Lead Review Article

August 2003: 261–271

Hydration: Issues for the 21st Century

Ann C. Grandjean, Ed.D., F.A.C.N., CNS, Kristin J. Reimers, M.S., R.D., and
Maxime E. Buyckx, M.D., M.B.A.

Historically, hydration research reflected critical issues of the day. War, illness, surviving a shipwreck or time in the dessert, supplying fall-out shelters, and space exploration drove hydration research in the first half of the 20th century. The fitness revolution of the 1970s spurred research on dehydration in physically active people and athletes. The 1990s introduced the "fluid/disease relationship." What will be the driving force behind hydration research in the 21st century? Where are the gaps in our knowledge? This review provides an overview of issues pertinent to determining future directions in hydration research.

Key words: hydration, dehydration, fluid requirements, fluid and elyctrolyte balance

doi: 10.131/nr.2003.aug.261–271

Introduction

How much fluid do healthy adults require daily? How does one measure hydration status? How do age, environment, physical activity, and other factors affect fluid needs? Is there an optimal fluid intake beyond that needed for water balance? Do foods and beverages differ in their contribution to water balance? Whereas limited scientific evidence exists to answer these questions, guidance abounds. There exist myriad recommendations ranging from those that are based on research, to expert opinion, to "best guesses," to pure myth. It is worthwhile, therefore, to strive for a more complete scientific underpinning to these and other pertinent questions.

The purpose of this article is to review the scientific literature on selected hydration issues and to stimulate discussion. For purposes of comparison, special populations and situations will be mentioned, but the paper's primary focus is the healthy adult who is not under physiologic or thermal stress. The paper begins with a brief overview of fluid and electrolyte balance/imbalance, but the reader is referred to other publications for an in-depth review of fluid and electrolyte balance and perturbations thereof.[1–3] The selected topics reviewed here include methods and indicators commonly used to measure hydration status, consumption data, recommendations for daily intake, and fluid intake as it relates to disease.

Water Balance

Water balance is defined as a balance between water input and water output.[4] Total body water is tightly controlled with sensitive mechanisms that respond to changes in consumption and losses. The regulation of both the total water content and the electrolyte content of the body is achieved primarily by the kidney via feedback mechanisms capable of sensing a one to two percent change in tonicity.[5]

Water Output

Water loss (or output) consists mainly of urine, insensible losses, sweat, and fecal loss. The minimal amount of fluid loss from the body that can occur is referred to as the obligatory water loss. An obligatory urine loss occurs because of the need to remove various solutes from the body. The minimum water required for urine is dependent on the daily solute excretory load, primarily determined by diet, and the maximum urinary concentration achievable.[5,6] Urinary concentrating ability varies with age[7,8] and with renal disease. Under normal conditions, fecal water loss is quite small, estimated at about 100 mL/day.[9,10]

Water that passes through the skin (transepidermal diffusion) and is lost by evaporation, and water that is lost from the respiratory tract, is referred to as insensible water loss. Insensible water correlates with metabolic heat dissipation.[11,12] The estimate of insensible water loss has been shown to vary more in infants than in adults,[13] but Holliday and Segar[14] proposed an average

---

Dr. Grandjean is Executive Director of The Center for Human Nutrition, Omaha, NE 68105, USA. Ms. Reimers is Associate Director of The Center for Human Nutrition, Omaha, NE 68105, USA. Dr. Buyckx is Director of Nutrition and Health Sciences, The Coca-Cola Company, Atlanta, GA 30301, USA.

water loss of 50 mL/100 kcal to apply to all ages. Even when caloric expenditure and body surface area are equal, however, insensible water loss through the skin and lungs varies. Environmental temperature and humidity, altitude, volume of air inspired, air currents, clothing, blood circulation through skin, and water content of the body can all affect insensible water loss.[15]

Water loss via sweating is usually low in temperate, sedentary conditions, but profuse sweating can be a major source of water and electrolyte loss for persons exercising or laboring in extreme heat and/or humidity. In physically active individuals, sweating presents the most highly variable water loss. Sweat rates can reach 3 to 4 L/hour, with variation in sweat rate depending upon exercise intensity and duration, age, gender, training, heat acclimatization, air temperature, humidity, wind velocity, cloud cover, clothing, and individual sweat rate.[16] Total daily fluid requirements have been shown to range from as little as 2 L/day to 16 L/day depending on the work load and the level of heat stress.[17]

Perhaps the most significant conclusion that can be drawn from an examination of water output is the magnitude of its variability. Nonetheless, for purposes of pedagogy, it is common to describe or depict the daily water output of humans. Tables and figures representing "average" daily water output abound, reporting volumes ranging from 1500 to 3000 mL/day.[9,10,16,18–28] Contrary to familiar depictions of daily output, the literature reviewed for this paper yielded only one primary reference reporting total water output in a healthy adult under temperate conditions. A study published in 1930[29] reported five days of total intake and output data on one sedentary 60-kg male subject confined to the laboratory. The average output was 2675 mL, ranging from 2227 mL to 3205 mL. Insensible loss remained fairly constant (1073–1213 mL), whereas urine water ranged from 1149 to 2132 mL. As such, some of the commonly referenced average output values are much lower than this 60-kg male's documented output. Nonetheless, the wide range of average daily output reported appears to capture the variability within and among individuals.

Fluid Intake

Water intake includes fluid consumed as food and beverages, along with relatively small volumes of water created by oxidation of food (metabolic water) and breakdown of body tissue. Unlike output, intake is not tightly regulated. Many physiologic, psychological, and environmental factors influence the drinking behavior of humans. Certainly, water deficit is one,[30] but drinking behavior is also influenced by many factors other than fluid deficit, such as culture, sensory qualities of the beverages, availability, and convenience.[31] Thirst is the primary homeostatic mechanism that stimulates adequate drinking to replace fluid losses. Under normal conditions, when a variety of foods and drinks are available, voluntary fluid ingestion tends to exceed the volume necessary for fluid balance.[32] However, responding to thirst (i.e., drinking "ad libitum") is insensitive during conditions of physiologic stress.[33,34] This lack of thirst leads to the phenomenon called voluntary dehydration, defined as the delay in complete rehydration following body water loss. Voluntary dehydration (or "involuntary dehydration," terminology considered more appropriate by Greenleaf[35,36]) has been extensively described, but less is understood about its mechanisms.[37–42] Fluid unavailability, inadequate time to drink, lack of food intake, and unpalatable fluids can compound the delay in rehydration.[41–43]

Disorders in Fluid-Electrolyte Balance

The body strives to maintain fluid and electrolyte homeostasis despite wide variations in intake and losses. Nonetheless, physical, behavioral, and environmental conditions can surpass the limits of homeostatic mechanisms, resulting in fluid and electrolyte imbalances. Fluid imbalances are defined based on the amount of salt lost or gained in relation to water.

