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Advances in the study of sports nutritional supplements to enhance athletic performance

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ABSTRACT
With the increasing emphasis on health and sports, enhancing sports performance has become the focus of attention for many athletes and sports enthusiasts. Sports nutrition supplements, as an important auxiliary tool to enhance sports performance, have received extensive attention in scientific research and practical application in recent years. In this paper, we systematically review the mechanism of action and the latest research progress of mainstream sports nutrition supplements, such as proteins, creatine, caffeine, β-amino acids, nitrates, etc., and discuss their effectiveness, safety and individualized application in different sports scenarios. It was found that the scientific use of supplements can significantly improve the efficiency of strength, endurance and recovery, but it needs to be combined with the type of exercise, dose optimization and individual differences. Future research should focus on the development of novel supplements, precise nutritional strategies, and the evaluation of long-term health effects.

KEYWORDS
Sports nutrition supplementation; Athletic performance; Creatine; Protein; Personalized nutrition

1 Introductory

Sports performance covers a wide range of dimensions such as strength, speed, endurance, agility, coordination, etc., and is a reflection of an athlete's comprehensive ability in training and competition. In the context of the pursuit of higher, faster and stronger competitive sports, as well as the public's pursuit of health and good sports experience, sports nutrition supplements have attracted much attention for their ability to help athletes and sports enthusiasts break through their physical limits and enhance their sports performance to a certain extent. The proper use of sports nutrition supplements can replenish the capacity and nutrients consumed during exercise, promote body recovery, enhance muscle strength, improve endurance level, etc. However, the mechanism of action of different types of sports nutrition supplements varies, as do their applicability to different populations and methods of use, and the efficacy and safety of sports nutrition supplements remain controversial. Therefore, it is of great theoretical and practical significance to gain a deeper understanding of the research progress of sports nutrition supplements on improving athletic performance.

2 Background and Concepts of Sports Nutrition Supplements

Sports nutrition supplements first originated in foreign countries, the famous scholar Williams on the concept of nutritional supplements defined as "in order to make athletes in the process of sports training to achieve through the ordinary training methods can not be achieved, in order to fully tap the athletes' athletic potential, and the use of training means other than for the enhancement of the athletes' own energy production, the level of energy control, and the enhancement of energy utilization of a program or agent (Xuyu & Wang Wei). A program or agent to improve energy utilization (Zhang Xuyu & Wang Wei, 2008) ." Nutrition is divided into two parts: material metabolism and energy supply, for athletes' nutrition, the first consideration is energy intake, energy is like "fuel" for athletes, which is the source of power for them when they are exercising (Lu Zongcheng et al., 2016) . Energy balance is achieved when the total energy intake equals the total energy expended. The total energy expended is the basal metabolic rate (BMR), the thermic effect of food (TEF), and the thermic effect of activity (TEA) respectively (Donahoo, Levine, & Melanson, 2004) . When the total energy intake of an athlete is less than the total energy expended and energy intake is insufficient, it reduces the level of exercise and affects stamina, endurance, and musculoskeletal coordination system disorders. Chronic inadequate energy intake can lead to nutritional deficiencies, which can result in malnutrition, metabolic dysfunction, and endocrine disorders. On the contrary, adequate energy intake can maintain an optimal level of athletic performance. And often some athletes adjust their energy status by controlling energy intake and consumption, if energy deficiency can reduce fat and weight, and sufficient energy can promote the development of body functions and muscle growth (Kang Jie, 2016) . A recently popular concept in sports nutrition is called energy availability (EA), which suggests that optimal energy intake is required to maintain body function and athletic function, rather than simply energy balance.EA is defined as the amount of dietary intake minus the amount of energy consumed during exercise at a fat-minus-mass-moderate (FMM) body weight (BWM) that is needed to fulfill all other functions of the body. It emphasizes the fact that many of today's athletes are

underperforming, impaired, or have endocrine disorders related to inadequate EA (Thomas, Erdman, & Burke, 2016) . Energy is required by the body to sustain life activities and nutrition is what the body obtains from food to maintain normal physiological function. Energy or nutrition can be directly and efficiently replenished through sports nutritional supplements, which in turn can lead to improved athletic performance.

