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Sport nutrition: the role of macronutrients and minerals in endurance exercises

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Abstract: Athletes' nutrition optimization is very important for the nutritional support in all sport specializations. Macronutrients, as well as minerals and vitamins, are functionally active components that play an important role in nutrition of athletes especially in endurance sport. Optimal use of diets, including specialized sport nutrition, normalizes biochemical, immune, endocrine functions and restores athletes' energy balance at different stages of sport exercises. Non-optimal athletes' nutrition of different age groups, inadequate to their physiological needs, and no personalized approach to athletes' diets, violate their right to adequate safe nutrition, according to international standards and criteria. Nutritional factors are one of the most important key factors in the risk prevention measures for a large number of diet-dependent diseases (e.g. digestive, liver, pancreas, cardiovascular system, endocrine system, and kidney diseases). The review presents the information on energy requirements, balance and availability, types and content of functional products for athletes. It also gives an overview of the specialized food market in Russia.

Keywords: Sport nutrition, minerals, proteins, energy, carbohydrates, specialized products

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INTRODUCTION

Optimization of athletes' nutrition, which takes into account the phase state of the organism, athletes' individual, age-sex and other features, is very important for the nutritional support in all sport specializations. It is of a great importance for athletes involved in endurance sport, e.g. sportsmen of the world national teams. Particular attention should be paid to young athletes. A full-value optimal nutrition for all these categories of athletes creates conditions for maximum physical performance, increases a body's resistance to stress and the effects of any unfavorable factors. Control over the adequacy of nutrition, as well as its optimization, is included in the structure of the mandatory athletes' check-ups to ensure timely detection of health and fitness dynamics. Nutritional disorders significantly reduce the effectiveness of training activities, especially in trauma and stress, and increase the risk of pathology development. Along with other factors, they may adversely affect the effectiveness and duration of athletes' professional activity.

The introduction of specialized sport nutrition into the diet is crucially important in the medico-biological support of highly skilled athletes. It contains additional macronutrients as well as essential micronutrients, such as vitamins, minerals and other biologically active substances. There are different types of sport nutrition:

– foods and beverages containing high concentrations of different types of carbohydrates for creating and maintaining the glycogen in muscles for providing energy;
– protein enriched products for enhancing protein synthesis in muscles and adapting to exercises;
– multiple micronutrients (vitamins, minerals, biologically active substances) in different forms; and
– isotonic solutions for rehydration, additional energy supply and etc.

RESULTS AND DISCUSSION

Energy requirements, energy balance, and energy availability. An athlete's energy requirements depend on sport, the training period, competition cycle, and recovery period. It varies from day to day depending on changes in training volume and intensity level. It is well-known that energy consumption is directly proportional to the athletes' physical activity. Therefore, people involved in general fitness programs (for example, exercises for 30 to 40 minutes a day, 3 times a week) can usually meet energy needs, using regular foods in accordance with a normal diet. Their energy consumption can be in the range 1,800–2,400 kcal/day or about 25–35 kcal/kg per day [1, 2]. Athletes who have a moderate level of training (for example, 2–3 hours a day of training, 5–6 times a week) or a high intensity of training (3–6 hours per day of intensive training for 5–6 days a week) may additionally have energy consumption of 600 to 1,200 kcal or more per hour during a workout [1, 2]. For elite athletes energy consumption during endurance training or a competition can be huge, e.g. the estimated energy expenditure for cyclists participating in the Tour de France was 12,000 kcal per day [3, 4]. In addition, the requirement for calories for athletes with significant body weight (e.g., 100–150 kg) can range from 6,000 to 12,000 kcal per day, depending on the volume and intensity of various training skills [3]. That is why the only way to optimize the athletes' nutrition is the mandatory use of specialized products and dietary supplements. The violation of nutritional status, especially in highly qualified athletes with extreme physical activity, has a significant negative impact on health indicators. It is a serious risk factor for the development of many diet-dependent diseases which may be prevented by diet regulation.

Energy consumption in sports can be calculated in accordance with the recommendations, e.g., of the American College of Sports Medicine [5]. Energy balance occurs when total energy intake (EI) equals total energy expenditure (TEE), which in turn consists of the summation of basal metabolic rate (BMR), the thermic effect of food (TEF), and the thermic effect of activity (TEA).

$$TEE = BMR + TEF + TEA$$

$$TEA = \text{Planned Exercise Expenditure} + \text{Spontaneous Physical Activity} + \text{Nonexercise Activity Thermogenesis}$$

Below is the example of calculating of the energy availability (EA) for a sportsman with body weight of 60 kg, body fat 20%, FFM 80% (= 48.0 kg FFM), EI 2,400 kcal/day, and additional energy expenditure from exercise – 500 kcal/day:

$$EA = (EI - EEE) / FFM = (2{,}400 - 500)\ \text{kcal} / 48.0\ \text{kg} = 39.6\ \text{kcal/kg FFM}$$

One should also take into account the peculiarities of the three types of energy production, which differ drastically:

– aerobic energy production, which is typical of sports that require endurance exercises (marathon, skiing, road racing, etc.);

– anaerobic energy production, i.e. the ability to perform muscular work in conditions of oxygen deficiency, which is realized mainly in sports that require short-term energy release (weightlifting, sprinting, etc.); and

– mixed anaerobic-aerobic energy production, which is typical of sports with different alternating exercises (combat sports, game sports, etc.)