Dehydration

Varying ratios of fluid and electrolyte loss result in isotonic dehydration, hypertonic dehydration, and hypotonic dehydration.[44] Fluid and electrolyte losses originate from extracellular fluid (ECF). ECF includes plasma and interstitial fluid. Losses of intracellular fluid occur as a result of ECF hypertonicity pulling fluid from the cell. Table 1 outlines the aberration and potential etiologies of the aforementioned classifications of dehydration.

Water Intoxication/Hyponatremia

The importance of consuming adequate fluids to avoid dehydration has been aggressively communicated to physically active people. However, the importance of fluid consumption has, in some cases, overshadowed the risk of consuming too much water, which can lead to hyponatremia. This type of hyponatremia (serum sodium $<$130–135 mmol/L)[45] occurs when the individual, in an effort to avoid heat illness, diligently consumes copious amounts of water while consuming inadequate sodium. The condition has been reported to occur primarily during prolonged exertion, such as ultra marathons, recreational hiking, and military training.[46] If severe, hyponatremia leads to lung congestion and brain swelling.[45] Central nervous system symptoms include headache, fatigue, anorexia, lethargy, confusion, disorientation, hyper-irritability, nausea, vomiting, seizures, and coma. Musculoskeletal symptoms include cramps, muscle twitching, and weakness. Ironically, the symptoms

Table 1. Classifications of Dehydration

Type	Aberration	Potential Causes
Isotonic Dehydration	▪ Isotonic loss of water and salt from ECF ▪ Does not cause osmotic water shift from ICF	▪ Gastrointestinal fluid losses (vomiting, diarrhea, gastrointestinal ostomy output) ▪ Inadequate fluid and salt intake
Hypertonic Dehydration	▪ Water loss exceeds salt loss ▪ Osmotic shift of water from cells into ECF (plasma and interstitial)	▪ Inadequate water intake ▪ Sweat loss ▪ Osmotic diuresis (glucosuria) ▪ Diuretic therapy (if water intake is inadequate)
Hypotonic Dehydration	▪ More sodium lost than water ▪ Osmotic shift of water from ECF (plasma and interstitial) into cells	▪ Loss of sweat or other gastrointestinal fluid losses ▪ Water replacement without salt replacement ▪ Diuretic therapy (if free water intake is excessive)

ECF = extracellular fluid, ICF = intracellular fluid.

mimic heat illness, and if treated as dehydration, the situation worsens. Rapid correction of chronic hyponatremia may be dangerous leading to brain edema and seizures. In most cases, hyponatremia can be corrected with no long-term sequelae, but in extreme cases of water overload, called water intoxication, the situation is fatal.[45,46] Additional articles are available for a more in-depth discussion of hyponatremia.[45,47,48]

Assessing Hydration Status

Historically, assessment of hydration status has occurred in the context of clinical medicine, the military and sport, wherein significant changes in hydration status are measured with overt biochemical markers and symptoms. The "absence" of dehydration or hyperhydration, however, is not readily measured. Instead, normal hydration status has been the presumed condition of healthy individuals. As such, very little research has been conducted in the area of assessing normal hydration status.

Minor perturbations in hydration status are difficult to measure.[49,50] Because the body is constantly striving to preserve plasma volume and regain homeostasis, biomarkers are transient at any point during the process of dehydration and rehydration. As such, sensitivity of a given biomarker will vary based on the duration and severity of dehydration.[51,52] Investigators have repeatedly attempted to measure hydration status using biochemical markers[51–60] but none has identified an unequivocal correlate with acute, small changes in body weight.

Body Weight

In those who are consuming adequate diets, an acute (up to 72 hours) change in body weight will be due almost solely to a change in total body water.[3] Hence, serial measurement of body weight is a sensitive, accurate, straightforward, and affordable indicator of hydration status that is used universally.[3,24,49–52,54,56,58–63]

Urine

Urine is commonly used to assess hydration status.[51–54,59,64] Urinary measures such as specific gravity and osmolality have been reported to be more indicative of non-acute moderate levels of impending or actual hypohydration than are blood measurements such as hematocrit, serum osmolality, or plasma sodium.[51,53,55] For example, military personnel, studied over a period of 44 days, who where in a state of mild chronic dehydration as determined by >3% weight loss, had normal serum osmolality and hematocrit, but elevated urine specific gravity and creatinine.[51] Urine color has been correlated with urine specific gravity and osmolality in the field setting.[53,54] Urine specific gravity and osmolality have, however, been shown to lag behind plasma osmolality changes during rapid (<4 hours) dehydration (5% body weight).[52] Hence, the validity of urine markers depends on the clinical or research conditions. Additionally, renal function declines with aging; urine volume and concentration are not good indicators of hydration status in older adults.

Blood

Numerous blood indices such as plasma osmolality, testosterone, adrenaline, noradrenaline, cortisol, atrial natriuretic peptide, aldosterone, urea, sodium, potassium, hematocrit, plasma protein, blood volume, and plasma volume have been used as indicators of hydration status.[49,60,65–68] While osmolality is frequently used, plasma volume may be more sensitive than serum osmolality during dehydration.[60] Similar to urine, the blood parameter chosen as a marker depends on the situation, and corroboration with weight change and clinical signs increases validity of the marker.

Bioelectrical Impedance and Dilution Techniques

Serial measures of urine, blood, and/or body weight indicate body water change, but do not indicate total body water (TBW). Improved technologies offer the prospect for assessment of TBW, which would theoretically afford the opportunity, when measured repeatedly, to directly assess changes in hydration status. These technologies include bioelectrical impedance analysis (BIA), bioelectrical impedance spectroscopy (BIS), and dilution techniques. BIA or BIS use electrical current to measure conductivity of the body tissues. Dilution techniques use markers such as antipyrine, deuterium oxide (D_2O), and titrated water (HTO). Typically, the measure of TBW is not an end in and of itself. Common applications are to predict fat-free mass in the case of BIA, or used in combination with ^{18}O to predict total energy expenditure, as is the case with deuterium oxide dilution technique. At issue with these methodologies are inconvenience, cost, measurement error, and lack of validation in all populations.[3,67,69,70] The measurement error for the dilution technique is estimated at approximately 1% to 2%.[71] BIA and BIS have been found to vary from the dilution technique by two to three liters.[72,73]

Whereas urine and blood assays remain the cornerstone of clinical assessment of hydration, body weight change remains the most universal, valid, economical, and feasible surrogate for body water change. Impedance and dilution techniques may provide new research opportunities, but have limited practical use. Regardless of the method chosen, assessing hydration status with a series of measures increases the validity of the assessment.

