Water in nutritional health of individuals and households: An overview

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Abstract

This paper gives an overview of human water requirements (Part 1) and water quality for nutritional health (Part 2). A balance between water input and water output is needed to maintain a normal hydration status. Water requirements of individuals differ in different stages and circumstances in the healthy life cycle, e.g. childhood, pregnancy and lactation as well for the elderly. Various sources of dietary water as well as water consumption of the South African population are discussed. Water is needed to maintain a normal hydration status, yet the non-water ingredients of beverages may also have hydration and non-hydration-related (ill-) effects, mostly in the longer term. Furthermore, water quality can affect nutrition-related health. Water is a source of nutrients, with fluoride being the most important from a nutritional perspective. Water is needed for hygiene and there are various transmission routes for diseases related to water i.e. water-borne, water-washed, water-based and water-related. In South Africa, 2.6% of all deaths and disability adjusted life years (DALYs) are attributable to unsafe water, sanitation and hygiene. The figures are much higher for children under 5 years of age. Of the diseases associated with water, those that precipitate with diarrhoea remain among the most important causes of global childhood mortality and morbidity. There is some evidence that certain chronic diseases are associated with water-related pathogens. Water has a role to play in holistic multi-sectoral interventions addressing nutritional problems.

Keywords: Water, nutrition, human water requirements, hydration, waterborne diseases, diarrhoea, beverages, South Africa

Introduction

In order to address under- and over-nutrition, as well as other nutrition-related public health issues, 11 food-based dietary guidelines were developed to help South Africans choose an adequate but prudent diet. One of these guidelines specifically refers to water and spells out: ’*Drink lots of clean, safe water*’ (Vorster et al., 2001). This implies that optimal nutrition is intrinsically linked to water. The guideline distinguishes between a quantitative (‘*lots*’) and a qualitative (‘*clean and safe*’) component of water intake. In this review we discuss these two aspects – human water requirements and water quality for nutritional health – referring mainly to the prevention of the double burden of nutrition-related diseases facing South Africans: under-nutrition and obesity. The water-agriculture-food security pathway as determinant of nutritional status of South Africans is not covered, as this was recently reviewed (Wenhold et al., 2007; Wenhold and Faber, 2008).

PART 1: HUMAN WATER REQUIREMENTS

Water is not only a **food** in itself (hence its inclusion in the **food**-based dietary guidelines), it is also a chemically defined molecule, which constitutes a core **nutrient** essential for health and survival. Its many functions include acting as a solvent in which inorganic salts, organic compounds and dissolved gases interact, participating in metabolic reactions, maintaining the structure of macromolecules, stabilising cell membranes, thermoregulation, transporting nutrients, and maintaining hemostasis and body volume/weight (Armstrong et al., 2007; Bourne and Seager, 2001; Buyckx, 2007; Charney, 2008; Kleiner, 1999; Sawka et al., 2005).

Water balance and assessment of hydration status

Water comprises 50 to 70% of adult body weight, which must be regularly replenished through dietary intake, as the body has no provision for water storage. Water balance (homeostasis) is a balance between water input and water output, and euhydration would be synonymous with ‘normal body water content’. As is the case for some other nutrients, both under-supply (resulting in dehydration) and over-supply (hyper- or over-hydration, water intoxication, hyponatremia) of water are undesirable. In this context the total percentage of body weight contributed by water must be kept in mind (which varies with age, gender and percentage body fat). Also, the distribution of total body water into intra- and extra-cellular fluid (including the intra-vascular, i.e. in plasma and blood, and the inter-cellular, i.e. interstitial or water between cells) must be considered when overall hydration status is evaluated. Normal body functions require maintenance of optimal ionic strength, primarily of the intra-cellular fluid, where most metabolic activities occur. Water balance is closely associated with electrolyte and acid-base balance, and is usually described in relation to these bodily systems (Armstrong, 2007; Charney, 2008; Grandjean et al., 2003a; Oh and Uribarri, 2006).

Water **input** refers to fluids consumed as beverages, as either pure water or water contained in drinks, and as part of food (both of which are sometimes collectively called ‘preformed water’ [Raman et al., 2004]), along with small volumes resulting

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from the oxidation of food and the breakdown of body tissue ('metabolic water'). The oxidation of 100 g of fat, carbohydrates, or proteins will result in 107, 55 or 41 g of water respectively (Charney, 2008). Dietary intake of fluids depends on their availability, physiological control (via the thirst centre), as well as personal and social factors, e.g. palatability of drinks and time available for fluid intake.

On the other hand, water **output** includes water in urine, faeces, perspiration and insensible losses in the skin and respiratory tract. Urinary output depends on the total amount of solute to be excreted and urine osmolality (Oh and Uribarri, 2006). Data representing total 'average' daily output show major variability within and between individuals, ranging from 1 500 to 3 000 mℓ/d (Grandjean et al., 2003a). Environmental temperature and humidity, altitude, volume of air inspired, air currents, type of clothing, blood circulation through skin and water content of the body affect output.

