Executive Summary: Water is the largest single constituent in the human body. In healthy adults, it can account for approximately 60% of body mass, playing vital roles in physiological and biochemical functions. Although early hydration research focused on how much is needed to prevent dehydration in times of physical stress, recent studies have started to examine the role of fluids in the prevention of chronic illness. Other areas of water research include clarifying myths and misconceptions about fluid requirements, ways of assessing fluid balance, and how fluid requirements are satisfied under various conditions. To address these issues, the International Life Sciences Institute (ILSI) Southeast Asia Region and ILSI North America organized a concurrent symposium on Hydration and Human Health during the fourth Asian Congress of Dietetics held in Manila, Philippines, on April 24 to 26, 2006. The symposium dealt with the current knowledge on hydration, from the myths and science of hydration, to the assessment of the level of hydration of the individual, and to recommendations for the maintenance of water balance under normal conditions and during physical exercise. Nutr Today. 2009;44(1):6–13

Hydration Knowledge, Myths, and Science

Maxime E. Buyckx, MD

Abstract

Although the thirst mechanism is the basic and most important mechanism to maintain euhydration, many other factors also influence our ability to hydrate. These include genetic background, age, availability, as well as social environment and cultural factors. These latter influences have engendered many myths and misconceptions concerning water and beverages and their capabilities and their requirements to maintain normal hydration. Foremost among these myths are those involving the consumption of beverages. For example, it has long been thought that the consumption of caffeinated beverages can lead to total water deficit. It is now evident that caffeinated beverages, despite the mild diuretic effect of caffeine, seem to contribute positively to satisfy water requirements in those individuals who customarily consume caffeine-containing beverages. Finally, there is increasing research interest on defining optimal fluid intake for promoting health and preventing diseases, including urolithiasis, urinary tract infection, and other chronic conditions.

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Since ancient times, water has been recognized as essential for human life.¹ Today, many myths and misconceptions still remain concerning the consumption of water and beverages especially with regard to their capabilities and their requirements for maintaining euhydration. It is important that the public be better informed with accurate scientific information. The misconceptions that spread through word of mouth, health professionals, the media, and now the Internet must be countered with scientific facts.

**Water Requirements**

Although the thirst mechanism is the basic and most important mechanism to help us maintain proper hydration level, there are many factors that influence our ability to hydrate: genetic background, age, availability, as well as social environment and cultural factors.²-⁴ The National Academy of Sciences, Institute of Medicine of the United States, in its report on dietary reference intakes of water and some minerals,³ pointed to the fact that different types of beverages and foods contribute significantly to a person’s daily fluid needs. Because there is no single level of water intake that would ensure adequate hydration and optimal health under all environmental conditions, no estimated average requirement could be established. Instead, adequate intakes for different age groups, under normal living conditions, were recommended, for example, 3.7 and 2.7 L/d of total water intake for men and women from 19 to 70 years old and above, respectively. Approximately 80% of total water intake comes from drinking water and beverages, whereas the remaining 20% comes from food. Recommendations and percentages may vary for different populations with different diets and living under different environmental conditions.

**Effects of Caffeinated Beverages**

In the last decade, important work has been done to investigate hydration status relative to the consumption of different beverages.⁵ It has long been thought that consumption of caffeinated beverages, because of the mild diuretic effect of caffeine, may cause total water deficit. More recent scientific studies and data indicate that caffeinated beverages seem to contribute to the daily water intake similar to that contributed by noncaffeinated beverages.⁵-⁷

**Hydration and Health**

In the past, fluid and electrolyte research has focused on medical care, survival, and optimal physical performance during times of physiological stress, such as during a combat or a sports competition.⁸ Very little research has actually focused on the hydration needs of the average individual.⁹ Research is now more focused on the relationship of hydration to mental and physical performance, wellness, and lifestyle in sedentary individuals.¹⁰-¹² Increasing attention is also now being given on the possible impact of hydration in the prevention of chronic diseases. There are possible links between certain diseases and mild dehydration: urolithiasis, urinary tract infections, bladder cancer, constipation, bronchopulmonary disorders, hypertension, heart disease, venous thromboembolism, dental disease, and others. The Institute of Medicine’s review for the Dietary Reference Intakes, however, states that at this time, there is insufficient evidence to establish water intake recommendations as a means to reduce chronic disease. Additional scientific studies and clinical evidence are needed to further strengthen this link and fully understand the benefits of proper hydration for good health.