Fluid Requirements and Recommendations

Reviewing the research designed to define fluid requirements of humans, one has to appreciate the complexity of the issue. A multitude of intra- and inter-individual factors influence water requirements. As stated in the 1989 Recommended Dietary Allowances (RDA),[10] establishing a recommendation that meets the needs of all is impossible:

> "The primary determinant of maintenance water requirement appears to be metabolic, (Holliday and Segar, 1957) but the actual estimation of water requirement is highly variable and quite complex. Because the water requirement is the amount necessary to balance the insensible losses (which can vary markedly) and maintain a tolerable solute load for the kidneys (which may vary with dietary composition and other factors), it is impossible to set a general water requirement."

In spite of the impossible nature of assigning a general water requirement, researchers and practitioners have provided guidelines and recommendations. The following brief review of those recommendations is separated into recommendations for special populations (such as hospitalized patients, older adults, and those who are physically active), and those for adults under normal conditions.

Special Populations

The advent of parenteral nutrition gave rise to estimations of fluid requirements for acute fluid provision for patients.[14,74–77] Holliday and Segar,[14] based on estimated insensible water loss in controlled environments as determined by Levine et al.[13] and on their assumption of urine solute load on usual parenteral regimens, concluded that "…average needs for water expressed in milliliters equals estimated energy expenditure in calories." The Holliday-Segar formula resulted in the intake recommendation of 1 mL/kcal. This formula, and variations thereof, continues to be the basis for estimating basal fluid requirements in clinical settings.[6,78]

Dehydration is commonly reported in institutionalized elderly.[62,66,79,80] Blunted thirst response, decreased functional status, mobility disorders, voluntary fluid restriction to minimize incontinence, decreased renal concentrating ability, and medications place older adults at risk for dehydration.[62,81,82] The issue appears to be more related to intake than output. In response to this problem, recommendations for adequate fluid intake have been published.[78] By contrast to institutionalized older adults, dehydration in independently living older adults has not been documented.[83–85] Thus, research to date suggests that health status, more than age per se, influences fluid recommendations.

It has long been known that persons under thermal and physiologic stress need to pay special attention to fluid and salt intake.[86–89] Military personnel have been studied extensively in this regard. Monographs and scientific publications present some of the extensive research conducted for purposes of survival and endurance during World War II.[33,34,86,90,91] Scientific findings from the research on military and aerospace personnel continue to provide essential and fundamental information on fluid requirements under conditions of thermal and physiologic stress.[24,92–96] Maintaining hydration status is critical for military.[16,97] The 1985 Military Recommended Dietary Allowances (MRDA) recommend 1 mL of water per kcal during light-to-moderate activity in a temperate climate.[98] Research has shown, however, that requirements may increase up to threefold above normal in conditions of heavy work in a hot environment. Thus, separate recommendations have been established for such conditions.[99,100] Athletes, like military personnel, are a population wherein hydration status is critical to performance. Considerable research has therefore been carried out to explore measurement and consequences of dehydration during physical performance, as well as strategies and recommendations for fluid intake. Athletes are commonly instructed to replace body water lost (measured by change in body weight) during training and competition with an amount of fluid that is equal to or slightly greater than the amount lost, using the guideline that 1 kg equals 1 L. The reader is referred to the numerous monographs and papers on the subject.[1,101–106]

Adults Under Normal Conditions

The RDAs, which provide standards for the civilian population, have their roots in national defense. The Food and Nutrition Board (FNB), a part of the National Research Council, was established in 1940 "to advise on nutrition problems in connection with National Defense."[107] In 1941, the first table of RDAs for nine nutrients and calories was adopted.[108] Water was not addressed. The progression of the RDAs since their inception is summarized in Table 2. The amount of 1 mL water/kcal of energy expenditure has been the recommendation since 1945.[109] In 1989, the FNB added a higher amount: ". . .there is so seldom a risk of water intoxication that the specified requirement for water is often increased to 1.5 mL/kcal to cover variations in activity level, sweating, and solute load."[10]

Recommendations, however, are not requirements. Absolute requirement is the amount needed to replace losses. Whereas requirements are impossible to predict precisely except under controlled conditions, recommendations such as the RDAs and the Dietary Reference Intakes (DRI) are standards to be used in the assessment and planning of diets for individuals and for groups. There is considerable variation in intakes both within and between individuals, as well as limitations associated with the requirement estimate. Commonly expounded popular recommendations regarding specific amounts of fluid (i.e., eight 8-oz glasses/day) ignore the increasingly diverse diets consumed by North Americans and the impact the diet has on fluid intake. Thus, recommendations are useful for the intended purpose, but are of limited value to the individual unless all variables influencing the individual's fluid losses (i.e., requirements) are considered concurrently.

Sources of Water

Survey results show that the majority of individuals' fluid intake is not consumed as plain water, but instead from a variety of foods and beverages as influenced by cultural, economic, social, environmental, and sensory factors.[10,43] Ershow, Cantor, et al.[114] analyzed data from the 1977–1978 Nationwide Food Consumption Survey (NFCS). They found that water consumed as plain drinking water averaged 31.4% of total intake beverages other than plain water provided 43.6% and food provided 25% of total water intake. The water content of the food portion of the diet can vary widely. For example, whereas the mean intake of water from food for subjects

Table 2. Summary of Recommended Dietary Allowances for Water

Date RDA Published	Selected Excerpts
1941[108]	Water is not mentioned.
1943[107]	Water is not mentioned.
1945[109]	"A suitable allowance of water for adults is 2.5 liter daily in most instances. An ordinary standard for diverse person is one milliliter for each calorie of food. Most of this quantity is contained in prepared foods."
1948[110]	Reiterates 1945 excerpt shown above.
1953[111]	Reiterates 1945 excerpt shown above.
	"Under conditions of extreme heat or excessive sweating, the sensation of thirst may not keep pace with the actual water requirements, and forced intakes up to one liter per hour may be indicated for a short time."
1958[112]	"Water requirements are intimately related to salt requirements."
	"The requirement of a 70-kg man ingesting 3,200 calories daily is of the order of 2300–3100 milliliters daily."
1964[113]	"A reasonable standard for calculating water allowance is 1 ml/calorie of food."
1968[21]	"The multitude of factors determining water loss precludes the setting of a general value for minimal water requirement. Under ordinary circumstances, a reasonable allowance is 1 ml/kcal for adults and 1.5 ml/kcal for infants."
1974[22]	Reiterates 1968 excerpt.
1980[23]	Reiterates 1968 excerpt.
1989[10]	"Adults. For practical purposes, 1 ml/kcal of energy expenditure can be recommended as the water requirement for adults under average conditions of energy expenditure and environmental exposure. However there is so seldom a risk of water intoxication that the specified requirements for water is often increased to 1.5 ml/kcal to cover variations in activity level, sweating and solute load."

of both sexes, 20 to 64 years of age participating in the 1977–1978 NFCS was 545 gm, the average for the 5th and 99th percentile were 223 and 1254, respectively.[114]

Analysis of data from the 1994–1996 Continuing Survey of Food Intakes by Individuals (CSFII) showed that approximately one-third of the total fluid intake of persons aged 20 to 64 years of age was consumed as plain water.[115] Data from the 1994–1996 CSFII[116] also showed that for all subjects the average consumption of milk and other beverages totaled 1115 grams/day. Of that, 35% as coffee and tea, 30% as carbonated soft drinks, 17% as milk, 9% as alcohol, and 9% as fruit drinks and ades.