Body weight and numerous direct and indirect laboratory and clinical measurements have been used to measure hydration status (Armstrong, 2007; Grandjean et al., 2003a; Shanholtzer and Patterson, 2003). In practice, plasma or serum osmolality is considered the primary indicator of hydration status (DRI, 2004): an osmolality of <285 mOsm/ℓ is often taken as indicative of water excess and an osmolality of >295 mOsm/ℓ as a water deficit (Charney, 2008). Yet, given that hydration is a dynamic fluid matrix, containing a number of interconnected compartments, Armstrong (2005) concluded 'there is currently no single, infallible method for assessing hydration status of a person'. In spite of the measurement problems, 'optimal hydration' is essential for day-to-day health (Buyckx, 2007; Ritz and Berrut, 2005), cognitive function (D'Anci et al., 2006; Grandjean and Grandjean, 2007; Lieberman, 2007; Shanholtzer and Patterson, 2003), for work (Kenefick and Sawka, 2007) and exercise/sporting performance (Murray, 2007; Shirreffs, 2005; von Duvillard et al., 2004), and for prevention of chronic (non-communicable) diseases (Bourne and Seager, 2001; Kleiner, 1999; Manz and Wentz, 2005; Manz, 2007a).

Iso-, hyper- and hypotonic dehydration can be distinguished, depending on the composition and origin of water loss (Table 1). Furthermore, degrees of dehydration (mild vs. severe), systemic vs. local, and acute vs. chronic dehydration have been differentiated (Manz, 2007a).

Whilst early identification and treatment of dehydration, particularly in children, can be life-saving, it may be difficult to differentiate the signs of dehydration (sunken eyes, skin pinch going back slowly and dry mouth) from those resulting from severe malnutrition. The cardiovascular dangers of fluid overload (too much fluid too fast) should also be kept in mind particularly in severely malnourished children (Ashworth and Burgess, 2003).

Intake reference values (How much is 'lots of…'?)

As mentioned before, water needs of individuals range widely. The result is that there is currently no recommended dietary allowance (RDA) for water (the RDA is defined as the intake that meets the nutrient needs of almost all individuals), because the scientific evidence is inadequate to set an estimated average requirement (EAR) (the EAR is defined as the intake that meets the estimated nutrient needs of 50% of individuals per gender in a given life-stage). Instead, for the USA the Institute of Medicine of the National Academy of Sciences' Dietary Reference Intake (DRI) Panel has officially established adequate intakes (AIs), which are an approximation of average intakes of groups of healthy people, and should meet the water needs of the majority of healthy adults (DRI, 2004). These AIs have been set as 3.7 ℓ/d and 2.7 ℓ/d respectively for men and women older than 19 yr. This refers to total water intake of an individual, including about 80% from fluids and 20% from foods (in the case of the typical American diet).

The intake need not be only water; individuals can obtain their water from a variety of beverages and foods (DRI, 2004), as foods may contain significant amounts of water, e.g. over 90% for strawberries, cucumbers, tomatoes and watermelons; 80 to 90% in the case of apples, oranges and pears; 70 to 79% for eggs, peas, some fish and casseroles; while baked goods, beef, pasta, nuts and bread contain less than 70% of water (Campbell, 2007; Charney, 2008). It is possible that a food's hydration value derives from an interaction between its water content and the presence of other constituents, including nutrients (e.g. carbohydrates and electrolytes), in the food. This property is used particularly in the hydration of sports people (Sharp, 2007).

TABLE 1
Classification of dehydration

Type of dehydration	Abnormality	Possible causes
Isotonic	• Equal loss of water and sodium from extra-cellular volume • Does not cause osmotic water shift from intra-cellular volume	• Gastrointestinal fluid losses (e.g. vomiting, diarrhoea)
Hypertonic	• Water loss exceeds sodium loss • Intra-cellular volume is reduced because of osmotic shift of water into extra-cellular volume • Sometimes called intra-cellular dehydration	• Inadequate water intake because of a defective thirst centre, unconsciousness, lack of available water or inability to drink • Excessive perspiration loss • Osmotic diuresis (i.e. loss of water due to glucose in urine) • Diuretic therapy with insufficient water intake
Hypotonic	• Sodium loss exceeds water loss • Intra-cellular volume is expanded because of osmotic shift of water from extra-cellular volume into cells • Sometimes called extra-cellular dehydration	• Excessive perspiration or other gastrointestinal fluid losses • Water replacement without sodium replacement • Diuretic therapy with excessive unrestricted water intake

(Sources: Ferry, 2005; Grandjean et al., 2003a; Oh and Uribarri, 2006)

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In the absence of abnormality in urine concentration and dilution, a wide range of fluid intake will cause neither dehydration nor over-hydration of an individual. Oh and Uribarri (2006) have reasoned that underestimation of water requirements is safer than overestimation. Based on an example case of a total solute excretion of 600 mOsm/d, these researchers calculated that the urine would be 500 mℓ if urine were concentrated to 1 200 mOsm/ℓ and 15 ℓ if urine osmolality were 40 mOsm/ℓ. For such a person, the minimum water requirement would be 1 100 mℓ (500 mℓ for urinary water loss plus 600 mℓ for skin water loss at 8 400 kJ/d). Conversely, the maximal water intake would be 15.6 ℓ.

In the World Health Organisation (WHO) 2005 guidelines the individual water requirements (referring to water as food) to support hydration under 'average' conditions amount to 2.5 ℓ/d for males and 2.2 ℓ/d for females (assuming a 70 kg and a 58 kg adult reference male and female respectively) (WHO, 2005). When determining a household's water requirements for domestic use, water needed for food preparation and hygiene should also be accounted for (in addition to water needed for consumption). It is estimated that a minimum of 7.5 ℓ water per person per day is needed to meet the water requirements for domestic use of most people (WHO, 2003).

Healthy life cycle

Water requirements of individuals in different stages and circumstances in the healthy life cycle, e.g. childhood, pregnancy and lactation as well for the elderly, differ.

