Exercise and Functional Foods

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Abstract

Intake of appropriate nutrition is an essential prerequisite for exercise for effective improvement of athletic performance, conditioning, recovery from fatigue after exercise, and avoidance of injury. The nutritional supplements containing carbohydrates, proteins, vitamins, and minerals have been widely used in the sporting scene corresponding to an elevation of recommended daily allowance. In addition, several natural factors have also been found to show physiological effects, and some of them are considered to be useful for ergogenic aid or for prevention of injuries. These foods should be used with backing by clear scientific evidence and with understanding physiological changes by exercise. This article described functional foods that have been reported to be effective for athlete or health promotion up to date with physiological changes occurred by exercise.

Introduction

Intake of appropriate nutrition is an essential prerequisite for exercise. Proper nutrition is critically important for effective improvement of athletic performance, conditioning, recovery from fatigue after exercise, and avoidance of injury during exercise. Although it is important for athletes to take a well-balanced basic diet, there are several nutritional factors which are difficult to be adequately obtained from the usual diet since athletes require nutrients more than the recommended daily allowances of normal person. Thus, nutritional supplements containing carbohydrates, proteins, vitamins, and minerals have been widely used in the sporting scene, partly because of being easily taken before, during, and/or after exercise. Further, several natural food factors have been shown to exert additional physiological effects, and some of them are considered to be useful (when taken at high doses or continuously) for improving athletic performance or for prevention of homeostasis disturbance by strenuous exercise. Recently, the food factor having benefit physiological function is called "functional food" and its effects on the body have been scientifically studied. This paper introduces functional foods, including basic nutrients, which has been demonstrated benefit effects on the physiological phenomena that occur by exercise.

Replenishment of Water

Water is the main constituent of the human body, and it plays an essential role in circulatory function, chemical reactions involved in energy metabolism, elimination of waste products, and maintenance of the body temperature and plasma volume. When the body temperature rises due to the intense exercise or a high ambient temperature, sweating occurs in order to radiate heat [1-3], leading to the loss of a large amount of water and electrolytes such as sodium. This loss of body fluid impairs thermoregulation and circulatory system, leading to a decline of athletic performance [4, 5]. Therefore, to maintain homeostasis and athletic performance, replenishment of water and electrolytes is essential before and during or after exercise. Generally, it is believed that intake of isotonic fluid which contains electrolytes such sodium, potassium, and chloride at concentrations close to that of body fluid. Also, it has been suggested that intake of hypotonic fluid may exert the similar or more rapid effect on replenishment of body water [6, 7] because it is absorbed rapidly from the small intestine by electrochemical potential, resulting from that the sodium concentration (and the osmolality) of sweat is lower than that of extracellular fluid, so the loss of water is much greater than the loss of electrolytes, leading to an increase in the osmotic pressure of plasma. On the other hand, replenishment of water alone is unlikely to maintain homeostasis of body fluid in prolonged exercise that produces high sweat rates. Taking in only water in prolonged exercise leads to hyponatremia and a decrease in the osmotic pressure of body fluids and inhibit the release of antidiuretic hormone resulting in that water intake is suppressed and the urine output is increased (spontaneous dehydration) [8]. Latzka et al. [9] suggested that during prolonged exercise lasting longer than 90 minutes, fluid drink containing electrolytes and carbohydrate, not water alone, should be considered to provide to sustain carbohydrate oxidation and endurance performance. Furthermore, several studies have suggested that glycerol loading has been advocated as one of methods which prevent high temperature and dehydration in exercise [10, 11]. Oral administration of 1.0-1.2g/kg B.W. glycerol with water temporarily results in an increase of 300-700 ml body fluid [10, 11] and improves endurance performance compared with placebo [12-14]. Glycerol acts as an osmolyte in body fluid, which would lead to an elevation of plasma osmolality [10]. Consequently, water reabsorption in the kidney is increased and urine excretion is decreased, which is considered as one of mechanisms of the effect.

