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EFSA Panel on Dietetic Products, Nutrition, and Allergies (NDA); Scientific Opinion on Dietary reference values for water

EFSA Publication; Tetens, Inge

Link to article, DOI:
10.2903/j.efsa.2010.1459

Publication date:
2011

Document Version
Publisher's PDF, also known as Version of record

SCIENTIFIC OPINION

Scientific Opinion on Dietary Reference Values for water[1]

EFSA Panel on Dietetic Products, Nutrition, and Allergies (NDA)[2, 3]

European Food Safety Authority (EFSA), Parma, Italy

ABSTRACT

This Opinion of the EFSA Panel on Dietetic Products, Nutrition, and Allergies (NDA) deals with the setting of dietary reference values for water for specific age groups. Adequate Intakes (AI) have been defined derived from a combination of observed intakes in population groups with desirable osmolarity values of urine and desirable water volumes per energy unit consumed. The reference values for total water intake include water from drinking water, beverages of all kind, and from food moisture and only apply to conditions of moderate environmental temperature and moderate physical activity levels (PAL 1.6). AIs for infants in the first half of the first year of life are estimated to be 100-190 mL/kg per day. For infants 6-12 months of age a total water intake of 800-1000 mL/day is considered adequate. For the second year of life an adequate total water intake of 1100-1200 mL/day is defined by interpolation, as intake data are not available. AIs of water for children are estimated to be 1300 mL/day for boys and girls 2-3 years of age; 1600 mL/day for boys and girls 4-8 years of age; 2100 mL/day for boys 9-13 years of age; 1900 mL/day for girls 9-13 years of age. Adolescents of 14 years and older are considered as adults with respect to adequate water intake. Available data for adults permit the definition of AIs as 2.0 L/day (P 95 3.1 L) for females and 2.5 L/day (P95 4.0 L) for males. The same AIs as for adults are defined for the elderly. For pregnant women the same water intake as in non-pregnant women plus an increase in proportion to the increase in energy intake (300 mL/day) is proposed. For lactating women adequate water intakes of about 700 mL/day above the AIs of non-lactating women of the same age are derived.

KEY WORDS

Water, total body water, hydration, osmolarity, water balance, regulation, distribution, consumption, water loss, water requirement, adequate intake

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1 On request from the European Commission, Question No EFSA-Q-2008-464, adopted on 04 December 2009.
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3 Acknowledgement: The Panel wishes to thank for the preparation of this Opinion: Henk van den Berg, Karin Hulshof, Albert Flynn, Alan Jackson, Ambroise Martin, and Hildegard Przyrembel.

Suggested citation: EFSA Panel on Dietetic Products, Nutrition, and Allergies (NDA); Scientific Opinion on Dietary reference values for water. EFSA Journal 2010; 8(3):1459. [48 pp.]. doi:10.2903/j.efsa.2010.1459. Available online: www.efsa.europa.eu

SUMMARY

Following a request from the European Commission, the EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA) was asked to deliver a scientific Opinion on Population Reference Intakes.

Water is consumed from different sources, which include drinking water (tap and bottled water), beverages, moisture content of foods, and water produced by oxidative processes in the body. Water intake from beverages and foods is defined as total water intake, while the sum of total water intake and oxidation water constitutes total available water.

Water is essential for practically all functions of the body and is particularly important for thermoregulation.

A water intake which balances losses and thereby assures adequate hydration of body tissues is essential for health and life.

The water content of the body and the distribution of body water over the intracellular and extracellular compartments of the body changes with age, but is under tight homeostatic control for an individual in a given stage of life.

Loss of body weight, denoting loss of body water, of about 1% is normally compensated within 24 hours. Without compensation and further increases of losses of body water, reductions in physical and cognitive performance, in thermoregulation and cardiovascular function occur. A loss of 10% or more of body water can be fatal.

Water intoxication with life-threatening hypo-osmolarity is rare but can occur in rapid rehydration, with near-drowning in fresh water and in overconsumption of water, which exceeds the kidney's maximal excretion rate of 0.7-1.0 L/hour.

Water requirement varies between individuals and according to environmental conditions. Therefore, only adequate intakes have been defined for specific age groups from a combination of observed intakes in population groups with desirable osmolarity values of urine and desirable water volumes per energy unit consumed.

The Panel has decided that the reference values for total water intake should include water from drinking water, beverages of all kind, and from food moisture.

The Panel concludes that on the basis of available data, adequate intakes can be defined for infants in the first half of the first year of life based on water intake from human milk in exclusively breast-fed infants (100-190 mL/kg per day).

For older infants adequate intakes can be derived from observed intakes of human milk and typical patterns of complementary food and beverages. The Panel concludes that a total water intake of 800 to1000 mL/day is adequate for the age period 6 to 12 months. For the second year of life an adequate total water intake of 1,100 to 1,200 mL/day is defined by interpolation, as intake data are not available.

The Panel concludes that adequate intakes of water for children can be derived from observed intakes, corrected for a desirable water-energy relationship and corrected for inter-individual variation, particularly from those studies in which the water contribution by food has been or can be assessed (see section 3): 1,300 mL/day for boys and girls 2 to 3 years of age; 1,600 mL/day for boys and girls 4 to 8 years of age; 2,100 mL/day for boys 9 to 13 years of age; 1,900 mL for girls 9 to 13 years of age. Adolescents of 14 years and older are considered as adults with respect to adequate water intake and the adult values apply.

The Panel concludes that available data for adults permit the definition of adequate intakes and that these adequate intakes should be based both on observed intakes and on considerations of achievable or desirable urine osmolarity. Adequate total water intakes for females would have to be 2.0 L/day (P 95 3.1 L) and for males 2.5 L/day (P95 4.0 L). The Panel defines the same adequate intakes for the elderly as for adults. Despite a lower energy requirement, the water requirement in the elderly per unit of dietary energy becomes higher because of a decrease in renal concentrating capacity.

The Panel did not find data on habitual water intake in pregnant women and proposes the same water intake as in non-pregnant women plus an increase in proportion to the increase in energy intake (300 mL/day).

The Panel recommends adequate water intakes for lactating women of about 700 mL/day above the adequate intakes of non-lactating women of the same age.

These adequate intakes apply only to conditions of moderate environmental temperature and moderate physical activity levels (PAL 1.6). Water losses incurred under extreme conditions of external temperature and physical exercise, which can be up to about 8,000 mL/day have to be replaced with appropriate amounts. In such instances concomitant losses of electrolytes have to be replaced adequately to avoid hypo-osmolar disturbances.

Too high intakes of water which can not be compensated by the excretion of very dilute urine (maximum urine volumes of about one litre/hour in adults) can lead to hyponatraemic, hypo-osmolar water intoxication with cerebral oedema. No maximum daily amount of water that can be tolerated by a population group can be defined, without taking into account individual and environmental factors.

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BACKGROUND AS PROVIDED BY THE EUROPEAN COMMISSION

The scientific advice on nutrient intakes is important as the basis of Community action in the field of nutrition, for example such advice has in the past been used as the basis of nutrition labelling. The Scientific Committee for Food (SCF) report on nutrient and energy intakes for the European Community dates from 1993. There is a need to review and if necessary to update these earlier recommendations to ensure that the Community action in the area of nutrition is underpinned by the latest scientific advice.

In 1993, the SCF adopted an opinion on the nutrient and energy intakes for the European Community[4]. The report provided reference intakes for energy, certain macronutrients and micronutrients, but it did not include certain substances of physiological importance, for example dietary fibre.

Since then new scientific data have become available for some of the nutrients, and scientific advisory bodies in many European Union Member States and in the United States have reported on recommended dietary intakes. For a number of nutrients these newly established (national) recommendations differ from the reference intakes in the SCF (1993) report. Although there is considerable consensus between these newly derived (national) recommendations, differing opinions remain on some of the recommendations. Therefore, there is a need to review the existing EU reference intakes in the light of new scientific evidence, and taking into account the more recently reported national recommendations. There is also a need to include dietary components that were not covered in the SCF opinion of 1993, such as dietary fibre, and to consider whether it might be appropriate to establish reference intakes for other (essential) substances with a physiological effect.

In this context the EFSA is requested to consider the existing population reference intakes for energy, micro- and macronutrients and certain other dietary components, to review and complete the SCF recommendations, in the light of new evidence, and in addition advise on a Population Reference Intake for dietary fibre.

For communication of nutrition and healthy eating messages to the public it is generally more appropriate to express recommendations for the intake of individual nutrients or substances in food-based terms. In this context the EFSA is asked to provide assistance on the translation of nutrient based recommendations for a healthy diet into food based recommendations intended for the population as a whole.

TERMS OF REFERENCE AS PROVIDED BY EUROPEAN COMMISSION

In accordance with Article 29 (1)(a) and Article 31 of Regulation (EC) No. 178/2002, the Commission requests EFSA to review the existing advice of the Scientific Committee for Food on Population Reference Intakes for energy, nutrients and other substances with a nutritional or physiological effect in the context of a balanced diet which, when part of an overall healthy lifestyle, contribute to good health through optimal nutrition.

In the first instance the EFSA is asked to provide advice on energy, macronutrients and dietary fibre. Specifically advice is requested on the following dietary components:

- Carbohydrates, including sugars;
- Fats, including saturated fatty acids, poly-unsaturated fatty acids and mono-unsaturated fatty acids, *trans* fatty acids;

[4] Scientific Committee for Food, Nutrient and energy intakes for the European Community, Reports of the Scientific Committee for Food 31st series, Office for Official Publication of the European Communities, Luxembourg, 1993.

- Protein;
- Dietary fibre.

Following on from the first part of the task, the EFSA is asked to advise on Population Reference Intakes of micronutrients in the diet and, if considered appropriate, other essential substances with a nutritional or physiological effect in the context of a balanced diet which, when part of an overall healthy lifestyle, contribute to good health through optimal nutrition.

Finally, the EFSA is asked to provide guidance on the translation of nutrient based dietary advice into guidance, intended for the European population as a whole, on the contribution of different foods or categories of foods to an overall diet that would help to maintain good health through optimal nutrition (food-based dietary guidelines). Although water was not specifically mentioned in the terms of reference, the Panel decided that it should be included in the task because water and adequate hydration of the body is essential for health and life.

ASSESSMENT

A draft of this Opinion, agreed by the NDA Panel on 11 April 2008, was published on the EFSA website[5] for public consultation between 8 August and 15 December 2008. The draft Opinion was also discussed at a National Expert Meeting with Member States on Dietary Reference Values held in Barcelona on 7 and 8 September 2009. All the public comments received and comments from Member States that related to the remit of EFSA were assessed and the Opinion has been revised taking relevant comments into consideration. The comments received, a report on the outcome of the public consultation, and the minutes of the meeting with Member States have been published on the EFSA website.

1. Introduction

Water is involved in practically all functions of the human body. It is particularly important for thermoregulation. Water is the main constituent of the human body: about 60% of body weight in adult males, 50 to 55% in females, because they have a higher proportion of body fat than males, and up to 75% in a newborn infant. Total body water, hydration of the intracellular and extracellular compartment and the balance between input and output of water are under homeostatic control by mechanisms which predominantly modify excretory pathways and secondarily stimulate intake (thirst). Feed-back mechanisms which act primarily on the kidney are capable of sensing changes in tonicity of body fluids of 1 to 2%. Nevertheless, water is often either disregarded in national and international recommendations for nutrient intake or very cursorily treated.

2. Definition/category

In this text the term “water” comprises the liquid part of the human body (total body water distributed over the extracellular and intracellular compartment), of the diet (tap and bottled water, beverages, solid food moisture), and of the body excretory and evaporative losses (urine, sweat, faeces, evaporation via respiration and the skin), and the water produced in the body through oxidation of substrates. In this Opinion, tap and bottled waters are referred to as drinking water.

For the purpose of this Opinion “total water intake” is equivalent to the water content of food and of beverages, including drinking water, while “total available water intake” is equivalent to total water intake plus water produced with oxidative processes in the body.

2.1. Physico-chemical data

Water (H_2O) molecules have a high affinity for each other in forming hydrogen bonds, and present a partly ordered structure in liquid form. The polarity and hydrogen-bonding capability make water a highly interactive molecule, e.g. as solvent for other polar molecules, by weakening electrostatic forces and hydrogen bonding between such other molecules. Because of its high dielectric constant (80 at 20°C) it forms oriented solvent shells around ions and thereby enables them to move freely. High specific heat capacity of water (4.182 kJ/kg at 20°C) enables it to absorb and transport heat arising from metabolism in the body.

Although 1 mL of water weighs only 0.99 g, for simplicity’s sake, where in the referenced literature amounts of water are given in g or kg, this is assumed to be equivalent to mL and litres, respectively.