The water metabolism of infants and children is fraught with uncertainty, leading Manz (2007b) to conclude that only the breastfed child may be optimally hydrated. The elderly are considered a vulnerable group. In the presence of inappropriately addressed infections, dehydration is a common reason for hospitalisation and even death amongst senior citizens (Ferry, 2005). On the other hand, Bossingham et al. (2005) found that healthy, older adults appear to have water input, output and balance comparable to those of younger adults. They did not find apparent changes in overall hydration status.

There are different underlying models for defining recommended total water intake (Manz, 2007b). Standards of fluid intake (under average environmental conditions) can be expressed by body weight and age, or relative to energy intake (e.g. 1 mℓ/kcal consumed for adults or 1.5 mℓ/kcal consumed by infants), as was done in previous RDAs, e.g. in 1989 (Bonzetti, 2003; Campbell, 2007; Charney, 2008). Each of these approaches may be problematic when a person is either under- or overweight. Raman et al. (2004), for example, demonstrated that only 4 to 8% of the inter-individual variability of water turnover of adult Americans aged 40 to 79 years could be explained by age, weight and height. The possibility of racial differences has also been suggested by the latter researchers. The current AIs for total water are based on age, and differentiate by gender from 9 years onwards (Table 2).

TABLE 2
Adequate intakes (AI) for total water

Age group	AI (ℓ/d)	
0-6 mo	0.7	
7-12 mo	0.7	
1-3 yr	1.3	
4-8 yr	1.7	
	Male	**Female**
9-13 yr	2.4	2.1
14-18 yr	3.3	2.3
19-70+ yr	3.7	2.7

(Source: DRI, 2004)

Healthy adults under special circumstances

The fluid requirements of healthy individuals participating in sports, living in extreme weather conditions or working in the military or other occupational settings, where perspiration output may exceed fluid intake, deserve special attention.

Internationally, but also in South Africa, considerable research has been conducted on the fluid needs of athletes, mainly those involved in endurance type exercise. On the one hand the focus is on dehydration in the presence of high environmental temperatures. On the other hand water intoxication of athletes is cause for concern (Hew-Butler et al., 2006; Murray, 2007; Noakes et al., 1985). Also in non-endurance activities, i.e. strength, power and skill performance, hydration may be relevant (Shirreffs, 2005).

It has been proposed that occupational hydration guidelines are set up which take into account factors such as work intensity, environmental temperatures, protective clothing and work-to-rest-cycles for optimal cognitive functioning, productivity, safety and employee morale (Kenefick and Sawka, 2007). The unique factors (e.g. changes in microgravity, body composition, exercise habits, sleep cycles) to which space flight astronauts are exposed, affect their fluid balance in very special ways (Lane and Feeback, 2002).

It has been postulated that high dietary protein intakes, by increasing renal solute load, may increase fluid requirements. A preliminary investigation into this relationship showed that the effect of increasing protein intakes (0.8 vs. 1.8 vs. 3.6 g/kg·d) on various indices of hydration was minimal (Martin et al., 2006). This was also the case for older adults (Bossingham et al., 2005).

Diseases

For many diseases of multi-factorial origin, chronic mild dehydration may be one of the contributory factors. According to Manz (2007a), however, the relationship between hydration and various diseases is mostly based on evidence from descriptive studies, rather than the meta-analysis of randomised controlled trials. Nonetheless, of the papers reviewed by Manz (2007a), at least one randomised controlled trial supported the association between hydration and the following three different conditions: kidney stones, renal toxicity of certain drugs and cystic fibrosis.

The non-specific, but literal, instruction to 'drink **plenty** of fluids' abounds in the medical literature. For example, an Internet search on www.scirus.com (27 November 2007) yielded 52 journal references for the exact phrase. The instruction is made in relation to many conditions, e.g. the management of therapy-induced side-effects of cancer treatment, prevention of haemorrhoids and kidney stones, asthma, ketosis, symptoms of withdrawal from addictive drugs and excessive alcohol consumption, constipation, etc. In some cases the approach seems to be based on clinical experience and may be considered 'common sense' despite poor understanding of the underlying scientific rationale or little empirical investigation (Joon Yun et al., 2005). In other conditions, e.g. in acute respiratory infections in infants, questions have been raised regarding the scientific evidence (Guppy et al., 2004).

Specific and meticulously monitored hydration protocols are indicated for individuals with diseases affecting their fluid balance and in critical or long-term care where tube feeding is used (Oh and Uribarri, 2006).

Sources of water

A healthy diet does not rely on fluids to provide energy or nutrient requirements. Consequently, potable (or alternatively bottled) water (i.e. water, the food,) could be used to meet practically all the fluid needs of healthy individuals (Popkin et al., 2006), and solid foods could provide the energy and (non-water) nutrient needs. To consider the sources of water is nevertheless important, because (at least according to public perception) beverages and foods (i.e. the sources of preformed water) vary in their capacity to maintain hydration status or to achieve a particular outcome (Grandjean et al., 2003a; Grandjean et al., 2003b; Manz, 2007b) and because non-water beverages constitute a significant part of daily intake and contain also other nutritive and non-nutritive substances (Mattes, 2006; Popkin et al., 2006). For example, (black) tea, whole milk and squash (cordial made with water) were among the 25 most frequently consumed foods among children aged 1 to 9 years, according to the 1999 National Food Consumption Survey of South Africa (Labadarios et al., 2000). In the 24 h period preceding the interview of that survey, rooibos tea and sour milk were additionally in the list of 25 food items most often reported (Labadarios et al., 2000).

