REVIEW

Hydration and health: a review

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Summary

Water is essential for life and maintaining optimal levels of hydration is important for humans to function well. Water makes up a large proportion of our body weight (60% on average), distributed between the intracellular (inside cells) and extracellular (water in the blood and in between cells) compartments. Water is the major component of body fluids, such as blood, synovial fluid (fluid in the joints), saliva and urine, which perform vital functions in the body. The concentration of solutes (osmolality) in body fluids is closely controlled, and even very small changes in osmolality trigger a physiological response; either to increase body water by reducing urinary output and stimulating thirst; or to excrete excess water as urine. Generally, body water is maintained within narrow limits. However, if water losses are not sufficiently replaced, dehydration occurs. Extreme dehydration is very serious and can be fatal. More mild dehydration (about 2% loss of body weight) can result in headaches, fatigue and reduced physical and mental performance. It is also possible to consume too much water and in rare cases this can result in hyponatraemia (low levels of sodium in the blood).

We can get water from almost all drinks and from some foods in the diet. Food provides about 20% on average and this could vary widely depending on the types of food chosen. We also get water from all the drinks we consume, with the exception of stronger alcoholic drinks like wines and spirits. All these can contribute to dietary water, but also have other effects on health both positive and negative. The major concerns with regards to beverages are their energy content and their effect on dental health. With obesity levels continuing to increase it is important for many in the population to control their energy intake, and drinks as well as foods must be considered for their energy content. With regards to dental health, there are two concerns; dental caries and dental erosion. Dental caries are caused by a reduction in pH due to bacterial fermentation of carbohydrates, and so the frequency of consumption of drinks containing sugars is a concern for risk of caries. Dental erosion occurs at a lower pH and is caused by the consumption of acidic foods and drinks, in particular, citrus juices and soft drinks containing acids.

Individual water needs vary widely depending on many factors including body size and composition, the environment and levels of physical activity. Thus it is very difficult to make generic recommendations about the amount of water to consume. The FSA currently recommends drinking about 1.2 litres per day (about 6–8 glasses).

Keywords: Beverages, dehydration, fluid, hydration, water

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Introduction

Water is vital for survival, and there is currently great interest in the benefits of good hydration for people to function well, and to look and feel good. However, messages surrounding hydration have become increasingly confused. Some sources suggest drinking litres of plain water on top of other fluids, while stories of consumers dying as a result of consuming too much water may leave many in doubt about how to achieve a healthy level of hydration. This paper aims to summarise and clarify the evidence about how the body controls water balance, the relative of various sources of fluid effects on hydration and health, and current data on fluid intakes. This paper is generally relevant for healthy adults, but the requirements of children, older adults and other population groups with specific physiological needs will also be discussed.

Why do we need water?

Water is essential for life and, although humans can survive for a number of weeks without food, they cannot normally go without fluids for more than a few days. The human body is made up of between 45% and 75% water by weight (average 60% in men and 51% in women, equivalent to approximately 42 litres(l) in a 70-kg man and about 26 l in a 50-kg woman) depending on body composition (Thomas & Bishop 2007). Lean tissue contains more water (about 70%) than fat tissue (about 20%) so that a higher percentage of body fat results in a lower percentage of body water overall. The water in the body is distributed into intracellular (inside body cells) and extracellular (outside cells) fluid compartments that contain approximately 65% and 35% of total body water, respectively (Sawka *et al.* 2005). The extracellular fluid can be further divided into the interstitial fluid (present in the spaces between cells) and plasma (fluid in the blood that transports blood cells around the body). This is represented schematically in Figure 1.

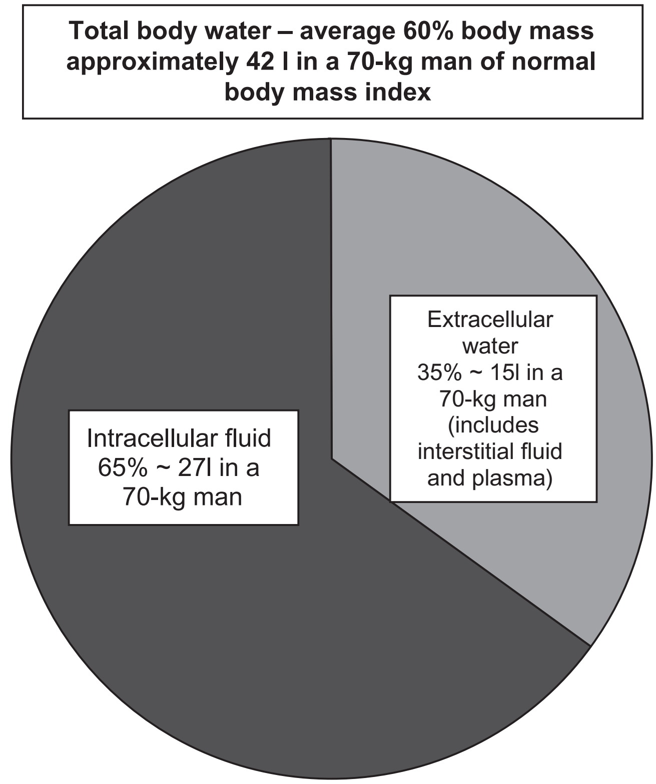

Figure 1 A representation of the compartments and amounts that make up total body water.

Water performs a number of essential functions in the body. It is a key component of the fluid that forms the basis of saliva that helps us to swallow, of synovial fluids that cushion the joints and of the fluids that fill and lubricate our eyes (vitreous humour and tears). Fluid provides a medium for most chemical reactions in the body to occur, acts as a cushion for the nervous system (cerebrospinal fluid), allows us to get rid of waste products principally via the kidneys and urine production, and helps to regulate body temperature by the process of sweating (Grandjean & Campbell 2004). The body produces a small amount of water when hydrogen atoms in nutrients are oxidised as part of the process of metabolism. However, this is much less than we need (in the order of 250 ml per day), and so, we need to obtain water from other sources every day in order to keep the body well hydrated (see Lunn & Foxen 2008). It is important to note that it is the concentration of solutes in body fluids, and not just the amount of water in the body, that is critical for water balance. More detail is provided in Box 1.

What are the effects of dehydration (too little water)?

Body water volume is tightly controlled and, under normal conditions, fluctuates by less than 1% per day. Dehydration can be defined as a 1% or greater loss of body mass (assuming that there is no weight loss occurring because of negative energy balance) due to fluid loss (Kleiner 1999), for example, the loss of 0.7 kg (1 lbs) of body weight in a 70-kg (11st) person. Dehydration resulting in loss of body mass of 2% or more can result in impaired cognitive function (Ritz & Berrut 2005), reduced physical performance (Shirreffs 2005), headaches and symptoms of fatigue (Shirreffs *et al.* 2004). In

Box 1 The concentration of solutes in body fluids and hydration

Fluids in the body are not pure water but solutions containing a number of solutes at precisely controlled concentrations. The main solutes in the extracellular fluid are salts (mostly sodium chloride, *i.e.* salt); bicarbonate (HCO_3) and small but important concentrations of calcium, potassium and magnesium, as well as a wide range of substrates, such as metabolites and hormones. The intracellular fluid contains mostly potassium salts (phosphates and proteinates); small amounts of sodium, magnesium and bicarbonate; a little chloride; and a very small quantity of calcium. The concentration of these solutes in body fluid, known as osmolality, is critical for the body to function and is tightly controlled. Various physiological processes, such as eating or exercising, cause temporary disturbances in solute concentrations in the blood, however, sodium concentration is the most important osmolar control. Osmolality of the extracellular fluid is determined mainly by its concentration of sodium, and that of the intracellular fluid by the concentration of potassium. Sodium and potassium can cross cell membranes, and cells in the body are constantly pumping out sodium that has diffused into cells, and pumping potassium back in as part of the regulation of cell function. Water can also cross cell membranes, but provided the osmolality of both intracellular and extracellular fluids are the same, there is no osmotic gradient that pushes water in or out of cells, keeping both intra- and extracellular fluid volume constant. The osmolality of body fluids is maintained at a constant level by adjusting water intake and excretion by controlling the amount of water lost as urine and the intake of water via the thirst mechanism. If plasma osmolality increases, then more water is needed, and signals are sent to the kidneys to conserve water, and thirst is stimulated. If plasma osmolality decreases, then water needs to be excreted, and the kidneys increase urine production. Even very small changes in plasma osmolality, of about 1%, stimulate mechanisms either to conserve or excrete water. Thus, hydration is determined, not only by the supply of water, but also by the supply of sodium and potassium. In cases of severe dehydration where large amounts of water and sodium have been lost, water alone cannot provide rehydration, as this does not allow the body to restore osmolality to the correct level, and sodium must be included in rehydration fluids to allow recovery. However, water is the primary concern to remain hydrated, unless the person is ill or performing endurance exercise.

experiments using fluid restriction to induce dehydration, it has been shown that loss of body mass of about 1% can be seen after 13 hours, about 2% after 24 hours and nearly 3% after 37 hours when no fluids and only relatively dry foods are consumed. The authors noted that the subjects undergoing fluid restriction had a strong desire to drink and would have been unlikely to become dehydrated to such an extent accidentally (Shirreffs *et al.* 2004).

