A Review of Hydration

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SUMMARY

THIS ARTICLE REVIEWS THE GUIDELINES AND CONSIDERATIONS OF HYDRATION APPLICABLE TO VARIOUS POPULATION GROUPS AND RESPECTIVE CONDITIONS. AN AREA OF INTEREST AND CONTROVERSY WITH HYDRATION IS THE IMPACT OF ADDING PROTEIN, AS COMPARED WITH CARBOHYDRATE OR THE COMBINATION OF THE TWO, ON OVERALL HYDRATION AND PERFORMANCE STATUS.

The Institute of Medicine (IOM) in 2004 put forth official recommendations as related to water/hydration needs. This official recommendation is a new step within the paradigm of recommended daily intake/allowance as before 2004, when the IOM stated that it was impossible to set a water recommendation (11). The IOM has created a level of water intake deemed to describe the "adequate intake" (AI). The AI is meant "to prevent deleterious, primary acute, effects of dehydration, which include metabolic and functional abnormalities" (11). Water is the largest constituent of the human body. It accounts for more than 60% of the human body's volume. Water is essential for cellular homeostasis, playing important roles in physiological and biochemical functions. Many factors impact daily hydration needs and our ability to hydrate.

How the body regulates and uses water/hydration is relevant to the realm of nutrition and physical activity. For example, an increase in core body temperature during exercise is coupled with heat dissipation. Heat dissipation will result in cutaneous vasodilation and change in heat transfer and exchange. If heat transfer via radiation and convection is not adequate in reducing the heat load, sweating will occur, and heat will be lost by evaporation. If the water loss exceeds fluid intake (a condition referred to as hypohydration), then dehydration will ensue.

Water is a macronutrient that is underappreciated. It has to be recognized that there is extreme difficulty in establishing a specific level of water intake that ensures adequate hydration and promotes optimal health under all potential conditions and populations. Understanding the relationship between hydration states and optimal wellness along with disease relationships allows for the belief that there is a relationship between hydration and disease. Moreover, it is believed that hydration may play a role in the prevention of prolonged labor, urolithiasis, urinary tract infections, bladder cancer, constipation, pulmonary/bronchial disorders, heart disease, hypertension, venous thrombosis, and other conditions (9,16).

The purpose of this review is to provide a basic background of information as related to the aspects that affect hydration needs and fluid balance. The provision of fluid guidelines for the physically active adult and the nonactive adult is included. Total life cycle hydration is not covered herein but may be obtained through outside resources (3).

TOPICAL OVERVIEW OF WATER

Fluid intake's impact on health is well recognized. Surprisingly, however, the attention in which water/hydration is given is often undermined because the media infatuates with nutrition-related research focusing on carbohydrates, protein, and fat in hope of shedding light on prevalent obesity epidemics. The body is composed of 50–70% water (the average of 60% is the norm), and water/fluid is stored or circulating. For example, muscle contains about 73% water, blood 93%, and fat mass has 10%. It is known that approximately 5–10% of total body water is turned over daily through obligatory losses (respiration, urine, and sweat). Respiratory water losses are typically recouped by the production of metabolic water formed by substrate oxidation. Fluid losses during and after exercise also affect overall fluid balance. By definition, fluid balance is the achievement of a balance between fluid output and intake. It has been reported that physically active adults who reside in warmer climates have daily water needs of 6 liters with highly active populations needing even more to remain euhydrated (32). It also appears that as we age, our hydration needs also increase (26,36).

Water is a fluid that acts as a solvent and a transport system within the human body. Water can affect many metabolic processes, attributes of physical performance, and mental acuity because it plays a primary role in thermoregulation, optimal health, and its acute status. A disruption in fluid balance, as minimal as a 2% total body water reduction, can significantly hinder aerobic performance, orthostatic tolerance, and cognitive function.

The average fluid intake in the United States is currently 1,440 mL/d with

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19% of the fluid intake coming from foods (2). The IOM recommends, in general, that men aged 19–70 and older consume 3.7 L/d and women aged 19–70 and older ingest 2.7 L/d of all water sources (water, other liquids, and foods). Hence, Americans are typically underhydrated based on the following IOM guidelines.

