European Journal of Clinical Nutrition (2010) 64, 115–123
 0954-3007/10 $32.00
www.nature.com/ejcn

REVIEW

Water as an essential nutrient: the physiological basis of hydration

E Jéquier[1] and F Constant[2]

[1]*Department of Physiology, University of Lausanne, Pully, Switzerland and* [2]*Nestlé Waters, Paris, France*

How much water we really need depends on water functions and the mechanisms of daily water balance regulation. The aim of this review is to describe the physiology of water balance and consequently to highlight the new recommendations with regard to water requirements. Water has numerous roles in the human body. It acts as a building material; as a solvent, reaction medium and reactant; as a carrier for nutrients and waste products; in thermoregulation; and as a lubricant and shock absorber. The regulation of water balance is very precise, as a loss of 1% of body water is usually compensated within 24 h. Both water intake and water losses are controlled to reach water balance. Minute changes in plasma osmolarity are the main factors that trigger these homeostatic mechanisms. Healthy adults regulate water balance with precision, but young infants and elderly people are at greater risk of dehydration. Dehydration can affect consciousness and can induce speech incoherence, extremity weakness, hypotonia of ocular globes, orthostatic hypotension and tachycardia. Human water requirements are not based on a minimal intake because it might lead to a water deficit due to numerous factors that modify water needs (climate, physical activity, diet and so on). Water needs are based on experimentally derived intake levels that are expected to meet the nutritional adequacy of a healthy population. The regulation of water balance is essential for the maintenance of health and life. On an average, a sedentary adult should drink 1.5 l of water per day, as water is the only liquid nutrient that is really essential for body hydration.
European Journal of Clinical Nutrition (2010) **64,** 115–123; doi:10.1038/ejcn.2009.111; published online 2 September 2009

Keywords: water; hydration; dehydration; dietary requirements

Introduction

Water is the major constituent of the human body. The latter cannot produce enough water by metabolism or obtain enough water by food ingestion to fulfil its needs. As a consequence, we need to pay attention to what we drink throughout the day to ensure that we are meeting our daily water needs, as not doing so may have negative health effects.

Water is the main constituent of cells, tissues and organs and is vital for life (Lang and Waldegger, 1997). Despite its well-established importance, water is often forgotten in dietary recommendations, and the importance of adequate hydration is not mentioned. As a consequence, health professionals and nutritionists are sometimes confused and question the necessity of drinking water regularly: how much should we drink, and how to know whether patients are well hydrated or not. The purpose of this paper is to review the main functions of water and the mechanisms of daily water balance regulation, which constitute a clear evidence of how much water we really need.

Correspondence: Honorary Professor E Jéquier, Department of Physiology, University of Lausanne, Av. de Rochettaz 10, Pully 1009, Switzerland.
E-mail: emjequier@hispeed.ch
Received 20 March 2009; revised 16 June 2009; accepted 7 July 2009; published online 2 September 2009

Water as a vital nutrient: a multifunctional constituent of the human body

Water as a building material

Water, present in each cell of our body and in the various tissues and compartments, acts first as a building material. This primary function leads to nutritional recommendations, as water needs are higher during the growth period of the body.

Water as a solvent, a reaction medium, a reactant and a reaction product

Water has unique properties: it is an excellent solvent for ionic compounds and for solutes such as glucose and amino

acids (Häussinger, 1996). It is a highly interactive molecule and acts by weakening electrostatic forces and hydrogen bonding between other polar molecules. It has a high dielectric constant and it forms oriented solvent shells around ions, thus enabling them to move freely. Water as a macronutrient is involved in all hydrolytic reactions, for instance, in the hydrolysis of other macronutrients (proteins, carbohydrates, lipids and so on).

Water is also produced by the oxidative metabolism of hydrogen-containing substrates in the body. Theoretically, for 1 g of glucose, palmitic acid and protein (albumin), 0.6, 1.12 and 0.37 ml water, respectively, is endogenously produced, or for 100 kcal of energy, 15, 13 and 9 ml water is produced.

Water as a carrier

Water is essential for cellular homeostasis because it transports nutrients to cells and removes wastes from cells (Häussinger, 1996). It is the medium in which all transport systems function, allowing exchanges between cells, interstitial fluid and capillaries (Grandjean and Campbell, 2004). Water maintains the vascular volume and allows blood circulation, which is essential for the function of all organs and tissues of the body (Ritz and Berrut, 2005). Thus, the cardiovascular and respiratory systems, the digestive tract, the reproductive system, the kidney and liver, the brain and the peripheral nervous system, all depend on adequate hydration to function effectively (Häussinger, 1996). Severe dehydration therefore affects the function of many systems and is a life-threatening condition (Szinnai *et al*., 2005).