The perception exists that beverages vary in their capacity to maintain hydration status, with caffeine containing beverages purported to have a diuretic effect. This appears to be based on studies showing acute increased urine output after caffeine doses in caffeine naïve individuals.[117–123] However, research shows that a tolerance to caffeine develops.[124–129] As such, those who are not caffeine naïve do not experience increased urine output or altered indicators of hydration status after consuming caffeinated beverages.[57,101,124]

In addition to unsubstantiated warnings about caffeine, unsubstantiated claims about the essentiality of plain water in meeting fluid requirements are also touted. Public perception holds that plain drinking water is more "hydrating" than other beverages even though it has long been put forth in medical, military, nutrition, and physiology texts that water from foods and beverages can meet fluid needs.[9,10,19,21–23] Limited research has been published regarding the efficacy of various beverages specifically on hydration.[57,130] Aside from hydration issues, potential benefits[131–135] and/or risks[136,137] of consuming plain water must also be considered.

Emerging Data/Issues of Fluid and Disease

Research on the relationship of drinking water and the incidence of cancer has been an area of study for some time. For the most part, such studies have been concerned with contaminants in drinking water as a cause of cancer.[135–138] More recently, studies have examined the relationship between beverage volume, and in some studies, the specific types of fluids consumed as related to the incidence of various diseases.

Studies examining the fluid-disease relationship have considered various combinations of variables including dehydration, hyperhydration, fluid volume consumed, and types of beverages, as they relate to the absences, presence, or treatment of certain diseases or conditions. For example, dehydration has been linked to increases in risk for urinary tract infections, dental disease, broncho-pulmonary disorders, constipation, kidney stones, and impaired cognitive function.[139–144] A relationship between a high fluid intake and decreased risk of a variety of maladies including urinary tract stones, colon and urinary tract cancer, and mitral valve prolapse has been shown.[132,135,139,145–154] Some studies examining the relationship between fluid intake and specific diseases have found no correlation with the types of beverages consumed,[135,138,145,151,152] while others have.[131,133,154–156] For example, one study[131] found an inverse correlation between water intake and risk of fatal coronary heart disease and a positive correlation between intake of other fluids other than water and risk. As the authors noted, however, potential confounding variables need to be considered. Perhaps the water drinkers were more health conscious. Subjects in the study had an intake of milk higher than the U.S. population, and the type of milk consumed was not reported. Perhaps water drinkers consumed less fat. As with all epidemiologic research, known and unknown confounding variables make it impossible to draw cause-effect conclusions.

Whereas the available information on a fluid-disease relationship is far from conclusive, current data indicates need for further study. Determining the amount of fluid necessary to maintain hydration is one concern when trying to discern recommendations on fluid intake; determining fluid intake necessary to treat or decrease risk of certain diseases or disorders is another.

The value of further exploring the fluid-disease relationship is prudent and supported by the studies published to date. Additionally, the committee responsible for drafting DRIs for electrolytes and water are charged with considering levels of intake that may decrease risk of developmental abnormalities and chronic disease. The following is part of the justification given for replacing the RDAs with the DRIs.[157]

"Scientific knowledge regarding the roles of nutrients has expanded dramatically since the inception of the RDAs. Contemporary studies address topics ranging from the prevention of classical nutritional deficiency diseases, such as rickets, to the reduction of risk of chronic diseases such as osteoporosis, cancer, and cardiovascular disease. This expansion has extended the basis for the development of Dietary Reference Intakes."

Future Challenges

This review has touched on several issues pertinent to practical application of and future research on the hydration status of normal healthy adults. Although they are outside the scope of this paper, many other hydration issues are deserving of attention in the future. This paper focused on healthy normal adults, but healthy pediatric and geriatric populations are deserving of attention as well. The effect on hydration status of specific foods and fluids, such as alcoholic beverages, is an area worthy of review.

For six decades, the driving force behind fluid and electrolyte research has been medical care, survival, and optimal performance during times of physiologic stress. Thus, empirical and clinical research have been conducted on military personnel, athletes, and hospitalized patients. Missing, however, is hydration research more pertinent to "average" individuals who comprise the majority of the population.

In the 21st century, research is surfacing that moves beyond water requirements per se, and examines the relationship between optimal fluid intake and disease prevention. With the transition to DRIs,[158] consideration of the roles of essential nutrients has been expanded beyond preventing nutrient deficiency diseases and moving toward contributing to longer and healthier lives. The public's interest in the relationship between nutrition and health combined with the handful of studies examining fluid and disease relationships brings a new focus to optimal fluid intake.

The challenge, current and future, is to continue research on topics such as fluid recommendations for various ages, hydrating properties of foods and specific fluids, and the relationships between disease and type and volume of fluids consumed. Research in these areas, combined with effective and science-based communication, will begin to fill the gap between hydration myth and reality.

Acknowledgements

The authors wish to thank the members of the ILSI North America Project Committee on Hydration for their review of the manuscript.

