymes in mammals. Zinc-containing enzymes participate in many pathways of macronutrient metabolism and cell replication. In addition, some zinc-containing enzymes, such as carbonic anhydrase and lactate dehydrogenase, are involved in intermediary metabolism during exercise. Another zinc-containing enzyme, superoxide dismutase, presents a protective role as an endogenous antioxidant against free radical damage. Selenium, another main trace element, is essential for major metabolic pathways, including oxidative stress, as it is a component of glutathione peroxidase enzyme. Finally, mammals need chromium to maintain balanced glucose metabolism, and thus chromium may facilitate insulin action and has therefore indirect insulinogenic properties. Biochemical properties of trace elements have been extensively described by many authors, including Lukasky¹⁰.

There is no definitive data on suitable concentrations of trace elements for people having regular physical activity. One possible approach to study these elements under a certain physical stress is to evaluate their fluctuations during exercises. A recent study¹¹ has been carried out to investigate the effect of swimming frequency on serum concentrations of some trace elements, including among others, chromium, zinc and selenium. Three groups of different-level male swimmers were included in the study, as elite swimmers (n = 14), amateur swimmers (n = 11), and sedentary individuals (n = 10). Elite and amateur swimmers followed a 3-week training program. At the end of the period, all volunteers had to perform a controlled swimming test, and blood samples were collected at the beginning (time 0), immediately after (time 1), and 1 h after the activity (time 2). Authors observed that changes in magnesium, calcium, copper, zinc, and selenium levels exhibited a common pattern in all study groups, with higher post-test serum concentrations. A drop of copper, zinc, and selenium levels at 1 h after the test in elite swimmers was also observed. Anyway, further studies on relationship between trace elements and physical performances should be carried out in order to better understand mechanisms and consequences of this possible association.

Anthropometric assessment

Sport kinanthropometry has great utility as it enables the assessment of morphological characteristics, as well as its control throughout the sport season. The anthropometric technique allows us to measure body mass, height, length, diameter, perimeter and skinfolds. Information is processed by applying different equations, obtaining information on somatotype, body composition, and the proportionality of different parts of the body¹².

Anthropometric measurement should be performed following the protocol of "The International Society of Advancement of Kinanthropometry" (ISAK)¹². This Protocol recommends that measures should be on the right side, contrary to the recommendation of the WHO, who recommends on the left side. The anthropometric material used is: (a) height measuring rod, with a precision of 1 mm and a range (130-210 cm); (b) body mass scale with a precision of 0.1 kg and a range (2 kg - 130 kg); (c) metal, narrow and inextensible metric tape, with a precision of 1 mm; (d) small bone diameters caliper, with a precision of 1 mm; (e) large osseous diameters caliper, with a precision of 1 mm; (f) skinfold caliper, with a precision of 0.2 mm (accuracy: 0.2 mm) g) supplementary material (pencil identified to mark the individual, template for collection of measures and software for data processing).

Once all data are collected, the fat mass and the muscle mass (Table I) of athletes can be estimated by means of different equations¹².

Table I
Equations used in the calculation of the fat mass and musculoskeletal mass

Fat mass

Faulkner's equation.

Derived from the Yuhasz's equation after studying a swimmers' team.

% Fat mass (males) = 0.153 x (TS+ SBS+ SPS+ AS)+5.783

% Fat mass (females) = 0.213 x (TS+ SBS+ SPS+ AS)+7.9

Fat mass (kg) = (% fat mass x body mass (kg)) / 100

Carter's equation.

Derived from the Yuhasz's equation, and applied to Olympic athletes (Studies published in the Montreal Olympic Games Anthropometric Project).

% Fat mass (males) = 0.1051 x (TS + SBS + SPS+ AS + MTS + CS)+2.58

% Fat mass (females) = 0,1548 x (TS + SBS + SPS+ AS + MTS + CS)+3.58

Fat mass (kg) = (%fat mass*body mass (kg)) / 100

Jackson & Pollock's equation.

Sample: 403 males 18-61 years.

The results allow to obtain the density and subsequently body fat percentage as calculated from the Siri's equation (% Fat mass = (495/BD) - 450).

BD males = 1.17615 - 0.02394 x log Σ 7S - 0.00022 x (A) - 0.0075 x (AP) + 0.02120 x (FP)

BD females = 1.112 - 0.00043499 x (Σ 7S) + 0.0000055 x (Σ 7S) 2 - 0.00028826 x (A)

Withers' equation.