Water and thermoregulation

Water has a large heat capacity, which contributes to limiting changes in body temperature in a warm or cold environment. Water has a large capacity for vaporization of heat, which allows a loss of heat from the body even when ambient temperature is higher than body temperature (Montain *et al*., 1999). When sweating is elicited, evaporation of water from the skin surface is a very efficient way to lose heat.

Water as a lubricant and shock absorber

Water, in combination with viscous molecules, forms lubricating fluids for joints; for saliva, gastric and intestinal mucus secretion in the digestive tract; for mucus in airways secretion in the respiratory system and for mucus secretion in the genito-urinary tract.

By maintaining the cellular shape, water also acts as a shock absorber during walking or running. This function is important for the brain and spinal cord, and is particularly important for the fetus, who is protected by a water cushion.

Distribution of body water

Water is the main constituent of our body, as about 60% of our body weight is made of water. This water content varies with body composition (lean and fat mass) (Dietary Reference Intakes, 2006). In infants and children, water as a percentage of body weight is higher than in adults. This is mainly due to higher water content in the extracellular compartment, whereas the water content in the intracellular compartment is lower in infants than in older children and adults. Body composition changes rapidly during the first year of life, with a decrease in the water content of the fat-free mass and an increase in the content of protein and minerals.

In adults, about two-thirds of total water is in the intracellular space, whereas one-third is extracellular water. A 70-kg human has about 42 l of total body water, of which 28 l is intracellular water and 14 l is extracellular fluid (ECF) (Wang *et al*., 1999). Of the latter, 3 l is in blood plasma, 1 l is the transcellular fluid (cerebrospinal fluid, ocular, pleural, peritoneal and synovial fluids) and 10 l is the interstitial fluid, including lymph, which provides an aqueous medium surrounding cells.

The constancy of the amount and composition of ECF is a necessity for the function of cells. This constancy is due to the homeostatic mechanisms that monitor and regulate its composition, osmotic pressure, pH and temperature (Ganong, 2005). These mechanisms rely on the function of the main systems of the body, such as the circulatory, respiratory, renal and alimentary systems. The monitoring and regulation of these systems are coordinated by the nervous and endocrine systems. The composition of the intracellular fluid is maintained by solute movement across the cell membrane by passive or active transports (Ganong, 2005).

Water balance: water inputs and outputs

Under usual conditions of moderate ambient temperature (18–20 °C) and with a moderate activity level, body water remains relatively constant. This implies a precise regulation of water balance: over a 24-h period, intake and loss of water must be equal. It has been estimated that water balance is regulated within 0.2% of body weight over a 24-h period (Grandjean and Campbell, 2004).

Water inputs

Water inputs are composed of three major sources (Table 1): the water we drink, the water we eat and the water we produce. The water we drink is essentially composed of water and other liquids with a high water content (85 to >90%). The water we eat comes from various foods with a wide range of water content (40 to >80%). The water we produce results from the oxidation of macronutrients (endogenous or metabolic water).

Table 1 Water balance in sedentary adults living in temperate climate

	Water inputs (ml/day)				*Water outputs (ml/day)*		
	Min	*Max*	*Average*		*Min*	*Max*	*Average*
Beverages	1400[a]	1750[a]	1575	Urine	1200	2000	1600
Foods[b]	600[a]	750[a]	675	Skin	450	450	450[c]
Subtotal	2000[d]	2500[e]	2250	Respiration	250[c]	350[c]	300
Metabolic water	250	350	300	Faeces	100	300	200[c]
Total	2250	2850	2550	Total	2000	3100	2550

[a]It is normally assumed that the contribution of food to total dietary water intake is 20–30%, whereas 70–80% are provided by beverages. This relationship is not fixed and depends on the type of beverages and on the choice of foods.
[b]Foods with a wide range of water content (<40 to >80%).
[c](EFSA, 2008).
[d]Average total water intakes in sedentary women (EFSA, 2008).
[e]Average total water intakes in sedentary men (EFSA, 2008).

It is normally assumed that the contribution of food to total water intake is 20–30%, whereas 70–80% is provided by beverages. This relationship is not fixed and depends on the type of beverages and on the choice of foods (EFSA, 2008).

For an individual at rest under temperate conditions, the volume that might be drunk in a day is on an average 1.5 l. This has to be adapted according to age, gender, climate and physical activity. The water content of food can vary within a wide range, and consequently the amount of water contributed by foods can vary between 500 ml and 1 l a day. Endogenous or metabolic water represents about 250–350 ml a day in sedentary people.

The adequate total water intakes for sedentary adults are on an average between 2 and 2.5 l per day (women and men, respectively) (EFSA, 2008). In conclusion, the total water inputs for sedentary adults are on an average between 2 and 3 l.

Water outputs. The main routes of water loss from the body are kidneys, skin and the respiratory tract and, at a very low level, the digestive system (Table 1).