Specialized foods that include easily recyclable energy sources, micronutrients and biologically active substances allow regulating and activating the main functional processes (biochemical, immune, cardiac, endocrine etc.) at various stages of the training process.

At the same time, the unbalanced athletes' nutrition, inadequate to their physiological needs, the lack of a personalized approach to athletes' diets violate their right to adequate safe food, according to international standards and criteria (Resolution number 2001/25 of April 20, 2001, the human rights mission of the United Nations).

History of sports nutrition. Sports nutrition is the application of basic nutritional principles to improve the training process, athletic performance and recovery of athletes in post-training periods.

It is believed that the first evidence-based research on athletic nutrition is closely related to the studies of carbohydrate and fat metabolism, conducted in Sweden in the late 1930s. In the late 1960s, Scandinavian scientists began to study the processes of storing, consuming and re-synthesizing glycogen in muscles during long-term sports training. Technologies for assessing the response of human tissues to physical activity were also developed. Later, in 1965, the scientific advances gave an opportunity to a group of researchers at the University of Florida, led by Dr. Robert Cade, to develop and scientifically prove the possibility of using a carbohydrate-containing beverage in sports. Thus, in 1965 *the Gatorade* appeared – one of the first well-known sport drinks.

In the 1970s, physiologists from all over the world, including the leading scientists of the Soviet Union, began to develop a new direction – the physiology of sports. These studies were carried out mainly in highly skilled athletes, especially in long-distance runners as these athletes developed the fastest and most life-threatening depletion of glycogen stores in the muscles. In addition, this sport was easily modeled in laboratories with the use of treadmills and exercise bikes. In this regard, much of the initial research of sports nutrition has been associated with the study of carbohydrate-containing foods.

Many studies in this area were empirical and largely subjective, primarily related to the use of protein products by body builders. Despite a large number of studies on the use of protein products in sports, many fundamental questions about the quantity, quality and timing of protein intake remained unrevealed. Despite the recommendations for optimal protein intake in different sports and for athletes of different ages, many aspects of this problem remained controversial.

In the 1980s, physiological research ultimately contributed to the research conducted by sport physiologists and nutritionists. This was a necessary step, since many aspects of nutrition in sports laid in the plane of dietetics. Physiologists, on the basis of studies by marathon runners and cyclists for long distances, determined the need for consumption of about 8 g of carbohydrates per 1 kg of body weight. But it was nutritionists' domain of competence to determine which drinks, foods, and carbohydrates athletes should to use in their diet to maintain the balance.

Thus, in the 1980s sports nutrition appeared as a new direction in the nutrition science. Taking into account the importance of sports nutrition products in maintaining high sports results, a significant part of the research was aimed at increasing the endurance of athletes when using sports nutrition products.

By the 1990s, educational programs in many countries appeared not only in sports medicine but also in sports nutrition. They were developed not only for dietitians, but for athletes and coaches.

Winter Olympics ‘Sochi-2014’ played a special catalytic role in the development of research and educational programs, expanding the range of sports and technology of food production. The event revealed the problem and forced further studies.

Types of specialized products for athletes. The need to use specialized sport nutrition is due to the fact that during training a large volume and high intensity recovery efficiency and basic metabolic functions cannot be accomplished with traditional foods and diets.

In this regard, in the athletes’ diets, especially those with high physical activity, various ‘specialized foods for athletes’, or ‘sports nutrition’, are introduced.

In accordance with the official regulatory acts No. 1414 of the Ministry of Sports of the Russian Federation, there are following types of sports nutrition:
– carbohydrate (energy) drinks with high concentration of carbohydrates;
– sport/rehydration drinks (isotonic solutions);
– non-liquid carbohydrate nutrition;
– natural proteins of animal and plant origin (animal meat, fish, dairy – casein and whey proteins, egg white, soy protein);
– hydrolyzed proteins with different degree of the hydrolysis (mixture of peptides of different structure and amino acids);
– individual amino acids or mixtures of 2 to 3 amino acids;
– product for body weight control; complexes of vitamins and mineral supplements;
– sports dietary supplements – individual compositions of protein and non-protein nature that activate biochemical processes (carnitine, creatine, succinate, ribose, etc.); and
– additives for recovery after intensive workloads and injuries.