Improvement of Endurance

Energy fuel during exercise is mainly carbohydrate and lipid, and then it is important for improvement of endurance to regulate metabolism of the two substrates. In endurance exercise, glycogen, an energy substrate for muscular contraction is gradually depleted, resulting in difficult to continue exercising. In order to improve endurance, it is effective to increase the glycogen stores in the skeletal muscle and the liver before commencement of exercise. When tissue glycogen is depleted, glycogen synthetase activity is transiently increased, so it leads to increase glycogen storage by carbohydrate intake at that time [15, 16]. For instance, it has been reported that glycogen storage for a competition can be improved by eating low carbohydrate foods for 3 days, starting from 6 days prior to competition, and high carbohydrate foods for the next 3 days, resulting in the storage of 1.5 times more glycogen than normal diet [17]. If citrate, which has an inhibitory action on glycolysis, is taken concurrently with high carbohydrate food, the glycogen stores will be further increased due to inhibition of glycolysis [18, 19]. Also, it is important for athletes to recover the glycogen stores in post-exercise of training period, which could lead to prepare energy for the next training. For rapid recovery of the glycogen level, a high-carbohydrate diet can effectively store glycogen [19, 20]. Further, protein intake with carbohydrate could be more effective for the rapid replenishment of muscle glycogen after exercise compared with a carbohydrate supplement alone [21, 22].

When prolonged exercise is performed, such as in a marathon, taking carbohydrates immediately before or during the exercise is also effective for improving endurance. Under such conditions, it is desirable to take monosaccharides or oligosaccharides, because these are rapidly absorbed and transported to the peripheral tissues after ingestion. On the other hand, intake of carbohydrates inhibits the degradation of another energy substrate, body fat, by stimulating insulin secretion [23, 24]. This leads to impairment of energy production through lipid metabolism and to acceleration of glycolysis as another energy production pathway. As a result, the consumption of muscular glycogen will increase, and the intramuscular pH will decrease due to increased lactic acid production, which may lead to impairment of muscular contraction. Therefore, it needs to take the kind of carbohydrate which does not inhibit lipids metabolism. It has been suggested that supplements containing fructose, which causes less stimulation of insulin secretion and is unlikely to inhibit lipolysis, rather than commonly used carbohydrates such as glucose and sucrose, may be better for improving endurance [25]. Furthermore, simultaneous intake of citrate can be expected to direct energy consumption toward lipids through inhibition of glycolysis [26]. This will spare glycogen, as well as inhibiting lactic acid production, and weakening of muscular contraction will be delayed. An amino acid, arginine, has been reported to modulate hormones that control the blood glucose without inhibiting lipid metabolism, and delay glycogen depletion during exercise [26, 27]. Therefore, concurrent supplementation of citrate and arginine with carbohydrates that cause little stimulation of insulin secretion before or during exercise may be an effective way to improve energy metabolism and to supply the optimum energy sources in prolonged exercise.

If there is a shift from a predominantly glucose-based fuel to lipid-based fuel, it may lead to improvement of endurance via economy of glycogen storage and inhibition of intramuscular pH decrease resulting from lactate generation during exercise. Several studies have reported about the factors that stimulate lipid metabolism while there is not sufficiently evidence for the efficacy. Carnitine is an essential intracellular enzyme for fatty acid transport across the mitochondrial membrane into the mitochondria, and it acts to promote the β–oxidation of fatty acids [28, 29]. Carnitine supplementation is expected to activate lipid metabolism in skeletal muscles, and to also achieve sparing of glycogen. It has been reported that, in persons who are performing aerobic training, intake of 2 g to 4 g of carnitine before exercise or on a daily basis increased the maximum oxygen consumption (an aerobic threshold) and inhibited lactate accumulation after exercise [30, 31]. Also, the effect of caffeine ingestion on endurance performance has been studied. It inhibits phosphotidiesterase activity by cathecholamines release and increases hormone sensitive lipase (HSL) activity, which leads to increased free fatty acid in circulation and further improved endurance performance [32, 33]. Further, capsaicin in red hot pepper is likely to enhance fat metabolism by altering the lipolytic hormones and fat oxidation capacity in skeletal muscle [34, 35].