Firstly, do all fluids have the same effect on hydration status? Grandjean et al. (2003b) found that two dietary intake regimens, identical except that one included plain water (the other supplied the same amount of fluid, but from non-plain water sources, e.g. diet drinks), did not differ in terms of their effect on various markers of hydration, when environmental circumstances, physical activity and other potentially confounding factors were held constant. Furthermore, various combinations of beverages (caffeinated, non-caffeinated, energetic and non-energetic) did not differ in their effect on hydration (Grandjean et al., 2000). It follows that the source of water does not matter when bodily hydration is the outcome measure (DRI, 2004), and the common '8x8' recommendation as contained in the advice to 'drink at least 8 glasses of **water** a day' (where the volume of a glass is taken to be 8 oz [240 mℓ]) seems to have hardly any scientific backing for healthy adults in a temperate climate leading a largely sedentary existence (Valtin, 2002; Khumalo, 2007).

Secondly, in a society like South Africa where excess body weight is also a major risk to health (Joubert et al., 2007), the balance between energy and nutrient content of a beverage is critical when defining the role of beverages in a 'healthy' diet (Popkin et al., 2006). The reasons are that beverage consumption patterns and hydration status may be associated with weight gain and obesity and do influence diet quality (Davy et al., 2008; Larowe et al., 2007; Malik et al., 2006; Popkin et al., 2005; Stahl et al., 2007). However, not everybody agrees with the former (Sun and Empie, 2007). Beverages tend to have a lower energy density (<1 470 kJ/355 mℓ) than most solid foods, thus the energy density of a beverage should be considered relative to other beverages, when ranking groups of beverages.

In the beverage guidance system published for use by Americans (see Table 3) water is the most preferred beverage, followed by tea and coffee (without energy-yielding additions), low-fat (1.5% or 1%) and skimmed (fat-free) milk, non-energetically sweetened beverages (diet drinks), energy-yielding beverages with some nutrients (fruit and vegetable juices, full-cream milk, sports drinks, alcoholic beverages), and, energetically sweetened beverages without nutrients – in this order (Popkin et al., 2006). Thus, at least in societies affected by the obesity epidemic, water remains the foundation of current beverage intake recommendations.

In the context of the role of fluids in the causation of overweight, their satiating properties may be an additional feature to keep in mind. In this regard it has been claimed that alcoholic and clear beverages do not lead to satiety, whilst soup and viscous energy-dense drinks ('shake-type' beverages) appear to have satiating properties. On the other hand, clear and shake-type drinks (i.e. the energetically sweetened beverages) are

TABLE 3
Beverage consumption guide

Ranking	Beverage group	Suggested % of daily volume consumed[a]	Intake range (mℓ)	Suggested intake (up to 10% of energy)	Acceptable intake (14% of energy)
				Example volume[b] (mℓ)	Example volume[b] (mℓ)
Most preferred	Water	51	600-1 500[c]	1 500	750
	Tea or coffee, unsweetened	29	0-1 200[c]	800	1 000
	Low-fat and skimmed milk	16	0-500	500	250
	Non-energetically sweetened[e]	4	0-1 000[c]	0	340
	Energy-yielding with some nutrients[f]	0	0-250[d]	0 (alcohol)	340 (alcohol)
				125 (fruit juice)	250 (fruit juice)
Least preferred	Energetically sweetened without nutrients[g]	0	0-250	0	0
TOTAL		100	600-4 700	2 925	2 930

[a] for persons >6 years
[b] for a person with daily energy requirement of 9 240 kJ
[c] water and non-energetically sweetened beverages can substitute for tea and coffee; BUT caffeine is the limiting factor: up to 400 mg/d (± 960 mℓ coffee/d)
[d] 100% fruit juices: 0 to 250 mℓ; alcoholic beverages: 0 to 1 drink/d for women and 0 to 2 drinks/d for men (one drink = 340 mℓ beer, 150 mℓ wine or 45 mℓ distilled spirits); full cream milk: 0 mℓ/d
[e] soft drinks or fruit drinks sweetened with non-energy providing sweeteners such as aspartame, saccharin
[f] fruit and vegetable juices, full cream milk, sports drinks and alcoholic beverages
[g] carbonated (fizzy) and non-carbonated (still) drinks usually sweetened with high-fructose syrup or sucrose (sugar)
(Source: Popkin et al., 2006, adapted)

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associated with overweight, whereas this seems not to be the case with soup and alcoholic beverages (Mattes, 2006). At least in respect of alcohol there are, however, many unresolved issues, including the level of consumption (social vs. heavy drinking) and short- and longer-term metabolic effects (Jéquier, 1999).

Thus, if water balance is the only outcome of interest, the type of dietary fluid (preformed water) appears to be irrelevant. Euhydration could, however, be considered a short-term goal only. The non-water ingredients of beverages may have non-hydration-related (ill-) effects, mostly in the longer term. Here the possible association of energy-yielding beverage consumption with overweight and obesity should be kept in mind. Non-water beverages are, on the other hand, an integral part of a cultural group's cuisine. Equally, wise selection may contribute to dietary diversity and nutrient intakes, particularly in sub-groups with monotonous or inadequate consumption patterns or those with problems consuming solid fruits and vegetables, e.g. the frail and elderly. The health and nutritional effects of other ingredients of water as a food are discussed in Part 2 of this paper.