By the effect on metabolism, special nutrients in sports nutrition products are divided into the following groups:
– with metabolic action, i.e. aimed at stimulating the processes of anaerobic and aerobic metabolism;
– with anabolic action, i.e. enhancing the processes of synthesis of substances in the body;
– used to maintain the biochemical homeostasis of the body; and
– aimed at accelerating recovery processes after physical training with antioxidant and antihypoxic effect.

Market of specialized products for athletes in the Russian Federation. At present, in the Russian market there is a large number of specialized food products for athletes (SFPA) with different ingredients that can be characterized both by their ‘basic’ component and by the intended purpose.

The greatest demand on the sports nutrition market is for protein (59%), followed by vitamins and minerals (50%), amino acids (48%), creatine (38%), energy (30%), and gainers (18%).

The sports nutrition market is rapidly growing. In 2013 it exceeded 1.3 billion rbls. It is more than 70% higher than in 2012. According to IndexBox, the supply in the Russian market of sports nutrition in 2012 was 40% higher than in 2011. The high growth rate of the sports nutrition market was also observed in 2010–2011 (142% and 148% respectively) and extremely high during 2014 Winter Olympics in Sochi.

According to the Discovery Research Group agency, more than 90% of goods at the present sports nutrition market in Russia is occupied by foreign products. The volume of imported goods in value terms following the results of 2012 amounted to more than 1.7 billion rbls., by the end of 2013 – more than 2.0 billion rbls. The protein compositions were more than 40% of the total SFPA and about 17% is creatine-containing SFPA. The analysis shows that most Russian consumers prefer foreign-made goods. Only 13% of consumers choose sports foods of domestic production.

In the end of 2015, the United States became the undisputed leader in the supply of sports nutrition, accounting for 70% of the total import volume. The production of Germany accounted for about 18% of the sports nutrition supplied to the Russian market. Products from Canada, which accounted for about 7% of all supplies, took the third place.

The analysis of specialized products for athlete nutrition held at the Federal Center of Nutrition and Biotechnology (Moscow) showed that over the period 2011–2016, more than 1000 SFPA of various composition and different food and energy values were submitted for examination. Protein and protein-carbohydrate products were most popular, followed by carbohydrate enriched with biologically active substances, crystalline amino acids and their mixtures, isotonic drinks, carbohydrate-mineral complexes with or without vitamins, as well as vitamin and mineral complexes and their combinations. For the last years, the number of biologically active substances of plant origin, mostly from Asian countries, as well as supplements that are used mainly for the nutrition of athletes (creatine and L-carnitine in the form of various compounds, carnosine, lipoic acid, hydroxymethylbutyrate, etc.) has increased dramatically.

About 60% of products are based on concentrates and isolates of whey proteins and about 15–20% –on amino acids. L-carnitine, creatine, glutamine, HMB (hydroxymethylbutyrate), glucosamine, chondroitin, leucine, and arginine are used more often.

Recently, the products of sports nutrition (mainly of foreign origin) contain such new ingredients as hydroxyisocaproic acid (HICA), agmatin, β-alanine, and norvaline.

As for protein-containing products, two types are represented in the market:
– concentrated protein, which consists of 70–90% protein in the form of a monocomponent without or with additives in different compositions with vitamins, minerals, creatine, individual amino acids, digestive enzymes, plant extracts, etc.;

– carbohydrate-protein containing 18–35% protein with or without similar additives.

The most popular ones and often found in the SFPA are:
– milk proteins;
– combination of whey proteins with egg albumin;
– combination of whey and soy proteins;
– meat proteins;
– soy proteins per se;
– proteins of peas;
– collagen hydrolyzates; and
– proteins of plant origin.

Whey proteins are the most commonly used source of protein. They are used as whole and hydrolyzed proteins. Caseins and their salts in the form of caseinates, both as mono-components and as mixtures of these whey protein fractions, are also popular among athletes.

A protein component in the products imported into the Russian Federation and recently undergoing research is almost always represented by whey proteins or their mixture with casein or chicken egg protein. Attention is drawn to the fact that there is practically no soy both in foreign products and those manufactured in the Russian Federation. This fact is apparently explained by the active anti-advertising in Russia on soy due to its genetically modified forms.

In a number of products, hydrolyzed collagen (usually with milk and egg protein) is present as an integral part of the protein base. At the same time, a limited amount of protein products is made on the basis of pure collagen (hydrolyzate), usually with the addition of vitamin and mineral complexes, and is advertised as a source of individual components to maintain the functions of the skeletal muscles.

A sufficiently large segment in the total amount of sports nutrition products is taken by mixtures of crystalline amino acids, which come in the form of capsules, tablets, and in liquid form. A pure BCAA (a mixture of branched amino acids) is the most popular, while BCAA with other components, including various amino acids and vitamins, takes a second place, and a complex of essential and non-essential amino acids comes next. In some cases, as a source of amino acids, products are declared in the form of hydrolysates of milk, whey proteins or collagen.