Enhancement of Muscle Strength

It is well recognized that muscle strength is generally proportional to the cross-sectional area of a muscle, and it is necessary to increase muscle bulk in order to enhance strength. Muscle tissues are mainly composed of protein, such actin and myosin, and water, and for increase of muscle bulk, it is important to increase the protein content by modulating protein metabolism. In other words, muscle bulk and strength can be increased by accelerating protein synthesis or by inhibiting protein degradation. Resistance exercise that aims at increasing the muscle bulk also enhances the secretion and production of growth hormone and various growth factors [36]. Thus, resistance exercise more strongly promotes protein synthesis and muscle mass compared with aerobic exercise. In order to maximize the effect of resistance exercise, it is important to maintain the muscular pool and the blood levels of amino acids that are substrates for the synthesis of muscle proteins. For this purpose, it needs to maintain a positive nitrogen balance by increasing dietary protein intake. Several studies have shown that protein requirement for strength-training athletes are elevated above those of sedentary individuals [37-40]. The daily recommended protein intake is estimated as 1.4 – 1.8 g/kg for resistance exercise under conditions where intake of energy and carbohydrate is adequate [41, 42] although 1.0 g/kg of protein intake is generally sufficient for endurance athletes excluding a minority of elite athletes [43]. It may be difficult to maintain such a high intake of protein from the diet, so use of protein supplements can be effective. A wide variety of raw materials are utilized for production of powdered protein supplements, and products derived from soy beans or eggs and further derived from whey separated from lactoprotein are commercially available. All of these products contain essential amino acids in a well-balanced ratio, and the amino acid score is 100 for many of these products. In particular, whey protein is believed to be an ideal source for building muscles, since such protein is well digested and is easily absorbed, resulting in a rapid increase in the blood level of amino acids [44, 45]. In addition, the contents of branched-chain amino acids and glutamine, which promote synthesis of muscle protein, are high in whey protein [44, 46]. In addition, not only the amount of protein intake but also the timing of intake is important for building muscle efficiently. A meal right after resistance exercise may contribute to an increase in the muscle mass compared to ingesting a meal several hours later [47-49]. Carbohydrates intake with protein can also accelerate the synthesis of muscle protein via the effect of insulin which increases protein synthesis and inhibits its catabolism [50, 51].

Also, it has been reported that intake of amino acids or peptides is beneficial. Free amino acids and peptides do not need to be digested and thus rapid absorption can be expected. Additionally, amino acids are not only utilized as substrates for the synthesis of muscle protein, and some amino acids also exert a variety of physiological effects. Attention has been paid to the role of branched-chain amino acids (BCAAs) valine, leucine, and isoleucine, which are known to be relatively high content in both muscular and food proteins [52]. Most amino acids are metabolized in the liver, but

BCAAs are metabolized through special processes in the muscles [52, 53]. BCAAs are utilized as energy substrates and their oxidation is enhanced by exercise by activation of branched-chain-α-keto acid dehydrigenase (BCKDH) complex [54]. Further, they can modulate protein metabolism in the muscles by promoting synthesis and inhibiting the degradation of protein [54-56], resulting in anabolism of muscle protein. Also, glutamine is reported to promote muscular growth by inhibiting protein degradation [57-59]. It is the most abundant free amino acid in muscle [60] and thus its intake leads to increase of the volume of myocytes, resulting in stimulation of muscle growth [57-59]. Glutamine is also contained at relatively high concentrations in many human tissues and has an important role in homeostatic functions [60]. Therefore, during various catabolic states including exercise, glutamine in skeletal muscle is released to plasma because it is used for maintenance of glutamine level in other tissues

[61]. Arginine is a precursor for nitric oxide and creatine, and further its injection promotes the secretion of growth hormone [62, 63], which may lead to facilitate muscle mass and strength. Whereas the effect of oral arginine on protein synthesis is equivocal, recent studies indicate that combined intake of arginine with compounds improves exercise performance [64-66].