If dehydration becomes severe, for example, in conditions such as cholera where large amounts of body water are lost because of severe diarrhoea, then it can be fatal (Thomas *et al.* 2008). For most people who live in a temperate climate and who have ready access to safe drinking water and food, serious dehydration is generally unlikely, but there may be some population groups and situations where the risk of dehydration is increased (see 'How much water do we need?'). However, mild dehydration of 1% to 2% loss of body mass, which is sufficient to impair physical and mental performance, may occur in the general population if insufficient fluids are consumed. Table 1 shows potential weight losses at different degrees of dehydration.

In the long-term, there is evidence to suggest that chronic mild dehydration is associated with increased risk of a number of conditions, including constipation, urinary tract infections, hypertension (high blood pressure), coronary heart disease (CHD) and stroke (Manz & Wentz 2005a). It should be noted, however, that these are multifactorial conditions, and other risk factors may have a greater influence on overall risk of developing such diseases.

What are the effects of overhydration (too much water)?

Under normal circumstances the kidneys are able to excrete excess water (see 'How does the body balance water intake and water output?'), but extreme overconsumption of fluids can overwhelm this mechanism. In rare cases, this leads to hyponatraemia (low levels of sodium in the blood), which causes lung congestion, brain swelling, headache, fatigue, lethargy, confusion, vomiting, seizures and, eventually, coma (O'Brien *et al.* 2001). Overhydration is particularly associated with psychotic illness, but has on rare occasions reported in athletes and as a result of ill-advised 'detoxing' regimens, where large quantities (>3 l) of water are consumed over a short period of time (Almond *et al.* 2005; Lunn & Foxen 2008). It is therefore important to be

Table 1 Loss of body mass at differing levels of dehydration

Level of Dehydration	Mild		Moderate	Severe
Loss of body mass (resulting body mass)	1%	2%	5%	10%
70-kg (11st) man	0.7 kg (69.3 kg) 1.5 lbs (10st 13 lbs)	1.4 kg (68.6 kg) 3.1 lbs (10st 11 lbs)	3.5 kg (66.5 kg) 7.7 lbs (10st 7 lbs)	7 kg (63 kg) 1st 1 lb (9st 13 lbs)
50-kg (7st 12 lbs) woman	0.5 kg (49.5 kg) 1.1 lbs (7st 11 lbs)	1 kg (49 kg) 2.2 lbs (7st 10 lbs)	2.5 kg (47.5 kg) 5.5 lbs (7st 7 lbs)	5 kg (45 kg) 11 lbs (7st 1 lb)
35-kg (5st 7 lbs) child	0.3 kg (34.7 kg) 0.7 lbs (5st 6 lbs)	0.7 kg (34.3 kg) 1.5 lbs (5st 6 lbs)	1.8 kg (33.2 kg) 4 lbs (5st 3 lbs)	3.5 kg (31.5 kg) 8 lbs (4st 13 lbs)

aware that drinking excessive amounts of fluid, as well as too little, is associated with health risks.

How does the body balance water intake and water output?

The balance of water in the body is determined by how much fluid is consumed plus the small amount of water produced by metabolism in the body *vs*. the amount of water lost from the body. Water loss occurs via the kidneys as urine, through the skin as sweat, and in faeces. Other routes of water loss, often referred to as 'insensible water loss', include the evaporation of water from the lungs and skin.

Loss of water in urine normally makes up the largest part of overall water loss and is controlled by the kidneys. The kidneys play a central role in maintaining the balance of water in the body, and also, in the balance of solutes (*i.e*. sodium, bicarbonate, potassium and chloride) in body fluids (Grandjean & Campbell 2004). The kidneys are able to conserve water when fluid intake is restricted and to excrete additional (excess) water when fluid intakes are high. Daily urine output is typically between 1200 ml and 2000 ml, but this can vary greatly depending on, for example, the amount of fluid consumed and the amount of sweat produced (Youngson 2001). The brain can detect very small changes in plasma osmolality (the concentration of solutes in the blood), which cause the release of hormones, signalling to the kidney to conserve or excrete water. The amount of urinary water loss is tightly controlled, as this is important not only for water balance, but also for maintaining the correct solute concentrations in body fluids and for getting rid of waste products (Khan *et al*. 2000).

Water is also lost by sweating, when the loss of heat from the body by the process of heat radiation is not sufficient to dissipate excess body heat. Sweat also contains sodium and small amounts of other electrolytes, and so is a route of solute loss. The composition of sweat is highly variable, but it is inevitably hypotonic (more dilute) compared with plasma (Shirreffs & Maughan 1997). The amount of sweat produced depends on a number of variables, including interindividual variation in sweat rates, environmental conditions and levels of physical activity and fitness. When sedentary in a cool climate, little fluid is lost as sweat, but if temperatures and levels of physical activity are high, then significant amounts of fluid can be lost via sweating, greatly increasing water requirements, for example, up to 15 l per day (Adolph 1947). Acclimatisation to high temperatures allows higher, more sustained sweat rates and also increases the ability to retain sodium, causing a reduction in the sodium concentration of sweat (Sawka *et al*. 2007).

Insensible water loss, which is the evaporation of water from the skin and lungs, may also be affected by factors such as environmental conditions and physical activity. Insensible water loss from faeces depends on the amount of water in stools and is greatly increased in cases of diarrhoea. Estimates of water losses in sedentary and physically active adults are shown in Table 2. It can be seen that the estimated losses in sedentary adults range from 1300 to 3450 ml/day, and from 1850 to 8630 ml/day in physically active adults.

In terms of water gain, although a small amount of water is produced by metabolism in the body, the majority of water needs must be provided by the foods and drinks we consume. Thirst is the physiological mechanism that drives us to drink and is initiated when the brain detects a rise in plasma osmolality (*i.e*. the solutes such as sodium in the blood are becoming more concentrated).

Thirst is initiated when the body detects that fluid is required or, in some cases, when the mouth and throat are dry. There is some debate as to whether thirst is an accurate and sufficient indicator of hydration status. The body's first response to an increase in plasma osmo-

Table 2 Estimates of the range of minimal water losses in sedentary adults (assuming minimal loss from sweating) and with additional sweat loss from physical activity

Source	Range of minimal water loss (ml/day)	Reference
Respiratory loss	250–350	Hoyt and Honig (1996)
Urinary loss	500–1000	Adolph (1947)
Faecal loss	100–200	Newburgh *et al.* (1930)
Insensible loss	450–1900	Kuno (1956)
Total loss (sedentary)	1300–3450	
	Sweat loss range from physical activity (ml/day)	
	1550–6730	Burke (1997)
Total loss (active)	1850–8630	

Source: Adapted from Sawka *et al.* (2005).

lality (caused by a decrease in body water) is to conserve water by signalling the kidney to concentrate the urine, reducing urinary water loss. The initiation of the thirst response then occurs after this, when loss of body mass is 1% to 2% – the level at which adverse effects on physical and mental functions can be detected (Armstrong 2005). Providing individuals consume adequate fluid in response to thirst, this should, in theory, restore hydration levels. However, it is important to note that there may be numerous physiological and behavioural variations in how people respond to thirst, which could modulate the effectiveness of thirst in preventing dehydration. For healthy people living in a temperate climate, fluid intakes may be driven by food and drink preferences or by cultural and social factors rather than primarily by thirst (Wrong 2001).

Overall, homeostatic systems in the body generally ensure that body water balance is maintained by regulating sensations of thirst and the quantity of urine excreted. In most healthy people, this results in a very precise control of water balance, and it is estimated that changes are maintained within 0.2% of body mass over 24 hours (Grandjean *et al.* 2003). However, although the body can minimise water loss by reducing urine excretion, there is an upper limit to the urine concentration that can be achieved, which means that some loss of water as urine, in addition to insensible water losses, is inevitable. If this water loss is not sufficiently balanced by fluid intake from food and drinks, then dehydration cannot be prevented.

What are the dietary sources of water?