The carbohydrate component in the products is usually represented by corn maltodextrin and/or simple carbohydrates (sucrose, fructose). The latter are often the basis of liquid forms of products. Carbohydrate products with vitamins and/or mineral components make up the hypo- and isotonic group and are more often present as ready-made beverages or liquid concentrates that require additional dilution.

In addition to protein products, carbohydrate or mixed basis with a high food and energy value, a sufficient amount of products is made up of specialized products that can equally be attributed to biologically active additives to food, but designed to feed athletes: creatine, glutamine, caffeine, taurine; carnitine, glucosamine and chondroitin, omega-3 fatty acids, vitamins and/or vitamins-mineral complexes, herbal compositions and their extracts (guarana, ginseng, ginkgo biloba, green tea, bearberry, garcinia etc.). The listed components, with the exception of plants, are usually offered both as mono-components (in the form of powders, tablets, capsules), and in the form of various combinations.

One of the trends observed in the last few years was the presence of specialized products from abroad, mainly from the USA, except for long-used creatine monohydrate, amino acids in L-form, carnitine and other components that are products of intermediate metabolism in energy cycles or their substrates: lipoic acid, alpha-ketogluthorate, ketogluthorates of amino acids and esters of ketoforms of amino acids, acetylated forms of amino acids, creatine compounds in the form of taurine or ethyl ether yl or hydroxymethylbutyrate, or other compounds (beta-alanine, norvaline, agmatine, etc.). These components are also produced as individual additives and are often present in the composition of sports products in the form of complexes not only in carbohydrate, but also in carbohydrate-protein compositions.

Carbohydrates in the diet of athletes. It is known that the consumption of carbohydrates is extremely important for optimal adaptation to frequent stress signals, which is typical of sports. Adequate and timely intake of carbohydrates is one of the key factors for the recovery of glycogen, the work of muscles and liver [6].

With increasing of physical exercise activity, the total demand for carbohydrates increases significantly. At endurance sports, the daily requirement for carbohydrates is 5–8 g per 1 kg of body weight [7].

Carbohydrates are the key energy factor for both aerobic and anaerobic pathways of metabolism, the main nutrients for muscle contraction during physical exercises of varying intensity. The degree of use and depletion of carbohydrates accumulated in muscles is different for different sports and largely depends on the duration and intensity of the training process, as well as the degree of hydration of the organism and, the athletes' level of training [8]. Along with this, the lack of carbohydrates becomes a limiting factor for the cognitive functions of athletes [9, 10].

The carbohydrate component in the products is usually represented by corn maltodextrin and/or simple carbohydrates (sucrose, fructose). The latter are often the basis of liquid products.

One of the products of European origin is amylopectin barley starch 'Vitargo®' (Sweden). The chain length of its carbohydrates is 500,000–700,000 (carbohydrate chain length of starch-like foods is more than 2.5 x 10^8 D, maltodextrin – 1,000–10,000 D, dextrose – 180 D). Besides, it is characterized by low osmolality in comparison with other carbohydrates. The molecular structure of the carbohydrate resembles glycogen, which ensures its rapid entry into the blood. Clinical trials have shown it to be significantly more effective than dextrose and maltodextrin. Carbohydrate products with vitamins and/or mineral components constitute a group of hypo- and isotonic agents.

It should be noted that different carbohydrates differ in glycemic index (food rating depending on the response of blood glucose to reference food) and are accordingly applied for different phases of training, competitive, and recovery processes. Glycemic index of sucrose is 65, fructose – 23, glucose – 100, and maltodextrin – 96.

Given the significant differences in the properties and types of carbohydrates used in sports practice, glycemic index (GI) is extremely important criteria for their usage in different periods of the sports process. It is used to characterize the rate of carbohydrate to glucose conversion in blood using the concept of glycemic index. GI ranks all products in relation to glucose, less often – white bread. The glycemic index is determined by the rate of a given carbohydrate (or product) causing an increase in blood sugar levels. Glucose has a high glycemic index, sucrose – moderate, fructose – low.

Foods with a high GI provide a rapid increase in blood sugar levels. Carbohydrates contained in the relevant products are easily digested and absorbed by the body; they are quickly used to produce energy and glycogen. Foods with a high glycemic index are best used immediately before or immediately after training. When using products with a low glycemic index, the blood sugar level increases more slowly. Carbohydrates from such foods are not acquired immediately, but provide a more lasting effect, so it is more appropriate to use it at least 1.5–2.0 hours before training.

There are special features when using the form of carbohydrates, e.g., combined carbonated drinks used in sports. One of the criteria for assessing the tolerability, and absorption of specialized foods is osmolality, which characterizes the osmotic pressure of liquids and is the sum of cations, anions, and non-electrolytes, i.e. of all kinetically active particles in 1 l of water (or 1 kg of water) and is expressed in MMol per liter (mOsm/l) or MMol per kg (mOsm/kg).