3 Common sports nutritional supplements and their effects on athletic performance

3.1 Protein-based supplements

Protein is an important material basis of muscle tissue and plays a key role in maintaining muscle mass and promoting muscle repair and growth. During exercise, especially after high-intensity strength training or prolonged endurance training, muscle proteins will break down, leading to muscle fatigue or muscle damage. Timely protein supplementation can provide essential amino acid raw materials for muscle repair and promote muscle protein synthesis, thus helping to improve athletic performance. Studies have shown that protein plays an indispensable role in the neurological function system, immune regulation and fatigue elimination in athletes (Gao Mingyou, Wang Chao, & Yang Dandan, 2022) .

Whey protein is a high-quality protein extracted from milk, rich in essential amino acids, and the amino acid composition is close to the pattern of human needs, with extremely high bioavailability. In particular, branched-chain amino acids (BCAAs) rich in whey protein, especially leucine, can activate the rapamycin-targeting protein (mTOR) signaling pathway, and whey protein supplementation after strength training can significantly increase muscle strength and muscle mass (Kerksick et al., 2018) .

Soy protein is a high-quality protein derived from plant sources and is an important source of protein supplementation for vegan athletes or those who are allergic to animal proteins. Although the amino acid composition of soy protein differs slightly from whey protein, it has the same ability to promote muscle protein synthesis. Long-term supplementation with soy protein has been found to improve muscle function and post-exercise recovery (Tang, Moore, Kujbida, Tarnopolsky, & Phillips, 2009) .

Protein has many benefits for enhancing athletic performance, and research has shown that supplementation of whey protein along with resistance training resulted in significantly higher increases in muscle strength and cross-sectional area than those who did not supplement (D. G. Burke et al., 2001) . In endurance sports, protein serves as a supplemental energy source, especially to feed muscles and delay fatigue when carbohydrate reserves are low late in prolonged exercise (Tipton & Wolfe, 2004) . Although protein is beneficial for athletic performance, excessive intake may increase kidney burden and may also lead to calcium loss. It is generally recommended that athletes consume 1.2-2,0 grams of protein per kilogram of body weight, depending on the intensity and goals of the exercise (Kerksick et al., 2018) .

3.2 Creatine

Creatine is one of the most intensively researched and more obviously applied sports nutrition supplements. In muscle cells, creatine mainly exists in the form of phosphocreatine (PCr), which is a high-energy phosphoric acid compound. During muscle contraction, PCr rapidly transfers high-energy phosphoric acid bonds to ADP to generate ATP, which supplies energy for muscle contraction and thus significantly improves muscle explosive force and strength output. In addition, creatine promotes intracellular water retention in muscle cells, increases cell volume and stimulates protein synthesis (Kreider et al., 2017) .

Numerous studies have shown that creatine supplementation significantly improves strength training and high-intensity interval exercise performance. In strength training, it can increase muscle strength, explosive power, and endurance; in sprinting and weightlifting programs, it can improve the ability of rapid muscle contraction and reduce fatigue (Rawson & Volek, 2003) . The commonly used regimen is a loading period (20g per day in 4 doses for 5-7 days) and a maintenance period (3-5g per day), which can result in a significant increase in creatine reserves within the muscle (Kreider et al., 2017) .

Creatine supplementation may lead to weight gain due to water retention in the calculated cells. It is also important to drink plenty of water during supplementation to prevent an increased burden on the kidneys. Although creatine is relatively safe, the safety of long-term heavy use has not been further studied.