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[5] http://www.efsa.europa.eu/EFSA/efsa_locale-1178620753812_1211902045161.htm

2.2. Total body water and its distribution

Quantitative measurement of total body water (TBW) can be performed either by dilution techniques (using markers like antipyrine orisotopes (^{2}H, ^{18}O, ^{3}H)) or by bio-electrical impedance techniques). These techniques provide different results.

On average, total body water is about 60% of body mass (range 45 to 75%) and varies with body composition (higher with low fat mass and high skeletal glycogen, e.g. in athletes) (Neufer et al., 1991; Olsson and Saltin, 1970). Overall, total body water decreases with age from 75% in newborns (range 64 to 84%) to 56% (47 to 67%) and 47% (39 to 57%) in men and women older than 50 years, respectively. Females, beginning around puberty, show lower water percentages than males because of higher fat mass (Novak, 1989). The water content of adipose tissue and of bone is low (around 10% and 22%, respectively) in comparison to all other organs of the body (kidney 83%, liver 68%) (Pivarnik and Palmer, 1994).

The intracellular water compartment is about 68% of total body water. Fat free mass (FFM) of adults has a water content of 70 to 75%, both in males and females, and this does not change in a significant manner with age (Visser et al., 1997; Wang et al., 1999a).

The extracellular water compartment (about 35% of TBW) consists of interstitial (24%) and intravascular (plasma) water (7% of TBW). In addition, there is a small amount of transcellular water contained in joints, eyeballs and the cerebrospinal system (less than 7%). A male with a body weight of 70 kg will have about 42 L of total body water, of which 28 L is intracellular, and 14 L extracellular, with 3.1 L of the latter as plasma (Wang et al., 1999b).

In infants and children water as a percentage of body weight is higher than in adults and the distribution of water over the extra- and intracellular space is different (higher water content in the extracellular compartment and lower water content in the intracellular compartment in infants than in older children and adults) and changes rapidly especially during the first half of the first year of life: while the water content in FFM decreases, the content of protein and minerals increases.

The age-related water content of the body and FFM of infants and children, which has been determined with different methodologies, is given in Table 1. In one study (B), TBW (dilution of $^{2}H_2O$), total body potassium (TBK by whole body counting of naturally present ^{40}K) and bone mineral content (BMC by dual-energy x-ray absorptiometry DXA) were repeatedly measured during 2 years in a cohort of healthy term infants and body composition was calculated using a multi-compartment model (Butte et al., 2000). A combination of available data from different sources and obtained with different methods (chemical analysis of tissues and whole body, TBW and extracellular and intracellular fluid (TBK) space from different dilution studies, roentgenography) was used with interpolation for missing age-specific data in a two-component model (F) (Fomon et al. 1982; Fomon and Nelson, 2002). Both models and the methods applied have some uncertainties, which are responsible for the differences of some of the results, especially during the first three months of life. These differences concern predominantly the absolute numbers for the weight of the body components, whereas the relative amounts given as a percentage of body weight or of FFM are quite similar. TBW as percentage of body weight differs most. The trend for a decrease of percentage in TBW over the first two years of life is 10 to 20%. Relative FFM in females is somewhat smaller than in males in infancy, thereafter the difference increases and is very apparent at the age of 10 years (females lower by 6 relative %, 80% versus 86% of body weight).

Pregnancy is accompanied by a weight gain of 10 to 15 kg, with a stage-specific rate, which is low during the first half, highest in the second trimester and slightly lower again in the third trimester. Overall, the total weight gain is composed of the foetus (25%), the placenta (5%) and the amniotic fluid (6%). The maternal weight increment consists for 62% of water with wide variability, of which about 10% is due to expansion of the extracellular, extravascular fluid volume (Hytten, 1980a). The high water content of gained weight is reflected in the lower energy cost (4.7 to 6.4 kcal/g of weight gained) in comparison to the energy cost (8 kcal/g) for weight gain in non-pregnant women (Durnin, 1987; Hytten, 1980b; Forbes, 1988). As a consequence, the hydration of the FFM increases from about 72.5% at ten weeks of gestation to about 75% at 40 weeks, particularly in women with oedema (van Raaij et al., 1988), and there is a decrease in the ratio of intra- to extracellular water. Plasma volume expansion is hormonally induced, maximal during the second trimester (plus 50%), and accompanied by a lowered set-point of plasma osmolarity (minus about 10 mosm/L) and a fall in plasma sodium and associated anions. The increase in plasma volume is lower in pre-eclampsia and in pregnant women with a foetus showing growth restriction throughout the second half of pregnancy, and this precedes the demonstration of lowered aldosterone levels in plasma (Salas et al., 2006).

Increased glomerular filtration rate and effective renal plasma flow increase to levels 50 to 70% above non-pregnant values very early in pregnancy and well before the increment in total body water and plasma volume. They decrease again during the last weeks of pregnancy (Davison, 1983). Despite this increase in glomerular filtration rate and renal plasma flow, no increase in renal loss of water occurs, and filtered solutes are reabsorbed with high efficiency (>99%) (Lind, 1983).

Table 1: Body weight, total body water (TBW), fat-free mass (FFM), extracellular and intracellular water, and hydration of FFM [TBW/FFM] of reference children (F)[a] and of 72 children followed prospectively until 2 years of age (B)[b]

Age	Body weight [kg]		TBW [kg]	TBW [% of body weight]		FFM [kg]		Extracellular water [% of body weight]		Extracellular water [% of FFM]		Intracellular water [% of body weight]		Intracellular water [% of FFM]		Hydration of FFM [TBW/FFM]
	F	B	B	F	B	F	B	F	B	F	B	F	B	F	B	B
Males																
Birth	3.55			69.6		3.06		42.5		49.3		27.0		31.3		
0.5 m		3.76	2.8		73.9		3.35		46.3		51.6		27.6		31.0	0.84
1 m	4.45			68.4		3.78		41.1		48.4		27.3		32.1		
2 m	5.51			64.3		4.41		38.0		47.4		26.3		32.9		
3 m	6.44	6.33	3.54	61.4	56.5	4.94	4.37	35.7	32.9	46.4	47.2	25.8	23.6	33.6	33.8	0.81
4 m	7.06			60.1		5.32		34.5		45.8		25.7		34.1		
5 m	7.58			59.6		5.66		33.8		45.2		25.8		34.5		
6 m	8.03	8.04	4.54	59.4	57.2	5.99	5.63	33.4	32.9	44.7	46.4	26.0	24.3	34.9	34.2	0.81
9 m	9.18	9.13	5.34	60.3	59.2	6.98	6.71	33.0	32.6	43.5	43.6	27.2	26.9	35.8	36.2	0.80
12 m	10.15	10.03	5.86	61.2	59.0	7.86	7.40	32.9	31.6	42.5	42.5	28.3	27.4	36.5	36.9	0.79
18 m	11.47	11.43	6.69	62.2	59.1	9.09	8.55	32.3	30.1	40.8	39.4	29.9	29.4	37.7	38.8	0.78
2 y	12.59	12.46	7.21	62.9	58.1	10.13	9.13	31.9	26.6	39.6	35.7	31.0	30.7	38.5	41.3	0.79
4 y	16.69			64.8		14.03		30.5		36.3		34.2		40.7		
6 y	20.69			66.0		17.90		29.6		34.2		36.4		42.0		
8 y	25.30			65.8		22.01		28.3		32.6		37.5		43.1		
10 y	31.44			64.8		27.12		26.7		31.0		38.0		44.1		
Females																
Birth	3.33			68.6		2.83		42.0		49.3		26.7		31.3		
0.5 m		3.64	2.67		73.2		3.12		47.0		53.2		26.2		29.9	0.86
1 m	4.13			67.5		3.46		40.5		48.3		26.9		32.1		
2 m	4.99			63.2		3.94		37.1		47.1		26.1		33.1		
3 m	5.74	6.03	3.34	60.9	55.6	4.38	4.11	35.1	32.8	46.0	47.7	25.8	22.8	33.9	33.4	0.81
4 m	6.30			59.6		4.72		33.8		45.2		25.8		34.5		
5 m	6.80			58.8		5.03		33.0		44.6		25.9		34.9		

Age	Body weight [kg]		TBW [kg]	TBW [% of body weight]		FFM [kg]		Extracellular water [% of body weight]		Extracellular water [% of FFM]		Intracellular water [% of body weight]		Intracellular water [% of FFM]		Hydration of FFM [TBW/FFM]
	F	B	B	F	B	F	B	F	B	F	B	F	B	F	B	B
6 m	7.25	7.60	4.20	58.4	54.9	5.34	5.21	32.4	31.7	44.0	46.5	26.0	23.2	35.4	34.2	0.81
9 m	8.27	8.62	4.89	59.3	56.9	6.20	6.12	32.0	31.4	42.7	43.9	27.3	25.5	36.4	35.9	0.80
12 m	9.18	9.50	5.40	60.1	56.9	7.01	6.88	31.8	29.7	41.6	40.9	28.3	27.4	37.1	37.9	0.78
18 m	10.78	10.94	6.26	61.3	57.8	8.43	7.99	31.5	29.0	40.3	39.3	29.8	28.5	38.1	38.9	0.78
2 y	11.91	12.02	6.97	62.2	57.7	9.48	8.99	31.5	29.0	39.5	38.7	30.8	29.4	38.7	39.3	0.77
4 y	15.96			64.3		13.20		31.2		37.8		33.1		40.0		
6 y	19.52			64.7		16.31		30.8		36.8		34.0		40.7		
8 y	24.84			63.8		20.52		29.6		35.8		34.2		41.4		
10 y	32.55			62.0		26.23		28.1		34.9		33.9		42.0		

a Fomon and Nelson, 2002; Fomon et al., 1982.
b Butte et al., 2000

Plasma and interstitial water have similar electrolyte contents and consequently osmolarity. Exchange between intravascular and interstitial water occurs in the capillaries which show organ-specific permeability for water and solutes. Water filtration and uptake in the capillaries is driven by hydrostatic and oncotic forces. The latter are the osmotic pressure due to the differences in protein concentration between intravascular and interstitial fluids. The typical extracellular cation is sodium and the predominant anions are chloride and bicarbonate, while in the intracellular fluid potassium, magnesium and protein are most abundant. Water exchange between the extra- and the intracellular compartment follows osmotic differences to equalise the total of anion and cation concentrations in the two compartments. The differences in sodium and potassium concentrations are maintained by active ATP-driven ion pumps which consume one-third of resting energy expenditure. Organ-specific water channels, aquaporins mediate water permeability of cell membranes (Goodman, 2002). Hydration of cells and their content of organic osmolytes (sorbitol, taurine, betaine, myoinositol) is under the influence of hormones, nutrients, oxidative stress, ambient osmolarity and nerve stimulation and determines cellular metabolism and gene expression, e.g. in the liver (Häussinger, 2004). In the kidney of rats and mice an osmotic response element-binding protein in cells of the collecting ducts was found to increase the synthesis or import of organic osmolytes into the cells upon stimulation by hypertonicity and to regulate the expression of urea tansporters UT-A1 and UT-A2 and of aquaporin AQP2 (Lam et al., 2004).

The osmolarity of body fluids is typically 290 mosm/L (both intra- and extracellularly). In pregnancy it is typically lower by approximately 10 mosm/L. Sweat is hypotonic compared to plasma and tissue, while the kidney is capable to produce both hypo- and hyperosmolar urine compared to plasma osmolarity in response to changes in volume and composition of the extracellular fluid.

2.3. Body water losses

Water is lost from the body predominantly via the kidney and via sweat. These losses vary widely with intake, diet, activity level, temperature and clothing. Other losses occur insensibly via the skin and the lungs, and in the faeces. Water balance is achieved when water losses are compensated by intake with food and beverages plus metabolic water production.

2.3.1. Urine

Urinary water loss and its regulation determine the volume and composition of the extracellular fluid (ECF) via neuro-endocrine feedback mechanisms capable of sensing small changes in tonicity. The minimal or obligatory urine volume is dependent both on the macronutrient and salt content of the diet and the amount of end-products of metabolism to be excreted and on the maximal concentrating ability of the kidney. The maximum urine osmolarity in adults has been determined to be 900 to 1,400 mosm/L (Isaacson, 1959; Gamble, 1944; Mertz, 1963a, b), while newborn and especially premature infants can concentrate to 700 to 1,100 mosm/L only (Pratt et al., 1948; Winberg, 1959). The minimum osmolarity of urine is 50 mosm/L, meaning that there are limits both to the concentrating and to the diluting ability of the kidneys. The maximum concentrating ability of the kidney is decreased in protein-deprived or malnourished humans (Badaloo et al., 1999; Sands 2003). The reabsorption of the large fraction of water filtered in the glomerulus occurs in the proximal renal tubule with the help of aquaporins (AQP1). Different aquaporins (AQP2, possibly AQP3 and 4) in the collecting ducts and urea transporters – UT-A2 localised in the thin descending limb of the loop of Henle, UT-A1 and UT-A3, localised in the inner medullary collecting ducts, and UT-B, localised in the descending vasa recta – are active in maintaining the inner medullary interstitial urea concentration higher than in the ascending limb of the loop of Henle and higher than in the ascending vasa recta. This permits the establishment of a gradient for passive sodium chloride absorption, the absorption of water and the concentrating of urine. UT-A1, UT-A3 and AQP2 are upregulated by vasopressin (Goodman, 2002; Sands, 2003).