The results allow to obtain the density and subsequently body fat percentage as calculated from the Siri's equation (% Fat mass = (495/BD) - 450).

BD males = 1.078865 - 0.000419 x (AS + MTS +CS + CHS) + 0.000948 x (NP)- 0.000266 x (A) - 0.000564 x (S-M P)

BD females = 1.14075 - 0.04959 x (AS + MTS +CS + CHS) + 0.00044 x (A) - 0.000612 x (WP)+ 0.000284 x (H) - 0.000505 x (HP) + 0.000331 (CHP)

Musculoskeletal mass

Lee's equation.

Sample: 324 (244 non-obese and 80 obese). Valid for male and female.

MME (kg) = H x (0.00744 x AGC 2 + 0.00088 x MTC² + 0.00441 x CGC²) + (2.4 x Sex) -0.048 x Age + Race + 7.8.

% MME: MME(kg) x 100/body weight(kg)

AGC= Relax arm girth - (3.1416 x (triceps skinfold/10)).

MTC= Mid-thigh girth - (3.1416 x (MTS /10)).

CGC= Calf girth - (3.1416 x (CS/10)).

TS: Triceps skinfold; SBS: Subscapular skinfold; SPS: Supraspinale skinfold; AS: Abdominal skinfold; MTS: Mid-thigh skinfold; CS: Calf skinfold mm; BD: Body density; IS: Ileocrestal skinfold; CHS: Chest skinfold; MAS: Mid-axila skinfold; AP: Abdominal girth; FP: Forearm girth; NP: Neck girth; S-M P: Supramalleolar girth; WP: Waist girth; HP: Hip girth; CHP: Chest *mesoesternal* girth; H: Height (cm); A: Age (years); Σ 7S: Sum of 7 skinfolds (TS + SBS + IS + AS + MTS + CHS + MAS); AGC: Relax arm girth corrected; MTC: Mid-thigh girth corrected; CGC: Calf girth corrected; Sex: Female=0; Male =1; Age (years); Race: Asian= -2; Afro-Americans= 1.1; Caucasian and Hispanic=0; Girth in cm; and skinfolds in mm.

In the same way, the different compartments of the somatotype are calculated (Table II), which is defined as the study of the morphology of the individuals¹².

The different values of fat mass, musculoskeletal mass and somatotype can be compared with references values by sport category or the values of previous assessments of the same athlete to guide nutrition decision or training¹².

Energy expenditure assessment

To give proper nutritional counselling, energy needs of the athlete must be known. Apart from self-reported and objective measurements (see Ara et al, and Aparicio-Ugarriza et al. also included in this supplement), there are tables including theoretically established

energy requirements of different sports by different procedures¹³, as well prediction equations, MET, or metabolic equivalent-based tables.

Energy expenditure (EE) prediction equations (Table III)

EE estimation is based on the use of predictive equations for calculating the resting metabolic rate (RMR) and daily physical activity energy expenditure¹⁴. Mostly used in athletes is the:

MET or metabolic equivalent

The most used and recommended method is the registration of 24 hours MET¹⁵. One MET is defined

Table II
Equations for predicting somatotype components

<i>Component</i>	<i>Equation</i>
Endomorphy*	$-0.7182 + 0.1451 \times X - 0.00068 \times X^2 + 0.0000014 \times X^3$
Mesomorphy**	$(0.858 \times HB + 0.601 \times FB + 0.188 \times AGR + 0.161 \times CGC) - (\text{Height} \times 0.131) + 4.5$
Ectomorphy***	-If $HRW \geq 40.75 \rightarrow = (0.732 \times HRW) - 28.58$. -If HRW between 38.25-40.75 $\rightarrow = (0.463 \times HRW) - 17.63$. -If $HRW \leq 38.25 \rightarrow = 0.1$.

*X= sum of triceps, subscapular and supraspinale skinfold (mm) x (170.18/Height (cm)).

**HB= Humerus breadth (cm); FB= Femur breadth (cm); AGR: Relax arm girth corrected; CGC: Calf girth corrected; Height in cm.