Over a 24-h period, a sedentary adult produces 1–2 l of urine.

Water is lost by evaporation through the skin; this is called insensible perspiration because it is an invisible water loss and it represents about 450 ml of water per day in a temperate environment.

Water is also lost by evaporation through the respiratory tract (250–350 ml per day).

Finally, a sedentary adult loses about 200 ml of water a day through faeces.

On an average, a sedentary adult loses 2–3 l of water per day. These water losses through the skin and lungs depend on the climate, air temperature and relative humidity.

When the internal body temperature rises, the only mechanism for increasing heat losses is the activation of sweat glands. Evaporation of water by way of sweat on the skin surface is a very efficient mechanism for removing heat from the body: 2.2 kJ is lost by the evaporation of 1 g of water. When exercising in a hot environment, the sweating rate can reach as much as 1–2 l of water loss per hour (Sawka *et al*., 2005). This can lead to dehydration and hyperosmolarity of ECF.

It is important to note that sweat is always hypotonic when compared with plasma or ECF. Sweat contains 20–50 mmol/l of Na+, whereas the extracellular Na+ concentration is 150 mmol/l. Intense sweating therefore leads to greater water than electrolyte losses (Sawka *et al*., 2005). The consequence is an increased extracellular osmolarity that draws water from cells into the ECF. Thus, the loss of water through sweating concerns both intracellular fluid and ECF, a situation that characterizes hypertonic dehydration. The need to drink hypotonic drinks during endurance exercise is well established. A person losing 4 l of sweat with no fluid replacement loses about 10% of body water, but only 4% of extracellular sodium (about 120 mmol of Na^+). This indicates that during exercise, fluid replacement is more important than salt replacement.

Dehydration and hyperosmolarity of ECF can affect consciousness and are involved in the occurrence of heat stroke when internal temperature rises above critical thresholds. The latter can occur when exercising in a warm and humid environment (Sawka *et al*., 2005).

Regulation of water balance

The intake of water is partially determined by thirst. When water losses exceed water intake, the osmotic pressure of ECF increases. By activation of hypothalamic osmoreceptors, an antidiuretic hormone (ADH) is released from the posterior pituitary gland (Ganong, 2005). Both the increased ECF osmotic pressure and ADH elicit the feeling of thirst (Figure 1). The receptors that elicit thirst have an osmotic threshold higher than the osmoreceptors involved in ADH release. Thus, ADH can act on the kidneys to increase water reabsorption before thirst is elicited. Thirst is often blunted in elderly subjects who are at risk of having an insufficient water intake in conditions of elevated ambient temperature and humidity (Phillips *et al*., 1984). Thirst is triggered by an