Knowing the amount of solutes for excretion and the concentrating ability of the kidneys the urine volume can be predicted (Diem and Lentner, 1975). When on a typical diet approximately 650 mosm of solutes must be excreted, a minimum of 500 mL water is necessary at a urine osmolarity of 1200 mosm/L. The potential renal solute load (PRSL) [mosm] of food can be estimated according to the formula:

$$\text{PRSL} = \text{Na} + \text{Cl} + \text{K} + \text{P} + \left(\frac{\text{nitrogen}}{28}\right).$$

Na, K, Cl and P contents of the food are given in mmol and the nitrogen content in mg. This formula assumes that all protein is converted to urea and all minerals in the food are to be excreted via the kidney and are not lost via other routes and that none is incorporated into body tissues e.g. during growth. Weight gain is accompanied by retention of 0.9 mosm of PRSL per gram of weight gained, resulting in the formula for estimated renal solute load (RSL):

RSL [mosm/day] = PRSL [mosm/day] – (0.9 x weight gain [g/day]).

The osmolarity (C) of urine can then be calculated as:

$$\text{C} = \left(\frac{\text{RSL} \quad [\text{mosmol/d}]}{\text{water intake - extrarenal water losses[L/da]}}\right) \text{ (Fomon, 1993).}$$

The potential renal solute load of human milk and of cows' milk is 97 and 307 mosm/L, respectively. The calculated renal solute load of an intake of 800 mL human milk or cows's milk/day would require 86 and 326 mL urinary water, respectively, assuming a urinary osmolarity of 700 mosm/L was reached. In the first case 618 mL of total water intake (88% of 800 mL=704 mL) would be available for growth and extrarenal water losses, in the second case only 378 mL.

Average urine volumes in adults are 1 to 2 L/day, but can increase to 20 L/day with large fluid consumption. Concentrating ability of the kidneys decreases with age by 3.4 mosm/L of urine/year after the age of 20 years (Manz and Wentz, 2003), meaning that the minimum urine output increases irrespective of the diet. A comparison of observed osmolarity in measured 24-h urine volumes with the "ideal" urine volume necessary to excrete the actual 24-h urine solutes at the average maximum -2 SD value of urinary osmolarity in a population permits the estimation of a so-called "free water reserve" and a judgement on the hydration status of an individual (Manz and Wentz, 2003).

Urine volume changes inversely with body hydration in a hyperbolic relationship, with a gradual decrease of urine output with increasing dehydration, a steep increase with hyperhydration, and an apex at approximately 50 mL urine/h at euhydration (Lee, 1964). With acute hyperhydration urine excretion can change dramatically to 600 to 1,000 mL/h (Noakes et al., 2001), and it can decrease to 15 mL/h during dehydration.

In addition, physical activity and heat will decrease urine output, while cold and hypoxia do increase it. Exposure to hypoxia in high altitude increases sodium and water diuresis and leads to a decrease in TBW, a depletion of circulatory volume and an increase in haematocrit. Stimulation of chemoreceptors by hypoxia was found to suppress the renin-angiotensin system in some but not all studies (Zaccaria et al., 1998).

2.3.2. Faeces

Faecal water losses under normal conditions are quite small and amount to 100 to 200 mL/d in adults. In healthy infants, faecal water losses of 10 mL/kg body weight per day are assumed. With diarrhoea this can increase 5 to 8 times (Fomon, 1993). Urea transporters have been found in the human intestine:

UT-A1 in the colon (You et al., 1993) and UT-B (Inoue et al., 2004) and UT-A6 (Smith et al., 2004) both in the small intestine and the colon. It is assumed that urea transport into the colon is facilitated and that the hydrolysis and salvage of nitrogen from hydrolysed urea is regulated by protein intake and need (Jackson, 1998). However, the UT-B from human colon was demonstrated to stimulate urea transport in both directions (Inoue et al, 2004). In rats protein abundance of UT-B in the colon was reduced on a low-protein diet both with and without supplementation of urea (Inoue et al., 2005).

2.3.3. Evaporation (skin and lung)

Evaporative (insensible) water losses from skin and lungs account for 80% of total non-renal water losses in normal infants under thermoneutral conditions and range from 30 to 70 mL/kg per day. With environmental temperatures of 32.5°C at humidity of 30 to 40% this has been observed to increase up to 145 mL/kg per day. The usual assumption of a 10% increase in evaporative water loss per increase of the body temperature of 1°C is not well documented (Fomon, 1993). In adults the transepidermal diffusion through the skin is about 450 mL/day, and it is influenced by environmental temperature, humidity, air currents, blood circulation in the skin and clothing. Respiratory water loss is dependent on the ventilatory volume and the water pressure gradient, which are dependent on physical activity, and oxygen or carbondioxide content of blood and environmental temperature, humidity and altitude (Newburgh and Johnston, 1942). The average daily respiratory water loss is 250 to 350 mL/day in sedentary people and about equal to metabolic water production. It can increase to 500 to 600 mL/day in active persons at sea level and further by about 200 mL/day at high altitudes (>4300 m), especially when temperature and humidity are low (Grandjean et al., 2003).

Sweat production is low at moderate ambient temperature and a sedentary state, but is profuse with strenuous physical activity, extreme heat and/or humidity and can result in serious water and electrolyte losses. Sweat glands possess AQP5 (Nejsum et al., 2002). Sweat evaporation serves to protect the body's core temperature by dissipating metabolic energy in the form of heat. One gram of sweat vaporised at 30°C is equal to 0.58 kcal lost as heat, while the amount of energy required to increase the body tissue temperature by 1°C is 0.84 kcal/kg (59 kcal/°C and 41 kcal/°C in a 70-kg man and a 50-kg woman, respectively). The amount of sweat needed to avoid a rise in body temperature or the rise in body temperature to be expected without sweating has been calculated. A workload corresponding to 600 W metabolic rate in the heat with an efficiency of 20% would require 480 W or 6.88 kcal/min to be dissipated to avoid a rise in body temperature. A 70-kg man with a heat capacity of 59 kcal (70 x 0.84 kcal) would experience a rise in body temperature of 1°C every 8.5 minutes (59 kcal: 6.88 kcal/minute) without the cooling effect of sweating and would need to evaporate approximately 12 mL of sweat/min (6.88 kcal/min: 0.56 kcal/mL) or 0.72 L per hour (IoM, 2005). The amount of sweat would have to be even higher with incomplete evaporation. Environmental factors which influence sweat evaporation are temperature, humidity, air current, intensity of sunshine and clothing. Water losses via sweat in hot dry climates can amount to more than 8 L/24 hours and to 3 to 4 L/h for short periods.

Heat intolerance characterised by an increase in oral temperature >38.4°C while working at high environmental temperatures (33.3°C dry bulb and 31.7°C wet bulb) at graded work loads (50% VO_{2max}) was accompanied by 50% lower sweat production (and smaller loss of body weight) in comparison to heat tolerant workers. Sweat production in heat intolerant workers became inadequate after 2 h to dissipate the increase in body heat (Senay and Kok, 1976).

2.4. Body water balance

Body water balance is determined by the difference between the sum of water intake and endogenous water production and the sum of losses.

Intake of water is homeostatically controlled but also influenced by non-regulated social and cultural behaviours and varies widely in children and adults with physical activity levels, environmental factors (climate) and diet. If water is freely available, intake over prolonged periods will match water needs, while a gap in fluid balance can occur temporarily during busy activities through reduced consumption of fluids.

Water is also derived from the metabolism of hydrogen-containing substrates in the body and has to be accounted for in water balance (see section 3.1).

Water balance is normally regulated within 0.2% of the body weight over 24 hours despite the wide variability of water output, which is reported to be on average 1,500 to 3,000 mL/day (Grandjean et al., 2003). Water output was measured over five days in a sedentary 60-kg male subject confined to the laboratory: total output was 2,227 to 3,205 mL/day, consisting of an almost constant insensible water loss of 1,073 to 1,213 mL and a urine volume which varied between 1,149 and 2,132 mL/day (Newburgh et al., 1930). Because water deficits and excesses are triggering compensatory changes in either water gain or losses until water balance is re-established, water balance studies with water available ad-libitum can be used for the estimation of the daily water requirement under the specific conditions of observation. Water balance studies in infants, children and adults (Ballauff et al., 1988; Consolazio et al., 1968; Goellner et al., 1981) demonstrate that infants require more water on a body weight basis than adults but about the same amount of water per unit of energy intake for the production of urine of similar osmolarity (or specific gravity) (80 to 210 mL of water per 100 kcal for urinary specific gravity of 1.006 and 1.030, respectively).

2.5. Body water turnover

Water turnover can be measured by following the decline of a dosis of administered isotope, e.g. deuterated water, over time in body fluids (e.g. urine). The isotope disappears because of loss of labelled water in the urine and evaporation via lungs and skin and by dilution via intake of unlabelled water. Water turnover in 171 healthy children between the age of six weeks and 15 years (83 boys, 88 girls) was determined to be 160 ± 34, 119 ± 19, 114 ± 27 and 97 ± 29 mL/kg per day in infants 1 to 3, 4 to 6, 7 to 9 and 10 to 12 months of age, respectively. Water turnover thereafter decreased with age more slowly and was found to be 64 ± 21, 63 ± 17, 54 ± 13, 46 ± 9 and 40 ± 7 mL/kg per day in children 1 to 3, 4 to 6, 7 to 9, 10 to 12 and 13 to 15 years of age, respectively. The relationship between body weight and water turnover could be expressed in the formula: water turnover [mL/kg/day] = $\frac{200}{\sqrt[3]{\text{age [months]}}}$ (r = 0.74).

When these turnover values were corrected for metabolic water production and compared to guidance intake levels for water (see section 5) it appeared that children's *ad libitum* intake of water differed from guidance levels of intake by factors between 1.2 and 2 (Fusch et al., 1993).

Values for daily water turnover in adults vary according to the conditions of climate, altitude and physical activity, but are generally higher than in water balance studies. For sedentary and active men water turnover rates were about 3.2 and 4.5 L/day, respectively. Women had lower water turnover rates by approximately 0.5 and 1.0 L/day, respectively. Water turnover above 5 L/day has been determined in both men and women under strenuous physical activity and at high altitudes (IoM, 2004).

Water turnover in the elderly can be compromised by a reduced thirst response to a fluid deficit. In the presence of lower total body water content in combination with alterations in renal homeostatic responses; this constitutes a risk for both dehydration and over-hydration, especially in individuals with physical or mental disabilities. Water turnover rates measured from the elimination of deuterated water over two separate 7-day periods in summer and winter in 22 elderly 69 to 88 years old living in their own homes and in 15 individuals 72 to 93 years old living in institutions were faster in the independent group (2.2 (1.3 to 3.6) L/day in summer and 2.1 (1.4 to 3.6) L/day in winter) than in the institutionalised group (1.5 (0.9 to 2.9) L/day in summer and 1.6 (1.0 to 2.8) L/day in winter). Median urine output was higher in the independent group (1.7 L/day both in summer and winter) than in the dependent group (1.1 L/day in summer and 0.9 L/day in winter) (Leiper et al., 2005).

2.6. Hydration status

Normal hydration status is the presumed condition of healthy individuals who maintain water balance. Minor alterations in hydration status are difficult to measure, because the body constantly strives to preserve plasma volume and regain homeostasis (Grandjean et al., 2003). Individual hydration of fat-free mass (TBW [kg]/FFM[kg]) is quite stable in adults at ~0.73 and does not change to a great extent with substantial shifts in the distribution of extracellular and intracellular water. It has been calculated that a 50% increase in the normal ratio of extracellular to intracellular water would result in an increase of FFM hydration of only 3%. At birth FFM hydration is much higher at ~0.81 because of a relative higher volume of extracellular water than intracellular water (see Table 1). There is a rapid decrease in FFM hydration with growth as a consequence of increases in FFM contents of protein and minerals (Wang et al., 1999b).

Measurements of TBW by dilution methods and bio-electric impedance analysis or bio-impedance spectroscopy are available but the required serial measures are inconvenient and costly for routine assessment. The measurement error for dilution techniques has been estimated to be 1 to 2%, while bio-electrical impedance techniques may not be sufficiently accurate to detect moderate dehydration, especially with isotonic fluid losses (O'Brien et al., 1999). In instances of dehydration and hyperhydration values derived with this technique can deviate from those obtained with dilution techniques by 2 to 3 litres (Grandjean et al., 2003).