We obtain water from all the foods and drinks we consume. The water content of foods varies, for example, it is more than 80% in most soups, fruit and vegetables; 40% to 70% in hot meals; less than 40% in cereal products such as bread and biscuits; and less than 10% in savoury snacks and confectionery. We also get water from all the fluids we consume, including water, juice and fruit drinks, tea and coffee. Alcoholic beverages also contain water, but their diuretic effects will affect how much of this is retained.

It is estimated that when we are relatively sedentary, food supplies approximately 20% of our water intake (Grandjean & Campbell 2004), although this will depend on the types of food consumed. However, if water requirements are greatly increased, then it is not possible to gain this increased requirement from food. For example, if 5 l of additional fluid is required to compensate for sweat losses when exercising in a hot climate, then it is necessary to obtain most of this from drinks, as the equivalent amount of food would simply be too bulky to consume. The relative effects of different beverages on hydration are discussed in the next section.

Does it matter where we get our water from?

We can absorb water efficiently from virtually all foods and drinks, although the rate of absorption can increase or decrease to some extent, depending on the composition of the food or drink, for example, its salt and sugar content (Sharp 2007). While the rate of water absorption is unlikely to be of concern, in most cases, if large amounts of water have been lost because of intensive exercise, the composition of fluids taken to replace this loss is important (see section on sports drinks). The water content of a selection of foods and drinks is shown in Table 3.

While water can be obtained from many dietary sources, the food or drinks that supply water may also have other potentially positive or negative effects on health. Thus, the balance of foods and drinks we consume is important, both for hydration and for the wider effect these sources of water have on our health.

Food

Although food is often overlooked as a source of water, foods supply a significant proportion of our water requirements, especially in sedentary people. It can be seen from Table 3 that the water content of foods varies widely from over 90% in some fruits and vegetables to less than 5% in savoury snacks and confectionery. Dietary guidelines focus on the provision of nutrients rather than on the hydration requirements. However,

Table 3 Water content of commonly consumed foods and drinks

Food/drink	Water content (%)
Tea, coffee, low-calorie soft drinks	90–99
Beer*	90–95
Wine*	80–90
Berries, melon, citrus fruits, pears, apples, salad vegetables, broccoli, carrots	90–95
Milk, soft drinks, fruit juice	85–90
Bananas, potatoes, sweetcorn	80–90
Yoghurt	75–80
Fish and seafood	70–80
Rice and pasta	65–80
Soup	60–95
Stews, casseroles, etc.	60–80
Spirits (e.g. gin, whisky)	60–70
Pizza	50–60
Meat	45–65
Cheese	40–50
Breads and biscuits	30–45
Breakfast cereals (without milk)	2–5
Savoury snacks and confectionery	1–10

Source: Grandjean and Campbell (2004).
*FSA (2002).

following advice to eat five portions of fruit and vegetables a day, to base meals around starchy foods and to consume foods that are high in fat and sugar in small quantities is likely to increase the water content of the diet. Consuming foods that have a high water content may be particularly important for those looking to control or reduce their body mass as the water content of foods is inversely proportional to their energy density (the amount of energy provided per gram) (Drewnowski 1998). Consuming a lower energy density diet is associated with a lower energy intake and lower body mass in epidemiological studies, and experiments where subjects have consumed a lower energy density diet have found that weight loss is enhanced, even when subjects eat *ad libitum* (Benelam 2009). Thus, although there is little research investigating the effect of dietary water on hydration status, consuming plenty of water-rich foods may be beneficial both for hydration and for dietary quality. Some studies investigating rehydration after exercise have found that consuming water-rich foods as well as drinks may aid rehydration after exercise-induced water loss, as this approach delivers both water and sodium (Maughan *et al.* 1996; Sharp 2007).

In addition to providing water themselves, eating foods may also stimulate drinking. Studies have found that 75% of fluid intake occurs while eating, and fluid intake with food may facilitate chewing and swallowing, enhance palatability and reduce the effect of irritants such as chilli (McKiernan *et al.* 2008).

Beverages

Although drinking water can supply all our hydration requirements, most people prefer to drink a variety of beverages. All beverages supply water, and some also provide nutrients that are beneficial for health. Beverages can also provide energy, and in the context of rising obesity levels, it is important for consumers to be aware that drinks as well as foods contain energy. The National Diet and Nutrition Survey (NDNS) of adults in 2002 estimated that drinks provided 10% of the energy intake of adults in the UK (Henderson *et al.* 2002). This energy was mainly provided by alcoholic drinks. The energy content of a selection of beverages is shown in Table 4.

Knowledge of the energy contribution from beverages is particularly important, as, in the current context of increasing obesity prevalence, many in the population need to control their energy intake. A number of studies have found associations involving consumption of energy from drinks, increased overall energy intakes and obesity (for reviews, see Vartanian *et al.* 2007 and Malik *et al.* 2006). However, evidence for these associations is inconsistent and other studies have not detected a positive relationship (see Gibson 2008 for a review). Although it has been suggested that the energy content of drinks is not fully detected by the body's appetite control systems, the evidence for this is inconsistent. For example, researchers found no differences between liquid and solid sources of energy in some studies, and some liquid foods, such as soup, appeared to be more filling than equivalent solid foods. In a review, Drewnowski and Bellisle (2007) suggested that consumption of energy as a drink to assuage thirst might be less likely to suppress later energy intake than consumption of energy as food in response to hunger (Drewnowski & Bellisle 2007). There is also some evidence that the greater speed of consumption of liquids compared with solids may lead to a decreased satiety response (Zijlstra *et al.* 2008)

Dental health is also of great importance when considering beverage consumption, specifically with regard to the sugar content of beverages and also their acidity. The mineral in teeth is a complex calcium phosphate salt that dissolves at low pH. The nature of the interaction of this mineralised tissue with acids is pH dependent. There are two mineralised tissues that form teeth: dentine and enamel, with a critical pH for demineralі-

Table 4 The energy content of beverages

Beverage	kcal/100 ml	Portion size (ml)	kcal*/portion
Water	0	Glass (200)	0
Hot drinks			
Tea (black)	Trace	Mug (260)	Trace
Tea with whole milk	8	Mug (260)	21
Tea with semi-skimmed milk	7	Mug (260)	18
Tea with semi-skimmed milk and one teaspoon of sugar	13	Mug (260)	34
Coffee (black)	Trace	Mug (260)	Trace
Coffee with whole milk	8	Mug (260)	21
Coffee with semi-skimmed milk	7	Mug (260)	18
Coffee with semi-skimmed milk and one teaspoon of sugar	13	Mug (260)	34
Latte coffee made with whole milk†	50	Regular (354)	176
	47	Large (473)	223
Sweetened gourmet coffee made with whole milk and flavoured syrup†	62	Regular (354)	221
	60	Large (473)	284
Hot chocolate made with semi-skimmed milk	73	Mug (260)	190
Hot chocolate made with whole milk and whipped cream†	122	Regular (354)	433
	117	Large (473)	556
Milks			
Whole milk (3.9% fat)	66	Glass (200)	132
Semi-skimmed milk (2% fat)	46	Glass (200)	92
1% milk	40	Glass (200)	80
Skimmed milk (0.1% fat)	34	Glass (200)	68
Soya drink (unsweetened)	26	Glass (200)	52
Soya drink (sweetened)	43	Glass (200)	86
Juices, smoothies and soft drinks			
Orange juice	36	Glass (200)	72
Fruit smoothie‡	57	Bottle (250)	143
Soft drink (e.g. cola or lemonade)‡	42	Can (330)	139
		Bottle (500)	210
Diet soft drink‡	0.5	Can (330)	2
		Bottle (500)	9
Sports and energy drinks			
Sports drink§	24	Can (250)	60
		Bottle (500)	120
Energy drink§	53	Can (250)	133
		Bottle (500)	265
Alcoholic drinks			
Premium lager	40	Half pint (284)	114
		Pint (568)	227
Sweet cider	42	Half pint (284)	119
		Pint (568)	246
Red wine or dry white wine	68	Small glass (125)	85
		Standard class (175)	119
		Large glass (250)	170
Sweet white wine	94	Small glass (125)	118
		Standard class (175)	165
		Large glass (250)	235
Gin and tonic (Slim line tonic)	50 (31)	183	92 (57)
Rum and cola (diet cola)	56 (31)	183	103 (57)
Vodka with energy drink	73	223	162
Cream liquor	350	50	175

Source: FSA (2002).
*Conversion factor for kcal to kJ = 4.182.
†Nutritional information from a high-street coffee shop.
‡Nutritional information from a popular supermarket brand.
§Average energy content of three popular brands.

sation of around 6 and 5.4, respectively. With 'mild' acid attack close to this pH, tooth decay occurs, whereas with 'stronger' acid attack (typically a pH of 2.5 or less), erosive damage to the teeth develops. The fundamental difference between these processes is that erosive damage results in immediate loss of tooth tissue while early carious lesions can be remineralised to restore tooth form.