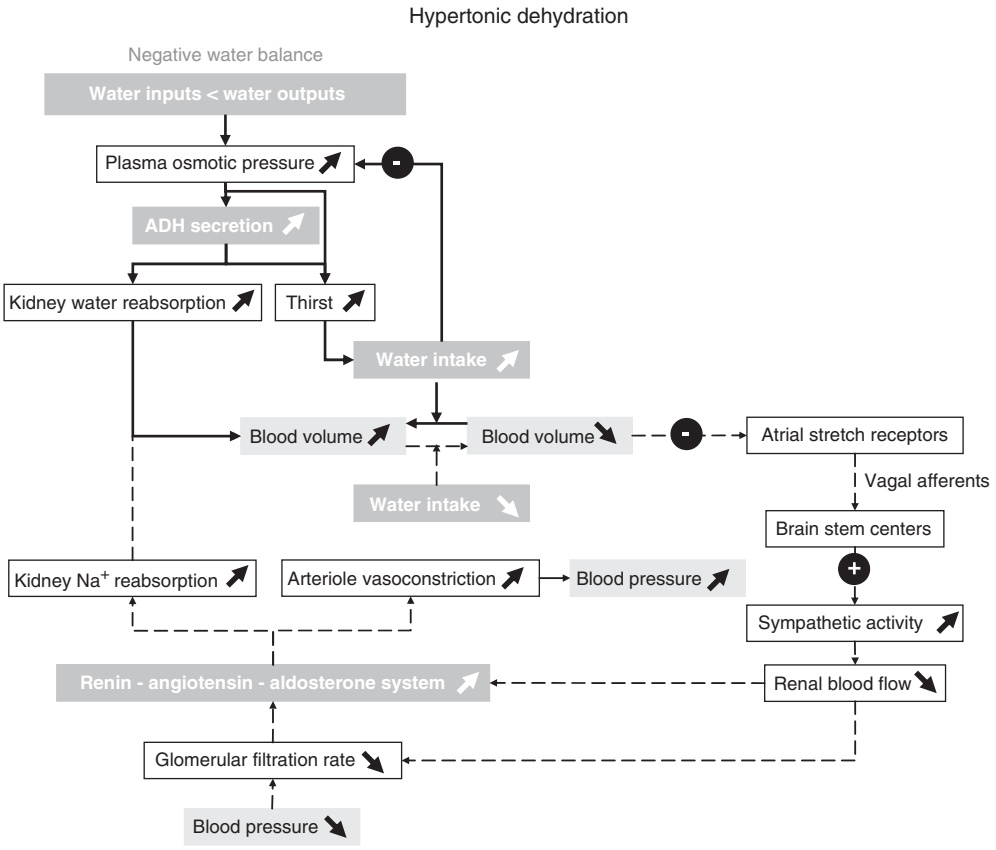

Figure 1 Feedback loops for water balance: main perturbations and physiological responses to hypertonic dehydration due to a negative water balance. Solid arrows show the responses induced by osmoreceptors when plasma osmotic pressure increases. Dashed arrows show the corrective mechanisms induced by insufficient water intake and a decreased blood volume to restore blood volume and blood pressure. Note that in the case of hypotonic dehydration due to a positive water balance, all perturbations and physiological responses that are induced occur in the reverse direction.

increase in plasma and ECF osmolarity, by reductions in plasma volume at water deficits that correspond to a body weight loss of 1–3% (EFSA, 2008). During rehydration, thirst can disappear before water balance is reached.

The set point of plasma osmolarity above which ADH secretion is stimulated is about 280 mosm/l. Furthermore, the sensitivity of ADH response to a rise in plasma osmolarity is enhanced when the circulating blood volume is lowered (Ganong, 2005).

Kidneys are the main regulators of water losses. They have the unique property to modify the osmotic pressure of urine within a large range in response to minute changes in plasma osmotic pressure.

There are two conditions that induce the production of a large volume of urine, and therefore a large water loss. Water diuresis occurs when water is ingested in excess of body requirements. This leads to a small decrease in plasma osmolarity, with a suppression of ADH secretion. As a result, a large volume of hypotonic urine is produced. In contrast, osmotic diuresis results from a filtered load of a solute that exceeds the renal tubules' maximum reabsorption capacity for this solute.

In summary, both deficit and excess water intakes are counterbalanced by subtle hormonal changes (ADH, aldosterone and atrial natriuretic peptide) that contribute to buffer the deleterious effects of these abnormal conditions. In the end, the final and precise regulation of water balance is dependent on thirst and on ADH release, with its predominant role in water reabsorption in the kidneys (Figure 1). Therefore, voluntary drinking of water is a key behavior for maintaining water balance. Consequently, drinking water before being thirsty is a good habit for maintaining a good body hydration status.

Measurement of hydration status

A normal hydration status is the condition of healthy individuals who maintain their water balance. It is of practical importance to be able to assess the degree of

hydration in individuals exposed to ambient conditions that can induce dehydration (Armstrong, 2005). In particular, elderly persons are prone to water deficit during the summer period because of blunted thirst and less efficient renal urinary concentrating mechanisms. Mild dehydration of 1 or 2% of body water can impair cognitive functions, alertness and capacity for exercise. Young infants are also prone to dehydration because they cannot express their sensation of thirst.

Body weight

The commonly used technique to measure changes in hydration status is the measurement of body weight changes that occur during short periods of time (Shirreffs, 2003). When an individual is in a caloric balance, a body weight loss essentially equals water loss. Measurements of body weight must be carried out under standard conditions, preferably in the morning in the fasted state and after micturition and defecation.

Tracer techniques

Total body water can be measured by using tracer techniques, such as the use of deuterium oxide, which is a stable isotope of hydrogen (Grandjean *et al*., 2003). By determining the amount of tracer given and the equilibration concentration of the tracer in a body fluid, one can calculate the volume into which the tracer has been diluted. Tracer methods are mainly research tools and are not used in clinical practice.

Bioelectrical impedance

It is a technique that measures the resistance of body tissue and water to an electrical current that flows through the body (Pialoux *et al*., 2004). The method is easy to use, but many factors reduce the reliability and accuracy of this technique. These factors include the site placement of electrodes and problems of inadequate skin contact of electrodes, changes in plasma osmolarity and plasma sodium concentration and effect of posture. In spite of improvements in the initial technique that used a single frequency, the technological advancements, which allow impedance to be measured at numerous frequencies, have not brought about a significant improvement, and the bioelectrical impedance method remains inappropriate for measuring small changes in total body water in the range of 1 l (Ellis and Wong, 1998; Gudivaka *et al*., 1999; Ritz, 2001; Mathie, 2005).

