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Review article

A review of ergogenic nutritional supplements for athletes

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Abstract

Ergogenic supplements are defined as substances that contribute to or support the doing or production of a job. These supplements are used for many purposes such as increasing the performance of athletes, accelerating recovery in athletes, improving capacity, and reducing and preventing muscle injuries and muscle fatigue. Ergogenic supplements, which are of great interest to athletes and trainers, are classified as nutritional aids, pharmacological aids, psychological aids, mechanical and biomechanical aids, and physiological aids. Among these supplements, they are the most actively used nutritional aids and attract attention in the market as muscle-building nutritional supplements, weight-reducing nutritional supplements, performance-enhancing nutritional supplements, and general health-promoting nutritional supplements. Protein and amino acids provide benefits in long-term or short-term explosive power activities. Fats are used as the main fuel in long-term aerobic exercises. In addition, caffeine, ginseng, antioxidants, and coenzyme Q10 also serve as ergogenic nutritional supplements. It has been reported in studies that minerals such as B, C and E vitamins, chromium, magnesium, iron, and zinc affect sports performance in a good way. In case of deficiency of the aforementioned vitamins and minerals in athletes, many negativities occur. In this study, the use of ergogenic nutritional supplements by athletes before, during, and after training was compiled using the current literature on the types of these supplements.

Introduction

The protection and improvement of the performance of the athletes before, during, and after the exercise depends on the optimal water balance and the consumption of macro and micronutrients at the same time, but it is known that the purpose of the use of ergogenic support is to maximize the sports performance in the athletes and to prevent possible injuries and to increase the recovery after sports [1]. In this regard, ergogenic optimal body mass is specific to their sports and eliminates deficiencies in the body [2]. Ergo or ergon, which forms the word ergogenic, means work in ancient Greek, and genic means produced or born. Ergogenic supports can be explained as substances and methods that contribute to and support doing or producing a job [3]. Generally, these are in the form of tablets, gels, powders, or liquids, and they are in the form of nutrients that are taken naturally into the body with daily nutrition. In order to increase and maintain performance during exercise, it depends on many dietary factors such as the intake of micro and macronutrients compatible with energy and water balance [4]. Ergogenic supports are frequently preferred by athletes in order to increase endurance and strength, to achieve targeted performance quickly, to prevent injuries that may occur during Ergogenic supplements can be considered as substances or methods such as certain minerals, vitamins, herbs, amino acids, metabolites, and other combinations. These

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substances or methods are used as additional supplements to the diets of athletes in order to provide appropriate energy, balance of systems, lean body mass, and muscle development [1]. Table 1 shows the mechanisms of action of some ergogenic supplements [5]. The mechanism of action of ergogenic supplements is based on stimulating the central or peripheral nervous system and can be listed as reducing/neutralizing metabolic by-products that cause restriction and facilitating recovery after heavy exercise [6]. There are five classifications of ergogenic supplements mechanical or biomechanical, psychological, pharmacological, physiological, and nutritional [5]. The methods or substances that aim to increase personal performance, strength, work efficiency, and success in individuals. It can be found in mechanical such as field, shoes, clothes, and vehicles, which are the materials used by people who do exercise and sports, physiological such as massage and sauna, pharmacological such as attention and energy-increasing drugs, psychological and motivational therapies such as psychological and nutritional aids that increase general health by increasing muscle mass [7].

