Review on Design and Application of Sports Drinks as Dietary Supplement

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Abstract

The athletic ability of athletes does not only depend on scientific training, excellent physical and psychological quality, but also on good health and adequate nutrition. The fluid infusion during exercising is aimed at replenishing water, maintaining physiological electrolyte balance, lowering the body temperature continuously raised up due to exercise, reducing the pressure of circulation system, and raising the carbohydrate inside the body to enhance the performance. The speed of gastric emptying is the main factor affecting the absorption of fluid and nutrient in small intestine, while the fluid volume, heat content, osmotic pressure, exercise, PH value, water and function affect the gastric emptying. On the other hand, factors affecting intestine absorption mainly include carbohydrate and osmotic pressure. Therefore, apart from water content, osmotic pressure, sodium, potassium, chlorine, magnesium, etc. of electrolyte balance, carbohydrate and flavor shall be considered when designing the supplementary fluid for exercise. As a new dietary supplement, sports drink has gained rapid development in recent decades. This thesis hopes to make a summary on its development and effects of sports nutrition.

Keywords

Sports Drink; Dietary Supplement; Dehydration; Gastric Emptying.

1. Introduction

Sports drink is developed concerning the energy consumption during exercise, change of internal environment of body, and functions of cells. It can rapidly replenish the body with water, electrolyte and energy so as to maintain the body fluid equilibrium and facilitate the quick recovery of body [1] before, during and after exercises. After 1 hour of continuous aerobic exercise with high strength, the hepatic glycogen of the athlete's livers is decreased by around 55%. After 2 hours, the hepatic glycogen in livers and muscles is nearly used up [2-3]. As is known to all, the adding of glycogen increases the duration of endurance training. Thus, researches on carbohydrate loading have emerged one after another. On the other hand, apart from carbohydrate loading, appropriately replenishing carbohydrates before, during and after the exercise is also very important to prolong racing time and improve the performance. Why is the fluid supplementary during exercise so important? This is because the dehydration caused by sweating during the exercise needs to be prevented. Dehydration refers to the dynamic imbalance of liquid (the speed of liquid supplementary cannot catch up with the losing speed), e.g. the sweat of an athlete for a 1 hour exercise of moderate-intensity is around 0.5-1.5L, while that of an exercise in thermal environment can be more. Weightlifting, wrestling, boxing and rowing athletes with explosive power may also encounter dehydration. So they try to "create" expected weight by dehydration for the purpose of entering the competition.

The purpose of formulating sports drink is to quickly supply energy to the muscles, tissue and organs during an exercise and replenish lost water and electrolyte due to sweating so as to effectively prevent dehydration and maintain body fluid equilibrium and normal physiological function. Therefore, apart from water, sports drink contains 6%-9% carbohydrate and moderate sodium, potassium, magnesium and other electrolytes. Since 1970s, the formula of sports drink has undergone a revolutionary change because of the deepening of researches on Sports Nutrition and Exercise Physiology. Transformed to the direction of functional nutrition from the initial carbohydrates or electrolyte, protein/amino acid sports drink has become the new trend of its current development. Along with the development of sporting and the constant improvement of regulations for competitive sport contests, Schneider and others [Marcie et al.,2011] have made more specific explanation on sports drink: Generally, sports drink contains carbohydrate, mineral substance, electrolytes, vitamins and other nutrients. But sport drink is different from functional drink. Apart from the nutrient content of sports drink, functional drink may contain caffeine and other substances. In the matter of the practicability of sports drink, there are documents indicating that quick weight loss by dehydration will not greatly affect the athlete's performance. On the contrary, dehydration can improve relative strength and explosive power of muscles [5], but this applies to sport event less than 1 minute only. For those events more than 1 minute, dehydration may cause damage to physiological functions and athletes will not get the best training status. Hence, athletes are more likely to get pyreticosis if they keep training when their bodies are sweating heavily. Because sweat is a hypotonic solution comparing to other solution of the body, great loss of sweat will raise the osmotic pressure of plasma and lower the heat tolerance. Circulatory function and exercise ability will affected by serious sweating. Therefore, it is very important to replenish fluid during exercise, which can supplement water, maintain physical electrolyte balance, lower the body temperature raised due to exercise and decrease the pressure of circulatory system. Moreover, performances and scores can be improved by ingesting carbohydrate drinks.