When sugars are consumed (in a food or drink), they are metabolised by bacteria that stick to the surface of teeth in a substance known as plaque. This process produces acid, reducing the pH of plaque on teeth to below the critical pH for demineralisation. Refined carbohydrates are most readily metabolised, particularly sucrose and glucose. Fructose and lactose can also be metabolised, but this is more difficult for the bacteria in plaque, so less acid is produced. Starches can also be metabolised by bacteria in the mouth, particularly when finely milled, but again, this occurs at lower levels than seen with sucrose or glucose (Walls 2009).

After production of acid and the fall in oral pH (typically below pH 5.3), there is a progressive increase in pH back to normal levels (about pH 6.8). During the period when the pH in the mouth is low, the tooth enamel is demineralised, then remineralisation takes place once pH has returned above the critical pH: this remineralisation process is catalysed by fluoride in a low concentration. The mouth has a finite capacity for repair and, if demineralisation is greater than remineralisation, then cavities are formed, which need to be treated by a dentist. The key to this process is that it is the frequency of ingestion of sugars, rather than the absolute amounts, that is most important in risk for dental caries (Walls 2009). For children, dentists recommend having no more than four episodes of sugar-containing foods and drinks per day, but there are no specific recommendations for adults. It is also very important to remove dental plaque (where bacteria reside) by regular brushing with fluoride toothpaste. Fluoride can both help teeth to remineralise following an episode of demineralisation and to develop greater resistance to demineralisation. This occurs because fluoride acts as a catalyst to enhance the remineralisation of demineralised enamel or dentine and the nature of this remineralisation process results in greater resistance from the tooth surface to further episodes of acid attack. This takes place both with episodic exposure to fluoride when brushing with fluoride toothpaste, and sustained exposure via water fluoridation. This is important in the maturation of children's teeth, but also has a direct benefit for the teeth of adults.

Dental erosion is also a concern when considering beverages with low pH, commonly from the presence of fruit acids or when drinks have added acids or contain elements that dissociate at low pH (for example, phosphoric acid in cola drinks). When exposed to pH levels below 2.5, the enamel or dentine surface will undergo catastrophic softening with overt dissolution and loss of bulk mineral. This is exacerbated if teeth are brushed immediately after consuming acidic foods or drinks, as the softened enamel is further damaged by brushing. Dental erosion is of particular concern when it occurs in childhood, as the loss of significant amounts of tooth enamel and dentine is irreversible (Walls 2009). The frequency of consumption of acidic drinks should be limited, and they should not be held in, or 'swished' around, the mouth. Drinking through a straw may help to minimise the effect acidic drinks have on teeth, and people should wait for at least one hour after consuming acidic foods or drinks before brushing teeth (BDF 2009). The health effects of a number of beverages are outlined below. It should be noted that this section on beverages applies mainly to adults and that some of the drinks discussed may not by suitable for consumption by children. A review conducted in the USA has also investigated the relative health effects of beverage consumption (Popkin *et al.* 2006).

Water

Drinking water has the advantage of fulfilling hydration requirements without providing additional energy or adversely affecting dental health. In the UK, drinking water is provided by both tap water and bottled water, and, from a nutritional point of view, bottled and tap water are not significantly different. In both cases, mineral content varies according to the water source, and (depending on the source) drinking water may provide small amounts of calcium, sodium and magnesium, although water is not a primary source of these minerals in the diet (Southgate 2001). According to the most recent NDNS of adults, 59% of men and 73% of women consume tap water, and 23% of men and 27% of women consume bottled water (Henderson *et al.* 2002). The NDNS of children aged 1.5–4 years old estimated that 92% of children consumed tap water and 4% consumed 'mineral or tonic waters' (Gregory *et al.* 1995), and about 60% of children aged 4–18 years old consumed tap water and 9% consumed bottled water (Gregory & Lowe 2000).

Waters flavoured with fruit extracts and other flavourings, in combination with either sugar or energy-free sweeteners, are also available and these may provide some energy, depending on their sugar content. Industry figures indicate that sales of bottled waters increased from 2002 to 2006 but decreased in 2007 and 2008. The consumption of bottled water per person per year in 2008 was estimated to be approximately 33 l (BSDA 2009).

Tea

Tea is the second most commonly consumed beverage in the world after water, and black, oolong and green teas are all produced from the leaves of the plant *Camellia sinensis* using different processing methods. Black tea is the most commonly consumed type of tea in the UK. According to the NDNS, 77% of adults in the UK drink tea, with a mean consumption (among consumers) of 540 ml (just over two mugs) per day (Henderson *et al.* 2002). Black tea infusions contain small amounts of potassium, magnesium, fluoride and phosphorus, and if consumed with milk, provide a range of additional nutrients in small amounts, including some calcium, B vitamins and energy. A mug of tea with semi-skimmed milk and no sugar provides approximately 18 kcal (73 kJ). Tea also contains caffeine (discussed in a later section) and a variety of polyphenolic compounds (Duthie & Crozier 2003). Tea drinking is associated with a decreased risk of CHD, and this may be because of its polyphenol content (Ruxton 2008a, 2009), although a mechanistic link between polyphenol intake and reduced risk of CHD has not been established. Tea has also been associated with reduced risk of cancer, dental caries and bone loss, although the evidence for these associations is weaker than for CHD (see Ruxton 2008a). In contrast, there has been concern that some polyphenols (tannins) in tea might inhibit the bioavailability of non-haem iron, increasing risk of sub-optimal iron status in at-risk groups. A review of the evidence in the UK suggested that those at risk of low iron status should avoid drinking tea at mealtimes, while there is no need to restrict tea consumption in those not at risk (Nelson & Poulter 2004). However, a recent draft report on iron from the Scientific Advisory Committee on Nutrition (SACN) found that, in practice, consumption of tea appeared to have a little effect on iron status in the UK population, and concluded that polyphenols in tea, and other potential inhibitors of iron absorption, were unlikely to be of importance in determining iron status in the UK (SACN 2009).

If tea is consumed with sugar added, this increases its energy content and may influence risk of dental caries, especially if good dental hygiene is not practised.

There are a wide variety of herbal teas available, for example, chamomile, peppermint and fruit teas, which are often caffeine free. These provide hydration without caffeine for those who wish to avoid it, and, if taken unsweetened, or with an energy-free sweetener, they do not provide energy.

Coffee

Coffee is also widely consumed in the UK, with 70% of adults reporting coffee consumption in the NDNS (Henderson *et al.* 2002). Coffee contains small amounts of potassium, calcium and phosphorus. It also contains a number of polyphenols including caffeine. As with tea, when consumed with milk, coffee provides small amounts of a range of additional nutrients, including some calcium, B vitamins and energy. If sugar is added to coffee, this increases its energy content and may influence risk of dental caries, especially if good dental hygiene is not practised.

Some coffees may be made with large amounts of milk, in which case, the quantity of nutrients and the energy content can increase significantly. Gourmet coffees may also contain added sugar syrups and/or cream, and there is concern that consumers should be made aware of the potentially large amounts of energy these beverages contain.

There are associations involving boiled-coffee consumption (boiling coffee grounds in water for approximately 10 minutes, as is popular in Finland, but not widespread in the UK), increased cholesterol levels and increased risk of cardiovascular disease (see Buttriss 2005). However, moderate consumption (about three and a half mugs – one mug being 260 ml per day) of coffee prepared by other methods (*e.g.* instant or filter) does not appear to increase risk of cardiovascular disease.

Caffeine in beverages

Caffeine is contained in tea, coffee, colas and some energy drinks. The caffeine content of a selection of drinks is shown in Table 5.

Caffeine has a mild diuretic effect, but moderate caffeine consumption (up to about 500 mg per day – the amount in about five mugs of instant coffee) does not appear to cause dehydration (Armstrong 2002; Armstrong *et al.* 2005). With a few exceptions (*e.g.* strong Turkish coffee), the fluid in a caffeinated beverage compensates for the short-term diuretic effect it produces.

Stookey (1999) suggested that each milligram of caffeine consumed stimulates the formation of 1.1 ml of

Table 5 Guide to the amount of caffeine in beverages

1 mug* of instant coffee	100 mg
1 mug of filter coffee	140 mg
1 mug of tea	75 mg
1 can of cola	Up to 40 mg
1 can of 'energy drink'	Up to 80 mg

Source: FSA (2008).
*A mug = 260 ml.

urine. However, the evidence suggests that the relationship is not linear, but rather there is a threshold level below which little or no effect on urine production is observed (Maughan & Griffin 2003). The review by Maughan & Griffin suggested the level of caffeine consumption below which, hydration status will not be compromised is 300 mg per day, although more recent studies indicate this may be 500 mg per day (Armstrong 2002; Armstrong *et al.* 2005). A review by Ruxton (2008b) found that there was some increase in urinary output when caffeine intakes were in the region of 600 mg per day, but no effect was observed below this level of consumption (Ruxton 2008b).