PROPERTIES OF WATER

Water is a multifunctional macronutrient. One of the utmost important functions of water is heat regulation (body heat). Water acts as a buffer when body temperature rises if there is high specific heat (the specific heat of water equals 1 when 1 kilogram of water is heated 1°C between 15 and 16°C). As aforementioned, the body is approximately 60% fluid; therefore, a 70 kg man will contain approximately 42 kg of water throughout the body (29). For every 1° rise in temperature in a 70 kg person, approximately 58 calories (kilocalories termed herein as calories) will be metabolized, thus the heat buffering effect of water also results in increased metabolic rate.

Thermoregulation is pertinent to exercise physiology (and thus, overall physical activity) as evidenced by the evaporation of sweat. For example, for every gram of sweat evaporated (liquid to vapor) from the skin, the body expends 0.58 calories (or 2.43 kJ) (29,8). In other words, there is a metabolic cost of exercise and that the caloric expenditure is related to hydration status. Therefore, water not only has high specific heat, it also assists in the transfer of heat from areas of production to dissipation. Heat transport occurs efficiently, with minimal change in actual blood temperature.

The body regulates fluid balance in a precise and proficient fashion. Water readily transverses all cell membranes in the body. Osmotic and hydrostatic gradients dictate the movement of water. Water is also affected by the activity of adenosine triphosphatase in sodium-potassium pump (Na-K pump). For example, when a person initiates a regularly conducted exercise regimen and is unaccustomed to doing so, fluid shifts occur and plasma volume will expand to accommodate upon commencement.

REGULATION OF THIRST AND HYDRATION

Thirst is subjective. The perception of being thirsty is also a subjective motivator to quench the thirst in animals and humans (21). Regulatory systems maintain body fluid levels essential for long-term survival. Fluid needs and urges to drink are influenced by various and interrelated factors including cultural and societal habits, internal psychogenic drive, and the regulatory controls to maintain fluid homeostasis. Regulatory control includes maintaining fluid content of various bodily compartments, the osmotic gradient of the extracellular fluids, or work with specific hormones to assist in the regulation.

When the body loses water, it is usually depleted from both the extracellular and intracellular spaces. These losses might not be equal in volume. A loss of water and sodium chloride (NaCl), the major solute of the extracellular fluid, results in proportionately more extracellular fluid depletion than if water alone is lost. In sweat, NaCl is lost at a rate of 7:1 compared with potassium (21). Thus, fluid losses of 1–2% of body weight or greater induce the need for fluid and electrolyte replacement. If fluid losses come from the gastrointestinal tract (i.e., diarrhea) and are of normal osmotic load (isotonic), then the depletion will be entirely from the extracellular fluid. However, if hypertonic fluid is added to the extracellular compartment, there will be an osmotic depletion of water from the intracellular compartment into the extracellular fluid, and this latter compartment will be expanded.

There is a range of compensatory responses that can occur in synchronicity with losses from the intra- or extracellular space. Understanding the effects of vasopressin secretion, stimulation of the renin-angiotensin-aldosterone system, sympathetic activation, and reduced renal solute and water excretion is important when addressing hydration in athletes. Hormonal responses to fluid losses, however, are not solutions to returning an athlete to a euhydrated state. The sole means of properly hydrating an individual is by replenishing by the standards of 600 mL per 0.46 kg weight loss (approximately 1,320 mL per kilogram weight lost) (11,13,17,18,23).

Thirst can be thought of as the "vocal" component, the body's response to fluid shifts or losses. The regulation of thirst includes osmoregulation. The osmotic pressure of the fluid (plasma osmolality) typically lies between 280 and 295 mosmol/kg/H_2O. Losses as small as 1–2% of body weight stimulates thirst. Thirst is a response to an increase in the osmotic gradient. Changes in NaCl and/or glucose induce this response by not crossing cell membranes easily. The osmotic differences between the intracellular and extracellular spaces are what dictate the flow of fluids (higher to lower concentration occurring typically by osmosis). Osmosis is partially regulated by osmoreceptors (relative to vasopressin) in the brain and in the liver. The hypothalamus is the center of the brain where thirst regulation is dictated (14).

Thirst regulation is, unquestionably, multifactorial. Within the central nervous system, osmotic, ionic, hormonal, and nervous signals are integrated and impact the perception of thirst. Overcoming hypo- or dehydration after the ingestion of water or fluid involves additional pathways and factors that are beyond the scope of this article. Furthermore, disease or metabolic disorder states' impact on hydration status is of noteworthy consideration that cannot be overlooked even in the apparently healthy athlete.