***Requires the calculation of the height (cm) divided by cube root of body mass (kg) (HWR).

Table III
The resting metabolic rate (RMR) prediction equations commonly used in athletes

Institute of Medicine, 2000:

Men= $662 - 9.53 + PA \times [15.91 \times \text{body mass (kg)} + 539.6 \times \text{height (m)}]$

Women= $354 - 6.91 + PA \times [9.36 \times \text{body mass (kg)} + 726 \times \text{height (m)}]$

PA (Physical activity):

1.0-1.39: sedentary and daily activities as walking, house keeping, etc.

1.4-1.56: low activity, daily tasks and 30-60 minutes / day of moderate activity as walking 5-7 km/hour.

1.6-1.89: active and daily activities, more 60 minutes / day of moderate activity.

1.9-2.5: very active, daily activities, with 60 minutes / day of moderate activity more 60 minutes / day of vigorous activity or 120 minutes / day of moderate activity.

Cunningham, 1980:

$RMR = 500 + 22 \times \text{lean mass (kg)}$

Greater prediction of RMR in athletes of both sexes who perform resistance training, as based on lean mass (fat-free).

De Lorenzo, 1999:

$RMR \text{ men} = -857 + 9.0 \times \text{body mass (kg)} + 11.7 \times (-\text{height (cm)})$.

51 men athletes involved in intensive training of water polo, judo and karate.

as the number of calories consumed per minute on an activity, related to basal metabolic rate (1 MET = 1 kcal/kg/h = 3.5 ml/kg/min of O₂). Data obtained by METs are valid for adults 40-64 years. However, in elderly they should be lower, while in young they are higher¹⁶.

The limitation of calculating energy expenditure caused by physical activity by this method is the great individual variability in relation to the level of fitness, skill, coordination, efficiency, environmental conditions, intensity or nature of the effort¹⁵.

Dietary and nutritional evaluation

Dietary assessment is an important tool for assessing the nutritional status of the athlete especially when referring to sports performance and health¹⁷. We have to assume that a state of balanced eating is an integral part of any sports program¹⁷. Therefore, information about food consumption and nutrient intake to establish the relationship between diet and health status¹⁸ and athlete's performance is needed.

A study revealed that 80% of survey assessment related to both knowledge and food intake had no supervision by a nutritionist-dietitian¹⁷. Performing

a good dietary assessment is not without difficulty, since it depends on:

- The memory of the athlete.
- The difficulty of the athlete estimating portions size.
- The possible under- or overestimation of food intake.
- The possible bias induced by the dietitian who interviews the athlete.
- The conversion of foods to energy and nutrients and the use of food composition tables.

However, there are strategies to reduce the implicit error in dietary assessment, including:

- Use a combination of quantitative and qualitative methods (dietary history, 24-hour recall, frequency of food consumption).
- Handle methods and techniques with dietary history, asking about some related general aspects that help the patient to recall a more detailed way, all food consumed in a day to reduce the error (24-hour recall multiple steps).
- Use photos or models of foods that help the athlete to estimate the consumed portions.

After obtaining the records, data must be transferred to a database for calculating energy, macro- and micro-nutrients from which to compare references regarding energy intake and carbohydrates, protein, lipids, water and micronutrients¹⁹.

Due to the heterogeneity of methods used to assess food intake in athletes and the general population, it is difficult to perform a meta-analysis indicating the effectiveness of these methods of nutritional assessment²⁰, so combining different methodologies²¹, is what gives us greater precision when evaluating food intake, in addition to the use of certain online tools that today allow to validate the intake of nutrients²².

Body water and liquids intake assessment

An adequate hydration status in athletes, young and old, is essential to maintain physical and mental performance during athletic activities¹⁹; dehydration can cause harmful effects on athletes' health. Hence the knowledge of fluid intake by the athlete is a matter of the utmost importance.

Hydration and Dehydration in exercise

Normal hydration, often called euhydration, is important for health and wellbeing. Even small losses of body water can have a negative effect on muscle strength, endurance and maximal oxygen uptake. Normal hydration status is the condition of healthy individuals who maintain water balance that depends on the difference between water gain and water loss²³.

Under normal conditions, water entry into the organism proceeds from fluid intake (around 2300 mL/day) as well as the production of water from reactions of cellular metabolism (200 mL/day). Concerning water output sources, the main output are in form of urine (1500 mL/day), followed by cutaneous perspiration (350 mL/day), pulmonary ventilation (350 mL/day), sweat (150 mL/day) and faeces (150 mL/day)²³. During exercise, as fluid losses by sweat increase, fluid intake should also increase².