Focusing on sports pharmacology can help future athletes improve and improve their quality of life by using a variety of drugs and other substances within certain limits and avoiding doping. Some of the more popular and interesting preferred substances and drugs are discussed [8]. Prescription and over-the-counter drugs, illicit drugs, and dietary supplements are substances that are claimed to have ergogenic potential. Some drugs known as doping or pharmacological ergogenic aids have been used to improve physical and psychological changes in athletes [5]. Doping can be defined as the use of substances or methods prohibited by the International Olympic Committee (IOC) by athletes to maximize the mental and physical performance of the athlete during exercise or competition. Since the side effects of doping are as important as their effects, overdose and long-term use of drugs for doping in healthy individuals constitute very serious health problems that can result in death [9]. Performance-enhancing drugs can be evaluated in several broad categories: improving concentration and alertness, increasing strength and explosiveness, improving the oxygen-carrying capacity of the blood, increasing athlete's recovery and rehydration, and improving inflammation and pain [10]. It is often difficult to detect most of the substances that violate sports performance ethics. It can be technically difficult to detect, especially if the substance is a naturally occurring compound of testosterone, erythropoietin, etc. Although methods exist to control the use of any of them, no test is 100% reliable. At the same time, ethically, doping is a social problem that quickly distorts the individual, pushing them towards corrupt practice and behavior contrary to the goals and objectives of sport [8].

Table 1: Mechanism of action and examples of some ergogenic supplements for sports.

Mechanisms	Examples for supplements
Providing energy substrate	Carbs: Energy for aerobic glycolysis Creatine: Phosphocreatine synthesis
Developing metabolic pathways by producing energy	B Vitamins: Coenzymes in glycolysis Iron: Oxygen transport and use
Enhances cardiovascular-respiratory systems function	Glycerol: Increases blood volume Sympathomimetics: Increases bronchodilation
Increase the size or number of energy-producing cells	Anabolic steroids: Increases muscle cell size Erythropoietin: Increases the number of red blood cells
Reduces metabolic byproducts associated with fatigue	Sodium bicarbonate: Buffer lactic acid Aspartate salts: Reduces ammonia accumulation
Prevents the catabolism of energy-producing cells	Antioxidants: Prevents lipid peroxidation Ginseng: Reduces physical stress (adaptogens)

Examples of physiological aids such as sodium bicarbonate, use of oxygen, creatinine, carnitine, phosphate salts, sodium citrate, and blood infusion are given as ergogenic support. Physiological ergogenic aids are used to directly improve specific physiological processes important for sports performance. They affect the functions of various places such as the cardiovascular system, and musculoskeletal system, and cause an increase in sports performance of people [5]. Sauna and massage are the preferred physiological aids for a quick recovery process after training or competition. In addition, the massage method is used for pre-training. The purpose of such aids is to prevent injuries that may occur by warming the athletes and to help the treatment of injuries [11].

The sports world is full of supplements to provide the athlete with a good performance advantage. References and advertisements claim that nutritional supplements are used for many reasons, such as long-term endurance, increase in muscle mass and lean mass, balancing body fat ratio, speeding up recovery after exercise, improving performance, and building resistance against diseases and infections [12]. Nutritional ergogenic aids; protein and carbohydrate supplements, melatonin, glutamine, coenzyme Q10, creatine, fish oil, garlic extract, ginseng, caffeine, bee pollen, linoleic acid, sports and energy drinks, vitamin and mineral tablets [7].

In this review, the use of ergogenic nutritional supplements by athletes before, during, and after training was compiled by the current literature on the types of these supplements.

Nutritional ergogenic supplements

Many foods can be said to be ergogenic when taken in high doses. Foods, nutritional supplements, special diets, and nutritional practices used by athletes can be called nutritional ergogenic supplements. Studies with athletes show that many consume supplements in the belief that they have ergogenic potential, often in much higher doses than those obtained in normal diets because the foods are considered legally ergogenic [11]. Nutritional ergogenic aids primarily aim to increase performance by affecting energy metabolism or by affecting the central nervous system, increasing lean body mass or muscle mass by stimulating protein synthesis and reducing body fat content, gaining strength, increasing endurance, delaying fatigue, and rapid recovery of the body after training [13]. Table 2 shows some nutritional ergogenic supplements along with examples [7,14]. Major categories targeting physically active individuals are mega doses of essential vitamins, metabolic by-products of essential nutrients, nutraceuticals or phytochemicals, and non-drug substances from plants that are claimed to affect metabolism. Substances such as ginseng and

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Table 2: Some compounds of nutritional ergogenic supplements and their examples.

