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 during exercise. There are several nutritional supplements containing carbohydrates, proteins, vitamins, and minerals have been widely used in the sporting scene. 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 in recent studies. 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 on the basis of human studies 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. There are several nutritional elements for which the recommended daily allowances cannot be adequately obtained from the usual diet, so 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. Several natural factors have also been found to show 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 disturbance of homeostasis by strenuous exercise. Several such products are available

commercially. For the purposes of nutritional supplementation, improvement of athletic ability, and protection of the body, however, such “sports foods” should only be used with a thorough understanding of the physiological phenomena that occur by exercise. This paper introduces sports foods for which function has been demonstrated scientifically with physiological changes occurred 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. When the body temperature rises due to the intensiveness of exercise or a high ambient temperature, sweating occurs in order to radiate heat [1-3]. Results in the loss of a large amount of water and electrolytes such as sodium. The sodium concentration (and the osmotic

pressure) 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. This loss of body fluid and consequent increase in the plasma osmotic pressure leads to a decline of athletic performance, and also impairs control of the body temperature and circulatory system [4, 5]. Therefore, in order to maintain homeostasis and athletic performance, replenishment of water and electrolytes is needed during (or before and after) exercise. Replenishment of water alone leads to a decrease in the osmotic pressure of body fluids, and this inhibits the release of antidiuretic hormone. As a result, water intake is suppressed and the urine output is increased (spontaneous dehydration). Therefore, there is no effective recovery of the body water content. Accordingly, it is believed that intake of isotonic fluid, which contain electrolytes and carbohydrates at concentrations such that the osmotic pressure is close to that of body

fluid, or intake of hypotonic fluid that is absorbed rapidly from the small intestine will lead to more rapid replenishment of body water [6]. Furthermore, glycerol loading has been advocated as one of methods which prevent high temperature and dehydration in exercise [7, 8]. Oral administration of 1.0-1.2g/kg B.W. glycerol with water temporarily results in an increase of 300-700 ml body fluid [7, 8]. Several studies have reported that the glycerol loading improves endurance performance compared with placebo [9-11]. Glycerol acts as an osmolyte in body fluid, which would lead to an elevation plasma osmolality [7]. Consequently, water reabsorption in kidney is increased and urine excretion is decreased, which is considered as one of mechanisms of the effect.

Improvement of Endurance

When exercise is performed for a long time, glycogen, an energy substrate for muscular contraction is depleted, and it becomes difficult to continue exercising. In order to improve endurance, it is important 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 is possible to increase glycogen storage by carbohydrate intake at that time [12, 13]. 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 usual [14]. 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 glycogenolysis [15, 16]. Where exercise is performed

for a long time, such as in a marathon, taking carbohydrates immediately before or during the event 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, carbohydrates inhibit the degradation of another energy substrate, body fat, by stimulating insulin secretion. 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 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 [17]. Furthermore, simultaneous intake of citrate can be expected to direct energy consumption toward lipids through inhibition of glycolysis [18]. 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 the delay glycogen depletion during exercise [18, 19]. Therefore, it is considered that concurrent supplementation of citrate and arginine with carbohydrates that cause little stimulation of insulin secretion before or during exercise is an effective way to improve energy metabolism and to supply the optimum energy sources.

There have been a few studies concerning the factors that stimulate lipid metabolism. Carnitine is an essential intracellular factor for fatty acid transport across the

mitochondrial membrane into the mitochondria, and it acts to promote the β–oxidation of fatty acids [20, 21]. Carnitine supplementation is expected to activate lipid metabolism in skeletal muscles, and to also achieve sparing of glycogen. Some authors have 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 [22, 23]. 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 [24, 25]. However, caffeine ingestion is defined as doping in IOC (International Olympic Committee) if it is detected over 12 μg/ml concentration in urine fluid. Further, capsaicin in red hot pepper enhances fat

metabolism by altering the lipolytic hormones and fat oxidation capacity in skeletal muscle [26, 27]. Some dipeptides that are abundant in skeletal muscle, carnosine and anserine, are known to have a pH-buffering effect [28]. Supplementation of these dipeptides is also possible to inhibit the decline of intramuscular pH via the buffering action of these dipeptides [29, 30].