Water consumption and access to water of (South) Africans

Very few publications deal explicitly with water or fluid consumption in South Africa. In the latter part of the 1980s the mean total intake of tap water (based on 24 h recalls) for the White population of Cape Town aged 1 yr and older (N=1 680) was reported to be 2.19 ℓ/d, whilst that for the Coloured population (N=1 088) was 1.26 ℓ/d. The mean water intake of Black inhabitants aged 5 yr and older (N=1 415) in the same population but from another study using the same methodology was 1.4 ℓ/d (Bourne and Seager, 2001; Bourne et al., 1987; Bourne et al., 1992). The adequacy of these intakes of tap water cannot be interpreted relative to the AI, as the AIs for water relate to total intake from all beverages and food.

Access to water is a prerequisite for consumption. In this regard, a 'very low' health concern can be expected with optimal access to water, which may be assumed to be present if water is supplied through multiple taps continuously, resulting in an average available water quantity of 100 ℓ/capita·d and above. On the other hand, a 'very high' health risk arises if access to water involves more than 30 min of total collection time (or if the water is more than 1 000 m from home), as the quantity of water collected in such circumstances then often is below 5 ℓ/person·d (WHO, 2003).

In the 2001 South African census 84.4% of households had piped water (either in the dwelling, the yard, or further away) as their main source of water. The rest relied on rivers, boreholes, springs and so forth (Statistics South Africa, 2003). For the country as a whole, the water supply varied hugely by province and by population group of the head of the household: only 9.4% of households in Limpopo Province had piped water inside the dwelling, compared with 67.4% in the Western Cape. Equally, 17.9% of Black Africans had a tap in their dwelling, compared to about 87% of Indians/Asians and Whites. Overall, only about a third (32.3%) of the households in the country had a tap inside the dwelling (Statistics South Africa, 2003).

Rosen and Vincent (1999) reviewed studies on household water use (for drinking, cooking, bathing, and domestic hygiene) in rural areas of sub-Saharan Africa. They concluded that a rough average for use of water in rural areas was around 10 ℓ /person·d with huge variations between countries, villages and households. This value is the same as that quoted by Kistemann (2004) as reflecting the amount of water used by 'the average person in the developing world'. Given the above-mentioned risk levels (WHO, 2003) this is far below what is commonly considered enough to maintain the level of personal and domestic hygiene needed for good health.

Water is necessary to prepare and cook food. Observations from Mozambique suggest that households with close access to water use more water for cooking than households whose water supply is distant. Rosen and Vincent (1999) were, however, unable to find estimates of the extent to which malnutrition in sub-Saharan Africa is exacerbated by inadequate water available for cooking. The additional energy expended by rural African women to carry water ranged from 910 to 1 010 kJ/d, which represents about 8 to 10% of their daily energy intake (Rosen and Vincent, 1999). This implies that access to water may affect nutrition in more than one way.

PART 2: WATER QUALITY FOR GOOD HEALTH AND NUTRITION

Water is a nutrient, food and also a non-food resource essential for daily living. Except when it comes from factories where it is distilled and deionised, water has a nutrient profile just as other foods do (even though few food composition tables list it) (Burlingame, 2003). Furthermore the non-nutrients it contains may positively or negatively affect well-being and nutritional status.

Water as a source of nutrients

Water contains numerous inorganic nutrients. Amongst these, fluoride is the most important from a nutrition perspective, as water (and not food) is its major dietary source.

Fluoride

Fluoride is a natural element found in varying concentrations in surface water, ground water and seawater. Water fluoridation is the process of adjusting the amount of fluoride present naturally in water to the recommended level of 1ppm fluoride, which is considered optimal and safe for prevention of dental caries (ADA Position, 2005). Drinking water and water-based (non-dairy) beverages provide the bulk of fluoride intake for most people, accounting for 66-80% of fluoride intake in US adults (Lennon et al., 2005).

Fluoride is important for the integrity of bones and teeth and is an important protective factor against dental caries. Fluoride enhances tooth mineralisation and remineralisation, reduces tooth demineralisation, thus contributing to the stability of enamel crystal, and inhibits the metabolism of the acid-producing bacteria responsible for dental caries (ADA Position, 2005; DePaola et al., 2006; Moynihan and Petersen, 2004). Fluoride affects dental caries both pre-eruptively and post-eruptively.

On the other hand, excessive fluoride intake (from water, mouth rinses, tablets or toothpaste) may lead to dental fluorosis. This is a hypomineralisation, mottling and discolouration of tooth enamel, with the primary and secondary teeth being affected in the case of endemic fluorosis (ADA Position, 2005; Watts and Addy, 2001). Dental fluorosis is more common in countries that have higher levels of fluoride in their water supplies (Sheiham, 2001). Skeletal fluorosis and fluoride toxicity can occur at very high intakes and for this reason some consumers have resisted universal fluoridation of public water supplies.

In South Africa fluoridation of drinking water to a concentration of up to 0.7 mg F/ℓ is mandatory (Department of Health, 2000). In the regulations related to bottled waters in South Africa, it is specified that bottled water containing more than

1 mg/ℓ fluoride shall be labelled 'contains fluoride'. If it contains more than 2 mg/ℓ the label must indicate that the product is not suitable for infants and children younger than 7 years (Department of Health, 2006).

Other nutrients in water

Inorganic substances in water that have received most of the attention because of their potentially harmful effects include the heavy metals such as aluminium, arsenic, asbestos, barium, cadmium, chromium, lead, mercury and nitrate/nitrite. Lead exposure can occur where lead pipes, for instance in old buildings, are common. Removal of old pipes is the most effective measure to reduce lead exposure to water.