2. Design Principle of Sports Drink

Water Content of Sports Drink

Profuse sweat is the main manifestation of athletes' water metabolism. The sweat rate of athletes is in direct proportion to exercise intensity, duration, heat radiation, ambient temperature and humidity and adaptability of the body. When the water loss accounts for 5% of the body weight, it is mild dehydration, while 5%-10% is moderate dehydration and over 10% is severe dehydration. When the figure reaches 20%, life will be endangered. The angiocarpy circulatory system will be overloaded, which causes heart rate acceleration, blood pressure drop and metabolic disorders, etc. Severe cases may lead to circulatory failure, collapse, obnubilation and even coma and other statuses [6]. Via research from the perspective of Physiology, Larry Kenney [7] found that when the athlete is in severe thirsty for hours, a mere wetting of lips will send a signal of quench to the brain and stop drinking water. But in fact, the body fluid is not fully replenished, which might cause imbalance of water intake and water loss when the athlete is in a long-duration training. The other reason of deficiency in fluid infusion is the quality of the sports drink. The flavor and taste, etc. of the drink might affect the athlete's intake. In addition, reasons of deficiency in fluid infusion also include the supply of drinks, containers of drinks, and the encouragement and supervision on fluid infusion from the coach, trainer, team doctor and parents. Generally, sports drink contains water, carbohydrates, electrolytes and other components. Replenishing those components has both single and multiple effects on the improvement of athletic performances. Thus, sports drink has a better effect [8-9] than sole water replenishment.

Carbohydrate Replenishment from Sports Drink

The replenishment categories of carbohydrate mainly contain monosaccharide, oligosaccharide, polysaccharide, etc. Normally, when the requisite amount of carbohydrate is satisfied by staple food, the fat mass ingested by the exercise group will accordingly increase. So athletes can take proper amount of sports drink to meet the required amount for carbohydrate. The flow of water in body is related to the flow of sodium, but blood volume is independent of the sodium concentration in blood. Researches find

that carbohydrate might be the key factor [10-11] to maintain the balance of blood volume. Apparently, some scholars believe that when the concentration of carbohydrate reaches 6%-8%, it can be ensured for the athlete to intake 60-70g carbohydrate per hour to generate energy. During lasting exercise or afterwards, replenishing sugary sports drink is able to facilitate glucose oxidation, protect muscle glycogen, delay fatigue, improve exercise performances, promote water absorption and effectively prevent hyponatremia. But it remains to be verified whether this applies to intermittent exercise.

Electrolyte Replenishment from Sports Drink

During exercise, the heat production of the body mushrooms. Large quantities of water and water-soluble nutrients will lose along with massive sweating and heat dissipation, causing disequilibrium of water-electrolyte balance. The increased loss of electrolyte in sweat is the main feature of the mineral metabolism. Exercising can accelerate the metabolism of electrolyte. The output of sodium, potassium, phosphorus and chlorine in urine is reduced except that of calcium, while the loss of ions of sodium, potassium, calcium, magnesium, zinc, ferrum and cuprum is increased. Study shows that sodium, potassium, calcium and magnesium are essential elements for maintaining the conduction of neural information and muscle contraction. Water ingestion without appropriate replenishment of sodium ion will cause syndrome of inappropriate antidiuretic hormone secretion (SIADH), restraining the secretion of aldosterone and increasing the volume of extracellular fluid. Hyponatremia [12] may be caused by the raised glomerular filtration rate (GFR) and restrained reabsorption of kidney tubules. Earlier researches indicate that sport drink contains 40-60mmol/L sodium which can effectively replenish the lost sodium in sweat, maintain the osmotic concentration of blood and keep the power [13] from stimulation. There are other scholars suggest that during the later phase of recovering, athletes should intake fluid which accounts for 125%-150% of sweat and contains 50-60mmol/L sodium to help eliminate dehydration and recover the body as soon as possible.

Protein and Amino Acid Replenishment from Sports Drink

Due to resultant hypermetabolism such as the increase of cytoclasis, the regeneration of myoglobin and erythrocyte, stress hormone and neuroregulation, negative nitrogen balance often occurs at the initial stage of strenuous exercise. Intense endurance training will enhance the protein metabolism and more muscular tissue is required for strength training, so it is of great importance to appropriately raise the replenishment of protein.