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 and water, and in order to increase 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. Thus, resistance exercise more strongly promotes protein synthesis and muscular enlargement 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. The daily recommended protein intake is generally estimated as 1.2 – 1.4 g/kg for endurance exercise and 1.4 – 1.8 g/kg for resistance exercise under conditions where energy intake is adequate [31]. 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 [32, 33]. In addition, the contents of branched-chain amino acids and glutamine are high in whey protein [32, 34].

Intake of amino acids or peptides is also beneficial. Free amino acids and peptides do not need to be digested, and rapid absorption can be expected. 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 long been paid to the role of

branched-chain amino acids, such as valine, leucine, and isoleucine, in physical activities, and contents of these amino acids are known to be relatively high content in both muscular and food proteins. Many amino acids are metabolized in the liver, but these branched-chain amino acids are metabolized through special processes in the muscles [35]. These branched-chain amino acids are utilized as energy substrates when the muscular glycogen content decreases, but they also modulate protein metabolism in the muscles by promoting synthesis and inhibiting the degradation of protein [36-38]. Also, glutamine is reported to promote muscular growth by inhibiting protein degradation and inhibiting the degradation of protein by mainly mediating increases of the volume of myocytes [39-41]. This amino acid can also be utilized as an energy source that is a substitute for glucose, and it has additional role in the regulation of intracellular pH and detoxication of ammonia. Thus, glutamine is an

important amino acid for athletes. Several other amino acids have also been suggested to enhance physiological function during physical activities, although their actual effects have not been demonstrated experimentally. Uptake of amino acids into myocytes is accelerated by insulin, so it is believed that amino acids can be more effectively utilized for the synthesis of body proteins when taken simultaneously with carbohydrates [42].

Currently, used of creatine has become popular for the enhancement of muscle power. The human body contains more than 100 g of creatine 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 [43, 44].

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 [45-47]. In addition, there has been a report that intake of creatine accelerates the increase in muscle bulk and muscle strength during resistance exercise [47-49].

β-Hydroxy-β-methylbutyrate (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 [50, 51]. 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.[52-54]

Prevention of Muscle Injury

Strenuous physical activity or unaccustomed exercise causes injury to the muscles, release of muscular protein, and muscle pain. The mechanism(s) underlying delayed muscle injury after violent physical activity are 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, an increased intracellular Ca concentration, and oxidative stress. From 1 to 3 days after violent exercise, a significant increase of oxidative products has been noted in the affected muscles and in the blood, so the extent of the increase can be used as an endpoint to evaluate the inhibitory effect of various agents on muscle injury. It has been estimated that the oxygen uptake of myocytes during exercise increases to 100-fold of that at rest. A small percentage of this oxygen is converted to active oxygen species by of the

electron transport system in the mitochondria, so the muscle tissue is naturally exposed to a high level of oxidative stress during exercise due to the increase of energy metabolism. The production of active oxygen species is also increased in vascular endothelial cells and phagocytes. When the production of these active oxygen species exceeds the antioxidant capacity of the body, various cellular components (including lipids, proteins, and nucleic acids) are subjected to oxidative injury. Since this oxidative damage is noted some time after exercise, it has been suggested that it can be directly ascribed to active oxygen species, especially those derived from phagocytes. Some authors have reported that 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 [55–61]. The doses of antioxidants should be selected carefully, however because these agents may exert an adverse effect

as oxidative substances when excessive doses are given beside their antioxidant effect.

Glucosamine and chondroitin are substances that protect the joints. Glucosamine is an amino acid synthesized by 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 [62, 63].

Prevention of Decreased Immunity

It is generally believed that an appropriate amount of exercise enhances immunocompetence and is effective for the prevention of inflammatory diseases and

cancer, while excessive physical activity leads to a decrease of immunocompetence and an increase of inflammatory and allergic disorders. Susceptibility to infections following excessive physical activity is ascribed to an increase in the secretion of immunosuppressive substances such as adrenocortical hormones and anti-inflammatory cytokines, leading to a decrease in the number and activity of NK cells and T cells in the blood as well as a decreased concentration of IgA in the saliva [64]. Therefore, athletes performing vigorous training are frequently exposed to a risk of decreased immunocompetence. Vitamins C and E have the action of promoting immunity, and are essential for the differentiation and maintenance of T cell function [64–66]. However, there is limited evidence for the effects of the vitamins supplementation on immune function in exercise. Glutamine is an important energy substrate for lymphocytes, macrophages, and neutrophils, and is an essential amino acid for the

differentiation and growth of these cells [39, 67]. Intense exercise decreases plasma glutamine concentration related to immune suppression [68]. Castell et al. reported that athletes who had consumed glutamine decreased infection rates after a marathon running race compared with placebo group [69]. They also demonstrated that the administration of glutamine resulted in an increase in the ratio of T-helper/T-suppressor cell [70]. Furthermore, glutamine enhances the functions of enterobacteria in the intestine, and inhibits the production of cytokines involved in inflammation and immunosuppression [67].