Plasma or serum osmolarity, plasma indices

The term osmolality (osmol/kg solvent) is also used instead of osmolarity (osmol/l solution). However, because in dilute aqueous solutions the molal concentrations (mol/kg water) closely approximate molar concentrations (mol/l solution), the terms osmolality and osmolarity are used interchangeably. Plasma or serum osmolarity is tightly controlled and rarely varies by more than 2% around a set point of 280–290 mosm/l. In well-hydrated individuals, a basal mean value of 287 mosm/l is maintained by hypothalamic osmoreceptors that control ADH secretion (Figure 1). An osmolarity increase of 1% is sufficient to initiate a sensation of thirst and to increase the ADH plasma concentration by 100% of the basal value. Therefore, measurement of changes in plasma osmolarity is the most widely used hematological index of hydration (Francesconi *et al*., 1987). However, if osmolarity is increased by solutes such as urea and glucose, which penetrate plasma membrane, ADH release and thirst are not initiated. Although hypernatraemia is a sign of hypertonic dehydration, an increase in blood urea is not a valid indicator of a negative water balance, as its value depends on kidney function and protein intake.

Urine indices

Urinary indices of hydration, such as urine osmolarity (Oppliger *et al*., 2005), urine-specific gravity or 24-h urine volume, may be used, but urine variables often mirror the recent volume of fluid consumed rather than the state of hydration (Armstrong *et al*., 1998). For example, the intake of a large volume of water rapidly dilutes the plasma and the kidneys excrete diluted urine even if dehydration exists.

In conclusion, even if there is no real consensus with regard to the method by which to measure hydration status, for clinicians and general practitioners, the urine colour chart can be used as an indicator (Mentes *et al*., 2006). This is used, for example, in nursing home residents because it is a low-cost and rapid method for assessing hydration status, which can help in early intervention. Depending on the colour of the urine sample that matches with the colour on the chart, one can identify patients who are well hydrated or those who are poorly hydrated and who should consume fluids.

Finally, an approximation of hydration status can be obtained by measuring the sensation of thirst with a simple numerical scale. This approach is, however, of limited value in elderly individuals who have a blunted sensation of thirst.

Types of dehydration

There are three types of dehydration (EFSA, 2008): (1) isotonic dehydration in which net salt and water loss is equal, (2) hypertonic dehydration characterized by loss of water in excess of salt and (3) hypotonic dehydration, characterized by loss of salt in excess of water.

1. In isotonic dehydration, salt may be lost isotonically from the gastrointestinal tract, such as after profuse diarrhoea (Grandjean and Campbell, 2004). Only the ECF volume is reduced, and treatment is the prescription of isotonic salt solutions, such as the World health Organization's

rehydration solution for the treatment of diarrhoea, a solution that is widely used in developing countries.

2. Inadequate water intake and excessive water loss are the two mechanisms responsible for the development of hypertonic dehydration (Grandjean and Campbell, 2004). Insufficient water intake may be caused by defective thirst or impaired consciousness, or by a lack of available water. Large water loss may result from osmotic diuresis or diabetes insipidus. Vomiting is accompanied by a loss of hydrochloric acid, which is almost equivalent to the loss of pure water because NaHCO3 (which is finally absorbed and passes into the blood) replaces it. Sweating can represent an important hypotonic fluid loss when exercising in a hot environment.
3. Hypotonic dehydration occurs when losses of gastrointestinal fluids (which are either hypotonic or isotonic in relation to plasma) are replaced by water, or by a solution that contains less Na^+ and K^+ than the fluid that has been lost (Francesconi *et al*., 1987). The reduced osmolarity of ECF causes a shift of water into the intracellular fluid to reach osmotic balance. Hence, cell volume increases in spite of a reduction in ECF. Treatment of hypotonic dehydration may need both hypertonic saline to restore the osmolarity of body fluids and isotonic saline to compensate the loss of ECF.

Signs of dehydration

Clinical symptoms and signs of dehydration generally have poor sensitivity and specificity (Thomas *et al*., 2008). Nevertheless, factors that have a sensitivity $>80\%$ are dry mucous membranes in the mouth and nose and longitudinal furrows on the tongue. Some other factors have good specificity ($>80\%$): speech incoherence, extremity weakness, dry axilla and sunken eyes.

Signs of mild-to-moderate and severe dehydration are listed in Table 2 (Mayo Clinic, 2008). More recently, it has been shown that mild dehydration corresponding to only 1–2% of body weight loss in adults can lead to a significant impairment in both cognitive function (alertness, concentration, short-term memory) and physical performance (endurance, sports skills) (Ritz and Berrut, 2005; Shirreffs, 2005). Populations at particular risk of dehydration include the very young and the elderly.