HYDRATION, HEALTH, AND DISEASE

Because many diseases have multifactorial origins (i.e., lifestyle, genetics, and environment), including the state of hydration, the various origins are worthy of examination. Mild dehydration is a factor in the development of various conditions and diseases. Conditions associated with the negative impacts of hypohydration or dehydration include alterations in amniotic fluids, prolonged labor, cystic fibrosis, and renal toxicity secondary to dehydration altering how contrast agents are metabolized.

The effects of chronic hypohydration or dehydration (systemic effects) include associations with (ranging from weak to mild) urinary tract infections, gallstones, constipation, hypertension, bladder and colon cancer, venous thromboembolism, cerebral infarcts, dental diseases, kidney stones, mitral valve prolapse, glaucoma, and diabetic ketoacidosis (16). Rehydration and proper hydration assist with condition management, disease prevention, and the betterment of health. Factors that can affect hydration include high ambient temperature, the relative humidity, high sweat losses (sweat rates), increased body temperature, exercise duration, training status of the individual, exercise intensity, high body fat percentage, underwater exercise, use of diuretic medications, and uncontrolled diabetes. The assessment of an athlete for hydration should include a review of all of the aforementioned factors.

The goal with each individual, regardless of athletic participation status or lack thereof, is euhydration. Hydration needs have been detailed by the IOM, as aforementioned, for both genders. However, the practicality of application is hard for the every day consumer. Easy "rule of thumb" hydration guidelines for general health are needed. Many dietitians recommend their clients shoot for a goal to drink the equivalence of ounces to half their body weight. Meaning that if you weigh 68 kg (150 pounds), your hydration goal, per day, with normal activities are 1500–2250 mL (50–75 oz) of nonalcoholic fluid.

HYDRATION AND PHYSICAL AND ATHLETIC PERFORMANCES

The overwhelmingly consistent conclusion across multiple research studies, academic societies, and training associations is that dehydration can significantly impact performance, with particular concern in warmer climate conditions (6,15–17,23). Thus, fluid replacement guidelines have been established to minimize exertional dehydration. Dehydration, as defined by a 2% loss of euhydrated body weight (30), negatively impacts athletic performance. Dehydration is associated with a reduction or an adverse effect upon muscle strength, endurance, coordination, mental acuity, and the thermoregulatory processes (1,4,6,9,15–17).

Water/fluid losses during exercise are impacted by many variables. The interindividual variation in sweat rates is wide, and no universal recommendations are used. As a general rule, for every pound of body weight lost between the initiation of exercise and the cessation, one replaces with 600 mL per approximately 1/5 kilogram of body weight lost (20 ounces [1.25 pints per pound] per pound of body weight lost).

Fluid and sodium losses occur during prolonged exercise. Human sweat contains 40–50 mmol sodium per liter (30). For the most part, in the normal healthy person, large fluid losses are followed by large sodium losses. The typical sodium to potassium ratio of losses is 7:1. An athlete engaged in prolonged exercise can lose 5 L of fluid per day with a range of 4,600–5,750 mg sodium and much smaller amounts of potassium. Heat-acclimated athletes benefit from enhanced sodium reabsorption that results in better protection of plasma volume by reducing the sodium losses. The training state of an athlete is very important when contemplating fluid needs. Sodium losses do not directly impact physical performance; however, using salts in fluid replacement is proven to enhance the thirst response and aid in rehydration (17,18,34).

Hypohydration (1% body weight loss) also decreases the ability of athletes to perform. Athletes, typically, do not replace sweat/sodium losses enough during the event. The average marathon runner will lose up to 3% body weight and if the run takes place in a temperate climate, losses could exceed up to 5%. According to Maughan, elite marathoners tend to lose salt/sweat at a rate of 2 L/h. This sweat rate exceeds intestinal absorption capability of the gut (33,19).

A plethora of studies clearly demonstrate a negative impact of hypohydration and dehydration on athletic performance (range from 1 to 8% fluid losses). Studies using sports or situations designed to mimic a sport have noted a decrement in performance for soccer, basketball, running/racing, cycling, and others (6,15–17,23). In addition, better hydration is associated with lower esophageal temperature, heart rate, and ratings of perceived exertion; all factors that, when increased, may impact performance (23).