Body weight is a sensitive, accurate and easily measured indicator of hydration status when measured regularly and under standard conditions. Acute losses in body weight are almost always due to changes in total body water. However, factors which can potentially influence body weight and losses of water as well as fluid intake have to be taken into account. Carbohydrate loading in athletes will increase body weight by retaining water with glycogen stored in muscle.

Control of body weight is particularly informative in the neonatal period and in breast-fed infants. While such infants tend to loose more body weight during the first days of life than formula-fed infants (6.6% versus 3.5%) and take longer to recover their birth weight (MacDonald et al., 2003), excessive weight losses (>10% up to 30% of birth weight) have been observed in severe hypernatraemic dehydration in breast-fed infants (Shroff et al., 2006; Zetterström, 2003).

Osmolarity of plasma and serum is tightly controlled and rarely varies by more than 2% around a set-point of 280 to 290 mosm/L, which increases somewhat with age. In early pregnancy plasma osmolarity decreases and this is not counteracted by secretion of vasopressin and increased diuresis (Davison, 1983). Loss of water in excess of loss of solutes will increase the osmolarity of the plasma and of the extracellular fluid, which will result in redistribution of intracellular water to the intravascular space and thereby triggers the release of arginine vasopressin (AVP) via osmoreceptors from the hypothalamus and the posterior pituitary. AVP binds to a receptor in the basolateral membrane in the renal collecting duct cells and starts a signalling cascade which leads to the redistribution of aquaporin-2 to the apical cell membrane which becomes permeable to water, and urine becomes more concentrated (Deen et al., 1994; Kamsteeg and Deen, 2000). In such instances, plasma osmolarity is a good marker for loss of total body water and dehydration status. When water and solute are lost in proportion (vomiting, diarrhoea), plasma osmolarity will not change and there will be no response of AVP. However, the decrease in ECF will stimulate the renin-angiotensin-aldosteron system and sodium and water will be retained in the kidney.

Sodium in plasma can increase when loss of water exceeds loss of electrolytes, but the negative correlation between total body water (or weight) loss and plasma sodium is less strong than for plasma osmolarity.

Plasma volume changes with both hyperhydration and hypohydration in a modest way. Individuals acclimatised to heat have smaller reductions in plasma volumes for a given body water deficit than unacclimatised persons which is due to the production of more dilute sweat and to their capacity of better maintaining haemodilution (Senay and Kok, 1976).

An increase of *blood urea nitrogen* in the presence of normal kidney function can be an indicator of hypohydration and hypovolaemia, however, there is also a direct relationship between protein intake and blood urea nitrogen. Both increased salvaging of urea nitrogen in the colon and vascular and tubular recycling in the kidney are attempts to maintain sufficient urea levels in plasma and renal medullary interstitium to enable concentration of urine.

Urine volume and colour can be indicators of hydration status. A urine output of 100 mL/h in a healthy adult will probably indicate good hydration while outputs of >300 and <30 mL/h over a certain period can indicate excessive fluid intake and deficient hydration status, respectively. Urine colour, although a useful indicator does not show a precise correlation with hydration status and is, moreover, dependent on dietary factors and medications.

Specific gravity and osmolarity of urine are strongly correlated with each other and increase with dehydration (Armstrong et al., 1994; Oppliger et al., 2005). However, there was only a weak and delayed correlation with plasma osmolarity when subjects were dehydrated progressively up to a body weight loss of 5% (Popowski et al., 2001). When 12 male athletes were dehydrated by exercising at 43^{o}C and 20% relative humidity on a bicycle or a treadmill with weight losses of 1% after 0.5, of 3% after 1.5 and of 5% after 2.5 hours, there was a progressive increase of plasma osmolarity from <290 to a maximum of 304 mosm/L and a decline to 291 mosm/L after 60 minutes of recovery, while neither specific gravity nor osmolarity of urine increased with a weight loss of 1%. Both urine parameters reached a maximum (1,032 and 672 mosm/L, respectively) during recovery after 30 minutes (Oppliger et al., 2005).

Under normal conditions specific gravity values between 1.010 and 1.30 are considered to indicate euhydration, while a specific gravity of >1.030 denotes dehydration but does not permit an estimate of the water deficit. Urine osmolarity varies between 50 and 1,200 mosm/L and has theoretical maximum of about 1,400 mosm/L. A newborn infant can concentrate his urine to 700 mosm/L, and by three months of age an infant will be able to concentrate up to 1,200 mosm/L. Urine osmolarity increases with glucose excretion in diabetes mellitus and is dependent on dietary renal solute load. Because urine osmolarity is physiologically limited between about 50 and 1,400 mosm/L, values of osmolarity measured in repeated 24-h urines from a group of 479 healthy boys and girls aged 4 to10 were used to calculate the upper and lower limit of urinary osmolarity signifying euhydration (mean of maximum - 2SD and mean of minimum +2SD, respectively). A comparison between the observed urinary volume at measured osmolarity and the calculated obligatory volume of urine to excrete the daily solute load then allows to determine the hydration status and the "free-water" reserve (Manz and Wentz, 2003; Manz et al., 2002).

Specific gravity of saliva is slightly higher than that of water and can increase together with osmolarity with dehydration (body weight loss of more than 2%), but the decrease of salivary flow, although variable in response, is much more apparent.

Thirst is triggered by both perceptual (taste, colour, flavour, temperature of beverages) and physiological mechanisms (increases in plasma (ECF) osmolarity, reductions in plasma volume) at water deficits which correspond to a body weight loss of 3% and more. Osmoreceptors respond in a very sensitive manner to intracellular dehydration, which occurs as a consequence of the movement of fluid from cells to the ECF following osmotic forces. Volume receptors respond to extracellular dehydration caused by loss of water from the vascular and interstitial space. The response to increases in osmolarity leads via the release of AVP in the first place to a reduction in urinary water excretion and with increasing osmolarity to thirst and to increased drinking (D’Anei et al., 2006). Volume receptors in the large veins and the right cardiac atrium stimulate via the vagal system drinking behaviour and preservation of water through activation of the renin-angiotensin-aldosterone system. Fluid losses of 2 to 3 litres of sweat over a few hours in the course of physical activity at high environmental temperatures are as a rule compensated within 24 hours by an increase in the fluid intake (Stricker and Sved, 2000).

Cellular hydration is a dynamic process and changes fast under the influence of nutrient supply, nerve stimulation, hormones and oxidative stress and it acts as a signal for cellular metabolism and gene expression. In hepatocytes hypo-osmotic swelling is known to increase among others protein and glycogen synthesis and to decrease proteolysis and glycogenolysis (Häussinger, 2004).

2.7. Pathophysiology of hydration

2.7.1. Dehydration

Dehydration is the process of loosing body water and leads eventually to hypohydration (the condition of body water deficit). Depending on the ratio of fluid to electrolyte loss, dehydration can be classified as isotonic, hypertonic or hypotonic.

Isotonic dehydration is characterised by isotonic loss of both water and solutes from the ECF, e.g. through vomiting, diarrhoea or through inadequate intake. There is no osmotic water shift from the intracellular fluid (ICF) to the ECF.

Hypertonic dehydration in which water loss exceeds salt loss, e.g. through inadequate water intake, excessive sweating, osmotic diuresis and diuretic drugs, is characterised by an osmotic shift of water from the ICF to the ECF.

Hypotonic dehydration, in which more sodium than water is lost, e.g. in some instances of high sweat or gastro-intestinal fluid losses or when fluid and electrolyte deficits are treated with water replacement only, is characterised by an osmotic shift of water from the ECF to the ICF (Grandjean et al., 2003).

Increasing dehydration with fluid losses of more than 1% leads successively to reductions in exercise performance, in thermoregulation, and in appetite; with fluid deficits of 4% and more severe performance decrements are observed as well as difficulties in concentration, headaches, irritability and sleepiness, increases in body temperature and in respiratory rates; when fluid deficits continue to exceed 8% death may ensue (Grandjean et al., 2003).

Cognitive function and motor control can be impaired, particularly in ill and older individuals. From several mostly small studies in healthy persons reported by various authors on the effects of induced dehydration on cognitive performance and motor function (fatigue, mood, target shooting, discrimination, choice reaction time, visual-motor tracking, short- and long-term memory, attention, arithmetics) it appears that a body water loss of >2% induced by exercise in the heat is sufficient to impair functions and performances (IoM, 2004). Young children and adolescents particularly are at risk of impaired cognitive function (concentration, alertness and short-term memory) due to insufficient hydration (D'Anei et al., 2006).

Likewise physical work performance (both aerobic and endurance type) is decreased by dehydration of 1 to 8% induced by heat or exercise only, by exercise in the heat, by fluid restriction with and without exercise. The effect depends strongly on the environmental temperature, the exercise task, and the fitness and heat tolerance of an individual. Heat enhances the negative effect on physical work capacity of water deficits of 2 to 5% and more (IoM, 2004). Children react with greater increases in body core temperature when they loose 1 to 2% of body weight than adults (Bar-Or et al., 1980).

Exercise in the heat with dehydration corresponding to losses of only 1% of body weight increases body core temperatures. The magnitude of that increase ranged from 0.1 to 0.23 °C for every percent of body weight lost and the effect is greater with high environmental temperatures. The rise in body temperature is a consequence of both reduced sweating and reduced skin blood flow induced by dehydration. Moreover, exhaustion occurred at lower body core temperatures with dehydration than in the well hydrated state.

Cardiovascular function impairment with increasing dehydration is a common phenomenon, with a rise in heart rate and difficulties in maintaining blood pressure. Mild dehydration (<2% loss of body weight) blunts baroreceptor control, while drinking water improves orthostatic tolerance (Charkoudian et al., 2003; Schroeder et al., 2002). The effects are more pronounced when heat stress is added to dehydration of 3 to 4%. Cardiac output decreases because the increased heart beat rate is insufficient to compensate the observed decrease in stroke volume (Montain et al., 1998). Mild dehydration also induced mitral valve prolapse presumably because of lower atrial filling pressure and volume. On rehydration symptoms disappeared (Aufderheide et al., 1995).

Arrhythmias and premature ventricular contractions have been demonstrated in healthy young men exercising in the heat and with body weight losses of 5 to 7% (Sawka et al., 1985).

Dehydration of more than 10% at high ambient temperatures is a serious risk for a life-threatening heat stroke with elevated body temperature, inadequate cardiac output leading to reduced perfusion of tissues and eventually to rhabdomyolysis and organ failure (Bouchama and Knochel, 2002). This risk is particularly high in infants with gastro-enteritis and receiving a formula with a high potential renal solute load (Fomon, 1993). In neonatal infants with life-threatening hypernatraemic dehydration arterial thromboses, arrhythmias, acute renal failure and seizures have been described (Shroff et al., 2006).

Chronic dehydration can increase the risk of infection, especially of the urinary tract. A decreased occurrence or recurrence of urinary tract infection with higher fluid intake has been reported (Pitt, 1989; Eckford et al., 1995).

Both from observational and some smaller interventional studies there is evidence that high total water consumption can prevent recurrent kidney stones (Hosking et al., 1983; Borghi et al., 1996), and from large prospective observational studies it appears that a higher fluid intake lowers the risk of incident kidney stones (Curhan et al., 1993; 1996; 1997; 1998). However a meta-analysis of randomised controlled trials (RCT) with increased water intake for the prevention of urinary calculi and their recurrence found only one trial which fulfilled the selection criteria (Borghi et al., 1996). In this trial 199 patients with idiopathic calcium nephrolithiasis were randomised to two different regimens of calcium, sodium and fluid intake. After five years of observation the group with the higher fluid intake (target value 2 L of urine/24 h) had a kidney stone recurrence rate of 12% versus 27% in the control group (RR 0.45; 95% CI 0.24 to 0.84; p=0.008). Because no other appropriate RCT were available, no definite conclusion on the effectiveness of high water intake for the primary and secondary prevention of urinary calculi was possible (Quiang and Ke, 2004). Apart from low urinary volumes (<2 L/day) and low urinary flow rates other risk factors for kidney stones exist. (Borghi et al., 2006).

Several observational studies report an increased risk for bladder cancer in individuals with habitually low fluid consumption. One study assessed the total daily fluid intake in 47,909 men and found that after 10 years of observation those with a fluid intake of less than 1.3 L/day had a significantly (p=0.002) increased risk of bladder cancer compared to those with an intake above 2.5 L/day. The risk was reduced by 7% for every additional daily fluid intake of 240 mL (Michaud et al., 1999). Other studies have not confirmed this finding (e.g. Geoffroy-Perez and Cordier, 2001).