In accordance with the medical and biological requirements for carbohydrate-mineral drinks intended to overcome the effects of dehydration and loss of electrolytes during training and competitions, their osmolality should be in the range of 200–330 mOsm/kg, preferably 270–330 mOsm/kg.

Carbohydrates make a significant contribution to the osmolarity of ready-made beverages. The degree of degradation of complex carbohydrates affects this index of the product, while mono- and disaccharides increase it. Mineral salts being used for replenishment of electrolyte losses also contribute to the osmolarity of beverages.

In this regard, to optimize the carbohydrate-mineral composition of the products being developed, studies have been carried out to determine the osmolarity of solutions of carbohydrates and mineral salts, which, as a rule, form part of hypo- and isotonic drinks. Glucose and fructose, related to monosaccharides, have a high osmolarity, and its values increase directly in proportion to the concentration of solutions. Thus, 6% solutions of glucose and fructose have osmolarity of 309 and 341 mOsm/l, and the sugar solution of this concentration has an osmolality of 180 mOsm/l. The smallest osmolality is represented by solutions of maltodextrins (dextrose equivalent value of 18.9%): a 20% solution has an osmolality of 200 mOsm/l. In this regard, for the preparation of an isotonic beverage, it is necessary to use several carbohydrate components in ratios, which would provide both the optimal osmolarity and the content of carbohydrates required for the restoration of the organism.

To prepare beverages for the replenishment of the body with carbohydrates and salts, various concentrations of salt-electrolyte solutions are introduced into their formulation: calcium lactate, magnesium citrate, potassium citrate, and citrate and sodium chloride, which affect the osmolarity of drinks. Osmolarity of solutions of all salts should be in a direct proportion to their concentration [11].

The principles and strategies for carbohydrates intake in different phases of the training process are presented in Table 1. The data are from [12].

Proteins in the diet of athletes. Proteins are the main 'building' material of the body. They are part of the muscles, ligaments, skin, and internal organs, used as an energy source (1 g of protein ideally gives 4.46 kcal, however, given the cost of digestion, this figure decreases to about 3 kcal).

The protein of the food hydrolyses into the amino acids, which are then used as a 'building material' for body proteins. Therefore, the amino acid composition of the protein is of great importance, especially leucine, isoleucine, and valine. They are a kind of basis around which the entire metabolism of proteins is built. The proteins of milk, meat, and eggs are optimal in nutrition. Meat is rich in glutamine, eggs in methionine. The most balanced composition of the whey protein is cow milk protein (lactoalbumin) and protein contained in egg yolk. Besides, milk contains casein, which is less valuable as a food protein, but not much. Egg protein (albumin) is also a very valuable component of food. Protein-rich foods are eggs, chicken, turkey, cottage cheese, cheese, yoghurt, kefir, milk, lean beef, fish, beans (peas, beans, lentils), and nuts. The assimilation of proteins is essentially related to its structure. Milk and egg proteins, which are in solution in the form of separate molecules 'rolled up into tangles', are absorbed quite well. However, when we get cottage cheese from milk or cook eggs, a process of protein denaturation takes place, in which some of the bonds in the protein molecules are broken, especially the sulfide bridges and weak bonds between some amino acid residues. At the same time, their assimilation becomes more complicated. On the contrary, proteins contained in meat foods, when heat-treated, become more easily assimilated, although their nutritional value decreases. Soy proteins, which have high biological value and good digestibility, are optimal. Proteins of leguminous plants are better absorbed after a long treatment. Plant proteins are mostly obtained from seeds, where the protein is stored as a 'building material' for the future plant. The proteins contained in mushrooms are undesirable, because they are poorly absorbed by the body (because of their fibrous structure, the presence of carbohydrate residues, etc.).