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Hydration: Assessment and Recommendations
Kristin J. Reimers, PhD, RD

Abstract
Water and electrolytes must be balanced between the intracellular and extracellular compartments, and many physiologic mechanisms control this balance. Water is lost through various routes. There are various sources of water intake from food and beverages. Although there is still no standard method for measuring water balance, measurement of body weight changes, measurement of urine concentration such as specific gravity and osmolality, determination of plasma osmolality, and physical examination are common clinical and research assessment methods. The US Food and Nutrition Board’s recommended fluid allowances are 3.7 and 2.7 L/d for adult men and women, respectively. It is possible to meet this allowance from a mixed diet of foods and beverages, with or without plain drinking water. Although interest in hydration in healthy individuals is increasing, more research is needed for science-based recommendations for optimum health.

Water is a major component of the body and the medium for all metabolic processes. In healthy individuals who are in a state of water and electrolyte balance, the extracellular fluid (ECF) and intracellular fluid water content and electrolyte concentrations are stable. This balance is tightly controlled with sensitive mechanisms that respond to changes in intake and output. Although tightly controlled, with redundant mechanisms to protect water balance, water and electrolyte balance can be disrupted under physical, behavioral, and environmental conditions that surpass the limits of homeostatic mechanisms. In hypohydration caused by sweating, vomiting, or diarrhea, water loss surpasses electrolyte loss, causing hypotonic ECF. Conversely, when hyperhydration occurs because of excess plain water intake in the absence of salt intake, the ECF becomes dilute, causing a shift from extracellular to intracellular fluid. In both conditions, when extreme, death can result.

Water Balance
Water balance exists when the amount of water taken replaces insensible losses from skin and breathing and water output from urine, sweat, and feces. In general, daily water loss is variable both within and among individuals. Minimal obligatory urine loss is estimated to be between 0.5 and 1.0 L/d. Under normal conditions, fecal loss is estimated at about 100 mL/d. Insensible water loss through the skin and respiratory tract depends on body surface area, environmental temperature, humidity, altitude, volume of inspired air, air currents, clothing, blood circulation through the skin, and water content of the body. Water loss from sweating is highly variable but can reach 3 to 4 L/h, with variations depending on exercise intensity and duration, age, sex, fitness level, heat acclimatization, air temperature, humidity, wind velocity, cloud cover, clothing, and individual sweat rate. Historical evidence shows that average minimal loss of men ranges from 1.3 to 3.45 L/d.

Water Intake
On the other hand, water intake including water that is consumed as food and beverages, along with relatively small volume of metabolic water, may range from 1.6 to 7.3 L/d under a variety of conditions. Drinking behavior is influenced by culture, sensory quality of the beverages, availability, convenience, beliefs about drinking, social setting, and environment. Thirst is the primary mechanism to stimulate adequate drinking. A major factor that influences intake is food consumption. Under normal conditions, when a variety of foods and drinks are available, voluntary fluid ingestion tends to exceed the volume necessary for fluid balance. However, responding to thirst is insensitive during conditions of physiologic stress, leading to voluntary dehydration.

Measuring Water Balance
Currently, we have no infallible standard method to measure the state of water balance. In fact, there is no universal definition of dehydration. Methods commonly used to assess hydration status include measuring significant changes in hydration status with body weight, biochemical markers, and physical examination. An acute change in body weight will be due almost solely to a change in total body water. Hence, serial measurement of body weight is a feasible indicator of hydration status. Measurement of urine concentration, such as specific gravity and osmolality, is also commonly used to assess hydration status.
However, the validity of urine markers depends on the duration and severity of dehydration. Blood indices such as plasma osmolality, concentration of various hormones, blood urea nitrogen, sodium, potassium, hematocrit, and plasma protein, as well as blood volume and plasma volume, have also been used as indicators of hydration status. Of these, plasma osmolality is the most universal blood marker. Various techniques of measurement of total body water, when done repeatedly, measure directly changes in hydration status. These techniques, such as bioelectric impedance analysis, bioelectric impedance spectroscopy, and dilution techniques, have also been used, but these are inconvenient, expensive, and subject to measurement error and require validation in all populations.