Exercise increases the metabolic rate, and because energy is converted into heat, water losses will occur. In cold climates (winter sports or outdoor sports in mild or cold climates), heat is lost via radiation and convection, and as the temperature increases, the losses are noticeable as sweat. The physiological response to exercise is to expand the blood volume and to increase the sensitivity for sweating to occur. Athletes and their coaches, trainers, and nutritionists must be cognizant of changes in osmolarity. Body temperature and the volume of the liquid being ingested as well as the osmolarity can affect performance.

Another impact of hypohydration or dehydration that should be a concern to the athlete or their training staff is the potential for detriment on cognitive ability. The mental aspect of sports coupled with neuromuscular integration cannot be understated. The neuropsychological impacts of hydration, as well as the biological mechanisms and behavioral relationships, are relatively new areas of research. Brain behavior and cognitive assessment is recently new to the exercise physiology field because many new cognitive assessment tools have become available. Interesting to note, however, is a pioneer research study related to fluid and salt intake (6,15). In a review by Lieberman, hypohydration and dehydration were found to have an association with increased fatigue, impaired discrimination, impaired tracking, impaired short-term memory, and impaired recall and attention. In addition, arithmetic ability decreased while response time to peripheral visual stimuli was also affected (6,15). Cognitive applications relative to Lieberman's study have been tested not only in academic exercise and psychology research but also with military personnel.

Heat- or temperature-induced dehydration yields the same cognitive performance decrements associated with exercise-induced dehydration. This indicates that the hydration status is central for maintaining cognitive and physical performance. Cognitive performance, under the influence of dehydration, most often results in increased fatigue and tracking errors (visual-brain connection) along with a decrease in short-term memory. Hyperhydration, on the other hand, allots an increase in short memory while having a neutral impact on the additional aforementioned factors, exclusive of any negative effects (4).

PRACTICAL MEASUREMENTS OF HYDRATION

When it comes to measuring hydration, there is no sole universal standard. There are at least 13 techniques used for assessing hydration. Water is the body's currency because it is the medium for circulatory function, biochemical reactions, temperature regulation, and other physiological processes. In addition, fluid turnover occurs because water is lost from fluid-electrolyte shifts, in addition to losses from the lungs, skin, and kidneys. In addition, aging affects hydration needs (water is gained through the diet as well as fluid intake).

The types of hydration assessment methods (in the field and lab) include

1. stable isotope dilution
2. neutron activation analysis
3. bioelectrical impedance (BIA)
4. body mass change
5. plasma osmolality
6. plasma volume change
7. urine osmolality
8. urine specific gravity
9. urine conductivity
10. urine color
11. 24-hour urine volume
12. salivary flow rate (osmolality, flow rate, and protein content)
13. rating of thirst

An additional practical tool that is used clinically is the Hydration Assessment Checklist (HA). The HA is a lengthy in-depth assessment designed to screen for hydration problems (35). The HA is most often used in clinical conditions and in an older population. Older adults, both in the community as well as in the nursing home, are grossly underhydrated, ingesting on average less than about 0.26 gallons (1 L) daily, which is substantially lower than recommended. Of the reported half-gallon of fluid, few take in actual water as their primary fluid source. Water is an essential element supporting cellular and organ health, electrolyte balance, medication absorption and distribution, and kidney, bladder, and integumentary functioning (26,36). In essence, the importance of fluid intake for older adults is of momentous concern.

The following factors have been detailed in the literature as to why 1 gold standard for measuring hydration is not possible (1).

1. The physiological regulation of total body water volume (i.e., water turnover) and fluid concentrations is complex and dynamic. Renal, thirst, and sweat gland responses are involved to varying degrees, depending on the prevailing activities. In addition, renal regulation of water balance (i.e., arginine vasopressin) is distinct from the regulation of tonicity.
2. The 24-hour fluid deficit varies greatly among sedentary individuals and athletes primarily because of the exercise and morphology. The deficit must be matched by food and fluid intake (the fluid portion of food is often overlooked).
3. Sodium and osmolyte consumption affects the daily water requirement. Regional customs impact the "normals" used within biochemical assessment of hydration. For example, the mean 24-hour urine osmolality in Germany is 860 mOsm/kg, in Poland, it is 392 mOsm/kg, and in the United States, it is in the range of 280–295 mOsm/kg.
4. The volume and timing of fluid intake alters measurement of hydration. Pure water or hypotonic solutions ingested rapidly can cause dilute urine before cellular equilibrium to occur.
5. Urine samples (spot) not representing the true 24-hour void.
6. Experimental designs that differ in assessment techniques (blood versus urine).
7. Use of stable isotopes to assess hydration. However, it is not known if the isotopes are uniformly distributed throughout the body, thus the assumption used in these techniques is faulty.
8. Exercise and physical labor (as well as pregnancy labor) increase blood volume while decreasing renal blood flow and altering the glomerular filtration rate affecting hydration.
9. Changes in osmolarity and osmolality can affect the readings for hydration on certain devices (i.e., BIA).