Table 1. Summary of guidelines for carbohydrate intake by athletes

Situation		Carbohydrate targets	Comments on type and timing of carbohydrate intake
Daily needs for fuel and recovery: (1) The following targets are intended to provide high carbohydrate availability (i.e, to meet the carbohydrate needs of the muscle and central nervous system) for different exercise loads for scenarios where it is important to exercise with high quality and/or at high intensity. These general recommendations should be fine-tuned with individual consideration of total energy needs, specific training needs, and feedback from training performance. (2) On other occasions, when exercise quality or intensity is less important, it may be less important to achieve these carbohydrate targets or to arrange carbohydrate intake over the day to optimize availability for specific sessions. In these cases, carbohydrate intake may be chosen to suit energy goals, food preferences, or food availability. (3) In some scenarios, when the focus is on enhancing the training stimulus or adaptive response, low carbohydrate availability may be deliberately achieved by reducing total carbohydrate intake, or by manipulating carbohydrate intake related to training sessions (e.g,, training in a fasted state or undertaking a second session of exercise without adequate opportunity for refuelling after the first session).			
Light	– Low intensity or skill-based activities	3–5 g/kg of athlete's body weight/d	– Timing of intake of carbohydrate over the day may be manipulated to promote high carbohydrate availability for a specific session by consuming carbohydrate before or during the session, or during recovery from a previous session – Otherwise, as long as total fuel needs are provided, the pattern of intake may simply be guided by convenience and individual choice – Athletes should choose nutrient-rich carbohydrate sources to allow overall nutrient needs to be met
Moderate	– Moderate exercise program (e.g., ~1 h/d)	5–7 g/kg/d	
High	– Endurance program (e.g., 1–3 h/d moderate to high-intensity exercise)	6–10 g/kg/d	
Very high	– Extreme commitment (e.g., > 4–5 h/d moderate to high-intensity exercise)	8–12 g/kg/d	
Acute fueling strategies – These guidelines promote high carbohydrate availability to promote optimal performance during competition or key training sessions			
General fueling up	– Preparation for events < 90 min exercise	7–12 g/kg/24 h as for daily fuel needs	– Athletes may choose carbohydrate-rich sources that are low in fiber/residue and easily consumed to ensure that fuel targets are met, and to meet goals for gut comfort or lighter "racing weight"
Carbo-hydrate loading	– Preparation for events > 90 min of sustained/intermittent exercise	36–48 h of 10–12 g/kg body weight/24 h	
Speedy refueling	– < 8 h recovery between 2 fuel-demanding sessions	1–1.2 g/kg/h for first 4 h then resume daily fuel needs	– There may be benefits in consuming small, regular snacks – Carbohydrate-rich foods and drink may help to ensure that fuel targets are met
Pre-event fueling	– Before exercise > 60 min	1–4 g/kg consumed 1–4 h before exercise	– Timing, amount, and type of carbohydrate foods and drinks should be chosen to suit the practical needs of the event and individual preferences/experiences – Choices high in fat/protein/fiber may need to be avoided to reduce risk of gastrointestinal issues during the event – Low glycemic index choices may provide a more sustained source of fuel for situations where carbohydrate cannot be consumed during exercise
During brief exercise	– < 45 min	Not needed	
During sustained high intensity exercise	– 45–75 min	Small amounts, including mouth rinse	– A range of drinks and sports products can provide easily consumed carbohydrate – The frequent contact of carbohydrate with the mouth and oral cavity can stimulate parts of the brain and central nervous system to enhance perceptions of well-being and increase self-chosen work outputs
During endurance exercise, including "stop and start" sports	– 1–2.5 h	30–60 g/h	– Carbohydrate intake provides a source of fuel for the muscles to supplement endogenous stores – Opportunities to consume foods and drinks vary according to the rules and nature of each sport – A range of everyday dietary choices and specialized sports products ranging in form from liquid to solid may be useful – The athlete should practice to find a refuelling plan that suits his or her individual goals, including hydration needs and gut comfort
During ultra-endurance exercise	– > 2.5–3 h	Up to 90 g/h	– As above – Higher intakes of carbohydrate are associated with better performance – Products providing multiple transportable carbohydrates (Glucose:fructose mixtures) achieve high rates of oxidation of carbohydrate consumed during exercise

The 'ideal' protein contains 40 mg of isoleucine, 70 mg of leucine, 55 mg of lysine, 35 mg of methionine and cystine (in total), 60 mg of phenylalanine and tyrosine (in total), 10 mg of tryptophane, 40 mg of threonine, and 50 mg of valine (in 1 g).

Using the composition of the 'ideal' protein, one can calculate the content of essential amino acids in a given protein relative to the ideal one. This criterion is then used to assess the balance of the diet. Analysis of this indicator immediately reveals what amino acids will be missing in nutrition. For example, if the food lacks sulfur-containing amino acids, you can supplement the diet with egg whites. It should be noted that exercises impose requirements on the quality of the protein, and even interchangeable amino acids must come from food in sufficient quantities.

The indicator of the biological value of the protein (BV) is 'the amount of protein stored by the body when eating 100 grams of this protein food'. For the whey protein of cow milk (lactoalbumin, albumin) BV is almost equal to 100, for casein and soy proteins – 75, and for proteins of meat and fish – 80. For most vegetable protein BV is approaching 50. The exception is the protein contained in potato and nuts. The thermal processing of food leads to a drop in the biological value of the protein, but it is necessary, and not only because of the organoleptic properties of food: eating cheese, eggs, for example, can lead to salmonellosis, and raw milk – to intestinal disorders.

Another widely used criterion is the protein efficiency index (PEI). It is determined by the effect of this protein on muscle growth. Performance indicators for different proteins are also different, but here again whey protein remains the leader. The balance of amino acids and the optimal chemical structure are the most important characteristics of the protein.