Compounds	Examples
Protein and amino acids	Arginine, aspartate, BCAAs, carnitine, creatine, glutamine, glucosamine, lysine, ornithine, b-hydroxy-b-methylbutyrate, whey protein, casein protein, soy protein
Oils	Medium chain triglycerides, Omega-3
Vitamins and Minerals	Iron, calcium, vitamins C and E, beta carotene, B vitamins
Sports Drinks	Hypotonic drinks, hypertonic drinks, isotonic drinks, milk, juice, energy drinks
Other Substances	Taurine, inositol, caffeine, carotenoids, coenzyme Q10, ginseng, antioxidants, tannins

creatine and pharmaceutical nutrients are diversified as legal substances naturally found in food or beverages consumed by humans, such as alcohol and caffeine [14-16].

Protein and amino acids

It is known that protein, whose building blocks are amino acids, has many functions in our body. Proteins differ according to the source from which the protein is obtained and the amino acid profile of the protein [17]. Meat, eggs, poultry, and fish as animal sources of protein; as for vegetable sources, foods such as cereals, legumes, and oil seeds are given as examples. The recommended daily requirement for protein in healthy individuals averages 0.8 g/kg/day in adults, 1.5 g/kg/day in children, and 1.0 g/kg/day in adolescents [18]. Apart from timing and quality, daily total protein intake is important for performance and body composition gains. Protein supplements are frequently consumed by athletes and recreationally active adults to achieve greater gains in muscle mass and strength and to improve physical performance [19]. Despite the recognition that athletes need additional protein, some athletes are well-fed enough to meet it from their diets. Additional protein needs are generally found in products such as whey protein, casein protein [KP], and soy protein [SP], mostly in milk and powder form [6,7].

Supplementation with many amino acids, especially arginine, ornithine, and lysine, is used in attempts to stimulate Human Growth Hormone [hGH] release [16]. Increasing serum hGH levels can stimulate the production and release of insulin-like growth factor-1. In this case, it can cause an increase in muscle mass and strength. On the other hand, amino acid supplementation is used to stimulate the release of another anabolic hormone, insulin. Both glutamine and arginine play a role in immunity [20]. Glutamine is known to be highly utilized by immune system cells, including neutrophils, lymphocytes, and macrophages, and is a precursor to glutathione, an antioxidant that protects cells from free radical damage. Glutamine supplementation increases muscle glycogen synthesis and reduces exercise-induced ammonia accumulation, especially when administered long-term (more than 5 consecutive days). However, more research is needed to determine a greater effect of glutamine compared to supplements containing carbohydrates or creatine monohydrate regarding glycogen synthesis. Arginine's involvement as a precursor to creatine and its potential to increase endogenous hGH make it a popular supplement among those seeking to improve their physical performance. These two amino acids are important amino acids for individuals who want to increase and develop muscle mass. They are known for their ability to stimulate hGH secretion and protein synthesis either directly or through an unmediated increase in muscle blood flow [21,22]. Glutamine blood levels above 750 mmol/L in athletes indicate high-dose supplemental glutamine intake whereas high-dose intake of glutamine is considered to be > 30 g/day [22]. For athletes, arginine intake of more than 9 g/day is accepted as a high dose [21].