Conclusion

Due to a social background that includes changes of the diet, 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. In the sports market, a

variety of functional foods are available, and both the kinds of functional foods and their physiological effects vary greatly. Among these functional foods, however, some have not clearly demonstrated any efficacy and others are advertised with inappropriate and exaggerated claims, so consumers are often confused. This article described functional food components that have been reported to be effective in humans and that are frequently used in the sporting world. Some of these food components need to 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 phenomena that occur during 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.

References

1. Buono MJ, Wall AJ: **Effect of hypohydration on core temperature during exercise in temperate and hot environments.** *Pflugers Arch* 2000, **440:**476-480.

2. Kenny GP, Periard J, Journeay WS, Signal RJ, Reardon FD: **Effect of exercise intensity on the postexercise sweating threshold.** *J Appl Physiol* 2003, **95:**2355-2360.

3. Kondo N, Tominaga H, Shibasaki M, Aoki K, Okuda S, Nishiyasu T: **Effect of exercise intensity on the sweating response to a sustained static exercise.** *J Appl*

Physiol 2000, **88:**1590-1596.

4. Nose H, Takamata A, Mack GW, Oda Y, Kawabata T, Hashimoto S, Hirose M, Chihara E, Morimoto T: **Right atrial pressure and forearm blood flow during prolonged exercise in a hot environment.** *Pfluger Arch* 1994, 426:177-182.

5. Fortney SM, Wenger CB, Bove JR, Nadel ER: **Effect of hyperosmolality on control of blood flow and sweating.** *J Appl Physiol* 1984, **57:**1688-1695.

6. Decombaz J, Gmunder B, Daget N, Munoz-Box R, Howald H: **Acceptance of isotonic and hypotonic rehydrating beverages by athletes during training.** *Int J Sports Med* 1992, **13:**40-46.

7. Robergs RA: **Glycerol. Biochemistry, pharmacokinetics and clinical and practical applications.** *Sports Med* 1998, **26:**145-167.

8. Riedesel ML: **Hyperhtdration with glycerol solutions.** *J Appl Physiol* 1998,

63:2262-2268.

9. Lyons TP: **Effects of glycerol-induced hyperhydration prior to exercise in the heat on sweating and core temperature.** *Med Sci Sports Exerc* 1990, **22:**477-483.

10. Montner P: **Pre-exercise glycerol hydration improves cycling endurance time.** *Int J Sports Med* 1996, **17:**27-33.

11. Anderson MJ: **Effect of glycerol-induced hyperhydration on thermoregulation and metabolism during exercise in heat.** *Int J Sport Nutr Exerc Metab* 2001, **11:**315-33.

12. Hulyman E, Nilsson LH: **Liver glycogen in men. Effect of different diets and muscular exercise. Advances in Experimental Medicine and Biology. Muscle Metabolism During Exercise.** *Pernow B and Saltin B eds., Plenum Press, New York* 1971; **2:**143-151.

13. Forgac MT: **Carbohydrate loading-a review.** *J Appl Physiol* 1980, **48:**624-629.

14. Evans WJ, Hughes VA: **Dietary carbohydrates and endurance exercise.** *Am J Clin Nutr* 1985, **41:**1146-1154.

15. Saito S, Yoshitake Y, Suzuki M: **Enhanced glycogen repletion in liver and skeletal muscle with citrate orally fed after exhaustive treadmill running and swimming.** *J Nutr Sci Vitaminol* 1983, **29:**45-52.

16. Saito A, Tasaki Y, Tagami K, Suzuki M: **Muscle glycogen repletion and pre-exercise glycogen content: effect of carbohydrate loading in rats previously fed a high fat diet.** *Eur J Appl Physiol* 1994, **68:**483-488.