Some minerals (apart from fluoride) which are essential for human health and which are found in drinking water at potentially significant levels include calcium (important in bone health and possibly cardiovascular health), magnesium (important in bone and cardiovascular health), sodium (an extra-cellular electrolyte), copper (a co-enzyme) and selenium (important in antioxidant function and immunity) (WHO, 2005). The relative contribution of water to total dietary intake of these nutrients is between 1% and 20%, with the largest proportion of intake from drinking water relative to that provided by food being from calcium and magnesium (Olivares and Uauy, 2005).

Several authors (Calderon, 2005; Klevay and Combs, 2005; Monarca et al., 2006) reviewed more than 80 observational epidemiological studies done in numerous countries. Most, but not all, of these studies reported an inverse (protective) association between cardiovascular disease mortality and increased water hardness (measured by calcium carbonate or another hardness parameter and/or calcium and magnesium content in water).

In South Africa magnesium levels in the drinking water of 12 districts and deaths due to ischemic heart disease were assessed in the 1980s, and a significant negative correlation was found between these two variables in White, but not Black, residents. Equally, in another South African study (by the same authors) an increased incidence of sudden death related to ischemic heart disease was reported in some geographical areas where the soil and drinking water lacked magnesium (Leary 1986 cited by Ong, 2005). Fortification of drinking water with magnesium was shown to reduce artherogenesis in mice (Sherer et al., 1999).

Other diseases that have been studied in relation to drinking water hardness and/or calcium/magnesium include, for example, renal stone formation, neural tube defects, cognitive impairment and diabetes (WHO, 2005). Total hardness, according to the *South African Water Quality Guidelines*, should be 'limited to between 50 to 100 mg/ℓ as $CaCo_3$, where possible' (Department of Water Affairs and Forestry, 1996).

Given the high prevalence of iodine deficiency worldwide, iodisation of drinking water has been successfully implemented in some parts of the world. In China iodisation of irrigation water has increased the iodine status of women and reduced neonatal and infant mortality (West et al., 2004). In South Africa water is not used as vehicle for iodine. Instead since 1995 the compulsory iodisation of table salt has been the main strategy to combat iodine deficiency (Jooste and Zimmermann, 2008). In Brazil the fortification of drinking water of day-care centres with iron and vitamin C was associated with improved haemoglobin levels and growth in preschool children (De Almeida et al., 2005).

Water needed for hygiene ('water-washed' diseases)

Safe and clean water is an important element of a health-promoting environment. Lack of such an environment is one of the underlying causes of malnutrition (UNICEF, 1990) and has been reiterated particularly for children from developing countries (Marino, 2007) and people living with HIV AIDS (Hayes et al., 2003). One of the targets of the Millennium Development Goals (MDGs) is to halve, by 2015, the proportion of the people without sustainable access to safe drinking water and basic sanitation (United Nations, 2005). Provision of safe water and sanitation is also one of the 8 core elements of primary health care as stipulated in the 'health for all' paradigm which was officially adopted by the South African Department of Health. The government's target for universal water supply is 2008 (UNDP, 2007). Finally, safety and cleanliness represent the second aspect of the South African Food-Based Dietary Guidelines Relating to Water – 'Drink lots of clean, safe water' (Vorster et al., 2001).

Waterborne and related diseases that impact nutrition

Poor household water supply could affect nutrition via the effect of diseases associated with water. Pesticides (e.g. DDT, chlorpyrifos and pyriproxyfen) and disinfectants (e.g. bromate and trihalomethanes) are among the chemicals that constitute water-borne hazards (Department of Water Affairs and Forestry, 1996; Kistemann, 2004; Olivares and Uauy, 2005; Solsona, 2002).

Unsafe and contaminated water can be associated with numerous diseases. Substances in water that can be related to health and well-being can be grouped in numerous ways. According to the WHO '*Guidelines for Drinking Water Quality Standards in Developing Countries*' (Solsona, 2002) substances can be grouped as microbiological, chemical (health-related), radiological and aesthetic. Chemical substances can be sub-divided into inorganic, organic (other than pesticides), pesticides, and disinfectants (e.g. chlorination) and disinfectant by-products. Microbiological substances and inorganic (nutritive) chemicals are discussed in more detail because their relationship to nutrition is relatively well documented and/or their impact is of public health concern. The potential effect of the other substances on nutritional status is, however, acknowledged.

The **microbiological** quality of drinking water concerns consumers, water suppliers, regulators and public health authorities. A commonly used classification of water-related diseases with a microbiological base is given in Table 4. Strictly speaking, not all of these are linked to drinking water quality (e.g. the 'water-washed' diseases), but for the sake of comprehensiveness the whole classification is given here. Equally the classification 'faecal-oral diseases' is often used to replace the water-borne category because this is the most common pathway of transmission, even though it would include water-borne and water-washed conditions (Rosen and Vincent, 1999). Using the word 'faecal-oral' implies the link between these diseases and matters of sanitation and hygiene, which tend to be closely related to water.

Based on information contained in Table 4, water, sanitation and hygiene as a composite risk factor thus includes various transmission pathways. Transmission can occur through:

- Ingestion of water contaminated with, for example, pathogens or chemicals
- Inadequate hygiene (e.g. scabies or trachoma) because of a lack of water
- Poor personal, domestic or agricultural hygiene by using, for example, contaminated water for irrigation or cleaning
- Contact with contaminated water (e.g. *Schistosoma* spp.)
- Vectors proliferating in water (e.g. malaria)
- Contaminated aerosols from poorly managed water systems (e.g. legionellosis) (Kistemann, 2004).