A slight state of dehydration, a water loss of only 1% - 2% of body weight, will negatively affect both physical and mental performance. Dehydration produces a negative effect on the cardiovascular system, thermoregulation, besides compromising metabolic, endocrine and excretory systems, resulting in decreased physical performance and also cognitive function.

During exercise, an increased rate of metabolic heat production and body temperature will rise if heat loss is not increased accordingly. There is a risk to health as a consequence of thermal and fluid balance homeostasis and exercise performance may be reduced in the heat. Therefore, athletes must be concerned to drink accordingly in order to reduce this performance loss. When intense exercise is combined with high

temperature or restricted heat loss, core temperature may rise by 2-3 °C and this may result in exertional heat illness²⁴.

Sweat loss is composed by water (99%), electrolytes (mainly sodium and chloride), nitrogen and nutrients. During exercise, small amounts of magnesium, calcium, iron, copper and zinc can be lost too. The mean concentration of salt in sweat is 2.6g (45 mEq) for each 1-1.45 L of sweat produced during exercise. During exercise, an excessive sweating can decrease levels of sodium and chloride by 5-7% and potassium by 1%, therefore it must be replaced in order to prevent a deficit.

The sweat rate depends on several factors such the environmental conditions (temperature, humidity); genetics, and the athletic conditioning of the athlete. Moreover, there is a large inter-individual variation in sweating even when the same or similar exercise is carried out in the same conditions or when the individuals are exposed to the same heat stress²⁴.

The sweat rate can be calculated by:

1. Weight lost: Total body mass after exercise (kg) - Total body weight after exercise (kg).
2. Sweating: Weight lost + total amount of liquid consumed during workout + total urine produced during exercise (mL).
3. Sweat rate: (Sweating/exercise duration).

Fluid replacement by providing water, specific drinks and liquids based on solutes, mainly carbohydrates and electrolytes, helps to maintain hydration and therefore health and performance in athletes. Water commonly represents the fluid chosen by many athletes who exercise regularly, its effect helps to counteract many of the negative effects of dehydration; however, over the past 50 years, investigations have confirmed the benefits of specific sport drinks.

An adequate sport drink must fulfill the following functions: have good palatability, replace fluids and electrolytes, enhance absorption, provide energetic substrates, and ability to maintain blood volume.

Composition and characteristics of sports drinks²:

Carbohydrate concentration (5-8%). An intake of CH in proper concentration has shown benefits in order to maintain intensity during high-intensity exercise lasting an hour or more, allowing maintaining adequate blood glucose and delaying the point of fatigue.

- Beverage temperature: 10 °C to 15 °C.
- Osmolarity (180-400 mEq / L).
- Mineral content (especially Na+) (20 to 30 mEq / L).
- Taste: must have a pleasant taste to encourage voluntary hydration and rehydration.

It is important to achieve an appropriate balance between fluid intake and fluid losses in athletes or what is the same optimal state of hydration before, during and after exercise.

It is well known that athletes should not begin competition in a state of deficit of fluid²⁴ as a fluid deficit can increase physiological stress and reduce performance. It is necessary not only to maintain adequate hydration status after starting the activity, but also before the start of the activity. There are several protocols which allow to achieve or approach as far as possible an euhydration status before, during and after activity

Hydration assessments methods

There is no universal agreement upon the optimal method to measure hydration status that could be universally applied. Over the last years, various options to assess hydration status have been described in detail by many authors²⁴.

Hydration status can be determined through a variety of methods but many of them have potential limitations. However, there are some authors who suggest that the “gold standard” is the combination of various factors.

Body changes

Body mass changes, rather than any measure of body water change, is typically used in research studies to quantify a change in hydration status²⁵. In most athletic settings, the use of body mass measurements in combination with some measure of urine concentration at the first urination of the morning allows large sensitivity for detecting daily deviations from normal hydration. The methods are simple, inexpensive, accurately distinguish euhydration from dehydration, and can therefore be used as a sole source for assessment.

Measurements should be made with subjects’ nude, or in light and dry clothes, being the clothes identical before and after exercise for both measurements. The weight test will be collected before and after exercise. It may be convenient that subjects urinate and defecate before weighing²⁶.

Bioelectrical impedance analysis (BIA)

Total body water content can be estimated by BIA method. Over the last years this noninvasive technique has attracted much attention; however, the lack of precision and the factors that can influence the results as skin temperature, posture and other factors do not recommend its use for monitoring hydration¹⁶.