3.3 Carbohydrate-based supplements

Carbohydrates are the main energy supplier and are stored as glycogen in the muscles and liver. During exercise, glycogen is broken down into glucose for energy. At the same time, carbohydrates can regulate insulin secretion and promote the entry of amino acids into cells, indirectly affecting muscle growth and repair (L. M. Burke, Hawley, Wong, & Jeukendrup, 2011) . Rational carbohydrate supplementation before, during, and after endurance exercise significantly

improves exercise endurance. Pre-exercise supplementation increases glycogen reserves, intra-exercise supplementation maintains blood glucose levels and ensures energy supply to the brain and muscles, and post-exercise supplementation helps to quickly restore glycogen reserves (Jeukendrup, 2004) . For high-intensity intermittent sports, such as basketball and soccer, carbohydrates can likewise improve explosive power and endurance during exercise. The appropriate type of carbohydrate and timing of supplementation should be selected based on the sport and time of day. Simple carbohydrates are absorbed quickly, but blood sugar fluctuates greatly; complex carbohydrates are digested and absorbed slowly, and can provide more lasting energy. It is also important to control the intake to avoid unnecessary weight gain.

3.4 Beta-alanine

Beta-alanine is a precursor for the synthesis of myostatin, a naturally occurring dipeptide found in muscle and brain. During high-intensity exercise, muscles produce large amounts of hydrogen ions, leading to acidification of the intramuscular environment and a decrease in pH, which in turn affects muscle contractile function and athletic performance. Myostatin has a strong buffering ability to bind hydrogen ions and maintain the acid-base balance of the intramuscular environment. Therefore, β-alanine improves muscle buffering capacity and delays fatigue by increasing muscle carnosine content (Hobson, Saunders, Ball, Harris, & Sale, 2012) .

One study found that beta-alanine supplementation significantly improved high-intensity intermittent exercise performance, such as multiple sprint runs, strength training, and other programs in which supplemented individuals completed more sets and higher-intensity training, maintained higher exercise intensity and capacity, and reduced the effects of fatigue (Saunders, Elliott-Sale, et al., 2017) . There is also a modest improvement in endurance sport performance (Saunders, Painelli, et al., 2017) . Beta-alanine supplementation may cause adverse effects such as skin tingling, which generally diminishes with longer supplementation. The generally recommended supplementation dose is 3-6g per day in 2-3 divided doses, and it is recommended that supplementation be initiated several weeks prior to exercise and continued.

3.5 Caffeine

Caffeine is a naturally occurring alkaloid found widely in coffee, tea, cocoa and other plants, and is also a frequent sports nutrition supplement. Caffeine is able to stimulate the central nervous system, increase alertness and attention, reduce fatigue during exercise, and thus enhance athletic performance. Its mechanism of action includes the following aspects: first, caffeine can block adenosine receptors, reduce the inhibitory effect of adenosine on the central nervous system, increase the release of neurotransmitters (such as dopamine, norepinephrine, etc.), and improve the excitability of the nervous system; second, caffeine can promote lipolysis, increase the concentration of free fatty acids in the blood to provide more energy substrates for the muscles, and reduce muscle glycogen consumption, thus improving exercise performance. depletion, thus improving exercise performance (Doherty & Smith, 2004) .

Several studies have shown that moderate intake of caffeine (3-6 mg/kg body weight) in endurance sports such as long-distance running, cycling, swimming, etc. can significantly improve athletic performance; in strength training and high-intensity interval sports, it can improve muscle strength and explosive power to enhance athletic performance, such as weightlifting, sprinting and other sports, which can improve athletes' reaction speed and muscle contraction (Wang, Zhu, Dong, Zhou, & Zheng, 2020). Dong, Zhou, & Zheng, 2020) . There are individual differences in the effects of caffeine, and some people may experience adverse effects such as palpitations, insomnia, and anxiety after intake. It is important to control the intake of caffeine, as excessive intake is detrimental to health. Caffeine may affect the results of doping tests, so athletes should be careful when using caffeine before participation.

4 Advances in the study of novel sports nutritional supplements

4.1 Nitrates

Nitrate-rich foods (e. g. beet juice) have received much attention in recent years as a sports nutrition supplement. Nitrate can be reduced to nitrite in the body, which in turn is converted to carbon monoxide (NO). NO has the effect of vasodilating blood vessels, lowering peripheral vascular resistance, and increasing muscle blood flow, which improves the delivery of oxygen and nutrients to muscle tissues, improves the aerobic metabolism of muscles, and regulates muscle contractile function (Jones, 2014) .