Milk proteins and soy protein are the main protein sources used in sports nutrition products [20]. The two main sources of protein in milk are caseins and Whey Protein (WP), the casein is responsible for curdling, and WP which refers to the watery part of milk, also the amino acid profile of WP is almost identical to that of skeletal muscle. WP provides nearly all the correct amino acids in their ratio in skeletal muscle. WP supplements are also the richest known source of Branched-Chain Amino Acids (BCAAs); leucine, isoleucine, and valine which for the athlete play an important role in muscle metabolism [23,24]. BCAAs are oxidized by muscle during exercise to provide energy after short-term glycogen stores are expanded. He points out that the leucine and isoleucine structure is actually oxidized by muscle. However, the metabolism of valine also provides important tricarboxylic acid cycle intermediates that help meet the increased energy demand for exercise [20]. There are 3 commonly used forms of WP hydrolysis form in which peptides are separated into amino acids, WP isolate form in which almost all lactose is isolated, and WP concentrate form, which is widely available in the market [7]. WP supplements are supported as part of weight loss and weight maintenance diets and in addition to endurance and resistance exercises to improve and enhance body composition. In conclusion, supplementation of 20 g of WP daily during resistance and endurance exercises is an effective strategy to increase gains in lean body mass in young, healthy, untrained men and women consuming slightly higher than recommended protein levels [25]. Another supplement, b-hydroxy-b-methylbutyrate, is a metabolite of ketoisocaproate and the amino acid leucine [20]. It is a dietary supplement originally used to increase muscle mass and reduce subcutaneous fat in livestock. Creatine, on the other hand, is a nutritional supplement used by athletes to increase strength gains in the center of gravity, exerting an impact on performance when muscle creatine levels rise significantly, but also enhancing muscle performance in short-term, high-intensity resistance exercises that rely heavily on the phosphocreatine shuttle for ATP. However, it has been observed that creatine supplementation can improve performance in field-type activities such as running and football [21,22]. Weight gain that can be observed with creatine intake is not indicated as a side effect, as it can be both a negative effect and a benefit depending on the sport in which the supplement is taken. Creatine is an amino acid found naturally in the daily diet in meat content. 1 kg of fresh beef contains about 5 grams of creatine. Studies have shown that intramuscular stores of total creatine and phosphocreatine can be increased by supplementing with oral creatine monohydrate at a dose of 20-25 g.d-1 for 5-7 days [25]. Carnitine, another potentially ergogenic nutritional supplement, is very popular among athletes of any performance category. Carnitine exists in tissues and fluids in esterified forms as short-chain and

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Table 3: Biological functions of some vitamins with their features and symptoms of their deficiency are presented.

Vitamins	Features	Symptoms of their deficiency
Thiamine (B1)	Carbohydrate and amino acid metabolism	Weakness, decreased stamina, muscle loss, weight loss
Riboflavin (B2)	Oxidative metabolism, electron transport system	Altered skin, mucous membrane, and nervous system function
Niacin (B3)	Oxidative metabolism, electron transport system	Irritability, diarrhea
Pyridoxine (B6)	Gluconeogenesis	Dermatitis, convulsions
Cobalamin (B12)	Hemoglobin formation	Anemia, neurological symptoms
Folic acid (B9)	Hemoglobin and nucleic acid formation	anemia, fatigue
Ascorbic acid (Vitamin C)	Antioxidant	Fatigue, loss of appetite
Retinol (Vitamin A)	Antioxidant	Susceptibility to infections and loss of appetite
Tocopherol (Vitamin E)	Antioxidant	Nerve and muscle damage

long-chain acyl-carnitines, and they maintain L-carnitine balance in the body (liver, kidneys, and brain) through biosynthesis [26]. They can meet about 75% of L-carnitine from dietary intake mainly by consuming animal-based food products. L-carnitine has an important role in fat metabolism. During the night fasting state, at rest, and during low to moderate-intensity exercise, long-chain fatty acids represent 80% of energy sources [27]. Carnitine has been widely used among wrestlers and other athletes where rapid reduction of body weight is important. According to some manufacturers, carnitine reduces body weight and saves energy at the same time. In general, protein supplements in sports are nutritional supplements that are very popular and positively evaluated throughout the literature, especially among individuals who do sports, to increase performance, lean muscle mass, and recovery in athletes [18].