Women in the UK who are pregnant are advised not to consume more than 200 mg of caffeine per day because intakes above this level are associated with greater risk of low birthweight and miscarriage (COT 2008).

Milk and non-dairy alternatives

A variety of milks, including cows', sheep's and goats' milks, and non-dairy alternatives, such as soya, oat and rice drinks, are consumed as a beverage, either alone or added to other drinks such as tea and coffee. Cows' milk is the most common type of milk consumed in the UK by far, with approximately 50% of adults consuming milk as a drink and 85% consuming milk on breakfast cereal or in puddings (Henderson *et al.* 2002). The majority of children consume some cows' milk, with 88% of 1.5-year-olds (Gregory *et al.* 1995) and 93% of 4–18 year-olds (Gregory & Lowe 2000) consuming milk as a drink, and 75% of 1.5 year-olds (Gregory *et al.* 1995) and 99% of 4–18 year-olds consuming cows' milk on cereal or in cooking (Gregory & Lowe 2000). Cows' milk is an important source of protein, calcium, magnesium, zinc, riboflavin, vitamin B12 and, in the case of whole milk, vitamin A. For UK adults, cows' milk provides 43% of calcium intake, 33% of riboflavin intake and 27% of vitamin A intake (Henderson *et al.* 2002). For children aged 1.5 to 4.5 years, milk provides 27% of vitamin A, 41% of riboflavin and 51% of calcium intakes (Gregory *et al.* 1995), and for those aged 4–18 years old, milk provides 16% of vitamin A, 25% of riboflavin and 27% of calcium intakes (Gregory & Lowe 2000). Milk consumption appears to protect against dental caries because of the presence of protective factors such as calcium, phosphate and casein (Moynihan 2000). Whole milk, in particular, is also a source of saturated fatty acids and provides approximately 9% of saturated fatty acid intake in the diet of UK adults (Henderson *et al.* 2002).

Thus, cows' milk provides hydration and is an important source of nutrients. However, the saturated fatty acid content of whole milk means that, for most of the population, consumption of semi-skimmed (approximately 2% fat), 1% and skimmed varieties rather than whole milk (3.9% fat) should be encouraged. Very young children should drink whole milk rather than reduced-fat varieties until they are at least 2 years old, after which semi-skimmed milk can be introduced gradually, provided the child is eating a varied diet and has a good appetite. One per cent or skimmed milk should not be given to children until they are at least 5 years old (FSA 2009).

Products such as milkshakes, hot chocolates and other sweetened milk drinks are also a source of hydration and nutrients. However, they generally contain added sugar, which provides additional energy.

Non-dairy milk alternatives, such as soya drinks, are from plant sources and so have a different nutrient profile to cows' milk, being lower not only in saturated fatty acids, but also in other nutrients, such as riboflavin, vitamin B12 and calcium. Commercial varieties are commonly fortified with calcium and may be sweetened. These products provide an alternative for those who cannot, or prefer not to, consume cows' milk, but care should be taken when consuming sweetened varieties, as these provide additional energy and frequent consumption may affect dental health.

Fruit juices, smoothies and other fruit drinks

Fruit juices are extracted from fruit, with most of the fruit pulp (and hence the fibre) removed. Smoothies typically contain a mixture of fruit juice and puréed fruit, and may also be blended with yoghurt or milk. Thirty-six per cent of 1.5–4.5 year-olds (Gregory *et al.* 1995), about 50% of 4–18 year-olds (Gregory & Lowe 2000) and about 45% of adults (Henderson *et al.* 2002) in the NDNS reported consuming fruit juices. Industry data suggest that fruit juice consumption increased year-on-year from 2002 to 2007, but decreased in 2008. Sales of smoothies, which saw large increases from 2002 to 2007, also decreased significantly in 2008. Estimated consumption in 2008 was 21 and 1 l per person per year for fruit juices and smoothies, respectively (BSDA 2009).

Juices and smoothies contain vitamins, such as vitamin C, and plant bioactives, such as carotenoids and polyphenols, depending on the fruits used (Saltmarsh *et al.* 2003). Fruit juice makes a significant contribution to vitamin C intakes in the UK population in both adults (Henderson *et al.* 2002) and young people (Gregory & Lowe 2000). There is some evidence from epidemiological and intervention studies that consumption of fruit juice may reduce the risk of CHD (Ruxton *et al.* 2006). Smoothies may contain some fibre, depending on the amount of fruit purée included. One 150-ml glass of fruit juice can count as one portion, and smoothies that contain at least 150 ml of fruit juice as well as 80 g of crushed/pulped fruit can count as two portions of the five portions of fruit and vegetables a day recommended by the Department of Health.

Although juices and smoothies supply water and nutrients, they do not provide equivalent amounts of fibre to whole fruit (although the purée in smoothies makes them richer in fibre than juices). In addition, their relatively high sugar content (naturally present from the fruit) means that they provide energy, and frequent consumption may be detrimental to dental health because of both their sugar content and relative acidity. Juice drinks are products that contain anything less than 100% pure fruit juice. This covers a wide range of products, including ready-to-drink and dilutable varieties (for more details, see Caswell 2009), and their sugar and energy contents will depend on their composition.

Soft drinks

Soft drinks include carbonated and some still beverages, which may be sweetened with sugars or energy-free sweeteners and flavoured with fruit or vegetable extracts or other flavourings. In the latest NDNS for adults, sugar-sweetened carbonated beverages were the most commonly consumed drink after tap water, tea and coffee, consumed by 52% of men and 42% of women. Low-energy carbonated soft drinks were consumed by 27% of men and 36% of women, respectively (Henderson *et al.* 2002). For children aged 4–18 years old, 78% of boys and 75% of girls consumed sugar-sweetened carbonated drinks, and 44% of boys and 46% of girls consumed low-energy soft drinks (Gregory *et al.* 1995). Sales figures indicate that consumption of carbonated soft drinks declined from 2002 to 2007, but increased in 2008 when consumption was estimated to be 97 l per person per year (BSDA 2009).

In the case of sugar-sweetened soft drinks, while they are a source of hydration for many consumers, it is important to be aware of their energy content and also of their potential adverse effect on dental health, both because of their sugar content and because they often have a high level of acidity. Diet versions of soft drinks, which are sweetened with low-energy sweeteners, have the advantage of supplying water without a significant amount of energy, but may still be acidic and so increase risk of dental erosion if consumed too frequently.

Sports and energy drinks

Sports drinks are designed to provide a source of carbohydrate for energy and to promote hydration before, during and after exercise, replacing fluids and electrolytes lost as a result of sweating. The rate at which water is absorbed into the body depends partly on the composition of the food or drink ingested. The concentration of solutes (*e.g.* sodium, potassium, bicarbonate and chloride) in body fluids is closely controlled, and the speed of water absorption from the gut is modulated, so that this balance is not disturbed. Thus, if the composition of a drink is manipulated in a particular way, then it can be absorbed more rapidly than pure water. Although the tonicity (osmolality compared with that of body fluid) of sports drinks is often perceived to be the most important variable, in fact, it is the specific ingredients used and their concentrations that determine a drink's efficacy at rehydrating and aiding recovery. Generally, sports drinks contain some form of carbohydrate, to address carbohydrate depletion, and electrolytes, to increase the rate of water absorption and to replace those lost in sweat. Evidence suggests that sodium is the only electrolyte that should be added to sports drinks, and without sodium, drinks will be ineffective at restoring fluid loss experienced during, for example, endurance exercise. However, optimal sodium concentrations (30–90 mmol/l) can make drinks unpalatable to many consumers, and commercial sports drinks tend to contain 20–23 mmol/l. Carbohydrate, usually in the form of sugars, is also added to sports drinks, usually at a concentration of about 6% weight by volume (w/v). Higher concentrations (>10%) may cause gastrointestinal disturbances because of a temporary secretion of additional water into the intestine (Shirreffs 2009).

The amount of fluid and sodium lost when exercising will vary according to the intensity of exercise, the environmental conditions and the sweat rate of the individual, but it has been suggested that the addition of carbohydrates and sodium to drinks, either as a commercial sports drink or home-made version, is necessary only when exercising intensively for about 40 minutes to an hour, or longer and losing 1% to 2% of body mass.