1. Gisolfi C, Lamb D. Fluid homeostasis during exercise. *Perspectives in Exercise Science and Sports Medicine*. Vol 3. Carmel, In: Benchmark Press Inc.; 1990.
2. Sawka MN, Coyle EF. Influence of body water and blood volume on thermoregulation and exercise performance in the heat. In: Holloszy J, ed. *Exercise and Sport Sciences Reviews*. Philadelphia: Lippincott Williams & Wilkins; 1999:167–218.
3. Valtin H, Schafer JA. *Renal Function Mechanisms Preserving Fluid and Solute Balance in Health*. 3rd ed. Boston: Little, Brown, and Co.; 1995.
4. Mudge G, Weiner I. Agents affecting volume and composition of body fluids. In: Goodman Gilman A, Rall T, Nies A, Taylor P, eds. *Goodman and Gilman's The Pharmacological Basis of Therapeutics*. Elmsford, NY: Pergamon Press, Inc.; 1990:682–707.
5. Singer G, Brenner B. Fluid and electrolyte disturbances. In: Fauci A, Braunwald E, Isselbacher K, et al., eds. *Harrison's Principles of Internal Medicine*. CD-ROM. NY, NY: McGraw-Hill; 1998.
6. Howard L. Enteral and parenteral nutrition therapy. In: Fauci A, Braunwald E, Isselbacher K, et al., eds. *Harrison's Principles of Internal Medicine*. CD-ROM. NY, NY: McGraw-Hill; 1998.
7. Bergmann KE, Ziegler EE, Fomon SJ. Water and renal solute load. In: Fomon SJ, ed. *Infant Nutrition*. Philadelphia: W.B. Saunders; 1974:245–266.
8. Phillips P, Rolls B, Ledingham D, et al. Reduced thirst after water deprivation in healthy elderly men. *N Engl J Med.* 1984;311:753–759.
9. Alper C. Fluid and electrolyte balance. In: Wohl MG, Goodhart RS, eds. *Modern Nutrition in Health and Disease*. Philadelphia: Lea & Febiger; 1968: 404–424.
10. Food and Nutrition Board. *Recommended Daily Allowances*. 10 ed. Washington, DC: National Academy Press; 1989.
11. Benedict FG, Root HF. Insensible perspiration: its relation to human physiology and pathology. *Arch Intern Med.* 1926;38:1–35.
12. Johnston M, Newburgh L. The determination of the total heat eliminated by the human being. *Clin Invest.* 1930;viii:147–160.
13. Levine S, Wheatley M. Respiratory metabolism in infancy and in childhood. *Am J Dis Child.* 1936;51: 1300–1323.
14. Holliday M, Segar W. The maintenance need for water in parenteral fluid therapy. *Pediatrics.* 1957; 19:823–832.
15. Newburgh L, Johnston M. The insensible loss of water. *Physiol Rev.* 1942;22:1–18.
16. Gisolfi C. Water requirements during exercise in the heat. In: Marriott B, ed. *Nutritional Needs in Hot Environments*. Washington, DC: National Academy Press; 1993:87–96.
17. Sawka MN, Montain SJ. Fluid and electrolyte balance: effects on thermoregulation in the heat. In: Bowman BA, Russell RM, eds. *Present Knowledge in Nutrition*. 8th edition. Washington, DC: ILSI Press; 2001:115–124.
18. Berdanier CD. Water. In: Berdanier CD, ed. *Advanced Nutrition: Macronutrients*. Boca Raton: CRC Press; 2000:31–61.
19. Bland JH. Basic physiologic considerations of body water and electrolyte. *Clinical Metabolism of Body Water and Electrolytes.* Philadelphia: Saunders; 1963:10–53.
20. Chauliac M. Water requirements: physiology and pathology. *Child Trop.* 1985;158:11–19.
21. Food and Nutrition Board. *Water*. 7th ed. Washington, DC: National Academy Press; 1968.
22. Food and Nutrition Board. *Water*. 8th ed. Washington, DC: National Academy Press; 1974.
23. Food and Nutrition Board. *Water and Electrolytes*. 9th ed. Washington, DC: National Academy Press; 1980.
24. Greenleaf JE, Harrison MH. Water and electrolytes. In: Layman DK, ed. *Nutrition and Aerobic Exercise*. Washington, DC: American Chemical Society; 1986:107–124.
25. Johnson R. Human nutritional requirements for water in long space flights. In: Helvey T, ed. *Nutrition in Space and Related Waste Problems*. Washington, DC: National Aeronautics and Space Administration; 1964:159–169.
26. Mitchell HH. *Comparative Nutrition of Man and Domestic Animals*. New York: Academic Press; 1962.
27. Robertson GL. Disorders of thirst in man. In: Ram-

say DJ, Booth DA, eds. *Thirst: Physiological and Psychological Aspects*. London: Springer-Verlag; 1991:453–477.

28. Wardlaw GM, Insel PM. Perspectives in nutrition. 3rd ed. St. Louis, MO: Mosby; 1996.
29. Newburgh L, Johnston M, Falcon-Lesses M. Measurement of total water exchange. *J Clin Invest.* 1930;8:161–196.
30. Adolph EF. Regulation of body water content through water ingestion. In: Wayner MJ, ed. *Thirst: First International Symposium on Thirst in the Regulation of Body Water.* New York: Macmillan; 1964: 5–17.
31. Ramsay DJ, Booth DA, International Life Sciences Institute. *Thirst: Physiological and Psychological Aspects*. London: Springer-Verlag; 1991.
32. de Castro JM. A microregulatory analysis of spontaneous fluid intake by humans: evidence that the amount of liquid ingested and its timing is mainly governed by feeding. *Physiol Behav.* 1988;43:705–714.
33. Adolph EF, Dill DB. Observations on water metabolism in the desert. *Am J Physiol.* 1938;123:369–378.
34. Pitts GC, Johnson RE, Consolazio FC. Work in the heat as affected by intake of water, salt and glucose. *Am J Physiol.* 1944;142:253–259.
35. Greenleaf JE. Problem: thirst, drinking behavior, and involuntary dehydration. *Med Sci Sports Exerc.* 1992;24:645–656.
36. Greenleaf JE. Involuntary hypohydration in man and animals: a review. Washington, DC: Scientific and Technical Information Division, National Aeronautics and Space Administration: for sale by the Superintendent of Documents, U.S. Government Printing Office; 1966.
37. Greenleaf JE, Sargent F. Voluntary dehydration in man. *J Appl Physiol.* 1965;20:719–724.
38. Hubbard RW, Sandick BL, Matthew WT, et al. Voluntary dehydration and alliesthesia for water. *J Appl Physiol.* 1984;57:868–875.
39. Rothstein A, Adolph EF, Wills JH. Voluntary dehydration. In: Adolph EFA, ed. *Physiology of Man in the Desert*. New York: Interscience Publishers, Inc.; 1947:254–270.
40. Szlyk PC, Hubbard RW, Matthew WT, Armstrong LE, Kerstein MD. Mechanisms of voluntary dehydration among troops in the field. *Mil Med.* 1987; 152:405–407.
41. Szlyk PC, Sils IV, Francesconi RP, Hubbard RW, Matthew WT. Variability in intake and dehydration in young men during a simulated desert walk. *Aviat Space Environ Med.* 1989;60:422–427.
42. Szlyk PC, Sils IV, Francesconi RP, Hubbard RW, Armstrong LE. Effects of water temperature and flavoring on voluntary dehdyration in men. *Physiol Behav.* 1989;45:639–647.
43. Rolls B. Homeostatic and non-homeostatic controls of drinking in humans. In: Arnaud MJ, ed. *Hydration Throughout Life*. London: John Libbey and Company Ltd.; 1998:19–28.
44. Oh MS. Water, electrolyte, and acid-base balance. *Modern Nutrition in Health and Disease*. Philadelphia: Lea & Febiger; 1994:112–143.
45. Montain SJ, Sawka MN, Wenger CB. Hyponatremia associated with exercise: risk factors and pathogenesis. *Exerc Sport Sci Rev.* 2001;29:113–117.
46. Garigan TP, Ristedt DE. Death from hyponatremia as a result of acute water intoxication in an Army basic trainee. *Mil Med.* 1999;164:234–238.
47. O'Brien KK, Montain SJ, Corr WP, Sawka MN, Knapik JJ, Craig SC. Hyponatremia associated with overhydration in U.S. Army trainees. *Mil Med.* 2001;166:405–410.
48. Speedy DB, Noakes TD, Schneider C. Exercise-associated hyponatremia: a review. *Emerg Med (Fremantle).* 2001;13:17–27.
49. Shirreffs SM. Markers of hydration status. *J Sports Med Phys Fitness.* 2000;40:80–84.
50. Walsh R, Noakes TD, Hawley JA, Dennis SC. Impaired high-intensity cycling performance time at low levels of dehydration. *Int J Sports Med.* 1994; 15:392–398.
51. Francesconi RP, Hubbard RW, Szlyk P, et al. Urinary and hematologic indexes of hypohydration. *J Appl Physiol.* 1987;62:1271–1276.
52. Popowski LA, Oppliger RA, Patrick LG, Johnson RF, Kim JA, Gisolf CV. Blood and urinary measures of hydration status during progressive acute dehydration. *Med Sci Sports Exerc.* 2001;33:747–753.
53. Armstrong LE, Maresh CM, Castellani JW, et al. Urinary indices of hydration status. *Int J Sport Nutr.* 1994;4:265–279.
54. Armstrong LE, Soto JA, Hacker FT Jr, Casa DJ, Kavouras SA, Maresh CM. Urinary indices during dehydration, exercise, and rehydration. *Int J Sport Nutr.* 1998;8:345–355.
55. Bergeron MF, Maresh CM, Armstrong LE, et al. Fluid-electrolyte balance associated with tennis match play in a hot environment. *Int J Sport Nutr.* 1995;5:180–193.
56. Gorelick MH, Shaw KN, Murphy KO. Validity and reliability of clinical signs in the diagnosis of dehydration in children. *Pediatrics.* 1997;99:E6.
57. Grandjean AC, Reimers KJ, Bannick KE, Haven MC. The effect of caffeinated, non-caffeinated, caloric and non-caloric beverages on hydration. *J Am Coll Nutr.* 2000;19:591–600.
58. Pollock N, Godfrey R, Reilly T. Evaluation of field measures of urine concentration. *Med Sci Sports Exerc*. 1997;29:iv–300.
59. Shirreffs SM, Maughan RJ. Urine osmolality and conductivity as indices of hydration status in athletes in the heat. *Med Sci Sports Exerc.* 1998;30: 1598–1602.
60. Yankanich J, Kenney W, Fleck S, Kraemer W. Precompetition weight loss and changes in vascular fluid volume in NCAA Division I college wrestlers. *J Strength Cond Res.* 1998;12:138–145.
61. Arant BJ. Fluids and electrolyte abnormalities in children. In: Kokko J, Tannen R, eds. Fluids and electrolytes. Philadelphia, PA: W.B. Saunders Company; 1996:819–829.
62. Weinberg AD, Minaker KL. Dehydration. Evaluation and management in older adults. Council on Scientific Affairs, American Medical Association. *JAMA.* 1995;274:1552–1556.
63. Wilmore JH, Costill DL. *Physiology of Sport and Exercise*. Champaign, IL: Human Kinetics; 1994.