Several studies, mostly case-control studies, found an inverse relationship between the amount of habitual water intake and the incidence of colon cancer: 30 to 40% lower risk in those with a water intake of more than 1.4 L/day (Slattery et al., 1999).

2.7.2. Hyperhydration

Overconsumption of water can lead under certain circumstances to water intoxication with potentially life-threatening hyponatreamia. This has been observed in psychiatric patients (psychogenic polydipsia), but also as a consequence of excessive electrolyte-free water consumption, e.g. in rehydration of athletes during and after prolonged physical exercise, and after near-drowning in fresh water. Under temperate circumstances four healthy young men whose habitual water intake was increased in steps of 2 L additional water per week over four weeks (final maximum water intake 7.4 to 9.6 L/day), showed constant serum osmolarity in the morning throughout but drops in serum osmolarity by 2 to 7% in the afternoon without increases in body weight in three out of four subjects. They complained about nocturia, mild nausea, diarrhoea, lassitude and occasional light-headedness despite appropriate increases in 24-hour urine volumes and adequate dilution of urine. Renal concentrating capacity was not impaired in the study subjects as demonstrated by weekly water deprivation tests (Habener et al., 1964).

The effects of hyperhydration and hyponatreamia (<130 mmol/L) depend on the rapidity of sodium decline and on its absolute level in serum and on the resulting move of extracellular fluid to the intracellular space. Intracellular volume expansion can lead to central nervous system oedema, lung congestion and destruction of muscle cells. The attempt to maintain the cell volume under hypo-osmolar conditions involves a rapid cellular efflux of electrolytes and osmolytes via stretch-activated voltage-gated K^+ channels and swelling-activated Cl^- channels (Pasantes-Morales et al., 2006), followed by both water diuresis and natriuresis (Verbalis, 2006). Rapid correction of chronic hyponatraemia (>10 mmol/L/day) can induce cellular dehydration and, at worst, result in osmotic demyelination of the brain (Murase et al., 2006).

Overconsumption of water that exceeds the kidney's maximal excretion rate of 0.7-1.0 L/hour is not easy to achieve under normal conditions and with normal dietary habits. It can occur in individuals after prolonged endurance activity and in clinical settings when hyponatramia is misdiagnosed as dehydration and inappropriately treated. Impaired renal water excretion in hospitalised patients and in endurance athletes is a contributing factor and often associated with inappropriate (with respect to actual osmolarity and volume of plasma) AVP secretion (Noakes et al., 2005). Both heat stress and exercise can reduce renal water excretion.

3. Intake data

3.1. Dietary sources

Intake of water is predominantly through consumption of drinking water and beverages (80%) plus water contained in food (20%). Food water content is usually below 40% in bakery products, between 40 and 70% in hot meals, >80% in fruit and vegetables and about 90 % in both human and cows' milk. Diets rich in vegetables and fruit provide significant amounts of the total water intake, while e.g. fast food products as a rule have low water contents (Przyrembel, 2006).
Water is also derived from the metabolism of hydrogen-containing substrates in the body. Theoretical stoichiometry for complete oxidation of 1 mol glucose and of 1 mol palmitic acid produces 6 and 16 mol water, respectively. If oxidised glucose is released from glycogen an additional 2.7 mL of hydration water is liberated per one gram glycogen converted to glucose. Per one gram of glucose, palmitic acid and protein (albumin), theoretically 0.6, 1.12 and 0.37 mL water is endogenously produced, or per 100 kcal of metabolisable energy 15, 13 and 9 mL water. In reality water production from fat oxidation varies somewhat with the fat source (triglyceride, free fatty acid, degree of unsaturation of the fatty acids). Water production from protein oxidation is also dependent on the molecular structure of the protein and, more important, leads to the production of urea (0.35 g per gram of protein) which has to be eliminated in the urine solved in water (15 mL water per gram urea or 5.25 g water per urea produced from one gram oxidised protein), if not excreted into the gut and salvaged by microbial metabolism (Jackson, 1998). Therefore, protein oxidation, although producing water, results

in net water loss of 3 to 8 mL H_2O per gram oxidised (Askew, 1996). Urea production and urea levels in blood and the renal medullary interstitium are important determinants of body water balance and this is due to the action of urea transporters with site-specific function in the kidney and potentially also in the intestine (You et al., 1993; Sands, 2003; Bagnasco, 2005).

The overall formula for calculating metabolic water production (in mL) = 0.41 x g protein oxidised + 0.60 x g carbohydrate oxidised + 1.07 x g fat oxidised (Lusk, 1928). It has to be corrected for obligatory losses due to urea and other solutes excretion and eventually for anaerobic metabolism of glucose to lactate during high work loads close to the maximum oxygen uptake velocity ($VO_{2\ max}$), when water production from glucose is only one third of that possible with complete oxidation.

Overall, metabolic water production increases linearly with energy expenditure. During exercise it can reach 13 times the rate observed at rest (Pivarnik et al., 1984). An estimate of average metabolic water production for sedentary persons is 250 to 350 mL/day, which can adequately compensate for respiratory losses. Metabolic water production of up to 600 mL/day with strenuous physical activity is possible and can usually compensate for concomitantly increasing respiratory water losses (Pivarnik et al., 1984).

3.2. Dietary intake

Data on water intake in European countries are unfortunately often not comparable because of differences in assessment and differences in the categorisation of beverages and liquid foods like milk. “Total available water” in Table 2 includes water content of food, beverages and metabolic water in the German data, while the data from the Netherlands, Italy and Sweden are total water intake. For the United Kingdom and Belgium total beverage intake is listed. From the available data it appears that the total water intake of men is 200 to 400 mL higher than that of women and that the intake is lower than the recommended or guidance values (see Table 5. The water intake per energy in Germany is higher in women than in men (1.02 versus 0.92 mL/kcal).

Observed intakes (median and 10^{th} and 90^{th} percentile) of total water in healthy male infants and young children at the age of 9, 12 and 18 months were 834 (652; 1,070), 907 (691; 1,063) and 910 (663; 1,204) mL/day or 93, 87 and 77 mL/kg per day. This corresponds to 0.96, 0.93 and 0.88 mL water/kcal of energy intake at median intakes and to 1.15, 0.95 and 1.01 mL/kcal at the 90^{th} percentile intake. For girls the corresponding figures were 839 (645; 1,114), 780 (616; 1,085) and 806 (629; 1,109) mL water/day or 99, 88 and 74 mL/kg per day at 9, 12 and 18 months of age. Median water intakes in relation to energy intake were 1.09, 0.98 and 0.89 mL/kcal and 1.18, 1.19 and 1.06 mL/kcal at the 90^{th} percentile of water intake (Alexy and Kersting, 1999).

The contribution of milk and milk products to total water intake decreased from 57% at the age of nine months to 52% and 43% at the age of 12 and 18 months, respectively in Dutch children, while beverages contributed 13%, 19% and 32% and fruit 14%, 13% and 11% over the same age range[6].

Data on total available water intake based on 3-day weighed dietary records per day, per kg body weight, and per energy consumed in German children 2 to 13 years of age are given in Table 3 and differentiated as to sources. Total available water intake per kcal is below 1 mL in all children over 4 years of age. The water comes for 33 to 38 % from food, for 49 to 55% from beverages (including milk) and for 12 to 13% from oxidation, while intake of energy-free water is less than 40 % of total beverage intake (Sichert-Hellert et al., 2001). The total water intake of Dutch children in 1987/1988 was 80 mL/kg per day in 1 to 3 year olds and 35 to 39 mL/kg per day in 10 to 12 year olds (Löwik et al.,

[6] Calculations performed by K. Hulshof on the raw data of the Dutch national food consumption survey among infants and toddlers conducted in 2002.

1994). In the United Kingdom in 1993/1994, 2 to 7 year old children had a total water intake of 941 to 1,018 mL/day (Petter et al., 1995), of which 320 mL was drinking water (Gregory et al., 1995).

The elderly are at special risk of too low water intakes due to loss of thirst sensation and appetite, and to a reduced capacity of their kidneys to concentrate the urine. Data on total water intake from the multi-centre SENECA study (Survey in Europe on Nutrition and the Elderly, a Concerted Action) in a cohort born between 1913 and 1918 from Belgium, Denmark, France, Italy, the Netherlands, Portugal, Switzerland, Poland and the United Kingdom from 1993 and from 1999 can be found in Table 4. Generally, the water intake of women is lower than in men, and a higher percentage of women consume less than 1700 mL/day of water. Women in the lowest tertile of water intake (<1604 mL/d) scored lower in mental state examination and activities of daily living than women with water intake corresponding to the second and third tertiles (1,604 to 2,062 and >2,062 mL/day, respectively (Haveman-Nies et al., 1997; Ferry et al., 2001).

Volkert et al. (2005) have recently reported water intake from beverages and from beverages and food in 1,372 independently living elderly persons (65 to 74 years, 75 to 84 years and >84 years of age): beverage intake was (median, 5th, 95th percentile) 1,567 (700/2,967) mL/day in men and 1,400 (600/2,467) mL/day and decreased with increasing age (51% below recommended amounts of 1310 mL/day in the over 84 years of age). Median total water intake from both beverages and food was 2,387 mL/day in men and 2,224 mL/day in women, but was below the recommended value of 1,990 mL in 28% of the younger elderly and in 41% of the oldest.

Table 2: Water intake in some European countries

	France* (Volatier, 2000)			Germany* (Manz and Wentz, 2005)				Italy* (Turrini et al, 2001)			Sweden (Becker and Pearson, 2002)			The Netherlands* (TNO, 1998)			United Kingdom* (Hoare et al, 2004; Henderson et al., 2002)			Belgium* (Devriese et al, 2006)		
	n	age (y)	mean (mL/d)	n	age (y)	mean (mL/d)	mL/kcal	n	age (y)	mean (mL/d)	n	age (y)	mean (mL/d)	n	age (y)	mean (mL/d)	n	age (y)	mean (mL/d)	n	age (y)	mean (mL/d)
Total available water**																						
men				507	18 ->65	2494	0.92															
women				682	18 ->65	2062	1.02															
children																						
boys				199	4-6.9	1310																
girls				181	4-6.9	1209																
boys				174	7-10.9	1640																
girls				174	7-10.9	1483																
Total water																						
men	672										585		2467	1252	22-50	2622						
women	802			507	18->65	2259	—				625		2455	1472	22-50	2402						
population	1474	15->65	1984	682	18->65	1875	—							5958	1->75	2222						
Total beverages														men /women					1988			
men	672	>15	1236	507	18->65	1530	—	909	1->64	1027			1911				1008	19-64	1988	1546	15->75	1465
women	802	>15	1130	682	18->65	1469	—	1069	1->64	917			1895				1243	19-64	1585	1537	15->75	1342
adults								1513	18-64	870										3083	15->75	1401
children	593	3-9	838	363	4-10.9	520-690	—	138	1-9	744										—	—	—
adolescents	425	10-14	920					150	10-17	757										760	15-18	807
elderly	245	>65	1105					167	>64	858										789	60-74	1393
non-alcoholic beverages			1023							846			men/ women 1656/17 66	1252/ 1472	22-50	1346/ 1463			men/ women	3083	15->75	1202
fruit juices			52							21			87/ 86			55/ 82			48/47			
lemonades			37							35			207/ 137			144/ 218			239/20 1	3083	15->75	284
(mineral) water			557							660			384/ 680						239/31 4	3083	15->75	658
coffee			199										489/ 431			730/ 553			318/24 3	3083	15->75	366

tea	70		114/ 123	212/ 398	411/410	3083	15->75	70
milk + milk drinks	108	130	376/ 312	357/ 332	225/200			
alcoholic beverages	156	112	255/ 129	355/ 100	500/139	3083	15->75	199

** median values for total available water

* 2-day dietary record (NL); 2-times 24 h recall (Belgium); 7-day dietary record (Italy, France, Germany, UK).

Table 3: Water intake in German children 2 to 13 years old a (Sichert-Hellert et al., 2001)

	Boys and girls 2–3 y N=858	Boys and girls 4–8 y n=1795	Boys 9–13 y n=541	Girls 9–13 y n=542
Total available water intake mean ± SD (mL/day)	1114 ± 289	1363 ± 333	1891 ± 428	1676 ± 386
(mL/kg per day)	77.5 ± 21.6	60.5 ± 13.4	48.9 ± 11.1	42.6 ± 10.0
(mL/kcal)	1,05 ± 0.26	0.94 ± 0.17	0.97 ± 0.19	0.97 ±0.18
From food mean (mL/day)	365	487	673	643
From beverages	614	693	969	823
From milk	191	177	203	144
From mineral water	130	179	282	242
From tap water	45	36	62	56
From juice	114	122	133	138
From soft drinks	57	111	203	155
From tea/coffee	77	69	87	87

[a] Sichert-Hellert et al., 2001

Table 4: Total water intake (mL/day) of (75 to 80 years and 81 to 86 years old) participants of the SENECA study[a].