Energy drinks generally contain sugars and flavourings and may contain stimulants, such as caffeine and herbal extracts such as guarana. Sales of both sports and energy drinks increased significantly between 2002 and 2008 (BSDA 2009).

Alcoholic beverages

Alcoholic beverages vary in their water and alcohol content, with a standard measure of beer containing much more water than a standard measure of spirits. Alcohol has a diuretic effect, and so the effect of consuming alcoholic beverages on overall water balance depends on the amount of alcohol *vs*. the water consumed. Consumption of strong alcoholic drinks without additional fluids can cause dehydration (James & Ralph 2001).

As can be seen in Figure 2, drinking dilute alcoholic beverages can result in a net gain of water, but as the strength and serving size of drinks increase, so does the net loss of fluid. This is shown in more detail in Table 6.

Alcohol provides energy (7 kcal/g), and so alcoholic beverages contribute to energy intake. As with other energy-containing drinks, consumption of energy from alcohol does not appear to reduce subsequent energy intake, resulting in an overall increased energy intake. In addition, alcohol may actually increase appetite through an aperitif effect in the short-term (Yeomans 2004). Some alcoholic beverages also contain sugar and fat, which increase their energy content.

When consumed in excess, alcohol can cause damage to every system in the body as well as having negative personal and social consequences for those concerned (Foster & Marriott 2006). However, the effects of moderate alcohol consumption are less clear and depend on drinking patterns and the type of alcoholic beverages consumed, as well as age, gender, risk of cardiovascular disease (CVD) and other lifestyle factors. Based on data in male middle-aged and older subjects with a high risk of CVD, there appear to be potential benefits to cardiovascular health associated with consuming one to two drinks per day for this population (Buttriss 2005), but this level of consumption for women seems to increase the risk of breast cancer. It is suggested that the current UK upper limits of no more than 2–3 units (16–24 g) of alcohol per day for women and no more than 3–4 units (24–32 g) of alcohol per day for men are sensible, but that it would be unwise to encourage alcohol consumption in those who

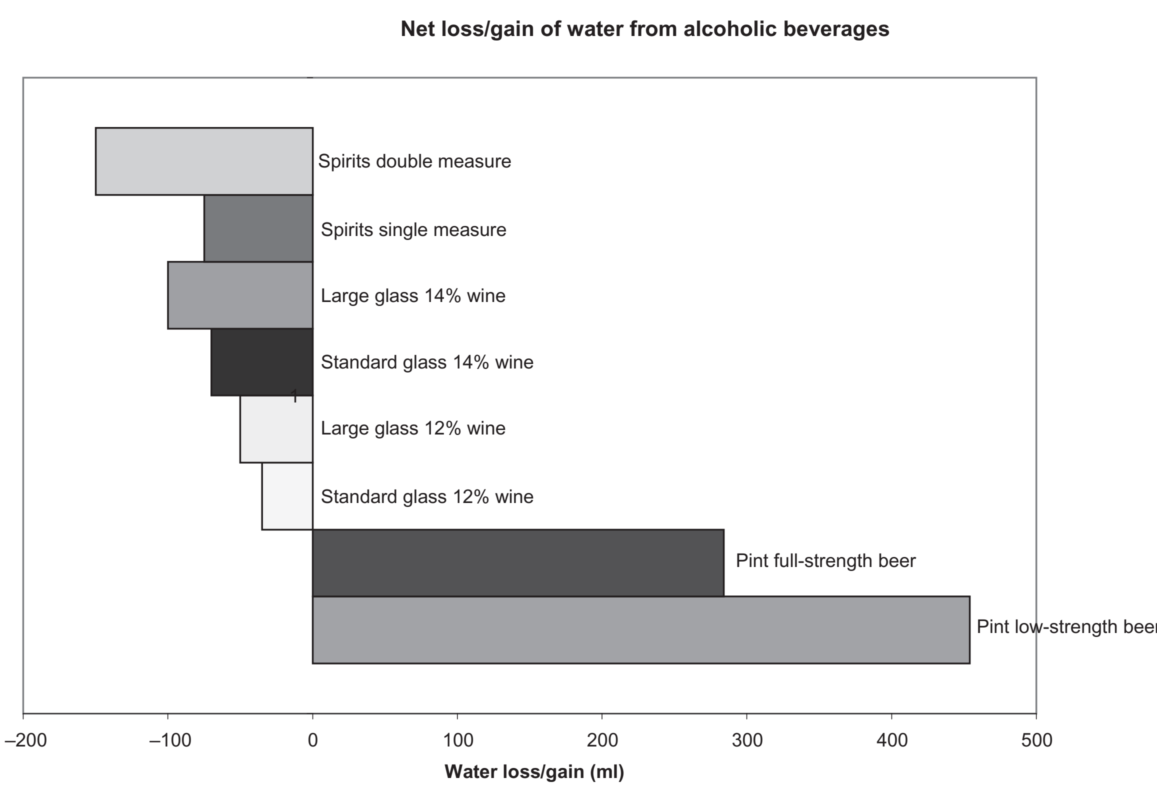

Figure 2 Effect of consumption of alcoholic beverages on body water balance.

Table 6 The effect of alcohol on water balance

Drink	Strength (% of alcohol)	Serving	Volume (ml)	ml of alcohol per serving	Loss of water in urine* (ml)	Net gain of water† (ml)
Low-strength beer, lager and cider	2	Bottle	330	6.6	66	264
		Can	440	8.8	88	352
		Pint	568	11.4	114	454
Beer, lager and cider	3	Bottle	330	9.9	99	231
		Can	440	13.2	132	308
		Pint	568	17.0	170	398
	4	Bottle	330	13.2	132	198
		Can	440	17.6	176	264
		Pint	568	22.7	227	341
	5	Bottle	330	16.5	165	165
		Can	440	22.0	220	220
		Pint	568	28.4	284	284
Super strength beer, lager and cider	9	Bottle	330	29.7	297	33
		Can	440	39.6	396	44
		Pint	568	51.1	511	57
Alcopops	5	Bottle	330	16.5	165	165
Spirits	40	Small	25	10.0	100	–75
		Large	35	14.0	140	–105
		Small double	50	20.0	200	–150
Wine and champagne (red, white rose or sparkling)	12	Small	125	15.0	150	–25
		Standard	175	21.0	210	–35
		Large	250	30.0	300	–50
	13	Small	125	16.3	163	–38
		Standard	175	22.8	228	–53
		Large	250	32.5	325	–75
	14	Small	125	17.5	175	–50
		Standard	175	24.5	245	–70
		Large	250	35.0	350	–100

*1 ml of alcohol = loss of 10 ml of water.
†Net gain of water = volume – net loss of water.

do not currently consume it (Grønbaiek 2009). There is some concern that guidelines on safe levels of alcohol consumption are not widely understood. A survey in 2006 found that almost two fifths of people could not say what the sensible drinking guidelines were. Further research, conducted in 2008, found that 77% of people did not know how many units were contained in a typical large glass of wine (PAC 2009). In this context, it is important to increase consumer understanding about the safe consumption of alcohol, which is being addressed by initiatives such as the Government's 'Know Your Limits' campaign.

Summary

Many foods and all beverages (with the exception of strong alcoholic drinks such as wine and spirits) contribute to our dietary water intake and can help to ensure that we are adequately hydrated. However, in choosing which beverages to consume, it is also important to consider the other health effects (positive and negative) these may have. The relative advantages and disadvantages of some of the beverages discussed are summarised in Table 7. Some beverages can supply nutrients and plant bioactives. In addition, the energy content of beverages should be considered, particularly for people who are trying to control or reduce their energy intake in order to maintain or lose weight. Finally, the effect of beverages on dental health is an important consideration, and the frequency of consumption of those that may damage teeth should be limited, particularly in children.

How much water do we need?