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TABLE 4
Infectious diseases associated with water

Transmission route	Description	Examples of infections	Control
Waterborne	Water acts as a passive vehicle for the infective agent, thus transmission is via consumption of contaminated water	• **Bacterial infections**, e.g. *Salmonella* typhoid [a], enterobacteria, cholera [a] • **Viral infections**, e.g. hepatitis A, rotavirus • **Parasitic infections**, e.g. amoebiasis, giardiasis, intestinal protozoa, ascariasis, hookworm	Improve water quality
Water-washed	Infections as a result of insufficient quantities of water for personal or domestic hygiene	• **Enteric infections**, e.g. certain diarrhoeal diseases and gastroenteritis • **Skin infections**, e.g. scabies • **Lice-borne infections**, e.g. typhus • **Eye and ear infections**, e.g. otitis, conjunctivitis, trachoma	Increase water supply; improve hygiene practices
Water-based	A necessary part of the life cycle of the infective agent takes place in an aquatic organism; thus infection is transmitted through repeated contact with or ingestion of contaminated water e.g. bathing or washing clothes	• **Infections caused by crustaceans**, e.g. guinea worm disease (dracunculiasis) [a] • **Infections caused by fish**, e.g. diphyllobothriasis • **Infections caused by shellfish**, e.g. flukes, schistosomiasis (bilharzias) [a]	Control snail populations; reduce surface water contamination
Water-related (vector-borne)	Infections spread by insects that breed in water or bite near it	• **Infections caused by mosquitoes**, e.g. malaria [a], yellow fever, haemorrhagic fever • **Infections caused by tsetse flies**, e.g. trypanosomiasis ('sleeping sickness') • **Infections caused by blackflies**, e.g. onchocerciasis ('river blindness') [a]	Destroy breeding groups; use mosquito netting

[a] *Common in sub-Saharan Africa (Rosen and Vincent, 1999)*
Source: Rosen and Vincent, 1999; Kistemann, 2004; Bourne et al., 2007

TABLE 5
Burden of disease attributable to unsafe water, sanitation and hygiene in South Africa, 2000

	Burden attributable to unsafe water, sanitation and hygiene			
	Total population		Children under 5 years of age	
	n	%	n	%
Deaths	13 434	2.6	8 910	9.3
95% uncertainty interval	12 718 - 13 905	2.4 - 2.7	8 435 - 9 222	8.8 - 9.6
DALYs	418 790	2.6	305 738	7.4
95% uncertainty interval	398 100 - 432 379	2.5 - 2.7	289 464 - 316 426	7.1 - 7.7

Source: Lewin et al., 2007

A significant proportion of the global burden of disease is linked to water-related illnesses. At any given time about half of the world's hospital beds are occupied by patients suffering from waterborne disease (Kistemann, 2004), and this has significant financial implications for the health care system. In South Africa 2.6% of all deaths and also of disability adjusted life years (DALYs, i.e. the number of years of life lost due to premature mortality added to the number of years of life lived with disability or illness, weighted according to the severity, and using time as the common measure) are attributable to unsafe water, sanitation and hygiene, with much higher figures applying in both cases to children under 5 years of age (Lewin et al., 2007; Table 5).

Diarrhoea

Of the diseases associated with water, those that precipitate with diarrhoea remain among the most important causes of global childhood mortality and morbidity. Patho-physiologically, diarrhoea results when excess water and electrolytes are actively transported into the lumen of the gut (secretory diarrhoea) or when water is retained in the lumen by osmotically active agents (osmotic diarrhoea). Finally, gastrointestinal motility (i.e. movement within the gut) affects transit time, thereby contributing to diarrhoea (Manas et al., 2003). Micro-organisms associated with water (see Table 4) can be the underlying cause of increased secretion or osmotic pressure (e.g. by means of fermentation), resulting in diarrhoea.

Diarrhoeal disease alone is estimated to cause 2.2 x 10^6 of the 3.4 x 10^6 global water-related deaths per year (WHO/OECD, 2003), with huge differences between developing and developed countries (Thapar and Sanderson, 2004). It is estimated that a baby born in sub-Saharan Africa has almost 520 times the chance of dying from diarrhoea compared with a baby born in Europe or the United States (WHO/UNICEF, 2005). Exact prevalence figures remain elusive because a significant proportion of water-related illnesses are likely to go undetected by general surveillance systems. The major reason for this is that the gastrointestinal symptoms are usually mild and self-limiting and are consequently not reported. Even among those events that are reported, few of the stools will be microbiologically analysed so that a causative micro-organism can be recorded.

In South Africa the incidence of diarrhoea is used as one of the indicators of the health status of the nation's children and for identification of potential environmental hazards. The '*diarrhoea incidence <5 per 1 000*' is defined in the South African Health Review (SAHR) as the number of children under 5 years of age with diarrhoea per 1 000 children under 5 years of age in the target population. The national figure for diarrhoea given in the 2007 SAHR in respect of 2006 is 214.9, with significant differences among provinces (Day and Gray, 2007).