Lipids and fatty acids

The use of lipids as an energy source during prolonged exercise is very important as they are broken down as triglycerides in adipose tissue, skeletal muscle, and plasma in the body. It is the primary organic energy storage, up to 60 times higher compared to glycogen. It has also been suggested that the ability to sustain exercise may be prolonged if the lipid supply is increased just before exercise since the rate of fatty acid oxidation is directly related to serum concentration levels [28].

Long-chain n-3 polyunsaturated fatty acids (PUFAs) continue to receive significant research interest as a potential ergogenic aid in the context of enhancing sports performance. The general rules for the majority of athletes, especially at the leisure level, are as follows: Fish oils should contain approximately 1-2 g/day of EPA (Eicosapentaenoic acid) and DHA (Docosahexaenoic acid) in a 2:1 ratio from EPA to DHA [29]. The background diet should balance the relationship between n-6 and n-3 PUFA by reducing n-6-rich oils such as corn oil, sunflower, safflower, cottonseed, and soybean oils. Applications of n-3 PUFA supplementation for sports performance apply to athletes from strength, endurance, and team-based sports, with recommendations tailored to the athlete's specific performance goals [30]. Based on current scientific evidence, n-3 PUFA supplementation has properties such as improving muscle and energy metabolism, promoting muscle recovery, and preventing injury. In addition to having many health benefits, intense exercise can cause oxidative damage to cellular components [29]. Skeletal muscle mostly produces free radicals, unstable molecules that oxidize other molecules to become stable in basal conditions, and this production increases during contractile activity. In this regard, omega-3 PUFAs may provide various advantages to athletes by reducing the formation of oxidative stress and thus improving muscle performance and immune function [31]. Taking omega-3 PUFA as a supplement for > 2 g/day is considered a high dose for athletes [30]. On the other hand, omega-3 PUFA supplementation opens up mTOR-related signaling proteins that play a role in stimulating muscle protein synthesis, increases oxygen efficiency during endurance exercise, and has a role in the daily recovery of team sports athletes to reduce muscle soreness and decrease muscle function. Because ergogenic aids can help an individual prepare for exercise, increase exercise efficiency, improve recovery after exercise, or prevent injury during intense training, omega-3 has a role in these processes, not only preventing exercise-induced inflammation but also improving muscle health and energy availability [29-31]. It has therefore been considered an ergogenic supplement. The specific physical and chemical properties of Medium-Chain Triglycerides (MCT) have been used in enteral and parenteral nutrition for the last 40 years. Drawing on results from clinical practice, some researchers have led to the use of MCT for ergogenic purposes. MCTs are composed of fatty acids with 6 to 12 carbon atoms in their chains [32]. MCTs group generally consists of caproic acid (C6:0, hexanoic acid), caprylic acid (C8:0, octanoic acid) and capric acid (C10:0, decanoic acid). MCTs are produced by hydrolysis of coconut or palm kernel oil and filtering and subsequent re-esterification of medium-chain fatty acids [33,34]. MCT does not delay gastric emptying but is absorbed faster in the intestine than long-chain fatty acids and is transported through the blood to the liver. MCTs are seen as an ideal energy source for prolonged exercise, as their metabolic rate is similar to glucose, which helps prevent the intake of both carbohydrates and MCTs from lowering glucose serum levels that typically occur during longer exercise [28]. MCT has positive effects on exercise performance. This is due to their rapid metabolism, their non-accumulation in adipose tissue, and their rapid passage into the body. This leads to increased energy expenditure and earlier satiety, which helps prevent overconsumption. The best experimental performance with carbohydrates and MCT is observed by observing the reduced glycogen oxidation state [35].