The amount of water different people need from food and drink varies considerably and is affected by numerous factors, including climate, clothing and physical

Table 7 The advantages and disadvantages of beverages for health

Beverage	Advantages	Disadvantages
Drinking water	Provides water without additional energy.	May not be sufficient for rehydration during or after intense exercise undertaken for more than 40 minutes–1 hour.
Tea	Provides water, some nutrients (especially if consumed with milk) and plant bioactives. Contains a small amount of energy. May help reduce risk of cardiovascular disease.	May increase risk of low iron status in at-risk groups if consumed with meals. Contributes to caffeine intake, which may be an issue for some consumers.
Coffee	Provides water, some nutrients and plant bioactives.	May lead to high caffeine intakes if caffeinated varieties are over consumed.
Fruit juice/smoothie	Provides water, and some vitamins and plant bioactives. Smoothies may provide fibre.	High natural-sugar content and, hence, energy content. May increase risk of dental caries and dental enamel erosion if consumed frequently between meals.
Milk	Provides water and a rich source of nutrients.	Source of saturated fatty acids.
Soft drinks	Provide water.	Sugar-sweetened versions have a high energy content. May increase risk of dental caries and dental enamel erosion if consumed frequently between meals.
Sports drinks	Some provide optimal amounts of sodium and carbohydrate for those performing intense exercise.	Moderate sugar and energy content, and not necessary for sedentary people or those doing moderate exercise.
Alcohol	More dilute alcoholic beverages such as beer, cider or shandy provide some water. Moderate alcohol consumption may have cardiovascular benefits for middle-aged and older adults.	Concentrated alcoholic beverages (*i.e.* wine and spirits) are dehydrating. Excessive consumption of alcohol is detrimental to health. Relatively high energy content and promotes overconsumption of energy. Some alcoholic beverages, particularly white wine, can contribute to dental erosion.

activity. This makes it very difficult to provide a specific recommendation as to how much water each of us needs (see 'What are the recommendations for water intake'). However, although there is uncertainty about the amount of fluid each of us requires, the body has sensitive mechanisms for controlling hydration, and, in most cases, total body water remains remarkably stable. This section looks at the factors that affect the water needs of different age groups and the effect of physical activity on water needs.

Infants and children

A newborn infant's body mass comprises 75% water – the highest proportion of body water at any stage of a person's life. This decreases to approximately 60% by the time the infant reaches 6 months. Initially, an infant's diet is made up entirely of breast- or formula milk, which fulfils hydration and nutrient requirements. There are a number of physiological differences between infants and adults, including a greater surface area compared with body mass, higher water turnover and less ability to sweat. This means that infants fluid requirements are proportionally much greater than those of adults. The average volume of human milk consumed by infants during the first 6 months of life is 780 ml/day (Grandjean & Campbell 2004), although the range of intakes is wide, from 525 ml/day for a 3.5-kg newborn to 1200 ml/day for an 8-kg 6-month-old, based on the recommended amount of 150 ml/kg/day (Heird 2004). In the case of a 5-kg infant, the recommended intake would be 750 ml/day. However, if this recommendation was applied to a 70-kg adult, this would amount to 10.5 l/day.

An infant's fluid requirements result in an increase in the fluid requirements of lactating women (see section 'Adults'). Breastfed infants consume sufficient water from breastmilk. However, formula-fed infants may require some cooled boiled water in hot weather to prevent overfeeding. In this case it is important to consult a health visitor to ensure the infant is not water loaded. As infants start to consume some solid foods, their fluid intake falls to about 120 ml/kg/day, and this will decrease further as more solid foods are included in the diet. As such, it is important to note that the recommendation of a fluid intake of 150 ml/kg/day is appropriate for young infants less than 6 months old who are exclusively breast- or formula fed. However, this would overestimate requirements for older infants consuming solid foods (V. Shaw, personal communication).

It is also important to note that infants have a very limited capacity to excrete solutes in the urine, making them very vulnerable to solute imbalance, for example, from insufficiently diluted formula milk (Grandjean & Campbell 2004) or from salt added to weaning foods.

As with infants, children have a higher proportion of body water than adults. They are also less heat tolerant and can become dehydrated when exercising, particularly in hot climates. Encouraging children to consume fluids regularly is particularly important in this context. Patterns of drinking behaviour appear to be established in childhood, so it is important that young children get used to drinking a range of appropriate beverages in order to maintain hydration (Saltmarsh 2001). Dietitians generally recommend that children more than one year of age consume 6–8 drinks per day, with toddlers having relatively small drinks (*e.g.* 120–150 ml per drink) and older children consuming larger drinks (*e.g.* 250–300 ml per drink for a young teenager).

Adults

Adult women tend to have lower water requirements than men because of their lower body mass and lower proportion of body water. It is estimated that the total water needs of sedentary men are approximately 2.5 l/day, increasing to 3.5 l/day if moderately active and approaching 6 l/day if active and living in a warm climate. There are fewer data on women's water requirements, but they are likely to be in the region of 0.5–1 l lower than those for men (Sawka *et al.* 2005).

Women may need slightly more fluid when pregnant, and significantly more when lactating. The estimated additional requirement is approximately 0.3 l/day for pregnancy [Institute of Medicine (IoM) 2005], and between 0.7 [European Food Safety Authority (EFSA) 2008] and 1.1 l/day (IoM 2005) for lactation.

Older adults

Water requirements are not different for older compared with younger adults. However, there are a number of physiological changes that take place during ageing that may affect water balance in this population, putting older adults at greater risk of both overhydration and, more commonly, dehydration. The thirst response declines in older people, and total body water is also lower, because of loss of muscle mass and a proportional increase in body fat. There is a reduction in kidney function in old age, meaning the kidneys are less able to concentrate urine, increasing urinary water loss, and also less efficient at producing large quantities of urine to address overhydration. This may be exacerbated by medications that affect kidney function. Other medical conditions may also affect older adults' ability to drink, including dementia, frailty, infections and difficulty in swallowing (Mentes 2006).

Adequate fluid consumption is associated with a number of positive health outcomes in older people, including fewer falls, lower rates of constipation (Robinson & Rosher 2002) and a reduced risk of bladder cancer in men (Michaud *et al.* 1999). Conversely, dehydration in older adults increases the risk of many conditions, including urinary tract infections, confusion or delirium, renal failure and increased wound healing time (Mentes & Culp 2003; Bennett *et al.* 2004), and dehydration is associated with increased mortality rates in hospitalised older adults (Warren *et al.* 1994).

The prevalence of dehydration in older adults is currently unclear (see McKevith 2009). Although the hydration status of healthy, free-living older adults has been found to be no different to that of younger adults (Bossingham *et al.* 2005), there is some doubt about the indices used to measure dehydration in this population (Stookey *et al.* 2005). One study in the USA suggested that 48% of a sample of older adults admitted to hospital were retrospectively identified as suffering from chronic dehydration (Bennett *et al.* 2004), and another study shows that 31% of nursing home residents were dehydrated in the period studied (Mentes *et al.* 2006). Higher ambient temperatures in a heated ward or nursing home may contribute to increased insensible water losses, as would being in the bed nearest to large windows when the sun shines, from research conducted on fluid balance on wards (C. Collins, personal communication). This suggests that older adults who are ill or have high levels of physical dependence are more at risk of dehydration than those who are in better health and that care needs to be taken in supporting and encouraging this population to drink (Primrose *et al.* 1999). In a small 6-month study in two residential care homes, it was found that making drinking water available and visible, with staff providing reminders for residents to drink regularly, resulted in participants experiencing an increased feeling of wellbeing, being more able to sleep through the night, feeling steadier on their feet, feeling less dizzy and an easing of bladder problems. One of the homes involved reported a 50% reduction in falls during the study. The main barrier participants reported to drinking more was a fear of increased trips to the toilet, and although toilet trips appeared to increase initially, this returned to baseline over the course of the study (Anglian Water 2009).

Hydration and physical activity

Physical activity raises body temperature, and, particularly in a warm or hot environment, sweating provides a mechanism to dissipate this excess heat and maintain a stable body temperature. Sweating is a route for loss of both water and sodium, and it is important to consider both in order to maintain hydration. The amount of sweat produced can vary greatly and depends on many factors, including the environmental conditions, the intensity of physical activity, clothing worn, and the fitness level and heat acclimatisation of the individual. Even accounting for these factors, individual sweating rates may be substantially different (Murray 2007). Women tend to have lower sweat rates than men because of smaller body size and a lower metabolic rate when active (Shapiro *et al.* 1980).

Sweat rates may reach 3 l/hour during vigorous exercise in a hot climate (Rehrer & Burke 1996). Acute sweat losses for team and individual endurance sports tend to be in the region of 1–2 l/hour (Sawka *et al.* 2005). Even when swimming, significant amounts of water can be lost as sweat (Kondo *et al.* 1995; Leiper & Maughan 2004) Thus, during physical activity, particularly for long periods in a hot climate, there is a risk of dehydration if fluids are not sufficiently replaced. It is well established that dehydration of more than 2% loss of body mass results in decreased physical performance and work capacity (IoM 2005) in addition to detrimental effects on cognitive function (Maughan *et al.* 2007). A 2% loss of body mass equates to a loss of 1.4 kg (roughly equivalent to 1.4 l of sweat) in a 70-kg person, and this level of dehydration after physical activity is not unusual in athletes, soldiers and manual workers (Sharp 2006). When water is lost as sweat, sodium is also lost, and an athlete losing 5 l of sweat per day can also lose the equivalent of more than 10 g of salt as sodium (Murray 2007), and thus, it is important that sodium as well as water needs are considered when sweat losses are high.