If it fails to provide exogenous amino acid, the concentration of amino acid in blood and muscle will be lowered as a result of the release of endogenous amino acid. Researches manifest that the transportation of intracellular amino acid and the concentration of that in muscles are the determining factor [14-15] to adjust the myoprotein synthesis. Studies of Dreyer and others[16] suggest that replenishing essential amino acid or protein rich in leucine after antagonistic training can ensure the proteometabolism balance and expedite the myoprotein synthesis. Reports from Pasiakos and others [17] show that in moderate endurance training, essential amino acid replenishers rich in leucine is more effective in expediting the myoprotein synthesis compared to other common replenishers. Its mechanism of action is that the branched chain amino acid promotes the myoprtein synthesis by lowering the degradation ratio of protein, showing that limbs of athletes' optionally take in branched chain amino acid during long-time exercise. This indicates that exercising can promote the ability of muscles to oxidize branched chain amino acid. Besides, protein metabolism and glucose metabolism are also related. Some scholars[18-19] hold the point that the insulin secretion almost completely depends on the concentration of glucose. However, other researchers believe that some amino acids can also lead to insulin secretion when the baseline level of glucose in blood slightly changes. When the glucose content is fixed, amino acid mixture or a certain amino acid will stimulate the pancreas and islet beta cells of isolated rat to secrete insulin, while taking in arginine orally will not work this way. In the cycling event, the metabolic level of glutamine can well predict the generation of pyruvic acid and the metabolic capability of the body. Though both glutamine and glucose polymer can increase the storage of muscle glycogen, applying them simultaneously will raise the muscle glycogen content [20,21] in exoskeleton. Hence, replenishing

protein or branched chain amino acid on the purpose of raising the concentration of leucine can effectively facilitate the muscle recovery after training.

Vitamin Replenishment from Sports Drink

As a water soluble vitamin, Vitamin B includes thiamine, riboflavin, nicotinic acid, pantothenate, biotin, glutamic acid, etc. These are coenzyme components, playing an essential role in the mitochondrial functions and energy generation of cells. Sports drink contains a certain amount of carbohydrate. Above vitamins are indispensable [22] in promoting the process where the carbohydrates in sports drink transform into energy. Thiamine serves its vital role in the tricarboxylic cycle to generate ATP. It takes part in the decarboxylation of branched chain amino acid and also plays a role as the componentof key enzyme in the metabolism of carbohydrates [23] . In the form of flavin adenine dinucleotide (FAD) and flavin mononucleotide, riboflavin takes part in coenzyme of multiple enzymes. It participates in the redox reaction and energy generation with some enzymes and respiratory enzyme through tricarboxylic cycle, playing a significant role in aerobic endurance training [24]. In the oxidation of cells, nicotinic acid transfers hydrogen and promotes the release of neurotransmitters, including levodopa, dopamine, serotonin, noradrenaline, etc. Those neurotransmitters are inseparable from athletic performances [25]. Manore [26] once reported that the vitality of glutamic oxalacetic transaminase of red blood cells can be increased when the athlete replenishes Vitamin B6 for a long run. The concentration of phosphopyridoxal in plasma and the content of Vitamin B6 in muscles are able to improve the maximal oxygen uptake and shooting ability of an athlete, whose excitation of muscles will be improved as well.

3. Replenishing Method of Sports Drink

Pre-exercise Fluid Infusion

When exercising in thermal environment, pre-exercise water replenishment can help the body postpone dehydration and heat pressure, increase sweating volume and lower the danger raised by core temperature. This leads to good exercising performances of athletes and frees them of pyreticosis. The speed of gastric emptying of water at break is 15-20ml/min, while that of heat material is 5-20ml/min. Athletes are suggested to intake 400-600ml cold water 20 minutes before the race to enlarge the gastric capacity and accelerate the emptying of fluid and nutrients. Because the gastric emptying of fluid is only about 1,000ml per hour during plain exercise, while sweat loss is about 2,000ml, it is suggested to replenish 150-250ml fluid every 10-15min during the exercise to maintain the material transportation in small intestine and the stationary capacity of gaster. In the aspect of carbohydrate replenishment, ingesting food with high-concentrate sugar 1 hour before exercise will sharply increase the blood sugar, which may cause excessive secretion of insulin and hypoglycemia And central nervous system is apt to be damaged when the athlete exercise with hypoglycemia. There will massive insulin secretion helping glucose enter muscles during exercise, but high concentration of insulin will restrain the steatolysis and reduce the metabolism of the free fatty acid in adipocytes. Judging from relative researches and reports [27], ingesting fluid with high-concentrated sugar 30min before the endurance training will accelerate fatigue. This is probably because the blood sugar quickly rises after 5-10mins of ingesting fluid with high-concentrated glucose, causing insulin effect and run out of the hepatic glycogen in muscles ahead of time. As a result, glucose shall be ingested at least 1 hour ahead of exercise so as to lower its negative effect, provide enough time for hormones to rebuild new balance before exercise.