Dehydration in infants

Infants have a higher percentage of water (75% of body weight at birth) (D'Anei *et al*., 2006) than do adults. Several factors make infants more vulnerable to fluid and electrolyte imbalance than adults: the high surface-to-body-weight ratio, the limited ability to excrete solutes and to concentrate urine, the low ability to express thirst and the high rate of metabolic rate (Gorelick *et al*., 1997). Problems of hydration may occur in case of fever (which increases insensible water loss), vomiting, diarrhoea and the use of formula not diluted appropriately. The adequate water intake for infants aged 0–6 months is 0.7 l/day (D'Anei *et al*., 2006).

Dehydration in the elderly

Elderly individuals have a higher risk of developing dehydration than do adults. Diminution of liquid intake and increase in liquid losses are both involved in causing dehydration in the elderly (Phillips *et al*., 1984).The diminution of the sensation of thirst (Phillips *et al*., 1984), the decreased renal ability to concentrate urine, the relative resistance of the kidney to ADH, the diminution of renin activity and the low secretion of aldosterone, all increase the risk of dehydration. In addition, the elderly may encounter difficulties in gaining access to drinks because of diminution of mobility, visual troubles, swallowing disorders, cognitive alterations and use of sedatives. Fear of incontinence may lead some elderly people to limit their liquid intake. Low

Table 2 Signs of dehydration

Signs of mild-to-moderate dehydration	*Signs of severe dehydration*
Dry, sticky mouth	Extreme thirst
Sleepiness or tiredness	Extreme fussiness or sleepiness in infants and children; irritability and confusion in adults
Thirst	Very dry mouth, skin and mucous membranes
Decreased urine output	Lack of sweating
Few or no tears when crying	Little or no urination—any urine that is produced will be dark yellow or amber
Muscle weakness	Sunken eyes
Headache	Shrivelled and dry skin that lacks elasticity and does not 'bounce back' when pinched into a fold
Dizziness or light-headedness	In infants, sunken fontanels—the soft spots on the top of a baby's head
	Low blood pressure
	Rapid heartbeat
	Fever
	Delirium or unconsciousness

Source: Mayo Clinic, 2008.

dietary intake also decreases the water intake that is held in aliments and contributes to a water deficit. Medications such as diuretics or laxatives can enhance water loss.

The clinical signs of dehydration include neuropsychic symptoms such as mental confusion, impaired cognitive functions (Lieberman, 2007), mucosal dryness, hypotonia of ocular globes, orthostatic hypotension and tachycardia (Sawka, 1992). Loss of body water also increases the risk of hyperthermia under conditions of high ambient temperature (Sawka, 1992). The risk of falls, kidney stones and urinary infections are also increased in dehydrated elderly individuals (Grandjean and Campbell, 2004).

Water requirements

Owing to the precise mechanisms regulating water balance, normal hydration is compatible with a wide range of fluid intake (Manz *et al*., 2002). Human water requirements are not based on a minimal intake as it might lead to a water deficit because of numerous factors that modify water needs (metabolism, climate, physical activity, diet and so on). Instead, water needs are based on experimentally derived intake levels that are expected to meet nutritional adequacy for members of a healthy population; this is the adequate intake determined for infants, adolescents, adults and elderly individuals (Sawka *et al*., 2005). Numerous factors, such as high ambient temperature and humidity levels, physical activity and exercise, and heat stress in particular, influence water needs. Thus, the adequate water intake determined for standard conditions does not meet these particular requirements and adequate intake must be increased in relation to these conditions.

According to the Food and Nutrition Board 2004, values for adequate intake of water coming from liquids are the following (Table 3): 0.7 l/day for infants 0–6 months old, 0.6/l day for infants 7–12 months old, 0.9 l/day for children 1–3 years old, and 1.2 l/day for children 4–8 years old. Male adolescents aged 9–13 years need 1.8 l l/day, those aged 14–18 years need 2.6 l/day and male adults need 3.0 l/day. Female adolescents aged 9–13 years need 1.6 l/day, those aged 14–18 years need 1.8 l/day and female adults need 2.2 l/day.

The European Food Safety Authority has been recently asked to revise the existing recommended intakes of essential substances with a physiological effect, including water, as this nutrient is essential for health and life. The values of water requirements mentioned in Table 4 are in agreement with its draft recommendations (EFSA, 2008).

When we compare the dietary reference intakes (DRIs) (also called dietary reference values or DRVs), for water that have been published in the United States with those proposed in discussion in Europe, the main differences are with regard to children aged 9–13 years and adults. This confirms a well-known fact that the establishment of dietary reference intakes is conditioned by the dietary habits of the population (food and beverage habits).This is the reason why it is necessary to have these recommendations set up by continent or by country when data are available.

In acute exercise, sweat losses can reach 1–2 l/h and this magnitude of fluid losses can be difficult to replace in the short term (Montain *et al*., 1999; Murray, 2007). Long recovery periods of *ad libitum* drinking are needed to recover water balance with adequate electrolyte replacement (Maughan *et al*., 2007).