Several studies have shown that nitrite supplementation improves endurance sports performance, such as cycling and running, where supplemented individuals can complete the same distance at a lower intensity or exercise at the same intensity for longer periods of time. In a study of cyclists, intake of beet juice resulted in a significant improvement in

athletic performance during high-intensity cycling, with lower blood lactate levels post-exercise, indicating reduced muscle fatigue (Lansley et al., 2011) . Research on the effects of nitrate on exercise performance is still in its infancy, with results varying from study to study. In the future, the optimal amount, time and mechanism of action of nitrate supplementation need to be studied in depth to clarify the application value.

4.2 Probiotics

The gut microbiota is critical to human health and metabolism. Probiotics may regulate the balance of gut microbiota, improve gut barrier function and reduce intestinal inflammation. By regulating the gut microbiota, it may indirectly affect energy metabolism, nutrient absorption and immune system function (Messaoudi et al., 2011) . Preliminary studies have shown that probiotic supplementation can help improve endurance exercise performance and post-exercise recovery, reduce exercise-induced fatigue, and increase the rate of physical recovery. However, there are fewer studies and larger, high-quality studies are needed (McDermott et al., 2022) . With the deepening of research on the relationship between gut microbiota and human health, probiotics have a broader perspective as potential sports nutrition supplements, and it is expected that personalized supplementation programs can be achieved in the future.

5 Rational application and precautions of sports nutrition supplements

5.1 Personalization options

Different sports, intensity and individual athletes have different needs for nutritional supplements. Strength-training athletes focus on protein, creatine, etc.; endurance-training athletes need more carbohydrates, caffeine, etc. At the same time, athletes' age, race, genetic factors, physical condition and dietary habits also affect the selection and effect of supplements. 2016, the American College of Sports Medicine and the Canadian Dietitians Association jointly released the "Nutrition and Sports Performance" indicates that athletes' nutritional programs not only need to be personalized, but also reflect the differences and specificity, and the nutritional program should be personalized to enhance the performance of sports nutrition supplements. Personalized nutrition programs provide a new rationale for sports nutrition supplements to enhance athletic performance. (Thomas et al., 2016) .

5.2 Follow a scientific approach to supplementation

The timing and dosage of sports nutrition supplements have a significant impact on effectiveness. For example, proteins should be replenished in time before and after exercise, and carbohydrates have different effects when replenished at different points in time before, during and after exercise. The dosage should be controlled strictly according to the product description or professional advice to avoid overdose or underdose. Sports nutrition supplements cannot replace regular meals. A reasonable dietary structure is still the basis for ensuring good health and sports performance . Sports nutrition supplements should be used as a supplement to the diet to help athletes and sports enthusiasts meet their additional nutritional needs under special training or competition conditions.

5.3 Security and potential risks

Although most sports nutrition supplements are safe under normal use, some supplements may have certain potential risks. Long-term high-dose use of certain supplements may burden the liver and kidney functions; some supplements may interact with drugs, affecting drug efficacy or increasing the risk of adverse reactions; in addition, the quality of sports nutrition supplements on the market varies, and there are counterfeit and shoddy products, which may be hazardous to human health. Therefore, when choosing and using sports nutrition supplements, it is important to pay attention to the quality and safety of the products, and consult a professional sports dietitian or doctor when necessary.

6 Reach a verdict

Sports nutrition supplements play an important role in improving sports performance. Through the proper use of common sports nutrition supplements such as proteins, creatine, β -alanine, caffeine, carbohydrates, branched-chain amino acids, nitrates, and conjugated linoleic acid, athletes and sports enthusiasts can, to varying extents, improve their performance indexes such as strength, speed, endurance, and recovery ability. However, the use of sports nutrition supplements needs to follow the principles of individualization, proper administration, coordination with diet, and concern for safety. In the future, research on sports nutrition supplements will develop towards revealing the mechanism

of action, exploring synergistic effects, developing new supplements and strengthening quality control, so as to provide more powerful support for the enhancement of sports performance.

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