64. Dauterman KW, Bennett RG, Greenough IWB, et al. Plasma specific gravity for identifying hypovolaemia. *J Diarrhoeal Dis Res.* 1995;13:33–38.
65. Hackeny AC, Coyne JT, Pozos R, Feith S, Seale J. Validity of urine-blood hydrational measures to assess total body water changes during mountaineering in the sub-Artic. *Arct Med Res.* 1995;54:69–77.
66. Lavizzo-Mourey R, Johnson J, Stolley P. Risk factors for dehydration among elderly nursing home residents. *J Am Geriatr Soc.* 1988;36:213–218.
67. O'Brien C, Freund BJ, Sawka MN, McKay J, Hesslink RL, Jones TE. Hydration assessment during cold-weather military field training exercises. *Arct Med Res.* 1996;55:20–26.
68. Zappe DH, Tankersley CG, Meister TG, Kenney WL. Fluid restriction prior to cycle exercise: effects on plasma volume and plasma proteins. *Med Sci Sports Exerc.* 1993;25:1225–1230.
69. Koulmann N, Jimenez C, Regal D, et al. Use of bioelectrical impedance analysis to estimate body fluid compartments after acute variations of the body hydration level. *Med Sci Sports Exerc.* 2000;32:857–864.
70. Thomas BJ, Cornish BH, Ward LC, Jacobs A. Bioimpedance: is it a predictor of true water volume? *Ann N Y Acad Sci.* 1999;873:89–93.
71. Schoeller DA. Hydrometry. In: Roche AF, Heymsfield SB, Lohman TG, eds. *Human Body Composition.* Champaign: Human Kinetics; 1996:25–43.
72. Ellis KJ, Wong WW. Human hydrometry: comparison of multifrequency bioelectrical impedance with H20 and bromine dilution. *J Appl Physiol.* 1998;85:1056–1062.
73. Visser M, Gallagher D. Age-related change in body water and hydration in old age. In: Arnaud MJ, ed. *Hydration Throughout Life*. John Libbey Eurotext; 1998:117–125.
74. Darrow DC, Pratt EL. Fluid therapy. Relation to tissue composition and the expenditure of water and electrolyte. *JAMA.* 1950;143:365, 432–439.
75. Heeley AM, Talbot NB. Insensible water losses per day by hospitalized infants and children. *Am J Dis Child.* 1955;90:251–255.
76. Pickering DE, Winters RW. Fluid and electrolyte management in children. *Ped Clin North Am.* 1954;4:873–899.
77. Wallace WM. Quantitative requirements of the infant and child for water and electrolyte under varying conditions. *Am J Clin Pathol.* 1953;23:1133–1141.
78. Holben DH, Hassell JT, Williams JL, Helle B. Fluid intake compared with established standards and symptoms of dehydration among elderly residents of a long-term-care facility. *J Am Diet Assoc.* 1999;99:1447–1450.
79. Morley JE, Miller DK, Zdrodowski C, Gutierrez B, Perry III HM. Fluid intake, hydration and aging. In: Arnaud MJ, ed. Hydration throughout life. John Libbey Eurotext; 1998:107–115.
80. Sansevero AC. Dehydration in the elderly: strategies for prevention and management. *Nurse Pract.* 1997;22:41–47, 63.
81. Kenney WL, Chiu P. Influence of age on thirst and fluid intake. *Med Sci Sports Exerc.* 2001;33:1524–1532.
82. Rolls B, Phillips PA. Aging and disturbances of thirst and fluid balance. *Nutr Rev.* 1990;48:137–144.
83. de Castro JM. Age-related changes in natural spontaneous fluid ingestion and thirst in humans. *J Gerontol Psych Sci.* 1992;47:321–330.
84. Lindeman RD, Romero LJ, Liang HC, Baumgartner RN, Koehler KM, Garry PJ. Do elderly persons need to be encouraged to drink more fluids? *J Geronotol Med Sci.* 2000;55A:M361–M365.
85. Lowik MRH, Westenbrink S, Hulshof KFAM, Kistemaker C, Hermus JJ. Nutrition and aging: dietary intake of "apparently healthy" elderly (Dutch Nutrition Surveillance System). *J Am Clin Nutr.* 1989;8:347–356.
86. Adolph EF. Heat exchanges, sweat formation, and water turnover. In: Adolph EF, ed. *Physiology of Man in the Desert*. New York: Interscience Publishers; 1947:33–43.
87. Council on Pharmacy and Chemistry. The addition of salt to drinking water. *JAMA.* 1945;129:131.
88. Johnson RE. Nutritional standards for men in tropical climates. *Gastroenterology.* 1943;1:832–840.
89. Strydom NB, Van Graan CH, Holdsworth LD. The water requirements of humans. *J Occup Med.* 1965;7:581–587.
90. Gamble JL. The water requirements of castaways. *Proc Am Phil Soc.* 1944;88:151–158.
91. Gamble JL. Physiological information gained from studies on the life raft ration. *The Harvey Lectures*. Lancaster: The Science Press Printing Company; 1947:247–273.
92. Buskirk ER, Mendez J. Nutrition, environment and work performance with special reference to altitude. *Fed Proc.* 1967;26:1760–1767.
93. Johnson RE. Water and osmotic economy on survival rations. *J Am Diet Assoc.* 1964;45:124–129.
94. Mohlman HT, Katchman BJ, Slonim AR. Human water consumption and excretion data for aerospace systems. *Aerosp Med.* 1968;39:396–402.
95. Strydom NB, Wyndham CH, Van Graan CH, Holdsworth LD, Morrison JF. The influence of water restriction on the performance of men during a prolonged march. *S A Med J.* 1966;40:539–544.
96. Van Reen R, Minard D, Dasler AR, Raica N Jr, Nelson RA. Nutrition of recruits during a summer habitability study. *J Am Diet Assoc.* 1964;45:117–123.
97. Marriott B, Institute of Medicine. Committee summary and recommendations. In: Marriott B, ed. *Nutritional Needs in Hot Environments*. *Applications for Military Personnel in Field Operations*. Washington, DC: National Academy Press; 1993:50.
98. MRDA. Military Recommended Dietary Allowances, AR 25-40 (1985). In: Marriott BM, Institute of Medicine, Committee on Military Nutrition Research, eds. *Nutritional Needs in Hot Environments. Applications for Military Personnel in Field Operations.* Washington, DC: National Academy Press; 1993.
99. Baker-Fulco C, Patton BD, Montain SJ, Lieberman HR. *Nutrition for Health and Performance, 2001:*