	Men			Women		
	n	mean	% below 1700 mL/day	n	mean	% below 1700 mL/day
Belgium	68	2239	22	61	2111	21
Denmark	55	2206	21	58	2182	29
France I	56	2318	13	53	2147	22
France II (75-80 y)	70	1953	29	72	1752	50
France II (81-86 y)	38	1888	–	46	1772	
Italy	69	1895	42	66	1605	65
The Netherlands	52	2239	14	69	2186	20
Portugal	77	2106	27	80	1643	63
Switzerland	71	1977	30	79	1976	33
Poland	47	1860	40	73	1612	62
UK	32	2039	28	38	1822	42

[a] Haveman-Nies et al., 1997; Ferry et al., 2001

4. Overview on available dietary recommendations

Table 5 is a compilation of available data and illustrates a great variability both in details and in definitions.

Belgium (2009)

For adults water intakes of 2.5 L/day both from drinking water, beverages and food moisture are considered necessary for ensuring water balance. It is recommended to drink about 1.5 L/day.

For children more detailed recommendations related to body weight are given which have been based on French recommendations (Dupin et al., 1992).

Austria, Germany, Switzerland (2008)

Guidance values for total available water intake (mL/kg per day) have been formulated with a view to achieve an osmolarity of the urine around 500 mosm/L and taking into account that the range of observed maximum urine osmolarity begins around 830 mosm/L. The guidance values correspond to a water intake of 1.5 mL/kcal for infants, of 1 mL/kcal for adults and of more than 1mL/kcal for the elderly in a temperate climate and should result in urine volumes above 1 L/day. The urine volume should be about equal to the volume of consumed beverages in adults. The maximum tolerable chronic daily water intake in adults at moderate temperature which did not cause decreases in serum osmolarity was estimated to be 10 L/day (D-A-CH, 2008).

France (2001)

The total water requirement for adults is estimated to be 25 to 35 mL/kg per day and 1 mL/1 kcal consumed. This is based on normal water losses per day of: total 2.500 mL of which 1.000 to 1.500 mL is urine, 500 to 1,000 mL insensible losses via skin and lungs, and 100 mL faecal losses. For one degree above normal body temperature an additional water loss of 300 mL is assumed. Metabolic water production is considered to be 300 mL/day, intake via food and beverages 1000 and 1200 mL, respectively (AFSSA, 2001).

Denmark, Finland, Norway, Sweden (2004)

Adequate total water intakes on a body weight basis have been defined for young children and for adolescents. In adults water intake should be 30 mL/kg per day or 1 mL/kcal. Individuals over 65 years of age should drink 1.5 L/day and lactating women should take an extra 600 to 700 mL/day of fluid (NNR, 2004).

The Netherlands (1989)

Based on fluid balance data per kg body weight per day, desirable individual amounts of total water intake can be calculated. The minimum water requirement for adults during fasting is 1 L/day and for adults at low levels of physical activity and moderate ambient temperature and who consume an average Dutch diet (85 to 100 g protein and 9 g NaCl/day) is estimated to be 1.5 L/day. For the elderly the minimum amount is considered to be 1.7 L/day. It was considered impossible to define adequate levels of total water intake (Netherlands Food and Nutrition Council, 1989).

World Health Organization (2003; 2005)

For sedentary adult men and women under average conditions 2,900 and 2,200 mL water/day, and 1000 mL/day and 750 mL/day for children weighing 10 kg (age 12 months) and 5 kg (age 3 months), respectively, are considered necessary for hydration. For physically active men, women and children at high temperatures 4,500 mL/day of water are required. The total daily needs of water in pregnancy and lactation are estimated to be 4,800 and 3,300 mL, respectively (WHO, 2005).

United States of America (2004)

The Food and Nutrition Board of the Institute of Medicine has defined adequate total intakes (AI) of water based on data for fully breast-fed infants for the first half of the first year of life and for all other age groups based on observed median intakes of total water in the National Examination Survey III (NHANES) 1988-1994. For adults a dietary energy intake of 2,200 kcal/day and 60 minutes of moderate exercise per day was assumed. The AI for elderly persons were based on observed intakes in young adults, with the idea to take into account age-related losses in renal concentrating and diluting capacity as well as reduced thirst experience (IoM, 2004).

All national authorities stress the necessity to achieve a daily balance between total water intake and water losses.

While most recommendations are based on observed intakes in healthy individuals, including pregnant and lactating women, and estimates of usual water losses (Belgium, France, Nordic Countries, the Netherlands, USA, WHO) and include advice to take into account special circumstances like climate (WHO), body temperature (France), pregnancy and lactation (Nordic Countries, WHO), and advanced age (German speaking countries, the Netherlands, USA), some national authorities support their recommendations by considerations referring to renal concentrating capacity (German speaking countries, USA).

Recommended total water intakes for adults range from 2.2 to 3.7 L/day, recommended drinking volumes are around 1.5 L/day, while total available water intake should be 1 mL/kcal of energy consumed for adults and 1.5 mL/kcal for infants, 1.2 mL/kcal for toddlers, and 1.1 mL/kcal for elderly (D-A-CH, 2008).

A minimum water intake of 1.5 L/day and 1.7 L/day for adults and the elderly, respectively has been set by the Netherlands, while a maximum tolerable chronic water intake of 10 L/day has been estimated for adults in German speaking countries from studies in four healthy volunteers without changes in serum osmolarity (Habener et al., 1964).

Table 5: Reference values for water

Age	**Belgium (2009)** [1] **total (infants and children)**		**D-A-CH (2008)** [2]					**AFFSA (2004)** [3]		**NL (1989)** [4]	**Nordic countries (2004)** [5]	**IoM (2004)** [6]	**WHO (2003, 2005)** [7]
	total	beverages	Total available water mL/d	beverages mL/d	food mL/d	metabolic mL/d	beverages + food mL/kg/d	total mL/kg/d	metabolic mL/d	Total available water, mL/kg/d	total (beverages)	total mL/d	total water mL/d
Infants Newborn	100–120 mL/kg/d							100		145			
0–4 months	130–150 mL/kg/d		680	–	620	60	130						750
0–6 months												700	
1–6 months								90					
4–8 months	120–130 mL/kg/d												
4– <12 months			1000	400	500	100	110						
7–12 months												800	
8–12 months	100–110 mL/kg/d												1000
Infants 6–8 months								80					
Children 1–3 y												1300	1000 4500 when active at high temperature
1– <4 y			1300	820	350	130	95						
1–6 y	75–100 mL/kg/d												
2–3 y											65–70 mL/kg/d		
4– <7 y			1600	940	480	180	75			83			

Age	**Belgium (2009)** [1] **total (infants and children)**		**D-A-CH (2008)** [2]					**AFFSA (2004)** [3]		**NL (1989)** [4]	**Nordic countries (2004)** [5]	**IoM (2004)** [6]		**WHO (2003, 2005)** [7]
	total	beverages	Total available water mL/d	beverages mL/d	food mL/d	metabolic mL/d	beverages + food mL/kg/d	total mL/kg/d	metabolic mL/d	Total available water, mL/kg/d	total (beverages)	total mL/d		total water mL/d
4–8 y												1700		
6–11 y	65–80 mL/kg/d													
7– <10 y			1800	970	600	230	60							
9–13 y												girls 2100	boys 2400	
10– <13 y			2150	1170	710	270	50							
11–14 y	65–70 mL/kg/d													
13– <15 y			2450	1330	810	310	40							
15 y											40 mL/kg/d			
14–18 y	45–60 mL/kg/d											girls 2300	boys 3300	
15– <19 y			2800	1530	920	350	40							
Adults 19–30 y	2500 mL/d	1500 mL/d						25–35	300	37	1 mL/kcal	women 2700	men 3700	women, sedentary 2200 men, sedentary 2900 women, actice 4500 men, active 4500
19– <25 y			2700	1470	890	340	35							
25– <51 y			2600	1410	860	330	35							
31–50 y												women 2700	men 3700	
51– <65 y			2250	1230	680	280	30							
51–70 y												women 2700	men 3700	
>65 y			2250	1310	890	260	30				1500 mL/d			
>70 y												women 2700	men 3700	
Pregnancy	–		2700	1470	890	340	35					3000		4800

Age	Belgium (2009) [1] total (infants and children)		D-A-CH (2008) [2]					AFFSA (2004) [3]		NL (1989) [4]	Nordic countries (2004) [5]	IoM (2004) [6]	WHO (2003, 2005) [7]
	total	beverages	Total available water mL/d	beverages mL/d	food mL/d	metabolic mL/d	beverages + food mL/kg/d	total mL/kg/d	metabolic mL/d	Total available water, mL/kg/d	total (beverages)	total mL/d	total water mL/d
Lactation	–		3100	1710	1000	390	45				plus 600–700 mL/d	3800	5500

[1] Belgium (2009): recommended or adequate intake
[2] D-A-CH (2008): guidance values
[3] AFSSA (2004): recommended intake
[4] NL (1989) (NL): recommended dietary allowances
[5] Nordic countries (Becker et al., 2004): adequate intakes
[6] IoM (2004): adequate intakes
[7] WHO (2003;2005): requirements

5. Criteria (endpoints) on which to base recommendations for water intake

5.1. Determinants of water requirement

There is an absolute requirement to replace all losses of water. A water intake that covers the need of everybody in any population group cannot be defined, because the individual need for water is related to caloric consumption, to insensible water losses and to the concentrating/diluting capacity of the kidney.

Infants consume 10 to 15% of their body weight as water compared to 2 to 4% in adults. Per unit body weight infants require a higher water intake than adults, however, the water requirement per energy value is quite similar.

On the basis of various achievable urinary specific gravity or osmolarity values the required amount of water intake, the amount of water per dietary energy value and the amount of water intake per kg body weight can be calculated for a given energy intake and body weight. Table 2 contains the results for a newborn with a caloric intake of 300 kcal/day and for an adult with a caloric intake of 3,000 kcal/day. When renal concentrating capacity is low, much higher water intake is necessary as when highly concentrated urine can be produced (Barness and Curran, 1996).

Table 6: Water requirements in a newborn infant (3 kg body weight) and an adult (70 kg body weight) calculated in relation to specific gravity of urine

	Newborn infant 300 kcal/day			**Adult 3000 kcal/day**		
Urine specific gravity	Water intake			Water intake		
	mL/day	mL/100 kcal	mL/kg/day	mL/day	mL/100 kcal	mL/kg/day
1.005 (100-120 mosm/L H_2O)	650	217	220	6300	210	90
1.015 (500-600 mosm/L H_2O)	339	113	116	3180	106	45
1.020 (700-800 mosm/L H_2O)	300	100	100	2790	93	40
1.030 (>1100 mosm/L H_2O)	264	88	91	2430	81	35

A procedure similar to that shown in Table 6 can be applied to intake data from European nutritional surveys: The potential renal solute load (PRSL) is estimated according to the formula given in section 3.2, and the volume of urine required to excrete these solutes is calculated assuming differences in concentrating capacity and therefore urinary osmolarities. The results are given in Table 7 for Swedish, Dutch, French and German adult men and women and illustrate the variability in dietary intakes, from which widely different PRSL derive. The influence of the concentrating capacity of the kidney on the required urine volume is clearly apparent. To this volume other water losses via skin, faeces and lung need to be added for an estimate of the total water intake requirement.

Table 7: Potential renal solute load (mosm/day) calculated from dietary intake surveys (protein, sodium, potassium, chloride, phosphorus) of Swedish, Dutch, German and French adults. The urine volumes necessary for the excretion of that load at three different urinary osmolarity levels (400, 800 and 1200 mosm/L) are given in the last two columns.