17. Mitsuzono R, Okamura K, Igaki K, Iwanaga K, Sakurai M: **Effects of fructose ingestion on carbohydrate and lipid metabolism during prolonged exercise in distance runners.** *Appl Human Sci* 1995, **14:**125-131.

18. Saitoh S, Suzuki M: **Nutritional design for repletion of liver and muscle glycogen during endurance exercise without inhibiting lipolysis.** *J Nutr Sci Vitaminol* 1986, **32:**343-353.

19. Palmer JP, Walter RM, Ensinck JW: **Arginine-stimulated acute phase of insulin and glucagon secretion. I. in normal man.** *Diabetes* 1975, **24:**735-740.

20. Brass EP: **Supplemental carnitine and exercise.** *Am J Clin Nutr* 2000, **72:**618S-623S.

21. Cerretelli P, Marconi C: **L-carnitine supplementation in humans.** The effects on physical performance. *Int J Sports Med* 1990, **11:**1-14.

22. Marconi C, Sessi G, Carpinelli A, Cerretelli P: **Effects of L-carnitine loading on the aerobic and anaerobic performance of endurance athletes.** *Eur J Appl Physiol* 1985, **10:**169-174

23. Vecchiet L, Di Lisa F, Pieralisi G, Ripari P, Menabo R, Giamberardino MA, Siliprandi N: **Influence of L-carnitine administration on maximal physical exercise.** *Eur J Appl Physiol* 1990, **61:**486-490.

24. Tarnopolsky MA: **Caffeine and endurance performance.** *Sports Med* 1994, **18:**109-125.

25. Ryu S, Choi SK, Joung SS, Suh H, Cha YS, Lee S, Lim K: **Caffeine as a lipolytic food component increases endurance performance in rats and athletes.** *J Nutr Sci Vitaminol* 2001, **47:**139-146.

26. Lim K, Yoshioka M, Kikuzato S, Kiyonaga A, Tanaka H, Shindo M, Suzuki M: **Dietary red pepper ingestion increases carbohydrate oxidation at rest and during exercise in runners.** *Med Sci sports Exerc* 1997, **29:**355-361.

27. Yoshioka M, Lim K, Kikuzato S, Kiyonaga A, Tanaka H, Shindo M, Suzuki M:

Effects of red pepper diet on the energy metabolism in men. *J Nutr Sci Vitaminol* 1995, **41:**647-656.

28. Quershi J, Wood T: **The effect of carnosine on glycolysis.** Biochem Biophys Acta 1962, **60:**190-192.

29. Harada R, Taguchi H, Urashima K, Sato M, Omori T, Morimatsu F.: **Effects of a chicken extract on endurance swimming in mice.** *J Jpn Soc Nutr Food Sci* 2002, **55:**73 – 78.

30. Harada R, Urashima K, Sato M, Omori T, Morimatsu F: **Effects of carnosine and a chicken extract on recovery from fatigue due to swimming in mice.** *J Jpn Soc Nutr Food Sci* 2002, **55:**209– 214.

31. Lemon PW: **Is increased dietary protein necessary or beneficial for individuals with a physically active lifestyle?** *Nutr Rev* 1996, **54:**S169-S175.

32. Ha E, Zemal MB: **Functional properties of whey, whey components, and essential amino acids: mechanisms underlying health benefits for active people (review).** *J Nutr Biochem* 2003, **14:**251-258.

33. Boirie Y, Dangin M, Gachon P, Vasson MP, Maubois JL, Beaufrere B: **Slow and fast dietary proteins differently modulate postprandial protein accretion.** *Proc Natl Acad Sci USA* 1997, **94:**14930-14935.

34. de Wit JN: **Marschell Rhone-Poulenc Award Lecture. Nutritional and functionalcharacteristics of whey proteins in food products.** *J Dairy Sci* 1998, **81:**597-608.

35. Harper AE, Miller RH, Block KP: **Branched-chain amino acid metabolism.** *J Nutr* 1984, **4:**409-454.

36. Shimomura Y, Murakami T, Nakai N, Nagasaki M, Harris RA: **Exercise promotes**

BCAA catabolism: effects of BCAA supplementation on skeletal muscle during exercise. *J Nutr* 2004, **134:**1583S-1587S.

37. Buse MG, Reid SS: **Leusine: a possible regulator of protein turnover in muscle.** *J Clin Invest* 1975, **56:**1250-1261.