Nutritional Guidance for Military Operations in Temperate and Extreme Environments. Natick, MA: U.S. Army Research Institute of Environmental Medicine; 2001.

100. Montain SJ, Latzka WA, Sawka MN. Fluid replacement recommendations for training in hot weather. *Mil Med.* 1999;164:502–508.
101. Armstrong LE. Caffeine, body fluid-electrolyte balance, and exercise performance. *Int J Sport Nutr Exerc Metab.* 2002;12:189–206.
102. Casa DJ, Armstrong LE, Hillman SK, et al. National athletic trainers' association position statement: fluid replacement for athletes. *J Athlet Train.* 2000; 35:212–224.
103. Convertino VA, Armstrong LE, Coyle EF, et al. American College of Sports Medicine. Postion stand on exercise and fluid replacement. *Med Sci Sports Exerc.* 1996;28:i–vii.
104. Epstein Y, Armstrong LE. Fluid-electrolyte balance during labor and exercise: concepts and misconceptions. *Int J Sport Nutr.* 1999;9:1–12.
105. Latzka WA, Montain SJ. Water and electrolyte requirements for exercise. *Clin Sports Med*. 1999; 18:513–524.
106. Sawka MN, Francesconi RP, Young J, Pandolf KB. Influence of hydration level and body fluids on exercise performance in the heat. *JAMA.* 1984; 252:1165–1169.
107. Food and Nutrition Board. *Recommended Dietary Allowances*. Washington, DC: National Academy Press; 1943.
108. Food and Nutrition Board. *Recommended Daily Allowances*. Washington, DC: National Research Council; 1941.
109. Food and Nutrition Board. *Recommended Dietary Allowances*. National Research Council; 1945.
110. Food and Nutrition Board. *Recommended Daily Allowances.* Washington, DC: National Research Council; 1948.
111. Food and Nutrition Board. *Recommended Dietary Allowances.* Washington, DC: National Research Council; 1953.
112. Food and Nutrition Board. *Recommended Dietary Allowances*. Washington, DC: National Research Council; 1958.
113. Food and Nutrition Board. *Recommended Dietary Allowances*. Sixth ed. Washington, DC: National Research Council; 1964.
114. Ershow AG, Cantor KP, Federation of American Societies for Experimental Biology, Life Sciences Research Office, National Cancer Institute (U.S.), Epidemiology and Biostatistics Program. *Total Water and Tapwater Intake in the United States Population-based Estimates of Quantities and Sources*. Bethesda, MD: Life Sciences Research Office, Federation of American Societies for Experimental Biology; 1989.
115. Heller KE, Sohn W, Burt BA, Eklund SA. Water consumption in the United States in 1994–96 and implications for water fluoridation policy. *J Public Health Dent.* 1999;59:3–11.
116. United States Department of Agriculture. 1994–96 Continuing Survey of Food Intake by Individuals. Available at: http://www.barc.usda.gov/bhnrc/foodsurvey/Cd94-96.html. Accessed October 1999.
117. Bellet S, Roman L, DeCastro O, Kim K, Kershbaum A. Effect of coffee ingestion on catecholamine release. *Metabolism.* 1969;18:288–291.
118. Dorfman LJ, Jarvik ME. Comparative stimulant and diuretic actions of caffeine and theobromine in man. *Clin Pharmacol Ther.* 1970;11:869–872.
119. Massey L, Wise K. The effect of dietary caffeine on urinary excretion of calcium, magnesium, sodium and potassium in healthy young females. *Nutr Res.* 1984;4:43–50.
120. Neuhäuser-Berthold M, Beine S, Verwied SC, Luhrmann PM. Coffee consumption and total body water homeostasis as measured by fluid balance and bioelectrical impedance analysis. *Ann Nutr Metab.* 1997;41:29–36.
121. Passmore AP, Kondowe GB, Johnston GD. Renal and cardiovascular effects of caffeine: a dose-response study. *Clin Sci (Lond).* 1987;72:749–756.
122. Robertson D, Frölich J, Carr R, et al. Effects of caffeine on plasma renin activity, catecholamines and blood pressure. *N Engl J Med.* 1978;298:181–186.
123. Wemple R, Lamb D, McKeever K. Caffeine vs caffeine-free sports drinks: effects on urine production at rest and during prolonged exercise. *Int J Sports Med.* 1997;18:40–46.
124. Colton T, Gosselin R, Smith R. The tolerance of coffee drinkers to caffeine. *Clin Pharmacol Ther.* 1968;9:31–39.
125. Denaro C, Brown C, Jacob PI, Benowitz N. Effects of caffeine with repeated dosing. *Eur J Clin Pharmacol.* 1991;40:273–278.
126. Goldstein A, Kaizer S, Whitby O. Psychotropic effects of caffeine in man. IV. Quantitative and qualitative differences associated with habituation to coffee. *Clin Pharmacol Ther.* 1969;10:489–497.
127. Myers M, Reeves R. The effect of caffeine on daytime ambulatory blood pressure. *Am J Hypertens.* 1991;4:427–431.
128. Robertson D, Wade D, Workman R, Woosley RL, Oates JA. Tolerance to the humoral and hemodynamic effects of caffeine in man. *J Clin Invest.* 1981;67:1111–1117.
129. Eddy NB, Downs AW. Tolerance and cross-tolerance in the human subject to the diuretic effect of caffeine, theobromine and theophylline. *J Pharmacol Exp Ther.* 1928;33:167–174.
130. Grandjean AC, Reimers KJ, Haven MC, Curtis GL. The effect on hydration of two diets, one with and one without plain water. *J Am Coll Nutr*. 2003;22: 165–173.
131. Chan J, Knutsen SF, Blix GG, Lee JW, Fraser GE. Water, other fluids, and fatal coronary heart disease: the Adventist Health Study. *Am J Epidemiol.* 2002;155:827–833.
132. Rodgers AL. Effect of mineral water containing calcium and magnesium on calcium oxalate urolithiasis risk factors. *Urol Int.* 1997;58:93–99.
133. Shannon J, White E, Shattuck AL, Potter JD. Relationship of food groups and water intake to colon cancer risk. *Cancer Epidemiol Biomarkers Prev.* 1996;5:495–502.
134. Stookey JD, Belderson PE, Russell JM, Barker ME.