Despite varying water needs, healthy humans regulate their daily water balance with precision. However, young infants and elderly people are at a greater risk of dehydration than are adults. Parents and caregivers should be aware of signs of dehydration in infants and elderly individuals and they should encourage water intake of individuals who are at risk of dehydration.

Table 3 Dietary reference intake values for total water in the United States (Institute of Medicine of the National Academies, Washington DC)

Life stage group	*Criterion*	*AI for males in l/day*[a]			*AI for females in l/day*[a]		
		From foods	*From beverages*	*Total water*[b]	*From foods*	*From beverages*	*Total water*[b]
0–6 months	Average consumption of water from human milk	0	0.7	0.7	0	0.7	0.7
7–12 months	Average consumption of water from human milk and complementary foods	0.2	0.6	0.8	0.2	0.6	0.8
1–3 years	Median total water intake from NHANES III	0.4	0.9	1.3	0.4	0.9	1.3
4–8 years	Median total water intake from NHANES III	0.5	1.2	1.7	0.5	1.2	1.7
9–13 years	Median total water intake from NHANES III	0.6	1.8	2.4	0.5	1.6	2.1
14–18 years	Median total water intake from NHANES III	0.7	2.6	3.3	0.5	1.8	2.3
>19 years	Median total water intake from NHANES III	0.7	3.0	3.7	0.5	2.2	2.7
Pregnancy 14–50 years	Median total water intake from NHANES III				0.7	2.3	3.0
Lactation 14–50 years	Median total water intake from NHANES III				0.7	3.1	3.8

Abbreviations: AI, adequate intake; NHANES III, Third National Health and Nutrition Examination Survey.
[a]The AI is not equivalent to the recommended dietary allowances, RDA.
[b]Total water represents drinking water, other beverages and water from food.

Table 4 Dietary reference intake values for total water in Europe

Life stage group	*Adequate intake of water for males (ml/day)*			*Adequate intake of water for females (ml/day)*		
	From foods[a]	*From beverages*[b]	*Total water*	*From foods*[a]	*From beverages*[b]	*Total water*
2–3 years	390	910	1300	390	910	1300
4–8 years	480	1120	1600	480	1120	1600
9–13 years	630	1470	2100	570	1330	1900
>14 years	750	1750	2500	600	1400	2000
Pregnancy				690	1610	2300[c]
Lactation				600	2100	2700[d]

[a]Foods with a wide range of water content (<40 to >80%).
[b]It is normally assumed that the contribution of food to total dietary water intake is 20–30%, whereas 70–80% are provided by beverages. This relationship is not fixed and depends on the type of beverages and on the choice of foods.
[c]There are no European data available, but assuming an increase of energy intake of 15% (equivalent to 300 kcal/day), an additional total water intake of 300 ml would be adequate (EFSA, 2008).
[d]Adequate water intakes for lactating women are about 700 ml/day above the adequate intakes of nonlactating women of the same age (EFSA, 2008).

Conclusion

Water, a vital nutrient, has numerous critical roles in the human body. It acts as a building material; as a solvent, reaction medium, reactant and reaction product; as a carrier for nutrients and waste products; in thermoregulation and as a lubricant and shock absorber. Consequently, the optimal functioning of our body requires a good hydration level. The regulation of water balance is very precise and is essential for the maintenance of health and life.

A better estimate of daily water requirements has been established owing to the knowledge of the main physiological functions of water and the understanding of the mechanisms of water balance regulation. On an average, a sedentary adult should drink 1.5 l of water per day, as water is the only liquid nutrient that is really essential for body hydration and is vital for the body to function properly.

Conflict of interest

The authors declare no conflict of interest.