In addition to the above, many questions exist regarding the use of plasma osmolality as a biomarker for hydration. These include questions regarding the fact that plasma osmolality varies widely depending upon the condition being tested, environment of the test, the preexercise hydration state, and the intervention being evaluated. One question is that is there a way to meld laboratory techniques with those in the field so that trainers, coaches, and related personnel can better help athletes?

The first item to discuss is the intervention and educational sessions that athletes should receive from appropriate professionals (i.e., exercise physiologist, registered dietitian, sports nutritionist, athletic trainer, and so on). Education is the key to preventing dehydration. Combining education with accessible fluid stations (on the field or in the general area of training), available to the athletes at specific intervals, may make euhydration an easier goal to maintain

For the field technique using the combination of weighing the athlete before and after the training or competition and using the weight change as the guide for rehydration may just be the best standard when controlling for applicability, financial impact, and ease of education. The rehydration is 600 mL per 0/5 kilogram of body weight lost. Other techniques that may be able to be used in combination with monitoring weight changes include using blood and urine testing if available. Testing for osmolality (both), sodium (both), and hematocrit levels (blood) are typical and inexpensive.

THE DIFFERENCE BETWEEN WATER AND OTHER MEANS OF REHYDRATION

Humans achieve normal hydration with a wide range of fluid intakes across their life span. Fluid homeostasis can be challenging to maintain during physical work and heat stress. Body water comprises 50–70% of body weight. Approximately 5–10% of total body water is turned over daily via obligatory losses and the need for replacement when coupled with exercise-related fluid losses becomes that much more apparent. The greater the fluid losses (from nonemergent situations, not medical or surgical), the longer the time it will take for rehydration (4% weight loss may take up to 24 hours to rehydrate), thus prevention and use of foods or fluids that may aid in more expedient rehydration is noteworthy for application (13).

Body water is maintained by matching daily water loss with intake. Metabolic water production also contributes to a small degree hydration (metabolic hydration yields approximately 250 mL/d). The Food and Nutrition Board has established an AI level of 3.7 and 2.7 L/d for men and women, respectively (11). The Continuing Survey of Food Intakes by Individuals concluded that adults receive about 25% of their daily fluid intake from foods (10).

Maintaining fluid and electrolyte balance means that active individuals need to replace the water and electrolytes lost in sweat. This requires that active individuals, regardless of age, strive to hydrate well before exercise, drink fluids throughout exercise, and rehydrate once exercise is over. As outlined by the American College of Sports Medicine and the National Athletic Trainers' Association generous amounts of fluids should be consumed 24 hours before exercise and 400–600 mL of fluid should be consumed 2 hours before exercise (this is approximately 6–10 oz) (23). During exercise, active individuals should attempt to drink approximately 150–350 mL (6–12 oz) of fluid every 15–20 minutes. If exercise is of long duration (usually >1 hour or 75 minutes) or occurs in a hot environment, sport drinks containing carbohydrate and sodium could be used. When exercise is over, most active individuals have some level of dehydration. Drinking enough fluids to cover approximately 150% of the weight lost during exercise may be needed to replace fluids lost in sweat and urine. This fluid can be part of the postexercise meal, which should also contain sodium, either in the food or beverages, because diuresis occurs (fluid losses) when only plain water is ingested. Sodium helps the rehydration process by maintaining plasma osmolality and the desire to drink.

Fluid content of foods should not be underestimated or underappreciated by health professionals. High water content foods, listed as food and percent water, include iceberg lettuce (96%), cooked squash (94%), pickle (92%), cantaloupe (90%), oranges (87%), apple (86%), and pears (84%) as compared with steak (50%), cheddar cheese (37%), white bread (36%), cookies (4%), and nuts (about 2%). Therefore, including the national recommendation of 5–9 fruits and vegetables in the day also assists with hydration.