The newest criterion for the quality of the consumed protein is the amino acid-adjusted digestibility index (PDCAAS). However, it does not take into account the significant difference in the nutritional value of proteins from different sources. Soy protein, caseinate, and egg white are the leaders – 1 (compare: beef – 0.92, peas – 0.69, canned beans – 0.68, oats – 0.8, canned lentils – 0.2, peanuts – 0.52, wheat –0.40, whole wheat gluten – 0.25).

Dietary protein during a workout acts as a trigger and substrate for the synthesis of contractile muscle fibers and metabolic proteins, and also contributes to structural changes in the ligament apparatus and bone tissue of athletes [13, 14]. Studies show that stimulation of the synthesis of muscle proteins in response to even a single sports load occurs for at least 24 hours, with an increase in sensitivity to the inclusion of dietary proteins in muscle tissue [15].

It is widely believed that the requirements for high physical loads in the protein are increased. It is believed that to increase endurance, it is necessary to compensate for the consumption of muscle protein consumed by oxidative processes. To increase strength, it is useful to give extra protein in order to build muscle mass (the so-called anabolic effect). At the same time, convincing scientific findings confirming these provisions have not been obtained at present (unlike the additional intake of carbohydrates, for which the effect of increasing stamina is a strictly proven fact). Moreover, giving hypothetical assumptions about the benefits of additional amounts of protein, one cannot ignore the obvious negative effects of its overdose, which can begin with a dose of 2–4 g of protein per 1 kg of body weight.

It is now established that, at high physical exercises, despite the increase in energy consumption, the need for protein does not increase very much. An adult who leads an average lifestyle should receive 11–12 % of the daily calorie intake from proteins (both animal and plant ones, approximately in equal proportions). In intensively trained athletes under certain conditions, the quota of protein intake can be slightly increased in comparison with these indicators.

A special role in the diet of athletes of any age and sports qualifications is given to protein products. Maintaining a balance between the synthesis, breakdown and re-synthesis of protein is the basis of physiological adaptation of athlete's muscles to stresses. The recommended protein intake for athletes varies from 1.2 to 2.0 g/kg per day. It is important to control not only the lack of protein in the diet, but also its excess, which affects not only the athletic performance, but also the safety for the body of athletes, especially young ones. Excessive consumption of protein can lead to osteoporosis, impaired renal function, and other pathologies.

The problem of protein dosing in athletes is still the subject of debates. One thing is clear that protein intake beyond these standards does not increase adaptation to the load [16].

It is now generally accepted that protein intake in the amount of 1.2–1.6 g/kg body weight per day provides the optimal amount of amino acids for growth, maintenance, and recovery of all tissues provided adequate calorie intake. In particular, it was shown that in actively trained cyclists (with more than 5900 kcal diurnal energy consumption), a positive balance of nitrogen is observed when the protein is consumed at 1.4 g/kg body weight, which is only 20–40% higher than the protein requirement among people who lead an average lifestyle [17, 18].

Studies have shown that protein synthesis in muscles is gradually optimized depending on physical loads by assimilating proteins with high biological value. Approximately 10 g of essential amino acids are included in the re-synthesis in the muscle tissue already in the early recovery period [14, 18], which is transformed into a recommended protein intake equal to 0.25–0.3 g/kg body weight or 15–25 grams per average weight of the athlete (60–80 kg). Higher doses of protein (e.g., > 40 g of dietary protein) do not have much effect and can be significant only for athletes with a large body weight or when weight loss is required [19].

The proportion of proteins of animal origin should be at least 60%, which provides the desired optimum for the amino acid composition. The remaining 40% should account for proteins of plant origin. In special cases, the proportion of animal proteins can be 80%: for example, during training, aimed at the development of speed-strength qualities, as well as increasing muscle mass, or performing long and intense training loads.

Minerals in sport. Mineral substances contained in food are extremely important for body's life. Thus, sodium is the main extracellular ion taking part in water transfer, blood glucose, generation and transmission of electrical nerve signals, and muscle contraction. Potassium is the main intracellular ion that takes part in the regulation of water, and acid and electrolyte balance. Chlorine is necessary element for the regulation of osmotic pressure, the formation of gastric acid (chloride ions concentrate mainly in the extracellular fluid).

With intensive training and increased sweating, additional sodium intake (in the form of salt) is recommended to prevent seizures. Excess sodium negatively correlates with the calcium content. The constancy of osmotic pressure and the constancy of the volume of fluid are important interrelated processes of the body. The change in the amount of salts in the body (their retention or loss) is associated with the corresponding compensatory changes in the volume of the liquid. Sodium regulates fluid balance in the intercellular space. Sodium ions are largely responsible for the distribution of water in the body. Consequently, the increase or decrease in sodium ions leads to a proportional fluid retention or loss. The constancy of the osmotic pressure is maintained by changing the volume of the liquid. Sodium also participates in the transport of amino acids, sugars, and potassium.