Vitamins and minerals

Adequate overall nutrient intake, including the proper

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balance between macronutrients and micronutrients, is essential for optimal physical performance. Vitamins and minerals are essential micronutrients for hundreds of metabolic reactions in the body, including those involved in energy metabolism. Vitamin and mineral requirements differ depending on variables such as metabolic, environmental, or genetic factors. Although studies do not provide conclusive evidence that athletes should use vitamin and mineral supplements for optimal performance, many athletes use vitamin and mineral supplements despite consuming adequate amounts of food sources [36,37]. Table 3 presents some vitamins used as ergogenic supplements and their biological functions [38]. Vitamin C exists in two forms: L-ascorbic acid or L-dehydroascorbic acid as the oxidized form. Ascorbic acid is known as the most important water-soluble antioxidant vitamin and it easily donates electrons, that is, it has reducing agent properties [39]. Vitamin C has certain biological functions that can affect physical performance. Carnitine and catecholamines, which transport long-chain fatty acids to the mitochondria, are required for epinephrine and norepinephrine synthesis, collagen synthesis, iron absorption, serotonin production, antioxidant function, and adrenal hormone release [38]. Doses of approximately 0.2 g per d^{-1} of vitamin C, consumed with five or more servings of fruit and vegetables per day, may be sufficient to reduce oxidative stress and provide other health benefits without impairing training adaptations. Due to its water-soluble nature, ascorbic acid cannot be stored in large quantities in the body, so most of it is transported in the plasma. Therefore, it appears that if vitamin C is effective in protecting against muscle damage, a single dose administered at an appropriate time may provide protection in raising plasma levels [39].

Vitamin E is a fat-soluble antioxidant vitamin that is absorbed in the small intestine and is available in eight different natural forms [40]. Vitamin E is found in almost all cell membranes, but the main reservoir of membrane-bound vitamin E is in the inner mitochondrial membrane, where the electron transport system is located. Vitamin E may play different roles in the oxidative metabolism of different muscle fibers. Human skeletal muscle consists of two main fiber types, type I (red, slow twitch) and type II (white, fast twitch). Type I fibers are abundant in myoglobin and mitochondrial enzymes and produce phosphocreatine more efficiently than type II fibers via oxidative phosphorylation. For this reason, it is also noticed that type I fibers can use more vitamin E than type II fibers [38]. As a result, it can be said that vitamin E is a key nutrient in supporting physical performance.

Thiamine, riboflavin, and pyridoxine are water-soluble B-complex vitamins. Various animal and plant products contain these vitamins. Thiamine is abundant in lean pork, yeast, legumes, and enriched cereals and breads. Riboflavin is found in eggs, lean meat, milk and dairy products, broccoli, and fortified breads and cereals. Pyridoxine is rich in meats, particularly in plant foods such as chicken and tuna, beans, cereals, and brown rice [41]. B vitamins are very important in physical exercise as they play a role in the regulation of energy metabolism by modulating the synthesis and breakdown of carbohydrates, fats, and proteins. Folate, one of the B vitamins, is reduced to tetrahydrofolate, which acts as an essential cofactor in methylation reactions, including the formation of vitamin B12-dependent methionine from homocysteine, and as a carrier of one-carbon units in the synthesis of purines. Folate deficiency causes abnormal cell replication, especially in the erythropoietic system, resulting in megaloblastic anemia. This type of anemia is also caused by a lack of vitamin B12. In the presence of B12 deficiency, additional folate can correct megaloblastic anemia but not B12 deficiency [38,42]. As thiamine pyrophosphate, another B-group vitamin, thiamine plays an important role in the metabolism of both carbohydrates and BCAAs. It is a coenzyme for pyruvate dehydrogenase (lipoamide), which catalyzes the conversion of pyruvate to acetyl CoA. Thiamine requirements are associated with energy metabolism, and physical activity emphasizes this energy metabolism and energy-producing metabolic pathways [41]. In addition to these, thiamine intake > 4 mg/1000 kcal is considered a high dose for athletes.