Preexercise, some athletes use beverages that contain >100 mmol/L NaCl, temporarily inducing hyperhydration, thus aiding in rehydration. Adding glycerol to the typical sports beverage or oral rehydration solution at a dose of 1.0–1.5 g/kg/body weight also assists in inducing hyperhydration (31).

Nonwater sources of hydration include caffeinated beverages. Caffeine is stated to be a mild diuretic; however, the vast evidence indicates that caffeinated beverages and water hydrate to the same degree over a 24-hour period. Fiala et al. (5) have found that caffeine is often rumored to be a mild diuretic, while noting that caffeine itself can enhance exercise performance (typical dose at 5 mg/kg). This study used 10 athletes who completed twice-a-day practices (2 h/practice = 4 h/d) for 3 consecutive days at 23°C. The study used a randomized double-blind design comparing a caffeine rehydration agent with one without caffeine (Coca-Cola versus caffeine-free version). The findings revealed that caffeine intake did not impair rehydration. No differential effects on urine or plasma osmolality, plasma volume, hematocrit, hemoglobin, or body weight were observed between the 2 groups. The caffeine (cola) intake was approximately 244 mg/d served in 7 cans/d of soda (approximately 35 mg caffeine/360 mL).

Grandjean et al. (7) found analogous results in a study of 18 males using a randomized crossover design with a free-living 24-hour capture design. The study tested 4 beverage treatments consisting of carbonated caffeine caloric cola, noncaloric caffeinated cola, and coffee and their respective effects on 24-hour hydration status. The researchers collected urine for 24 hours and analyzed for electrolytes, body weight, osmolality, hemoglobin, hematocrit, blood urea nitrogen, creatinine, and other biomarkers. The results clearly denoted no differences among the groups in any variable, therefore, eliminating the connotation that caffeine be disregarded from daily fluid intake. Subsequently, the evidence supports the consumption of caffeine-containing beverages for the use of added hydration.

Newer research data has started to support the inclusion of small amounts of protein with carbohydrates for hydration recovery. In 2001, 10 endurance-trained men were employed to investigate the ergogenic effects of isocaloric carbohydrate (CHO, 152.7 g) and carbohydrate-protein (CHO-PRO, 112 g CHO with 40.7 g PRO) drinks ingested after a glycogen-lowering diet and exercise bout. Treatments were administered in a double-blind and counterbalanced fashion. After a glycogen-lowering diet and run, 2 dosages of a drink were administered with a 60-minute interval between dosages. The CHO-PRO trial resulted in higher serum insulin levels (60.84 versus 30.1 mU/mL) 90 minutes into recovery than the CHO-only trail ($p < 0.05$). Furthermore, the time to run to exhaustion was longer during the CHO-PRO trial (540.7 $\pm$ 91.56 seconds) than the CHO-only trial (446.1 $\pm$ 97.09 seconds; $p < 0.05$). In conclusion, a CHO-PRO drink after glycogen-depleting exercise may facilitate a greater rate of muscle glycogen resynthesis than a CHO-only beverage, hasten the recovery process, and improve exercise endurance during a second bout of exercise performed on the same day (24). Subsequent studies have found that adding protein in the ratio of 1 part protein to every 4 parts carbohydrate has been found to induce exercise hydration on the magnitude of 15% better than the typical carbohydrate beverage and 40% more than water alone (12,27).

A study by Seifert et al. (27) actually concluded, "contrary to popular misconception, adding protein to a carbohydrate-based sports drink led to improved water retention by 15% over [a carbohydrate-only sports drink] and 40% over plain water." In the study, cyclists exercised until they lost 2% of their body weight (through sweating) and then drank a carbohydrate-protein sports drink (Accelerade), a carbohydrate-only sports drink (Gatorade), or water. Over the next 3 hours, measurements were taken to determine how much of each beverage was retained in the body (versus the amount lost through urination). The carbohydrate-protein sports drink was found to rehydrate the athletes 15% better than the carbohydrate-only sports drink and 40% better than water. All 3 drinks emptied from the stomach and were absorbed through the intestine at the same rate. In addition, there was no difference between the carbohydrate-protein drink and the carbohydrate-only drink regarding the effects on blood plasma volume. This suggests that the carbohydrate-protein drink resulted in increased water retention within and between cells. Therefore, when rehydration and fluid retention are of concern; a carbohydrate-protein sports drink may be preferable over plain water and a carbohydrate-electrolyte sports drink.