Country	gender		Potential renal solute load (mosm/d)									Required urine volume at different osmolarity levels (L)					
												Median PRSL			95 P PRSL		
			mean	SE	SD	Minimum	25 P	Median	75 P	95 P	Maximum	400	800	1200	400	800	1200
Sweden (Becker and Pearson, 2002)	men	PRSL	1046	10	211	614	905	1020	1166	1431	1970	2.6	1.3	0.9	3.6	1.8	1.2
	women	PRSL	837	7	160	453	721	823	915	1139	1522	2.1	1.0	0.7	2.8	1.4	0.9
Germany (Heseker et al., 1994)	men	PRSL				526*	797	956	1136	1646**		2.4	1.2	0.8	4.1	2.1	1.4
		water intake L/day				1.2	1.8	2.1	2.5	3.7							
	women	PRSL				388*	611	750	888	1246**		1.9	0.9	0.6	3.1	1.6	1.0
		water intake L/day				0.9	1.5	1.8	2.1	3.0							
The Netherlands (TNO, 1998)	men	PRSL				630***		1067		1690		2.7	1.3	0.9	4.2	2.1	1.4
		water intake L/day				1.6		2.5		3.9							
	women	PRSL				492***		859		1330		2.1	1.1	0.7	3.3	1.7	1.1
		water intake L/day				1.4		2.3		3.7							
France (Volatier, 2000)	men	PRSL	1041	9.7	253	490	863	1020	1180	1472	2375	2.6	1.3	0.8	3.7	1.8	1.2
	women	PRSL	815	6.6	185	212	688	790	922	1169	1484	2.0	1.0	0.7	2.9	1.5	1.0

* 2.5th percentile
** 97.5th percentile
*** 5th percentile

5.1.1. Infants

Compared with children and adults infants have a higher total water content of the body, a higher surface area to body mass ratio, a faster water turnover (Fusch et al., 1993), a lower sweating capacity and a limited capacity for the excretion of solutes via the kidney. Moreover, they have difficulties in expressing thirst. Besides water required to replace losses, some water is required for growth. The first priority in water expenditure is for evaporative loss and the second is for solvent water for the excretion of solutes. Water consumed in excess of these requirements is also excreted in the urine. Under thermoneutral conditions non-renal water expenditures of normal infants are:

for age 1 month (weight 4.2 kg):	evaporative loss 210, faecal loss 42, growth 18 mL/day;
for age 4 months (weight 7.0 kg):	evaporative loss 350, faecal loss 70, growth 9 mL/day;
for age 12 months (weight 10.5 kg):	evaporative loss 500, faecal loss 105, growth 6 mL/day (Fomon, 1993).

Evaporative losses can increase up to threefold at environmental temperatures above 30 °C and low humidity. Faecal water loss which normally makes up 16% of non-renal losses can increase eightfold with diarrhoea. Diarrhoea results in losses of both water and solutes in the faeces (approximately 150 mosm/L faeces). When formula with a PRSL of >150 mosm/L is fed, faecal water losses in diarrhoea will increase considerably and will be higher than the formula volume consumed, thereby increasing the risk for hypertonic dehydration and its neurologic sequelae (D'Anei et al., 2006). Water requirement for growth is 7% of total non-renal water expenditure during the first month of life, but decreases to 2% at the age of 4 months. Non-renal water losses and water requirement for growth are not influenced by water intake.

Water required for the excretion of solutes is determined by the composition of the diet and by the concentrating capacity of the kidneys (see sections 2.3 and 2.4).

Because of the low potential renal solute load of human milk healthy *ad libitum* breast-fed infants do not need additional water, even under conditions of high environmental temperature. Eight full-term exclusively breast-fed Argentinian infants between the age of 2 and 9 weeks were shown to have urine osmolarities between 105 and 160 mosm/L in night-time urine samples (temperature 20 to 25 ºC) and between 118 and 199 mosm/L in afternoon urine samples (temperature 35 to 39 ºC) at a relative humidity of 60 to 80% (Armelini and Gonzalez, 1979), while the osmolarity in mid-day urine samples of 15 healthy exclusively breast-fed Bedouin infants (age 6 weeks to 5 months) living in the dry hot desert of the Sinai (temperature 32 to 37 ºC, humidity 13 to 41%) was found to be between 55 and 320 mosm/L (average 164.5 mosm/L) (Goldberg and Adams, 1983). Other authors compared a group of 23 exclusively breast-fed infants with 22 breast-fed and water-supplemented infants in India in a clinical setting at temperatures of 34 to 41 ºC and relative humidities of 9 to 60%. Breast-milk intake was significantly higher in the first group (p=0.003) while total water intake was not-significantly higher (p=0.073). There were no significant differences in total urine output, urine and serum osmolarity (highest observed urine osmolarity 703 mosm/L, average 148 and 160 mosm/L, respectively) and in body temperature and weight change (Sachdev et al., 1991). Twenty-six 2 to 4- month-old breastfed infants were investigated in Pakistan (temperature 27.4 to 40.7 ºC, humidity 24 to 77%) during one week without water supplementation, followed by a week with *ad libitum* water supplementation. There was normal weight gain during both periods and there were no significant differences in haematocrit and serum sodium levels, and urine specific gravity did not increase during the week without water supplementation. All infants were demonstrated to have normal concentrating capacity of the kidney after administration of AVP (Ashraf et al., 1993). Normal hydration without additional water intake of a breast-fed infant can, however, be disturbed by insufficient milk transfer and by diarrhoeal disease.

Other feeding regimens, e.g. formula with higher renal solute load, and the introduction of weaning food with higher energy and nutrient density can result in a requirement of additional water intake. Urine volume was 58% of water intake between birth and 1 month of age, 56% of intake between 1 and 2 months, 53% between 2 and 4 months, 45 % between 4 and 6 months, and 45% between 6 and 12 months of age in infants on formula feeding (Goellner et al., 1981).

5.1.2. Children, Adolescents, Adults

Normal hydration status can be achieved with a wide range of total water intakes because of homeostatic control mechanisms. Physical activity, heat exposure and other environmental conditions, dietary factors and some pathophysiological states will influence the requirement for water individually.

5.1.2.1. Dietary factors

As discussed in section 2.3 the composition of the diet, particularly the amount of protein and sodium determine the obligatory amount of water needed for the urinary excretion of solutes. However, increasing the protein intake from 80 g to 180 g/day in the diet of eight men with constant energy and sodium intake and free access to water did not result in changes in water intake or urine volume, although both solute and urea excretion increased in proportion to protein intake (Luft et al., 1983).

The intake of carbohydrates on the other hand can decrease the water requirement by preventing the formation of ketones which would have to be excreted. An increase in the intake of dietary fibre by 5.1 g/day for 12 weeks was reported to almost double the faecal water loss (Baird et al., 1977).

Sodium intake has the potential to influence the water intake and urine volume. When 104 untreated hypertensive persons consumed either a high salt (350 mmol/day) or a low-salt (10 to 20 mmol/day) diet for five days each in a cross-over design, urine volume decreased from an average of 2.2 L/day to 1.3 L/day, parallel with a decrease of urinary sodium excretion from 277 to 20.8 mmol/day. A cross-sectional observational study of 634 hypertensive patients consuming their habitual diet also showed a highly significant ($p<0.001$) positive correlation between 24 h urine volume and 24 h sodium excretion. After adjustment for age, gender, race, body weight, blood pressure and urinary potassium and creatinine excretion, it could be calculated that a reduction of salt intake by 100 mmol would predict a decrease in urine volume by 345 mL/day. These data are supported by the results from the INTERSALT study, in which a positive correlation between urinary volume and sodium excretion ($p<0.001$) was found both in 1731 hypertensive patients and in 8343 non-hypertensive persons (He et al., 2001). However, how great the influence of dietary sodium intake on water intake is, compared to other factors, remains uncertain.

Caffeine, which is present in coffee, tea and chocolate and numerous beverages has a diuretic and natriuretic effect and decreases water and particularly sodium reabsorption in the kidney (Riesenhuber et al., 2006) and can potentially lead to a total body water deficit. A study with various doses of caffeine (45, 90, 180, or 360 mg) in eight men had shown that the 3-hour post-consumption urine volume increased significantly only after the 360 mg dose (Passmore et al., 1987). However, the consumption of caffeinated beverages (114 to 253 mg caffeine/day) by 18 healthy men (23 to 34 years of age) with a habitual caffeine intake between 61 and 464 mg/day under conditions of a constant diet and a constant fluid volume intake did not influence their hydration status (Grandjean et al., 2000). In another study 12 healthy volunteers who had abstained from caffeine intake for 5 days and who received on the first experimental day mineral water and on the second day the same volume but partly as coffee (642 mg caffeine/day), showed an increase in 24-hour urine volume by 753 mL ($p< 0.001$) and of renal sodium excretion by 80 mmol/day, a decrease in body weight of 0.7 kg ($p< 0.001$) and a decrease in total body water measured by bioelectrical impedance of 2.7% ($p<0.01$) (Neuhäuser-Berthold et al., 1997). This loss in body weight reflects a temporary contraction of the ECF due to increased excretion of urine with the same proportion of water and sodium as in the ECF and can be easily compensated by physiological regulation. Regular and moderate consumption of caffeine does not result in impairment of the hydration status (Maughan and Griffith, 2003).

Alcohol like caffeine has a diuretic effect due to suppression of AVP. Consumption of a dose of 1.2 g/kg body weight by healthy men increased urine volume for three hours thereafter, followed by an antidiuretic phase lasting from 6 to 18 hours post-ingestion (Taivainen et al, 1995). In subjects with a mild water deficit every gram of alcohol consumed was found to increase urine volume by 10 mL (Eggleton, 1942). Only in habitual consumers of high amounts of caffeine (≥600 mg/day) and of alcohol (≥50 g/day), either separately or combined, a correction of observed total water intakes for diuretic losses may be advisable in order to ensure that water intake is adequate (Stookey, 1999).

5.1.2.2. Physical activity and heat, altitude and cold

During exercise, core body temperature increases in proportion to the increased metabolic rate. As a compensatory effect skin blood flow increases and sweat is produced to dissipate the heat. Sweat production at prolonged exercise in a hot environment can exceed 1.5 L/h and, if not replaced with fluid consumption, lead to a body water deficit which means an increase in both thermal and cardiovascular strain. This leads to reduced heat dissipation and exercise performance. Acclimation to heat can reduce thermal and cardiovascular strain to a certain extent. Sweat production as a consequence of physical activity and environmental temperature can amount to 1 to 2 L/h, is dependent on exercise intensity and duration, on clothing, air movement and humidity and will affect water balance accordingly. Daily fluid requirements have been estimated to be between 3 to 6 L/day in sedentary, active and very active persons in temperate climates and between 4 to 12 L/day in hot climates, and sweating rates were predicted using an equation which includes metabolic rate, climate and clothing (Sawka and Montain, 2001).

The maximum capacity for replacement of hourly water losses through sweating is about equal to the maximum sweat production rate. The possibility for replacement is restricted by the gastric emptying rate (1 to 1.5 L/h) not by the maximal intestinal absorption rate. Gastric emptying rates are reduced by very high exercise intensities, by dehydration and by heat, and an inverse relationship between body core temperature (>38.5°C) and gastric emptying rate has been observed (Neufer et al., 1989). When ten healthy young males, who were not heat-acclimatised, exercised at ~50% VO2max in either a neutral (18 °C), a warm (35 °C) or a hot (49 °C) environment with 20% relative humidity, both rectal temperature (>39.5 °C) and heart rate increased in the hot environment to necessitate interruption of the test. Gastric emptying rate of administered fluid was lowest in the hot environment (13.9 ± 2.0 mL/min) compared to the neutral (21.0 ± 1.4 mL/min) and the warm environment (18.9 ± 1.1 mL/min). After heat acclimation, exercise in the warm environment was associated with a gastric emptying rate of 20.4 ± 1.1 mL/min) in the euhydrated state. However, when deliberate dehydration (5% loss of body weight) was added to exercise in the warm environment, gastric emptying rate decreased to 15.7 ± 1.9 mL/min (Neufer et al., 1989).

Activity at high altitude is accompanied by elevated respiratory water losses, by hypoxia-induced diuresis, possibly reduced fluid consumption and increased sweating as a consequence of a higher metabolic rate, and this combination can lead to total body water deficits and mostly iso-osmotic dehydration. Cold-induced diuresis is a physiological phenomenon and produces urine of low specific gravity (around 1.009).

5.1.3. Pathophysiological situations

Pathophysiological factors have to be considered in situations with disturbances of body hydration. They do not enter, however, into the formulation of recommendations for water intake for the population.

Diabetes mellitus which is not well controlled can lead to severe dehydration and volume depletion due to osmotic diuresis. Total body water deficits can exceed 5 litres. In uncontrolled experimentally induced diabetes mellitus in rats the abundance of UT-A1, of the sodium-potassium-chloride cotransporter NKCC2/BSC1 and of AQP2 proteins was shown to increase in the kidney (Kim et al., 2005).

In c*ystic fibrosis* the sodium chloride content of sweat is higher than that of healthy individuals and may approach plasma concentrations. Consequently, exercising sweating patients with cystic fibrosis will lose high amounts of sodium chloride. Therefore, their plasma sodium and chloride levels will decrease and low osmolarity will result, exacerbated by drinking water during exercise. These patients will not experience thirst triggered by hyperosmolarity and be at high risk for dehydration. Fluid volume intake can be increased by providing sodium chloride containing beverages (>50 mmol/L).

Diarrhoea and its consequences on hydration status are mentioned in sections 2.3., 2.7.1. and 5.1.1.