Mineral supplements are among the most common supplements used by athletes and active people. At least 20 different minerals are required in sufficient quantities to maintain the normal function of tissues and cells [43]. Most of these are only required in trace amounts, but some must be supplied in larger quantities. Minerals are important for various metabolic and physiological processes in the human body [16]. It has been observed that the physiological role of minerals, which are important for athletes, plays a role in muscle contraction, regulation of normal heart rhythm, nerve impulse transmission, oxygen transport, oxidative phosphorylation, enzyme activation, immune functions, antioxidant activity, bone health and acid-base balance of the blood. Since many of these processes are accelerated during exercise, adequate mineral intake is important for athletes for optimal functioning [44]. Athletes prefer to use mineral supplements to increase and improve sports performance, prevent diseases, gain strength in rigorous training, and compensate for weakness and malnutrition. Some minerals have effects on blood formation and bone development [38]. These effects provide the athlete with an advantage in improving sports performance. In Table 4, some minerals used as supplements in sports are shown with their properties and deficiency symptoms.

Magnesium has become one of the most used supplements to improve athletic performance. Great attention and importance is given to magnesium homeostasis in athletes. Magnesium plays a vital role in regulating energy metabolism, acting as a cofactor and activator for enzymes involved in more than 300 enzymatic reactions where food is metabolized and new products are formed. It also plays an important role in calcium metabolism and the maintenance of electrical gradients across nerve and muscle cell membranes. Dietary sources of magnesium include green, leafy vegetables and unprocessed grains, although some water sources can also be sources of magnesium [45]. It is suggested that fluctuations in blood magnesium levels are closely related to different types of exercise. Short-term exercise typically increases the concentration of magnesium in the blood, while long-

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Table 4: Biological functions of some minerals with their features and symptoms of their deficiency are demonstrated.

Minerals	Features	Symptoms of their deficiency
Magnesium	Energy metabolism, nerve conduction, muscle contraction	Muscle weakness, nausea, irritability
Iron	Hemoglobin synthesis	Anemia, cognitive impairment, immune abnormalities
Zinc	Nucleic acid synthesis, glycolysis	Anorexia, growth retardation, immune abnormalities
Chromium	Glucose metabolism	Glucose intolerance

term strenuous exercise can lower blood magnesium levels. Therefore, intense physical exercises such as marathons and triathlons may result in greater magnesium loss from whole body parts. Magnesium deficiency is often recommended as a solution to exercise-induced muscle cramps. In some countries, this idea is very stable, even though the same products are sold without adding magnesium salts in other countries, in most countries sports drinks for athletes are always sold with the addition of magnesium [46].

Iron is known as an essential trace element that is required for oxygen delivery to tissues and oxygen utilization at cellular and subcellular levels. It functions as a functional component of iron-containing proteins, including hemoglobin, myoglobin, cytochromes, and specific iron-containing enzymes. Iron plays a critical role in energy use during exercise. Although iron deficiency anemia is a frequently discussed topic, iron overload can potentially become a problem in male athletes, especially since men typically consume more energy than women [36,38]. For athletes, supplementary zinc intake of more than 40 mg/day and iron intake of > 35 mg/day are considered high doses while magnesium intake as supplementary for men > 350 mg/day and for women > 280 mg/day are counted as high amounts [38].

Zinc plays a role as a cofactor in many enzyme reactions and has many roles, including promoting tissue repair processes. It also has regulatory roles in various aspects of hormone metabolism, including the production, storage, secretion, and regulation of interactions between hormones and receptors, and end-organ response. Most of the body zinc content of about 2 g is found in muscle (60%) and bone (30%) [16]. Low concentrations are found in sweat and exercise can stimulate urine loss. Sufficient zinc is required for the integration of many physiological systems, such as immunity, reproduction, taste, wound healing, skeletal development, behavior, and gastrointestinal function. Since copper is found in a wide variety of foods, including shellfish, liver, whole-grain cereals, legumes, and nuts, its deficiency is rare, as it can be found in the daily diet [38].