Fluid Infusion in Exercise

Fluid infusion in exercise emphasizes the replenishment of carbohydrate. So food with high GI is the best choice. Food with high GI can lower the consumption of muscle glycogen (especially slow muscle) and maintain the normal glucose concentration in exercise to prevent headache, dim eyesight, gastric nausea and other disorder symptoms of central nervous system. When the athlete is taking an aerobic exercise with a maximal oxygen consumption of 60-80%, especially marathon, fatigue can be postponed for 15-30min if carbohydrates are replenished 30min before the expected exhaustion. The maximal oxygen consumption of endurance exercise is suggested not to exceed 75%. When it does, the intensity in the final stage shall be under 75% so that the carbohydrate replenishment can maximize its effect.

Before the exercise and in the 1st, 2nd and 3rd hour of the exercise, the cycling player can intake 400ml fluid containing 43g sucrose to maintain the concentration of blood sugar and postpone the exhaustion of glycogen. In this way, more glycogen will be available for the final anaerobic sprint and the player will get better performance [28].

Fructose will easily lead to gastric discomfort and poorer performances, so it is moderately applied into the sports drink. For electrolytes, sodium must be replenished. Glucose is absorbed by jejunum villus with mechanism of active transportation on small intestine. Sodium and sodium-glucose shared protein are required for the transportation. The concentration of sodium, potassium and chlorine in sweat are respectively 10-100mmol/L, 3-8mmol/L and 10-100mmol/L. When a trial subject runs on a treadmill for 2 hours and drinks only plain boiled water, the concentration of sodium and chlorine in plasma will drop, but the figure will remain unchanged as that before the exercise when the subject intake glucose-electrolyte solution with 20mmol/L Na, 2.4mmol/L K and 15.3mmol/L Cl.

Post-exercise Fluid Infusion

With proper replenishment of carbohydrates, the anaplerosis speed of glycogen is about 5-7% per hour. Carbohydrate consumption for at least 20 hours is required to regain the storage volume of glycogen under normal blood circulation system. Food with medium and high glycemic index (GI) is suggested for the anaplerosis of glycogen after endurance training[Depeint et al., 2006]. After exercise, the synthesis of glycogen will increase due to the high concentration of insulin, the increase of glucose transport protein and the decrease of the concentration of adrenaline. And when the exercise is just ended, 50-75g food with high GI shall be immediately replenished every 2 hours till each kilogram of the weight contains 7-10g; for races with high intensity, food with high GI shall be immediately replenished to conduct quick anaplerosis of glycogen. If it fails to replenish food with high GI for the anaplerosis of glycogen, 2.5g of which for each kilogram of the weight may be replenished after 2, 4, 6, 8 and 22 hours of the exercise. Therefore, drink with quick gastric emptying; low gastric discomfort and high sugar shall be selected for the fluid infusion after exercise. Another matter to be noticed after exercise is when such pyreticosis as heat exhaustion or heatstroke occurs or the body weight is decreased by less than 4% dude to dehydration, normal saline with 4.3% of glucose shall be injected intravenously. This has become a widely applied medical treatment. The formula can quickly replenish water, lower the core temperature and maintain the plasma osmotic pressure and the homeostasis of electrolytes.

4. Conclusion

Ideal sports drink supplement shall be tasty, quick-absorbed and free of gastric discomfort, being able to maintain the capacity and osmotic pressure of extracellular fluid and enhance athletes' sports performances. The basic principle of fluid infusion is to intake 5-8% carbohydrate-electrolyte solution for the purpose of adjusting the balance between body temperature and water in the body and postponing fatigue by supplying 5Kcal/min glucose as the energy source and glycogen storage. Nonetheless, the fluid infusion may change along with the interaction effect between environment and exercise conditions. Health and safety shall be the first things to be considered. For instance, an athlete will be suggested to intake less than 5% carbohydrate-electrolyte solution when he or she has exercised intensively in thermal environment for 30-60min; while the figure can be raised up to around 15% in cold environment for the dehydration is not severe. The fluid may contains glucose, fructose, sucrose, other oligose or starch, etc. Due to different properties of each component, the fluid infusion shall be adjusted in accordance with different physiological reactions before, during and after exercise and personal needs of players to obtain the best performance.

References

[1] Shi Xiaocai.,2002. Analysis of sports drinks [J]. sports science, 22 (2): 112-115.

[2] Jeukendrup, A.E., Mensink, M.,Saris, W.H., Wagenmakers,A.J.,1997.Exogenous glucose oxidation during exercise in endurance-trained and untrained subjects[J]. J. Appl. Physiol. , 83:835-40.