Renal disease with reduced excretory capacity or concentrating ability requires total water consumption appropriate for excretion of osmotically active ions and endproducts of dietary intake and metabolism and for replacement of water losses. This is also the case for untreated cases of diabetes insipidus.

Therapy with cyclosporine and lithium can result in impaired ability to concentrate urine. Cyclosporine reduced the abundance of UT-A2, UT-A3 and UT-B in the kidney of rats, while lithium reduced the abundance of UT-A1 and UT-B (Bagnasco, 2005).

6. Key data on which to base recommendations for water intake

Recommendations for water intakes aim for water balance, i.e. water intake is equal to water losses. Insufficient water intake is characterised by a decrease in well being, thirst, loss of body weight, reduced work capacity and more serious consequences for health, when body weight losses become greater than 4%.

6.1. Water intake and its sources

Sources of water are drinking water, beverages, food moisture and water from substrate oxidation. Total available water intake is composed of drinking water, beverages with high water content (85 to >90%), of food with a wide range of water content (<40% to >80%), and oxidation water from metabolism of macronutrients. The latter varies from about 250 to 350 mL/day in sedentary people to 600 mL/day in very active persons.

The Panel defines reference intakes for water as total water intake, that is water from beverages (including drinking water) and from food moisture. It is normally assumed that the contribution of food to total dietary water intake is 20 to 30%, while 70 to 80% are provided by beverages. This relationship is not fixed and depends on the type of beverage and on the choice of foods.

The type of beverages to be preferred should be advised as part of food-based dietary guidelines.

6.2. Water losses

Losses of water occur via skin, lung, urine and faeces. Losses via skin (including sweating) and lung vary with exercise, climate, clothing and other environmental conditions. Transepidermal water diffusion via the skin in adults is estimated to amount to 450 mL/day, while 250 to 350 mL/day are exhaled with respiration. Sweat production can add considerably to water losses over the skin. In hot, dry climates it can rise to more than 8,000 mL/day in adults. Faecal water loss is about 200 mL/day in an adult under normal conditions. Urinary water loss is quantitatively most important under normal conditions. It is variable and it is tightly regulated within a physiological range depending on dietary solute load and fluid intake in combination with the diluting and concentrating capacity of the kidney, theoretically between 500 mL and up to 20,000 mL/day. Normal urine volumes in adults are 1,000-2,000 mL/day.

6.3. Principles for determining water requirement

6.3.1. Balance between intake and losses

The minimum water requirement for any individual in a defined condition is the amount of water that equals losses and prevents adverse effects of insufficient water, such as hypohydration. Adding up the losses described above, total water intakes of between 1,400 mL in a sedentary adult and up to 12,000 mL in an active adult at high temperature, eating a diet providing an osmotic solute load of >1,500 mosm, and with reduced capacity to concentrate urine above 400 mosm/L water would be needed to balance losses (see Table 3).

Under temperate conditions without excessive muscular work load, the most important factors which determine the individual water requirement will be the diet and its osmotic solute content and the concentrating capacity of the kidneys. For safety concerns it appears prudent not to base this calculation on the maximum concentrating capacity of the kidneys, but to adopt the procedure proposed by Manz and Wentz (2003) and target the water intake recommendation to a urine osmolarity of about 500 mosm/L water in order to provide a safe margin of a “free water reserve”.

6.3.2. Relation between energy and water intake

Another possibility which arises from calculations like the one shown in Table 2 is to relate energy intake to water intake and to achievable or desirable urinary osmolarity and to recommend water intakes per unit of energy consumed (Stookey, 1999). France and the Nordic countries as well as the German speaking countries advise total water intakes of 1 mL/kcal in adults and of slightly higher values in the elderly and of 1.5 mL/kcal in infants. The latter two groups are known to have a lower concentrating ability of the kidneys.

6.3.3. Observational data in healthy population groups

Observations and estimates of total water intake and balance in apparently healthy individuals consuming average diets and at moderate levels of physical activity provide valuable information and permit to define adequate amounts of total water consumption.

6.4. Infants

Exclusively breast-fed infants do not need additional water. Observed milk volumes consumed can therefore serve as the basis for estimating adequate water intakes, corrected for water content of human milk (87%) during the first 6 months of life. An average daily volume of human milk is equivalent to a total water intake of 680 mL/day or 100 to 190 mL/kg per day over that period. For the second half of the first year of life estimates of water intake from both human milk (alternatively formula) and from complementary food and beverages can be used to determine adequate intakes. The majority of total water intake values of older infants and young children, both girls and boys, in section 3 are below national guidance levels on a body weight basis (110 mL/kg per day) and on a mL/kcal basis (>1 to 1.5 mL/kcal), but correspond to French and US American recommendations. It can be concluded that a total water intake of 800 to 1000 mL/day in this age group is adequate, to which about 100 mL of metabolic water can be added.

6.5. Children and adolescents

The available data on beverage consumption and water intake from food and on estimated total water intake in European children are mostly not comparable and underreporting appears to be a problem.

Water intake data for the second year of life are not available. For this age, therefore, a total water intake of 1,100 to 1,200 mL/day is considered to be adequate by interpolation. From the data provided on total available water intake of children between 2 and 13 years in Table 3 it appears that a reported average intake of 1,100 to 1,200 mL/day or 78 mL/kg body weight per day in children between 2 to 3 years of age is adequate. Water intakes of 60.5, 48.9 and 42.6 mL/kg body weight per day in children 4 to 8 and 9 to 13 years old, respectively resulted in available water of less than 1 mL/kcal consumed. This can best be amended by increasing the intake of preferably energy-free beverages (e.g. drinking water). It can be calculated that the consumption of beverages would have to be increased by about 100 mL/day in both boys and girls to achieve an available water amount of 1 mL/kcal. Total water intake (food moisture plus beverages) would have to be 1,300 mL/day, 1,700 mL/day and 1,520 mL/day in boys and girls 4 to 8 years old, in boys 9 to 13 years old and in girls 9 to 13 years old, respectively, or 56 mL/kg/day, 44 mL/kg per day and 39 mL/kg per day in boys and girls 4 to 8 years old, in boys 9 to 13 years old and in girls 9 to 13 years old, respectively. Because of standard deviations of between 22 to 24% of the mean values a total water intake of 1,600, 2,100 and 1,900 mL/day for the three age and gender groups is recommended. For adolescents 14 years and older the reference values for adults apply.

6.6. Adults

Adequate intakes should be based both on observed intakes and on considerations of achievable or desirable urine osmolarity. Numerous and detailed data on beverage consumption and food intake in adults are available in European countries. However, total water intake has not been calculated in all of them. Average total water intake ranges between 2,200 to 2,600 mL/day in men and between 1,900 and 2,400 mL/day in women. The data in Table 7 suggest that, to achieve a urine osmolarity of 500 mosm/L, females consuming a diet with a median PRSL would need urine volumes of 1.6 L and males of 2.0 L (for high water consumers these values would be 2.5 L for females and 3.2 L for males). Under the assumption that this amount of water should be provided by beverages of all types and that beverages usually contribute up to 80% of the intake of total water, adequate total water intakes for females would have to be 2.0 L/day (P 95 3.1 L) and for males 2.5 L/day (P95 4.0 L).

6.7. Elderly

Several studies show that elderly persons have lower total water intakes than younger adults, and that particularly women are at risk of too low intake (see Table 4). This has adverse effects on mental status and activities of daily life. Adequate intakes of water for the elderly, therefore, should not be based solely on observed intakes, but should take into account the decreases in renal concentrating capacity with age and the decrease in thirst sensitivity. The Panel has decided to follow the decision of the IoM to set, therefore, the adequate total intake of water for elderly at the same level as for younger adults.

6.8. Pregnancy

There are no European data on observed water intakes of pregnant women available, but due to weight gain and increase in energy intake, a proportional increase in water intake is appropriate. Assuming an increase of energy intake of 15% in the second trimester, equivalent e.g. to 300 kcal/day, an additional total water intake of 300 mL would be adequate. In the United States an increase of water intake of 200 to 300 mL/day was observed in comparison with the intakes of non-pregnant women of the same age.

6.9. Lactation

Water intake during lactation must compensate for the loss of water through milk production, therefore water intake needs to be at least as high as in non-lactating women of the same age plus water content of the milk produced (88% of 750 to 850 mL), that is 600 to 700 mL/day.

6.10. Maximum water intake

A chronic water intake which compensates all possible water losses and in addition exceeds the excretory and diluting capacity of the kidney will lead to water intoxication with the circulatory and distributional consequences described in section 2.7.2. This occurs more often in infants and young children, mostly as a consequence of inadequate parenteral or enteral administration of electrolyte-free fluids, or in the course of drowning accidents. In adults rapid application of hypo-osmolar fluids for the substitution of high losses of sweat due to extreme bodily exertion is the main cause. Water loads which exceed the dilution capacity of the kidney will by necessity lead to hypo-osmolarity of the extracellular fluid. Available data suggest that the volume consumed per time could be an additional factor in determining tolerance for water. It can be calculated that a renal solute load from the diet of 650 mosm/day excreted under maximal dilution (urine osmolarity of 50 mosm/L) would need a urine volume of 13 litres, before further water intake could lead to hypo-osmolarity of the serum, under the assumption that no other significant losses of water occur via faeces, lung and skin.

Therefore, no single upper tolerable intake level for total water intake can be identified, which does not take into account individual and environmental circumstances.

CONCLUSIONS

The Panel has decided that the reference values for total water intake should include water from beverages of all kind, including drinking and mineral water, and from food moisture.

The Panel concludes that on the basis of available data adequate intakes can be defined for infants in the first half of the first year of life based on water intake from human milk in exclusively breast-fed infants (100 to 190 mL/kg per day).

For older infants adequate intakes can be derived from observed intakes of human milk and typical patterns of complementary food and beverages. The Panel considers that a total water intake of 800 to 1000 L/day is adequate for the age period 6 to 12 months. For the second year of life an adequate total water intake of 1,100 to 1,200 mL/day is defined by interpolation, as intake data are not available.

The Panel concludes that adequate intakes of water for children can be derived from observed intakes, corrected for a desirable water-energy relationships and corrected for interindividual variation, particularly from those studies in which the water contribution by food has been or can be assessed (see section 6.5): 1,300 mL/day for boys and girls 2 to 3 years of age; 1,600 mL/day for boys and girls 4 to 8 years of age; 2,100 mL/day for boys 9 to 13 years of age; 1,900 mL/day for girls 9 to 13 years of age. Adolescents of 14 years and older are considered as adults with respect to adequate water intake and the adult values apply.

The Panel concludes that available data for adults permit the definition of adequate intakes and that these adequate intakes should be based both on observed intakes and on considerations of achievable or desirable urine osmolarity. Adequate total water intakes for females would have to be 2.0 L/day (P 95 3.1 L) and for males 2.5 L/day (P95 4.0 L). The Panel defines the same adequate intakes for the elderly as for adults, because both renal concentrating capacity and thirst are decreasing with age.

The Panel did not find data on habitual water intake in pregnant women and proposes the same water intake as in non-pregnant women plus an increase in proportion to the increase in energy intake (300 mL/day).

The Panel recommends adequate water intakes for lactating women of about 700 mL/day above the adequate intakes of non-lactating women of the same age.

These adequate intakes apply only to conditions of moderate environmental temperature and moderate physical activity levels (PAL 1.6). Water losses incurred under extreme conditions of external temperature and physical exercise, which can be up to about 8000 mL/day have to be replaced with appropriate amounts. In such instances concomitant losses of electrolytes have to be replaced adequately to avoid hypo-osmolar disturbances.

Too high intakes of water which cannot be compensated by the excretion of very dilute urine (maximum urine volumes of about one litre/hour in adults) can lead to hyponatraemic, hypo-osmolar water intoxication with cerebral oedema. No maximum daily amount of water that can be tolerated by a population group can be defined, without taking into account individual and environmental factors.

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GLOSSARY / ABBREVIATIONS

AFSSA	Agence Française de Sécurité Sanitaire des Aliments
AI	Adequate Intake
AQPx	Aquaporins
ATP	Adenosine triphosphate
AVP	Arginine vasopressin
C	Osmolarity
D-A-CH	Nutrition Recommendations for Germany, Austria and Switzerland
DXA	Dual-energy x-ray absorptiometry
EC	European Commission
ECF	Extracellular fluid
EFSA	European Food Safety Authority
FFM	Fat-free mass
H_2O	Water
ICF	Intracellular fluid
IoM	Institute of Medicine (United States)
PRSL	Potential renal solute load
RSL	Renal solute load
SCF	Scientific Committee for Food
SD	Standard Deviation
TBK	Total Body Potassium
TBW	Total Body Water
US	United States
UT-x	Urea Transporters
$VO_{2\,max}$	Maximum oxygen uptake velocity
WHO	World Health Organization