38. Tischler ME, Desautels M, Goldberg AL: **Does leucine, leucyl-tRNA, or some metabolite of leucine regulate protein synthesis and degradation in skeletal and cardiac muscle.** *J Biol Chem* 1982, **257:**1613-1621.

39. Antonio J, Street C: **Glutamine: A potentially useful supplement for athletes.** *Can J Appl Physiol* 1999, **24:**1-14.

40. Hankard RG, Haymond MW, Darmaun D: **Effect of glutamine on leucine metabolism in humans.** *Am J Physiol* 1996, **271:**E748-E754.

41. Vom Dahl S, Haussinger D: **Nutritional state and the swelling-induced inhibition**

of proteolysis in perfused rat liver. *J Nutr* 1996, **126:**395-402.

42. Doi T, Hamda K, Sakurai M, Ueno T, Imaizumi K, Yoshioka Y, Okamura K, Shimizu S: **Effect of postexercise glucose administration on the nitrogen metabolism and leucine turnover in dogs.** *Med Sci Sports Exerc* 1997, **29:**S126.

43. Balsom P, Soderlund K, Shodin B, Ekblom B: **Skeletal muscle metabolism during short duration high-intensity exercise: influence of creatine supplementation.** *Acta Physiol Scand* 1995, **1154:**303-310.

44. Balsom P, Soderlund K, Ekblom B: **Creatine in humans with special references to creatine supplementation.** Sports Med 1994, **18:**268-280.

45. Terjung RL, Clarkson P, Eichner ER, Greenhaff PL, Hespel PJ, Israel RG, Kraemer WJ, Meyer RA, Spriet LL, Tarnopolsky MA, Wagenmakers AJ, Williams MH: **American College of Sports Medicine roundtable. The physiological and health**

effects of oral creatine supplementation. *Med Sci Sports Exerc* 2000, **32:**706-717.

46. Casey A, Constantin-Teodosiu D, Howell D, Hultman E, Greenhalf PL: **Creatine ingestion favorably affects performance and muscle metabolism during maximal exercise in humans.** *Am J Physiol* 1996, **271:**E31-E37.

47. Kreider R, Ferreira M, Wilson M, Grindstaff P, Plisk S, Reinardy J, Centler E, Almada AL: **Effects of creatine supplementation on body composition, strength and sprint performance.** *Med Sci Sport Exerc* 1998; 30: 73-82.

48. Volec JS, Duncan ND, Mazzetti SA, Staron RS, Putukian M, Gomez AL, Pearson DR, Fink WJ, Kraemer WJ: **Performance and muscle fiber adaptations to creatine supplementation and heavy resistance exercise.** *Med Sci Sport Exerc* 1999, **31:**1147-1156.

49. Vandenburghe K, Goris M, Van Hecke P, Van Leemputte M, Vangerven L, Hespel P:

Long-term creatine intake is beneficial to muscle performance during resistance-training. *J Appl Physiol* 1997, **83:**2055-2063.

50. Alon T, Bagchi D, Preuss HG: Supplementing with beta-hydroxy-beta-methylbutyrate (HMB) to build and maintain muscle mass: a review. *Res Commun Mol Pathol Pharmacol* 2002, **111:**139-151.

51. Slater GJ, Jenkins D: **Beta-hydroxy-beta-methylbutyrate (HMB) supplementation and the promotion of muscle growth and strength.** *Sport Med* 2000, **30:**105-116.

52. Nissen S, Sharp R, Ray M, Rathmacher JA, Rice D, Fuller JC Jr, Connelly AS, Abumrad N: **Effect of leucine metabolite beta-hydroxy-beta-methylbutyrate on muscle metabolism during resistance-exercise training.** *J Appl Physiol* 1996, **81:** 2095-2104.

53. Gallagher PM, Carrithers JA, Godard MP, Schulze KE, Trappe SW: **Beta-hydroxy-beta-methylbutyrate ingestion, Part 1: effects on strength and fat free mass.** *Med Sci Sport Exerc* 2000, **32:**2109-2115.

54. Panton LB, Rathmacher JA, Baier S, Nissen S: **Nutritional supplementation of the leucine metabolite beta-hydroxy-beta-methylbutyrate (hmb) during resistance training.** *Nutrition* 2000; **16:**734-739.