Else, a large number of food factors have been studied about the effects on muscle strength and mass. A meta-analysis study quantifying previous studies between the year 1967 and 2001 suggested that two supplements, creatine and β-hydroxy-β-methylbutyrate (βHMB), have data supporting their use to augment lean body mass and strength gains with resistance exercise [67]. Creatine is contained more than 100 g in human body and almost all of it is stored in the skeletal muscles as creatine phosphate, which produces ATP during the process of degradation to creatine.

Since creatine metabolism occurs under anaerobic conditions, improvement of anaerobic metabolism can be expected by increasing the stores of creatine. Moreover, creatine stimulates water retention and protein synthesis [68, 69]. It has been reported that intake of 3 g/day of creatine or more increases the intramuscular content of creatine phosphate and improves endurance, especially during activities with a high power output, such as short distance running, resistance exercise, and muscle strength [70-72]. In addition, there has been a report that intake of creatine accelerates the increase in lean body mass and muscle strength during resistance training [72-74]. On the other hand, βHMB is a metabolite of another branched-chain amino acid, leucine, and it acts to increase muscle bulk by inhibiting the degradation of protein via an influence on the metabolism of branched-chain amino acids [75, 76]. It has been reported that intake of 1.5 to 3.0 g/day of βHMB for 3 to 8 weeks achieved a greater increase of muscle mass and power compared with the intake of placebo [77-79].

Prevention of Injury and Fatigue

Strenuous physical activity or unaccustomed exercise causes injury to the muscles, release of muscular protein, and muscle pain. The mechanism underlying delayed the muscle damage after intense physical activity is not fully understood, but it has been suggested that such delayed injury is due to an inflammatory reaction induced by phagocyte infiltration that is triggered by excessive mechanical stress [80, 81], an increased intracellular Ca^{2+} concentration [82, 83], and oxidative stress [84]. There are several reports which examined whether antioxidants attenuate the muscle damage since a significant increase of oxidative products is noted in the exercised muscles and in the blood in post-exercise parallel to other parameters of delayed-onset muscle damage.

Oxidative injury after acute exercise can be prevented by the intake of antioxidants, such as vitamins C and E, carotenoids, or polyphenols, not only during exercise, but also on a daily basis [84–91]. In contrast, several studies have indicated that antioxidants do not affect muscle damage and the inflammatory response caused by strenuous exercise [92-94]. One possibility on reason of the different results is that the effect of antioxidants is likely to be differences of exercise conditions, such intensity of mechanical stress and oxygen uptake. Reactive oxygen species (ROS) could be related to initiation of the muscle damage. ROS are generated from mitochondria and endothelium during exercise via elevation of the oxygen uptake of myocytes and ischemia-reperfusion process, which leads to invasion of phagocytes into the muscles after exercise via redox-sensitive inflammatory cascade. Therefore, the inflammatory response may be inhibited if ROS production during exercise is decreased just in large contribution of ROS on the initiation of muscle damage such endurance prolonged exercise not resistance exercise. Additionally, these antioxidants would be better to take several kinds at the same time because the organelle affected by the kind of antioxidants, such water or lipid soluble, is different and they can provide electron each other and prevent to change pro-oxidant.

Glucosamine and chondroitin are substances that protect the joints. Glucosamine is an amino acid synthesized in the body that is a component of synovial fluid, tendons, and ligaments in the joints. Chondroitin is mainly contained in cartilage, tendons, and the connective tissues of the skin, and plays an important role as a shock absorber due to its hygroscopic action. Supplementary oral intake of these substances is suggested to be effective for preventing or promoting recovery from osteoarthritis associated with exercise and aging [95, 96] while the effect of supplementation in exercise is not clear.