Diarrhoea and childhood malnutrition

In children malnutrition globally remains the major adverse prognostic indicator for diarrhoea-related mortality, emphasising the importance of nutrition in early management (Thapar and Sanderson, 2004) and, again, suggesting an interaction between nutrition and diarrhoea. Diarrhoea is often a manifestation of a number of infectious diseases, and the bi-directional interaction between nutrition, infection and immunity is well known and reflected in Fig. 1. Under-nutrition impairs immune defences and lowers resistance to invading pathogens. In turn, infection alters nutrient status and contributes to the undernourished state.

From the above discussion it is evident that ill-health, or more specifically the presence of (infective) diseases associated with water, features strongly as a mediating variable in the relationship between water and nutrition, thus resulting in what is sometimes called disease-related malnutrition.

It is possible that interventions to improve sanitation and hygiene are more effective in reducing diarrhoea morbidity and mortality than interventions that improve water supplies as such. In the late 1999s Rosen and Vincent (1999) investigated this but were unable to find any research from sub-Saharan Africa that separated these effects. Sanitation appears to be critical to specifically reduce faecal-oral diseases, but has little value in combating other conditions associated with water. Changes in nutritional status (weight-for-height, height-for-age and weight-for-age) suggest that provision of **optimal** (in contrast to intermediate or unimproved) services of **either** water **or** sanitation (whether separately or in tandem) generate health benefits in the form of improved growth and anthropometry of children in Africa (Rosen and Vincent, 1999). More recently, Merchant et al. (2003) were able to show that water and sanitation were independently associated with improved growth in two rural regions in Sudan. A systematic review of published studies and, where appropriate, meta-analyses of studies that reported interventions in water quality, water supply, hygiene, and sanitation in less developed countries showed that most of the interventions had a similar degree of impact on diarrhoeal illness (Fewtrell et al., 2005). The authors therefore argued that interventions for a given setting should be selected on the basis of their local desirability, feasibility, and cost-effectiveness.

Chronic diseases associated with water-related pathogens

In the 1990s some (preliminary) evidence became available that microbial infections associated with waterborne pathogens may also be linked to the development of chronic diseases long after the initial exposure. For example, diabetes mellitus was linked to the Coxackie B4 virus, miocarditis linked to the echovirus, Guillian-Barrè syndrome linked to *Campylobacter* spp., gastric cancers linked to *Helicobacter* spp., and reactive arthritis linked to *Klebsiella* spp. (WHO/OECD, 2003).

We can thus conclude by saying that microbiological contamination of water plays a major role in the global burden of mainly infective diseases, and in particular those that present with diarrhoea, but may also in the longer term be associated with chronic diseases.

Conclusion and outlook

As a food, water has a particular composition and may be consumed as such or be included as an ingredient in a dish. Water also has non-food roles that affect nutrition. Being a nutrient means that water is a chemically defined molecule contained in foods with certain functions in the human body.

For all individuals water – the nutrient – is essential. The requirements for water, the nutrient, are under-researched and highly variable. On the other hand, water, the food, is probably

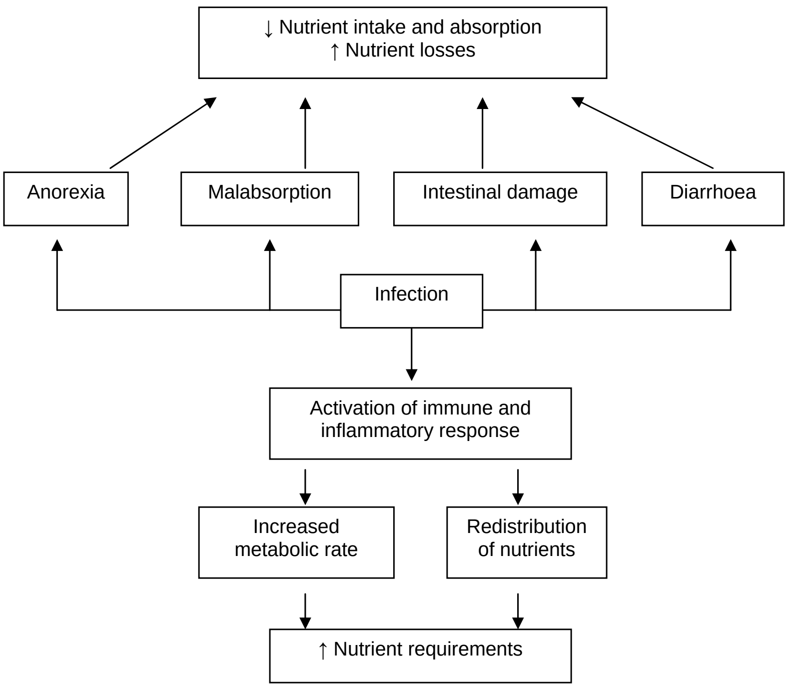

Figure 1
The inter-relationships between nutrition and infection (Source: Yaqoob and Calder, 2003)

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not essential, yet it is the preferred beverage for the prevention of obesity. It may be a source of other nutrients, but also of non-nutrients which may cause or contribute to the development of diseases that negatively impact nutritional status, particularly of children. For the prevention of malnutrition, including under- and over-nutrition, households and individuals should have enough safe and clean, as well as accessible and affordable water as food and non-food resource. This is not only a human right explicitly contained in the *South African Bill of Rights* (paragraph 27 (1) (b)), but core for the nutritional health of the nation.

Addressing problems of a nutritional nature requires holistic and multi-sectoral interventions, including attention to the immediate (inadequate dietary intake and diseases), underlying (household food insecurity; inadequate maternal and child care; insufficient health services and unhealthy environment) and basic causes of the manifestation. Water has a key role to play in this regard.

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