[3] Peter G Snell,Robert Ward,2010. Comparative effects of selected non-caffeinated rehydration sports drinks on short-term performance following moderate dedehydration[J].Journal of the international Society of Sports Nutrition,7: 28.
[4] Marcie Beth Schneider. Holly J. Ben jamin., 2011. Clinical report sports drinks and energy drinks for children and adolescents: are they appropriate?[J]. American Academy of Pediatrics, 27(6): 1182-1183.
[5] Jacobs, I.,2000. The effects of thermal dehydration on performance of the Wingate anaerobic test[J]. Int. J. Sports Med.,1：21-25.
[6] Chen Jidi, 2002.Sports nutrition. Beijing: Beijing Medical University Press, 63-64.
[7] Larry Kenney,Julie Burns,MS,et al., 2002. Why athletes often do not add enough fluid in the sport, how to make up for [J]. Sports Science, 22(1):138-139.
[8] Ronald, editor in chief, Yang Zeyi,2005. Sports nutrition[M]. Beijing: People's sports press, p221.
[9] Shi X,Gisolfi CV.1998. Fluid and electrolyte replacement during intermittent exercise[J] .Sports Med,25: 157-172.
[10] Barr SI,Costill DL,Fink WJ.,1991. Fluid replacement during prolonged exercise: effect of water Saline,or no fluid[J].Med Sci Sports Exerc,23,56-59.
[11] Schedl HP,Maughan RJ,Gisolfi CV,1994. Intestinal absorption during rest and exercise: implications for formulating oral rehydration solution (ORS)[J]. Med Sci Sport Exerc,26: 267-280.
[12] Verbalis,J. G.,2003. Best Pract. Res. Clin. Endocrinol[J].Metab,17: 471-503.
[13] Nose H,Mack GW,Shi X,et al., 1988.Shift in body fluid compartments after dehydration in humans[J]. J Appl Physiol,65(1):318-24.
[14] Dickinson JM,Rasmussen BB.,2010. Essential amino acid sensing,signaling and transport in the regulation of human muscle protein metabolism[J].Curr Opin Clin Nutr Metab Care,14:83-88.
[15] Hundal HS,Taylor PM,2009. Amino acid transceptors : gate keepers of nutrient exchange and regulators of nutrient signaling [J].Am J Physiol Endocrinol Metab, 296: 603-613.
[16] Dreyer HC,Drummond MJ., 2008. Leucine-enriched essential amino acid and carbohydrate ingestion following resistance exercise enhances mTOR signialing and protein synthesis in hunman muscle[J].Am J Physiol Endocrinol Metab,294: 392-400.
[17] Stefan M Pasiakos,Holly L McClung.,2011. Leucine-enriched essential amino acid supplementation during moderate steady state exercise enhances postexercise muscle protein synthesis [J].American Society for Nutrition, 94: 809-18.
[18] Nair KS,Schwartz RG,Welle S.,1992. Leucine as a regulator of whole body and skeletal muscle protein metabolism in humans [J].Am J Physiol Endocrinol Metab, 263: 928-934.
[19] Newgard CB,Matschinksy FM.,2001. Substrate control of insulin release. In: Jefferson LS,Cherrington AD,eds. The endocrine pancreas and regulation of metabolism [M].New York: Oxford University Press, 125-151.
[20] Ha E,Zemel MB,2003. Functional properties of whey,whey components,and essental amino acids: mechanisms underlying health benefits for active people[J].J Nutr Biochem ,14: 251-258.
[21] Norton LE,Layman DK.,2006. Leucine regulates translation initiation of protein synthesis in skeletal muscle after exercise[J].J Nutr ,136: 533-537.
[22] Ba A. 2008.Metabolic and structural role of thiamine in nervous tissues [J]. Cell Mol Neurobiol., 28(7): 923-931.
[23] Lakshmi AV., 1998. Riboflavin metabolism-relevance to human nutrition[J].Indian J Med Res,108(1): 182-190.
[24] Sauve AA.,2008. NAD + and vitamin B3: from metabolism to therapies[J].J Pharmacol Exp Ther,324(3):883-893.
[25] Spinneker A,Sola R,Lemmen V,et al.,2007. Vitamin B6 statatus,deficiency and its consequencesan overview [J]. NutrHosp, 22(1):7-24.
[26] Manore MM.1994.Vitamin B6 and exercise [J].Int J of Sport Nutr,4: 89-103.
[27] Davis JM,Lamb DR,Pate RR,et al.,1988. Carbohydrate-electrolyte drinks: effects on endurance cycling in the heat [J].Am J Clin Nutr,48:1023-1030.

[28] Shephard RJ,Leatt P,1987.Carbohydrate and fluid needs of the soccer player[J].Sports Med,4:164-176.
[29] Depeint F,Bruce WR,Shangari N,et al. 2006. Mitochondrial function and toxicity: role of the B vitamin family on mitochondrial energy metabolism [J].Chem Biol Interact, 163(1-2):94-112.