Most products, such as cheese, bread, meat products, fish, vegetables, and canned foods contain sodium chloride.

The main part of sodium and chlorine ions is excreted from the body with urine, and with intensive work, physical exertion, especially in conditions of elevated ambient temperatures, with sweat. The demand for sodium sharply increases during physical exertion (long-distance running, marathon, etc.). In this case, it is necessary to increase the amount of salt consumed, taking into account the food content of up to 20–25 g per day [20]. Sodium chloride is widely used as an additive to food. The intake of sodium chloride with food can fluctuate significantly. With excessive consumption of sodium chloride in the body, the liquid is retained. Increased salt intake is one of the main risk factors for the development of arterial hypertension [21], including in athletes.

At the same time, it should be noted, that to avoid the risk of dehydration and reduce performance people, who are engaged in heavy work or exertion, one should use drinks containing carbohydrates and electrolytes during and after physical activity. The use of dilute solutions of carbohydrates and electrolytes (including sodium chloride because of its loss with sweat) has a more favorable effect on the recovery of the organism under severe working conditions than the use of water only [22, 23].

With short physical exertion, there is no need to consume additional amounts of sodium. Evidently, the compensation of the losses of this electrolyte acquires in the course of prolonged heavy physical exertion, to maintain its concentration in the blood plasma and the osmotic pressure. Specialized food products, including beverages, can be used.

The sodium concentration in such beverages varies generally between 20 and 40 Mmol/l. The purpose of adding this electrolyte is not only to recover its reserves. It pursues the goal of maintaining the volume of extracellular fluid, increasing the rate of absorption of water and glucose in the small intestine. Moreover, the addition of sodium to the drink contributes to the desire to drink, and this can increase the amount of fluid consumed, which is favorable for maintaining the volume of extracellular fluid [24, 25].

The inclusion of various carbohydrates in beverages, including glucose, sucrose, and maltodextrin, has certain advantages both in terms of the rate of absorption of water and sugars, as well as in improving the taste of the drink [26]. Taste sensations play an important role, since they can affect the amount of drink consumed.

Thus, with heavy physical exertion and unfavorable environmental factors (high temperature), dilute solutions remain the advantage. In most situations, a carbohydrate concentration of 2–8% is recommended. As noted above, in practice, mixtures of various carbohydrates are often used, including free glucose, sucrose, maltose, and maltodextrin.

The addition of fructose is permissible, but it is worthwhile to avoid the use of high concentrations or fructose alone, since fructose absorption is worse than glucose, and, ultimately, high doses can lead to a risk of diarrhea. Rehydration after physical exertion is an important part of the recovery process. To compensate for losses, it is recommended to use a volume of liquid that exceeds by at least 50% its amount lost with sweat [27]. In order to quickly restore the body's resources, dilute solutions of glucose with the addition of sodium chloride are used, since these hypotonic solutions are most effective in reducing the retention in the stomach and absorption in the intestine.

Replenishment of fluid loss in the body of athletes should occur due to regular compliance with the drinking regime. It is shown that the loss of 9–12% of water is an emergency situation for the body and can lead to death. Loss of 2% of weight due to water reduces the workability by 3–7%, while with the loss of 40% of protein, fat and carbohydrates, a person can stay alive for a long time. In severe physical exertion it is necessary to monitor the state of the water balance and continuously replenish the fluid loss. Water comes in with liquids and foods and as a result of metabolic processes. The first way gives about 60% of the total water consumption, the second one – 30% and the third – about 10%. There are also different ways of removing water from the body. 50–60% of water per day is discharged with urine, about 20% - with exhaled air, 15–20% with sweat (depending on the intensity of exercise), and less than 5% – with feces. The average person needs about two liters of water a day to make up for the losses. With intensive loads, expenditure increases, reaching 3–4 l per day. It is proved that when the volume of fluid in the body decreases by 2%, the athlete's result may deteriorate by 15%.

Biochemical and physiological recovery of the body begins immediately after physical activity. The most efficient way to compensate for the loss of a large amount of water and salts can be with the help of weakly acidic and slightly sweet mineralized drinks, and the hypo-and isotonic solutions of carbohydrate-mineral complexes which are the most physiological.

CONCLUSION

Optimization of nutrition of athletes is very important for the nutritional support in all sport specializations. Macronutrients as well as minerals and vitamins are functionally active components, especially in endurance sport. Optimal uses of diets, including specialized sport nutrition, improves biochemical, immune, and endocrine body's functions and restores energy balance at different stages of sport exercises. Nutritional factors are one of the most important key factors in the risk prevention measures for a large number of diet-dependent diseases (e.g. digestive, liver, pancreas, cardiovascular system, endocrine system, kidney diseases).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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