**Myths About Fluid Needs**

Various myths and misperceptions still exist about how much fluids one needs; for example, statements such as “Everyone should drink eight 8-oz (8 × 8) glasses of water per day” and “Plain drinking water hydrates better than other beverages” are common. Although fluid requirements for individuals have not been quantified, recommendations for groups have been published. In the United States, the Food and Nutrition Board published its recommendations in the form of adequate intake (AI) instead of recommended dietary allowance. The AI recommendations are 3.7 and 2.7 L/d of total water for adult men and women, respectively. These recommended amounts include plain drinking water, water in beverages, and water that is part of food. Survey data show that most of an individual’s fluid intake is consumed from a variety of foods and beverages and not from plain water. In fact, it is possible to meet the AI for water without consuming plain drinking water if one consumes a mixed diet with high-water foods.

Lately, recommendations for water intake are beginning to be appreciated from a new perspective: optimal intake for promoting health. Increasingly, hydration research is focusing on the general population’s fluid intake as it relates to disease prevention and treatment. Various disease conditions have been linked to poor hydration, including urolithiasis, urinary tract infection, bladder and colon cancer, constipation, and many others. However, more research is needed to continue the progress toward evidence-based hydration assessment and recommendations for optimum health.

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Fluid Requirements During Physical Exercise

Chin Leong Lim, PhD, MBA, MS(PE), BS(PE)

Abstract

The physiological mechanisms of thermoregulation during physical exercise affect fluid homeostasis. Although there is consensus on the science of fluid homeostasis during exercise, there is, however, disagreement on the appropriate volume of fluid to ingest before, during, and after exercise. In 1996, the American College of Sports Medicine recommended ingestion of 500 mL of fluid 2 hours before an event, replacement of fluid loss at a rate equal to sweat rate, and consumption of the maximum amount of water that can be tolerated during exercise. In practice, these guidelines were translated into what is called volume-driven exercise hydration (ie, drinking by a fixed volume), with some scientists recommending drinking 2 L of water before exercise and 1.2 L/h of water during exercise in hot conditions. However, there is a considerable interindividual variation in sweat response, such that recommending a single volume of water intake during exercise may not be appropriate. Besides the fact that ingesting a high volume of fluid during exercise may not be tolerable by athletes, volume-driven exercise hydration may increase the risk of hyponatremia. The American College of Sports Medicine revised its position stand on fluid replacement during exercise in 2007. The revised guidelines agree that it is not possible to recommend a single volume of fluid replacement to suit everyone because of the variety of factors (body weight, environment, and training status) that influence fluid intake requirement during exercise. (This guideline was not published at the time of the symposium.) Dr Lim recommends drinking enough water to maintain a clear urine color before and after exercise and to prevent a fluid deficit of more than 2% of body weight during exercise. There is ongoing debate on whether drinking by thirst is sufficient to meet fluid intake requirement during exercise, but there is consensus that drinking about 0.4 to 0.8 L/h during exercise is sufficient to meet fluid replacement requirement for most people. Exercise and sports participants should establish their own fluid intake requirement by measuring body weight changes before and after exercise over a few training sessions. Dr Lim concludes that as the debate continues...
Heat and that

Although the volume-driven approach is involved in sustaining health and physical and mental performances during exercise. Thermal balance is a function of metabolic heat production and heat exchange between the body surface and the external environment. During intense exercise, metabolic rate is increased by 10- to 20-fold and heat production can increase by 100-fold. Heat generated through the metabolic process needs to be dissipated to the environment through conduction, convection, radiation, and evaporation so that body temperature is maintained within a physiologically tolerable range. The most significant source of heat dissipation during exercise is evaporation because more than 80% of body heat is dissipated to the environment through the evaporation of sweat during exercise. However, sweating alone, without evaporation, results in fluid loss without significant heat loss.