Other compounds of nutritional ergogenic supplements

Caffeine (1,3,7-trimethylxanthine) is one of the most commonly used ergogenic supplements in the world which is now in multiple recent products, including energy drinks, sports gels, alcoholic beverages, and diet aids [47]. It can be a potent ergogenic aid at levels well below the IOC's acceptable limit. Caffeine reduces the perception of fatigue during exercise and increases the desire to prolong exercise, while also increasing plasma concentrations of cortisol and β-endorphin in response to exercise. On the other hand, it potentially alters perceptions of pain and promotes euphoria. Given that toxic doses of caffeine are required to increase skeletal muscle contractility, the binding of caffeine to adenosine receptors is likely considered the primary physiological mechanism of caffeine's ergogenic effects [48]. According to IOC, the limit for caffeine in urine at 12 µg/mL urine. The permissible limit for exceeding the stated limit is up to 6 cups of coffee 1 hour before exercise. On the other hand, it is recommended that athletes should stay away from caffeine before and during competitions, even in low doses, as it may cause unfair competition in competitions [47,48].

Coenzyme Q10 is known as a lipid-soluble, vitamin-like substance found in the hydrophobic interior of the phospholipid bilayer of almost all cell membranes, primarily used in the treatment of various disorders related to suboptimal cellular energy metabolism and oxidative injury. In many mammalian species, it consists of a quinone head attached to a chain of 9 or 10 isoprene units. The best-known function of CoQ10 is to increase mitochondrial activity related to ATP synthesis. Also, CoQ10 supplementation has the potential to reduce tissue damage and oxidative stress associated with strenuous exercise in athletes [49]. Chronic consumption of relatively high doses of CoQ10 in the diet may increase CoQ10 concentrations, particularly in the mitochondrial fractions of the heart [50]. However, there is no absolute relationship between the increase of CoQ10 in plasma and muscle tissues. Overall, although the data are not conclusive, CoQ10 supplementation appears to be an important supplement in healthy or diseased individuals when used to optimize exercise performance [49,50].

Ginseng is one of the most well-known and researched herbal ergogenic supplements due to its beneficial psychophysiological effects that help improve endurance capacity, strength, nerve functions, immune system, and psychological parameters without any harmful effects on the body [51,52]. Known as a stimulant of brain and nerve functions, ginseng also has anti-inflammatory and antioxidant properties. It is one of the supplements used to prevent muscle damage, improve performance, and minimize fatigue in athletes. In one study, low (< 300 mg/day) and high (> 300 mg/day) dose-response for short-term (up to 4 weeks) and long-term (> 4 weeks) were examined to determine the effect of ginseng on physical performance level, vertical jump, etc. Ginseng showed significant short-term effects at high doses for vertical jump progress in athletes [52]. On the other hand, it was concluded that acute supplementation of 200 mg ginseng did not affect the heat endurance running performance of heat-adapted male recreational runners [51].

Conclusion

Proteins/amino acids, fats, vitamins, minerals, and other

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substances such as ginseng, coenzyme Q10, and caffeine known as nutritional ergogenic supplements, can increase performance, lean body mass or muscle mass, and body fat content with a regular and balanced diet. In addition to these, they can help to gain strength, increase endurance, delay fatigue, and allow the body to recover quickly after training. Especially, adequate dietary intake of vitamins and minerals is important in order to maintain the function of tissues and cells in a healthy individual. It appears that vitamins and minerals are very important for the health and physical performance of athletes, and no micronutrient is more important than others. Doping, known as substances or methods banned by the IOC, is known to depress the athlete mentally or physically during exercise. However, apart from this effect, doping substances can cause serious health problems as a result of high doses and long-term use. In short, it is understood that balanced and regular nutrition and ergogenic supports have a positive effect on athlete performance, while the use of doping substances causes health problems in athletes.

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