An additional sports application study by Seifert et al. (28) found that "ingestion of a carbohydrate-protein beverage minimized muscle damage indices during skiing compared with placebo and no fluid." Thirty-one recreational skiers were separated into 3 groups. All 3 groups skied 12 runs, which took about 3 hours. One group drank nothing. A second group drank 6 oz (.18 L) of a placebo (flavored water) after every second run. A third group drank an equal amount of the carbohydrate-protein sports drink (Accelerade). After the 12th run, blood samples were taken from each skier and analyzed for 2 biomarkers of muscle stress (myoglobin and creatine kinase). Subjects who received the carbohydrate-protein sports drink showed no signs of muscle damage, while indicators of muscle damage increased by 49% in subjects receiving only water. Thus, it is reasonable to conclude that in this type of sport using a carbohydrate-protein drink is more beneficial than water for maintaining skeletal integrity and hydration.

Typically hydration and rehydration for athletes is done with a 6–8% glucose-electrolyte solution. Newer research is finding that adding just a small amount of protein to this type of sports beverage not only enhances hydration and rehydration (or hydration maintenance) but also promotes muscle protein synthesis (which does not happen with CHO alone) and glycogen reaccumulation while reducing markers of muscle damage. These beverages are gaining popularity for their multiple benefits that seem to make them superior to the typical sports beverage during exercise or postexercise nutrition.

FLUID REPLACEMENT

Fluid replacement is a vital component and must be addressed in a diligent manner. In general, sports nutritionists use the following fluid recommendations (25,20):

- 480–600 cc fluid: 1–2 hours before exercise
- 300–480 cc fluid: 15 minutes before exercise
- 120–180 cc fluid: every 10–15 minutes during exercise
- In general, start fluid intake 24 hours before exercise event.

Fluid intake coming from food must also be considered. As aforementioned, however, hydration in the postexercise recovery is best achieved by the ingestion of either the typical glucose-electrolyte solution or a carbohydrate-protein mixture. However, if the exercise has duration of less than 60–75 minutes, then plain water (may be flavored) is recommended. There are no proven ergogenic effects or benefits from vitamin- or mineral-enriched waters except that they provide absorbable nutrients at lower caloric costs than some foods. Despite the lack of ergogenic enhancement, research shows that the volume of fluid intake generally increases when water or the beverage is flavored (22).

The athlete may consider taking note of the volume of his/her beverage intake to become more familiar with how their body responds to rehydration. The athlete can personalize his/her fluid intake based upon what types of beverages result in improved recovery as measured by hydration, return to normal body weight, subsequent exercise performance, and effects on mental abilities/cognition.

CONCLUSION

Exercise increases the metabolic rate. Energy production leads to heat loss, and fluid status is affected. The climate has an underappreciated effect on hydration status. In cold climates, the thermoregulatory response includes enhanced heat production by a variety of means; all resulting in increased fluid losses. Exercising in temperate climates is actually a little easier because the body's accommodation response is to increase blood volume and sweating mechanism sensitivity. Athletes, along with their trainers and coaches, must be cognizant about the physiological impacts of exercise, such as changes in body temperature and blood volume, in their surrounding climate. Elevated temperature is related to blood volume reduction and performance.

Maintaining fluid balance reduces the effects of climate and/or blood volume on hydration status. For exercise lasting less than an hour, water or noncaloric fluid is recommended. It is not well known if "nonintensive" exercise requires that the rehydration solution include carbohydrate and electrolytes. Most data note no need for supplemented calories and salts with short-term exercise bouts. If the exercise is longer in duration, maintaining hydration and rehydration is much more important. Beverages beneficial for enhancing rehydration include carbohydrate-electrolyte solutions and carbohydrate-protein beverages (C-P). Caffeinated beverages, with and without calories, also add to hydration and rehydration. Although in the immediate postexercise period, data are mounting for C-P to be the superior postexercise rehydration and recovery beverage.

Future research will focus on the multiple applications of this admixture beverage along with other potential beneficial effects. Taste acceptance is very important for any of these beverages to actually be used by athletes; therefore, overcoming taste issues for beverages that contain protein remains an issue for researchers and food scientists to overcome. In conclusion, maintaining euhydration and understanding how to rehydrate after exercise is an important aspect of sports nutrition that is underdiscussed and/or underappreciated.

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