**Fluid Needs During Exercise**

During exercise, about 25% of metabolic heat is harnessed and converted to mechanical work in the form of muscle contraction. The other 75% is latent heat, which has to be removed from the muscle convectively by muscle blood flow. The blood transports the excess metabolic heat to the skin by increasing cutaneous blood flow. In the skin, sweat is produced, and heat is removed by the evaporation of sweat. Sweating results in loss of plasma volume (PV) if the amount of fluid loss through sweat is not replaced. The volume of sweat loss can be as high as 1 to 2 L/h, which translates to a corresponding loss in body fluid. The loss in PV can be defended by the shifting of extravascular fluid into the central circulation, but this mechanism can sustain PV for up to a sweat loss volume of about 2% of body weight. The eventual decrease in PV causes a decrease in blood pressure, stroke volume, and blood flow rate, which compromises blood supply to the exercising muscle, skin blood flow, and venous return. A fluid deficit of 1% to 6% of body weight compromises cardiac functions, exercise tolerance, and thermoregulation. During exercise, the muscle and skin compete for blood flow to sustain exercise performance and heat dissipation, respectively. If fluid loss through sweat is not adequately replaced by a corresponding fluid intake, PV will continue to decrease until blood pressure and flow rate cannot be maintained to sustain the exercise and heat dissipation, ultimately resulting in syncope and symptoms of heat exhaustion. Besides physiological functions, dehydration also compromises cognitive functions and sense of well-being, all of which compromise exercise performance.

Although there is consensus on the science of fluid homeostasis during exercise, there is disagreement on the appropriate volume of fluid to ingest before, during, and after exercise. In 1996, the American College of Sports Medicine recommended the following:

- Have a balanced diet with adequate fluid 24 hours before the event.
- Ingest 500 mL of fluid 2 hours before the event.
- Replace fluid loss at a rate that is equal to sweat rate.
- Consume the maximum amount of water that can be tolerated (as opposed to drink by thirst sensation).
- Drink 600 to 1,200 mL of 4% to 8% carbohydrate drink when exercising for more than 1 hour.

Although these guidelines did not specify any volume to drink, in practice, these guidelines were translated into what is called volume-driven exercise hydration (ie, drinking by fixed volume), with some scientists recommending drinking more than 2 L of water before exercise and approximately 1.2 L/h of water during exercise. Although the volume-driven approach is consistent with the principles of maintaining fluid homeostasis during exercise, there is disagreement over the underlying principles of such an approach. There seems to be no empirical evidence to support the notion that drinking fluid during exercise reduces the risk of heat injury. For example, the lack of fluid intake did not contribute to the 20 heat casualties reported in 2 road races. Dehydration was reported in approximately 16% to 17% of heat casualties in Israeli and US Army personnel, suggesting that the absence of dehydration did not prevent heat injuries in the approximately 84% of heat casualties.

Recommending a single volume of water intake during exercise may not be appropriate because of large individual variations in sweat response. Besides differences in the number of sweat glands among individuals, sweat gland activity is influenced by a variety of factors, such as sex, exposure to physical training, heat acclimatization, and age. This position is consistent with the American College of Sports Medicine’s position stand on fluid replacement during exercise in 2007, which was not published at the time of the symposium. Furthermore, field observations and experimental data suggest that ingesting high volume of fluid during exercise may not be tolerable for athletes and that drinking by the sensation of thirst may be sufficient to meet fluid requirement during exercise. The ability of the thirst mechanism to drive sufficient fluid intake to meet fluid replacement needs during exercise is still being debated but has not been proven to be wrong. Perhaps, the strongest challenge against volume-driven hydration is the tendency of athletes to use replacement fluids and beverages that are not compatible with their preferences and dietary needs. However, there is a need to align hydration practices with the science of fluid homeostasis to ensure optimal performance and safety during exercise.
exercise hydration is that an overload of water intake increases the risk of hyponatremia. Athletes affected by hyponatremia experience varying levels of altered consciousness and can go into a coma. Other complications of hyponatremia include pulmonary edema with respiratory failure. It was the high number of hyponatremia cases that prompted the US Army to review its guidelines on fluid replacement in 1999, which resulted in a 55% reduction (from ~2 to ~1 L/h) in the recommended maximum fluid intake volume.\(^{25}\)