There are various kinds of factors expressing fatigue condition induced by exercise such glycogen depletion and accumulation of lactic acid during exercise, and hyperactivation of sympathetic nerve in post-exercise. As mentioned above, recovery of glycogen storage in muscle is promoted by high-carbohydrate diet. In this time, it is more effective to take the factor which exerts inhibitory effect of glycolysis such citrate and consider the timing of carbohydrate intake. Also, lactate accumulation in muscle inhibits capacity of muscular contraction associated with pH decrease in muscle, which could be one of fatigue conditions. Thus, dietary supplementation regulating production or clearance lactate may be effective. Dipeptides that are abundant in skeletal muscle, carnosine and anserine, are known to have a pH-buffering effect [97]. Supplementation of these dipeptides is also possible to inhibit the decline of intramuscular pH by exercise via the buffering action of these dipeptides [98-100].

Prevention of Decreased Immunity

It is generally believed that moderate exercise training enhances immunocompetence and is effective for the prevention of inflammatory diseases, infection and, cancer, while excessive physical activity leads to immunosuppression and an increase of inflammatory and allergic disorders [101-103]. Susceptibility to infections following excessive physical activity is ascribed to an increase in the secretion of immunosuppressive factors such as adrenocortical hormones and anti-inflammatory cytokines, leading to a decrease in the number and activity of natural killer cells and T cells in the blood as well as a decreased concentration of IgA in the saliva [104]. Therefore, athletes performing high intensity training are frequently exposed to a risk of decreased immunocompetence. Supplementation of carbohydrate during prolonged exercise at submaximal intensity attenuates the increase in plasma cortisol concentration and cytokines after exercise, which could lead to the inhibition of immunosuppression [105-107]. Vitamins C and E have the action of promoting immunity, and are essential for the differentiation and maintenance of T cell function [104, 108, 109]. However, there is limited evidence for the effects of the vitamins supplementation on immune function in exercise. Glutamine is an important energy fuel for lymphocytes, macrophages, and neutrophils, and is an essential amino acid for the differentiation and growth of these cells [57, 110]. Intense exercise decreases plasma glutamine concentration related to immune suppression [111]. Castell et al. [112] reported that athletes who consumed glutamine decreased infection rates after a marathon running race compared with placebo group. They also demonstrated that the administration of glutamine resulted in an increase in the ratio of T-helper/T-suppressor cell [113]. Furthermore, glutamine enhances the functions of enterobacteria in the intestine, and inhibits the production of cytokines involved in inflammation and immunosuppression [110].

Conclusion

Due to a social background that includes changes of the dietary custom, an aging population, increased medical expenses, and so forth, people have a growing interest in health and have come to expect complex and diverse actions of foods. With the background, in recent years, various food factors corresponding to such requirements have been scientifically evaluated whether they have physiological effects such prevention of diseases. In the sports market, a variety of functional foods are available, but among these functional foods, some have not clearly demonstrated any efficacy and others are advertised with inappropriate and exaggerated claims, so consumers are often confused. Some of the food components described in this article should be studied further because of differing views with regard to their efficacy in different reports. Furthermore, the effectiveness of the components may differ according to gender, between individuals, and with the mode of ingestion, so that the optimum method of intake the quantity and quality of foods to be ingested, and the timing of their intake need to be established in accordance with the purpose of using each food or food component, after understanding the physiological changes by exercise. In the future, guidelines for the use and evaluation system of sports functional foods should be established with backing by clear scientific evidence related to the individual foods.

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Table 1: Exercise and functional foods.

Physiological functions	A	B	C
Replenishment of water	Isotonic drinks	Hypotonic drinks Glycerol	
Improvement of endurance	High-carbohydrate Citric acid	Arginine Caffeine Carnitine	Capsaicine
Enhancement of muscle strength	Protein BCAA Creatine β-HMB	Glutamine	Arginine
Prevention of muscle/joint injuries or fatigue	High-carbohydrate Citric acid	Vitamins C and E Carotenoids, Flavonoids Carnosine, Anserine	Glucosamine Chondroitin
Prevention of a decrease in immunocompetence	Carbohydrate	Vitamins C and E Glutamine	

A: The factors in this group has been shown adequate scientific evidence.
B: The factors in this group has been shown suggestive evidence.
C: The factors in this group has been shown no evidence while possible to effective.