Blood

Changes in blood volume and composition reflect changes in hydration status (Table IV). Blood volume and plasma osmolality are the primary variables

homeostatically regulated, but both are very sensitive to variation by exercise, food ingestion, fluid intake, posture change and several factors. Blood tests for hydration will tend to include hemoglobin concentration, hematocrit, sodium concentration and osmolality. Otherwise it appears that changes in plasma osmolality that stimulate endocrine regulation of the reabsorption of renal water and electrolytes are delayed at the kidney when acute changes in body water occur²⁷.

Urine

Urine samples for assessment of hydration status may be collected at the first urination of the morning or may be collected immediately before training or competition²⁶. The collection time can be affected by several factors and this should be considered in the interpretation of the results. Urine tests for hydration can include:

Osmolality: Measurement of osmolality requires use of an expensive instrument and technical competence. It is most commonly measured by freezing point depression but equipment using vapor pressure analysis is also used. Values of urine osmolality of > 900 mOsmol/Kg reflect a body water deficit of about 2% of body mass²³. The American College of Sports Medicine²³ suggests a good index of hydration as a urine osmolality ≤700 mOsmol/Kg or a Urine specific gravity of <1020 g/mL.

Urine specific gravity (USG): USG is an accurate and rapid indicator of hydration status. Normal ranges are from 1.013–1.029; a USG of ≥1.030 suggests dehydration and 1.001–1.012 may indicate over-hydration. USG is more indicative of recent fluid consumption versus overall chronic hydration status²⁸.

Color: Urine color is determined by the amount of uro-chrome, resulting from the breakdown of hemoglobin in the sample. Research has identified linear relationships between urine color and specific gravity, and between urine color and conductivity. Therefore, urine color is an acceptable way to estimate hydration status in athletic or research settings when a high precision may not be needed or where self-assessment may be

Table IV
Serum markers and reference ranges of euhydration

<i>Serum marker</i>	<i>Reference ranges</i>
<i>Haemoglobin:</i>	
Men	14.0-17.0 g/dL
Women	11.5-16.0 g/dL
<i>Haematocrit:</i>	
Men	42-54%
Women	38-46%
<i>Serum sodium</i>	132-142 mmol/L
<i>Serum osmolality</i>	280-300 mOsmol/kg

required. Armstrong et al. (1998) have investigated the linear relationship between urine color and specific gravity and conductivity, and have developed a scale of eight colors. A lighter color indicates adequate hydration, while darker colors indicate the need for fluid consumption. However, diet, supplements, and medications can affect body weight and urine color, thus these factors must be considered when using this method. This method is universally accepted to be used in athletic or other fields to estimate hydration status when high precision may not be needed²⁹.

Saliva

Saliva osmolality rises in cases of acute dehydration (4% loss of body mass) induced by exercise in the heat, but there is a large variability in how individuals respond. Saliva osmolality can also be affected by a brief mouth rinse with water which makes it an unreliable marker of hydration status.

Questionnaires

Questionnaires are a qualitative tool that can provide important information about amount and types of ingested fluids, which can be rapidly administered to get information of the athlete. The food frequency questionnaire is a tool that is commonly used for assessing intake of foods and drinks; however, water is not contained as a beverage in several of them.

Although there are several measures to estimate hydration status, all have limitations. At present, there is no consensus for using any method over another in an athletic setting, although plasma osmolality and total body water are currently the best hydration assessment measures in the scientific field of fluid needs²⁴. Usually the use of body changes combined with some parameter of urine concentration as specific gravity or osmolality, in a sample collected during the first urine of the morning allows a good sensitivity for detecting significant changes in fluid balance (> 2% body mass) for training and competing athletes³⁰.

Conclusion

Due to high caloric output and intense physical activity, which affects physiological, metabolic and nutritional aspects and body composition, athletes differ from the general population. Assessment of nutritional status in athletes must consider specific aspects like the type of sport, specialty or playing position, training schedule and competition calendar, category, and other specific objectives. Due its complexity, there is consensus that the combination of different methods assures an effective data collection which will be useful to proceed in dietary and nutritional intervention. Combi-

ning biochemical assessment, sport kinanthropometry, dietary and hydration status assessment in athletes is essential to obtain reliable data.

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