The challenge is to recommend water intake volumes that are individualized as opposed to “one-size-fits-all” approach. Despite the ongoing debate on whether drinking by thirst is sufficient to meet fluid intake requirement during exercise, there is consensus that drinking about 0.4 to 0.8 L/h of fluid during exercise is sufficient to meet fluid replacement requirement for most people.\(^{25}\) Exercise and sports participants should establish their own fluid intake requirement by measuring body weight changes before and after exercise over a few training sessions. Under normal healthy conditions, clear colored urine indicates euhydration and unclear yellowish urine indicates dehydration. The following regimen is therefore recommended:

- The day before, drink sufficient water to maintain a clear urine color the day before an exercise event. Stop drinking 1 hour before bedtime so that all urine can be cleared from the bladder before bedtime.
- Before exercise, drink to maintain clear urine color.
- During exercise, drink enough water to prevent a fluid deficit of more than 2% of body weight. Using 1 L of water equal to 1 kg as a guide, measure body weight changes over a few training sessions to determine the volume of fluid intake needed to prevent a decrease in weight of more than 2%. As a guide, athletes should aim to drink 0.4 to 0.8 L/h of water.\(^{25}\)
- After exercise, continue to rehydrate at regular intervals until clear urine is achieved.

As the debate continues over an ideal model of exercise hydration—volume driven versus thirst driven—the ideal model needs to be aligned with the science of fluid homeostasis on one end and the practices and experience of athletes on the other end.

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REFERENCES

Dietary Guidelines Advisory Committee Selected
Thirteen prominent scientists will constitute the 2010 Dietary Guidelines Advisory Committee; the committee members are prominent medical and scientific researchers from universities and scientific institutions across America who are leaders in their field. Selected for their expertise in dietary intake, human metabolism, behavioral change, and health, the new committee members will advise the US Department of Agriculture and the Department of Health and Human Services on any nutritional and dietary revisions necessary to the existing Dietary Guidelines. Congratulations to the following for being selected as members of the 2010 Dietary Guidelines Advisory Committee and to federal officials for selecting such a strong committee:

- Linda V. Van Horn, PhD, RD, LD (chair), professor and interim chair, Department of Preventative Medicine, Feinberg School of Medicine, Northwestern University, Chicago, Illinois
- Naomi K. Fukagawa, MD, PhD (vice chair), professor of medicine and associate program director of the Clinical Research Center, University of Vermont and Fletcher Allen Health Care, Burlington
- Cheryl Achterberg, PhD, dean and professor, College of Human Sciences, Ohio State University, Columbus
- Lawrence J. Appel, MD, MPH, professor of medicine, epidemiology, and international health (human nutrition), Division of General Internal Medicine, and Director, ProHealth Clinical Research Unit, Johns Hopkins Medical Institutions, Baltimore, Maryland
- Roger A. Clemens, DPH, associate director, Regulatory Science, and adjunct professor, Pharmacology and Pharmaceutical Science, The University of Southern California, Los Angeles
- Miriam E. Nelson, PhD, director, John Hancock Center for Physical Activity and Nutrition, Tufts University, Boston, Massachusetts
- Sharon M. Nickols-Richardson, PhD, RD, associate professor, Department of Nutritional Sciences, The Pennsylvania State University, University Park
- Thomas A. Pearson, MD, PhD, MPH, senior associate dean, Clinical Research, and Albert D. Kaiser Professor, Department of Community and Preventive Medicine, University of Rochester School of Medicine and Dentistry, Rochester, New York
- Rafael Pérez-Escamilla, PhD, professor, Nutritional Sciences and Public Health, University of Connecticut, and director, Connecticut Center of Excellence for Eliminating Health Disparities Among Latinos, Storrs
- Xavier Pi-Sunyer, MD, MPH, professor, Applied Physiology, Columbia University Teachers College, and chief, Division of Endocrinology, Diabetes, and Nutrition, St Luke’s-Roosevelt Hospital Center, New York
- Eric B. Rimm, ScD, associate professor of medicine, Harvard Medical School, and associate professor of epidemiology and nutrition, Harvard School of Public Health, Boston, Massachusetts
- Joanne L. Slavin, PhD, RD, professor, Department of Food Science and Nutrition, University of Minnesota, Minneapolis
- Christine L. Williams, MD, MPH, vice president and medical director, Healthy Directions Inc, and former professor, Clinical Pediatrics, and director, Children’s Cardiovascular Health Center, Columbia University, New York