References

Armstrong LE (2005). Hydration assessment techniques. *Nut Rev* **63**, S40–S54.
Armstrong LE, Soto JA, Hacker Jr FT, Casa DJ, Kavouras SA, Maresh CM (1998). Urinary indices during dehydration, exercise, and rehydration. *Int J Sport Nutr* **8**, 345–355.
D'Anei KE, Constant F, Rosenberg IH (2006). Hydration and cognitive function in children. *Nutr Rev* **64**, 457–464.
Dietary Reference Intakes (2006). *The Essential Guide to Nutrients Requirements*. Institute of Medicine of the National Academies: Washington DC, 543 pp.
EFSA (2008). *Draft dietary reference values for water. Scientific Opinion of the Panel on Dietetic Products, Nutrition and Allergies*, (agreed on 11 April 2008 for release for public consultation).
Ellis KJ, Wong WW (1998). Human hydrometry: comparison of multifrequency bioelectrical impedance with H20 and bromine dilution. *J Appl Physiol* **85**, 1056–1062.
Francesconi RP, Hubbard RW, Szlyk PC, Schnakenberg D, Carlson D, Leva N *et al.* (1987). Urinary and hematologic indexes of hypohydration. *J Appl Physiol* **62**, 1271–1276.
Ganong WF (2005). *Review of Medical Physiology*, 22nd edn, LANGE-Science: New York.
Gorelick MH, Shaw KN, Murphy KO (1997). Validity and reliability of clinical signs in the diagnosis of dehydration in children. *Pediatrics* **99**, E6.
Grandjean AC, Campbell SM (2004). *Hydration: Fluids for Life. A monograph by the North American Branch of the International Life Science Institute*. ILSI North America: Washington DC.
Grandjean AC, Reimers CJ, Buyckx ME (2003). Hydration: issues for the 21st century. *Nutr Rev* **61**, 261–271.
Gudivaka R, Schoeller DA, Kushner RF, Bolt MJG (1999). Single and multifrequency models for bioelectrical impedance analysis of body water compartments. *J Appl Physiol* **87**, 1087–1096.
Häussinger D (1996). The role of cellular hydration in the regulation of cell function. *Biochem J* **313**, 697–710.
Lang F, Waldegger S (1997). Regulating cell volume. *Am Scientist* **85**, 456–463.
Lieberman HR (2007). Hydration and cognition: a critical review and recommendations for future research. *J Am Coll Nutr* **26** (Suppl 5), 555S–561S.
Manz F, Wentz A, Sichert-Hellert W (2002). The most essential nutrient: defining the adequate intake of water. *J Pediatr* **141**, 587–592.
Mathie JR (2005). Second generation mixture theory equation for estimating intracellular water using bioimpedance spectroscopy. *J Appl Physiol* **99**, 780–781.
Maughan RJ, Shirreffs SM, Watson P (2007). Exercise, heat, hydration, and the brain. *J Am Coll Nutr* **26** (Suppl 5), 604S–612S.
Mayo Clinic (2008): http://www.mayoclinic.com/health/dehydration/DS00561/DSECTION=symptoms.
Mentes JC, Wakefield B, Culp K (2006). Use of a urine color chart to monitor hydration status in nursing home residents. *Biol Res Nurs* **7**, 197–203.
Montain SJ, Latzka WA, Sawka MN (1999). Fluid replacement recommendations for training in hot weather. *Mil Med* **164**, 502–508.
Murray B (2007). Hydration and physical performance. *J Am Coll Nutr* **26** (Suppl 5), 542S–548S.
Oppliger RA, Magnes SA, Popowski LA, Gisolfi CV (2005). Accuracy of urine specific gravity and osmolality as indicators of hydration status. *Int J Sport Nutr Exerc Metab* **15**, 236–251.
Phillips PA, Rolls BJ, Ledingham JG, Forsling ML, Morton JJ, Crowe MJ *et al.* (1984). Reduced thirst after water deprivation in healthy elderly men. *N Engl J Med* **311**, 753–759.

Pialoux V, Mischler I, Mounier R, Gachon P, Ritz P, Coudert J *et al.* (2004). Effect of equilibrated hydration changes on total body water estimates by bioelectrical impedance analysis. *Br J Nutr* **91**, 153–159.

Ritz P (2001). Bioelectrical impedance analysis estimation of water compartments in elderly diseased patients: the source study. *J Gerontol* **56**, M344–M348.

Ritz P, Berrut G (2005). The importance of good hydration for day-to-day health. *Nutr Rev* **63**, S6–S13.

Sawka MN (1992). Physiological consequences of hypohydration: exercise performance and thermoregulation. *Med Sci Sports Exerc* **24**, 657–670.

Sawka MN, Cheuvront SN, Carter III R (2005). Human water needs. *Nutr Rev* **63**, S30–S39.

Shirreffs SM (2003). Markers of hydration status. *Eur J Clin Nutr* **57** (Suppl 2), S6–S9.

Shirreffs SM (2005). The importance of good hydration for work and exercise performance. *Nutr Rev* **63**, S14–S21.

Szinnai G, Schachinger H, Arnaud MJ, Linder L, Keller U (2005). Effect of water deprivation on cognitive-motor performance in healthy men and women. *Am J Physiol Regul Integr Comp Physiol* **289**, R275–R280.

Thomas DR, Cote TR, Lawhorne L, Levenson SA, Rubestein LZ, Smith DA *et al.* (2008). Understanding clinical dehydration and its treatment. *J Am Med Dir Assoc* **9**, 292–301.

Wang ZM, Deurenberg P, Wang W, Pietrobelli A, Baumgartner RN, Heymsfield SB (1999). Hydration of fat-free body mass: a review and critique of a classic body-composition constant. *Am J Clin Nutr* **69**, 833–841.