Relationship of food groups and water intake to colon cancer risk. *Cancer Epidemiol Biomarkers Prev.* 1997;5:495–502. *Cancer Epidemiol Biomarkers Prev.* 1997;6:657–658.

135. Wilkens LR, Kadir MM, Kolonel LN, Nomura AM, Hankin JH. Risk factors for lower urinary tract cancer: the role of total fluid consumption, nitrites and nitrosamines, and selected foods. *Cancer Epidemiol Biomarkers Prev.* 1996;5:161–166.
136. Mirvish SS, Grandjean AC, Moller H, et al. N-nitrosoproline excretion by rural Nebraskans drinking water of varied nitrate content. *Cancer Epidemiol Biomarkers Prev.* 1992;1:455–461.
137. Vena JE, Graham S, Freudenheim J, et al. Drinking water, fluid intake, and bladder cancer in western New York. *Arch Environ Health.* 1993;48:191–198.
138. Bruemmer B, White E, Vaughan TL, Cheney CL. Fluid intake and the incidence of bladder cancer among middle-aged men and women in a three-county area of western Washington. *Nutr Cancer.* 1997;29:163–168.
139. Borghi L, Meschi T, Amato F, Briganti A, Novarini A, Giannini A. Urinary volume, water and recurrences in idiopathic calcium nephrolithiasis: a 5-year randomized prospective study. *J Urol.* 1996;155:839–843.
140. Embon OM, Rose GA, Rosenbaum T. Chronic dehydration stone disease. *Br J Urol.* 1990;66:357–362.
141. Inouye SK. Prevention of delirium in hospitalized older patients: risk factors and targeted intervention strategies. *Ann Med.* 2000;32:257–263.
142. Lawlor PG, Gagnon B, Mancini IL, et al. Occurrence, causes, and outcome of delirium in patients with advanced cancer. A prospective study. *Arch Intern Med.* 2000;160:786–794.
143. Read NW, Celik AF, Katsinelos P. Constipation and incontinence in the elderly. *J Clin Gastroenterol.* 1995;20:61–70.
144. Ship JA, Fischer DJ. The relationship between dehydration and parotid salivary gland function in young and older healthy adults. *J Geronotol Med Sci.* 1997;52A:M310–M319.
145. Bitterman WA, Farhadian H, Abu SC, et al. Environmental and nutritional factors significantly associated with cancer of the urinary tract among different ethnic groups. *Urol Clin North Am.* 1991;18:501–508.
146. Braver DJ, Modan M, Chetrit A, Lusky A, Braf Z. Drinking, micturition habits, and urine concentration as potential risk factors in urinary bladder cancer. *J Natl Cancer Inst.* 1987;78:437–440.
147. Hosking DH, Erickson SB, Van den Berg CJ, Wilson DM, Smith LH. The stone clinic effect in patients with idiopathic calcium urolithiasis. *J Urol.* 1983;130:1115–1118.
148. Hughes J, Norman RW. Diet and calcium stones. *CMAJ.* 1992;146:137–143.
149. Iguchi M, Umekawa T, Ishikawa Y, et al. Clinical effects of prophylactic dietary treatment on renal stones. *J Urol.* 1990;144:229–232.
150. Lax D, Eicher M, Goldberg SJ. Mild dehydration induces echocardiographic signs of mitral valve prolapse in healthy females with prior normal cardiac findings. *Am Heart J.* 1992;124:1533–1540.
151. Lubin F, Rozen P, Arieli B, et al. Nutritional and lifestyle habits and water-fiber interaction in colorectal adenoma etiology. *Cancer Epidemiol Biomarkers Prev.* 1997;6:79–85.
152. Michaud DS, Spiegelman D, Clinton SK, et al. Fluid intake and the risk of bladder cancer in men. *N Engl J Med.* 1999;340:1390–1397.
153. Pohlabeln H, Jockel KH, Bolm-Audorff U. Non-occupational risk factors for cancer of the lower urinary tract in Germany. *Eur J Epidemiol.* 1999;15:411–419.
154. Slattery ML, Caan BJ, Anderson KE, Potter JD. Intake of fluids and methylxanthine-containing beverages: association with colon cancer. *Int J Cancer.* 1999;81:199–204.
155. Geoffroy-Perez B, Cordier S. Fluid consumption and the risk of bladder cancer: results of a multicenter case-control study. *Int J Cancer.* 2001;93:880–887.
156. Slattery ML, West DW, Robison LM. Fluid intake and bladder cancer in Utah. *Int J Cancer.* 1988;42:17–22.
157. Frequently asked questions about the DRIs. Institute of Medicine; 2002. Available at: http://www.iom.edu/iom/iomhome.nsf. Accessed November 2002.
158. Yates AA, Schlicker SA, Suitor CW. Dietary reference intakes: the new basis for recommendations for calcium and related nutrients, B vitamins, and choline. *J Am Diet Assoc.* 1998;98:699–706.