55. Takanami Y, Iwane H, Kawai Y, Shimomitsu T: **Vitamin E supplementation and endurance exercise. Are there benefits?** *Sports Med* 2000, **29:**73-83.

56. Aoi W, Naito Y, Takanami Y, Kawai Y, Sakuma K, Ichikawa H, Yoshida N, Yoshikawa T: **Oxidative stress and delayed-onset muscle damage after exercise.** *Free Radic Biol Med* 2004, 37: 480-487.

57. Kanter MM, Nolte LA, Holloszy JO: **Effects of an antioxidant vitamin mixture**

on lipid peroxidation at rest and postexercise. *J Appl Physiol* 1993, **74:**965-969.

58. Aoi W, Naito Y, Sakuma K, Kuchide M, Tokuda H, Maoka T, Toyokuni S, Oka S, Yasuhara M, Yoshikawa T: **Astaxanthin limits exercise-induced skeletal and cardiac muscle damage in mice.** *Antioxid Redox Signal* 2003, **5:**139-144.

59. Sumida S, Doi T, Sakurai M, Yoshioka Y, Okamura K: **Effect of a single bout of exercise and βcarotene supplementation on the urinary excretion of 8-hydroxydeoxyguanosine in humans.** *Free Rad Res* 1997, **27:**607-618.

60. Marquez R, Santangelo G, Sastre J, Goldschmidt P, Luyckx J, Pallardo FV, Vina J. **Cyanoside chloride and chromocarbe diethylamine are more effective than vitamin C against exercise-induced oxidative stress.** *Pharmacol Toxicol* 2001, **89:** 255-258.

61. Kato Y, Miyake Y, Yamamoto K, Shimomura Y, Ochi H, Mori Y, Osawa T:

Preparation of a monoclonal antibody to N(epsilon)-(hexanonyl)lysine: application to the evaluation of protective effects of flavonoid supplementation against exercise-induced oxidative stress in rat skeletal muscle. *Biochem Biophys Res Commun* 2000, **274:** 389-393.

62. Leffler CT, Philippi AF, Leffler SG, Mosure JC, Kim PD: **Glucosamine, chondroitin, and manganese ascorbate for degenerative joint disease of the knee or low back: a randomized, double-blind, placebo-controlled pilot study.** *Mil Med* 1999, **164:**85-91.

63. Beren J, Hill SL, Diener-West M, Rose NR: **Effect of pre-loading oral glucosamine HCl/chondroitin sulfate/manganese ascorbate combination on experimental arthritis in rats.** *Exp Biol Med (Maywood)* 2001, **226:**144-151.

64. Gleeson M, Nieman DC, Pederson BK: **Exercise, nutrition and immune function.**

J Sports Sci 2004, **22:**115-125.

65. Peake JM. Vitamin C: **Effects of exercise and requirements with training.** *Int J Sport Nutr Exerc Metab* 2003, **13:**125-151.

66. Moriguchi S, Muraga M: **Vitamin E and immunity.** *Vitam Horm* 2000, **59:**305-336.

67. Castell LM: **Glutamine supplementation in vitro and in vivo, in exercise and immunodepression.** *Sports Med* 2003, **33:** 323-345.

68. Keast D, Arstein D, Harper W, Fry RW, Morton AR: **Depression of plasma glutamine concentration after exercise stress and its possible influence on the immune system.** *Med J Aust* 1995, **162:**15-18.

69. Castell LM, Newsholme EA: **The effects of oral glutamine supplementation on athletes after prolonged, exhaustive exercise.** *Nutrition* 1997, **13:**738-742.

70. Castell LM, Poortmans JR, Newsholme EA: **Does glutamine have a role in reducing infections in athletes?** *Eur J Appl Physiol* 1996, **73:**488-490.

Physiological functions	Foods (Food components)
Replenishment of water	Isotonic drinks, Hypotonic drinks, glycerol
Improvement of endurance	Carbohydrates (fructose), citric acid, arginine, carnitine, caffeine, capsaicine, carnosine, anserine
Enhancement of muscle strength	Protein, branched-chain amino acids, glutamine, creatine, β-HMB
Prevention of muscle and joint injuries	Vitamins C and E, β-carotene, astaxanthine, flavonoids, glucosamine, chondroitin
Prevention of a decrease in immunocompetence	Vitamins C and E, glutamine

Table1: Exercise and functional foods