Although most moderately active people living in a temperate climate may not be at high risk of dehydration, those who are highly physically active, either for work or sporting activities, particularly in a warm or hot environment, need to ensure they remain hydrated. The aim should be to start any physical activity well hydrated. For those undertaking large amounts of physical activity, this process should start at least 4 hours beforehand, consuming beverages slowly so that urine output is not increased during activity. Consuming beverages with sodium, or having small amounts of salty foods, can help to stimulate thirst and to retain the fluid consumed (Sawka *et al.* 2007). Fluid can also be consumed during physical activity to prevent excessive dehydration. The amount needed will depend on the individual's sweat loss for a given activity, and calculations of fluid requirements can be made by measuring changes in body mass and estimating sweat rates (Maughan & Shirreffs 2008). For occupational activity, calculations of water requirements have been developed based on temperature and work cycles (Mountain *et al.* 1999). The composition of the fluids consumed may be important, and, for prolonged physical activity in hot weather, fluids containing carbohydrate and electrolytes such as sodium provide more effective hydration than pure water (see 'Sports and energy drinks' section). Sodium in fluids helps to replace that lost in sweat and stimulates thirst, while carbohydrate provides some energy (Murray 2007). After physical activity, enough fluid should be consumed to replace that lost during activity. It is recommended that, for rapid rehydration, 1.5 l of fluid is consumed for each kilogram of body mass lost during exercise, the additional 0.5 l of fluid compensating for increased urine production (Shirreffs & Maughan 1998). It is also important to replace sodium losses after activity, which can be achieved by drinking beverages or eating foods containing small amounts of sodium (Maughan *et al.* 1996).

It should be noted that pre-pubescent children have lower sweat rates than adults (Meyer *et al.* 1992) and so may be more susceptible to overheating when physically active in warm or hot climates. In older adults, the thirst response to dehydration may be weaker and the ability to concentrate urine decreased (see section on older adults), and so this population group and their carers should take care to maintain hydration, especially when older adults are physically active.

Hydration during the holy month of Ramadan

During the holy month of Ramadan, the ninth month of the Islamic calendar, Muslims abstain from eating, drinking, smoking and sexual relations from sunrise to sunset. Because the Islamic calendar is lunar and does not correspond to the Gregorian calendar, Ramadan's occurrence moves forward each year and so can take place in different seasons from year to year. Depending on latitude, the hours between sunrise and sunset, and thus the length of the fast, will vary according to the season. This means that Muslims around the world are exposed to differing environmental conditions and length of daily fasting duration during Ramadan, both because of their geographical location and the time of year. The occupational activity of Muslims within a

Table 8 Estimated fluid intake across Europe

	UK†	France‡	Germany§	Italy¶	Belgium**	The Netherlands††
Total water (ml/day)*		1984	1875			
Total beverages (male) (ml/day)	1988	1263	1530	1027	1465	2622
Total beverages (female) (ml/day)	1585	1130	1469	917	1342	2402

*Total water includes water obtained from food and beverages.
†Henderson *et al.* (2002) (7-day dietary record).
‡Volatier (2000) (7-day dietary record).
§Manz & Wentz (2005b) (7-day dietary record), figure includes metabolic water.
¶Turrini *et al.* (2001) (7-day dietary record).
**Devriese *et al.* (2006) (2-times 24 hour recall).
††TNO (1998) (2-day dietary record).

country or area will also vary. These factors affect the risk of dehydration during the Ramadan period. A review of studies on the health effects of Ramadan concluded that, although body water will be depleted during daylight hours, most Muslims in sedentary occupations would not be at risk of clinically significant dehydration during fasting. Headaches are commonly reported during Ramadan, which may be because of dehydration, although caffeine deprivation may be a more important cause. If the fasting period is very long (*e.g.* 18 hours) or physical work is carried out, especially in a hot climate, then risk of dehydration increases and may impair physical and cognitive performances (Leiper *et al.* 2003).

Do we need water to 'detoxify' ourselves?

Much attention has been given in the popular press to water and hydration as aids to 'detoxifying' the body, and the opinion that increasing fluid consumption helps the body to detoxify itself may be widely held. In fact, the body has sophisticated systems for the detoxification and excretion of harmful substances, mainly centred on the liver and kidneys, lungs and gut. The kidney uses various mechanisms to rid the body of toxins. These include glomerular filtration, where fluid in the blood is filtered across the capillaries of the glomerulus; tubular secretion, where selected molecules are transported from the blood into the filtrate; and various degradative metabolic pathways, which break down chemical compounds into less-complex substances.

Detoxification, or 'detox', is the process of extracting and eliminating toxins from the blood and tissues. The current 'popular' understanding of detox, however, also includes the cleansing of the body of residues of toxins such as pesticides, and other environmental pollutants, which are believed by many to be accumulating in the body (Fitzpatrick 2003). Although water intakes may affect the rate at which the kidney filters out toxins, it is not clear whether this is clinically significant. Indeed in some cases increased water intake has actually reduced filtration rates. Thus there is no evidence that consuming additional water when hydrated allows the body to excrete toxins more effectively (Negoianu & Goldfarb 2008). Although rare, drinking too much water can lead to intoxication with potentially life-threatening hyponatraemia (low levels of sodium in the blood) (see 'What are the effects of overhydration').

How much water are we currently drinking?

Data on current water consumption in the British population are not available. The most recent NDNS of adults collected data on food and beverage consumption in Britain in 2000/2001. The estimated average total fluid intake from drinks for adult British men aged 19–64 years was 1988 ml/day, and 1585 ml/day for women (Henderson *et al.* 2002). The EFSA has collated information on estimated fluid intakes, and, where available, estimated water intakes (*i.e.* including water from food as well as beverages) in a small number of countries in Europe. These are summarised in Table 8. Because of differences in the way national data on fluid intake are collected, the figures from the countries in Table 8 are not necessarily comparable.

The UK NDNS does not report estimates for total water intake (*i.e.* water obtained from food and beverages). However, data on the average daily consumption of various beverages, such as bottled water, tap water, fruit juice, carbonated soft drinks, tea and coffee, were reported, and a summary of these data is provided in Table 9. Respondents included in the NDNS were asked to record everything they consumed, including drinks of water.

Table 9 Daily consumption of beverages in Great Britain

	Average consumption of all respondents who kept a dietary record (includes both consumers and non-consumers) (ml/person/day)		Average consumption for consumers of the item (ml/person/day)	Percentage of respondents who consumed each item (%)
	Men	Women		
Tea, as consumed	415	411	536	77
Herbal tea, as consumed	9	24	178	9
Coffee, as consumed	598	470	744	71
Tap water	185	253	333	66
Bottled water	54	61	229	25
Soft drinks, not low calorie	154	100	211	60
Soft drinks, low calorie	85	101	240	39
Fruit juice	49	47	106	45
Alcoholic drinks	500	139	425	74

Source: Hoare and Henderson (2004); Henderson *et al.* (2002).

Table 10 UK soft drinks sales 2002–2008

	Million litres per year						
	2002	2003	2004	2005	2006	2007	2008
Bottled water	1760	2070	2060	2150	2275	2175	2055
Carbonated drinks	6240	6525	6195	6065	5915	5835	5935
Dilutables	3050	3175	3125	3100	3350	3350	3250
Fruit juice	1025	1090	1130	1215	1305	1330	1285
Still and juice drinks	885	985	1090	1190	1330	1370	1380
Sports and energy drinks	235	275	320	365	405	455	505
Flavoured water	295	350	365	360	350	305	290
Total	13 490	14 470	14 285	14 445	14 930	14 820	14 700

Source: BSDA (2009).

A recent report by the BSDA (2009) provides figures on the sales of soft drinks in the UK based on data provided from the UK soft drinks industry (see Table 10). Although there has been an increase in the UK sales of most types of soft drinks listed in Table 10, the annual percentage change in sales of soft drinks shows a general decrease since 2002 in bottled water, dilutables, and still and juice drinks, and a decrease since 2005 of fruit juice. In contrast, there was an increase in annual percentage sales of carbonated drinks from 2004 (see Fig. 3). Low-calorie carbonated drinks accounted for 36% of the total carbonated drinks purchased.

What are the recommendations for water intake?

A universal water intake recommendation that is applicable to all individuals is difficult to define as there are many factors that affect an individual's need for water, such as environmental conditions, changing physical activity levels of the individual, their age, gender and body mass. Similarly, no single upper tolerable intake level for total water intake can be identified that is universally applicable regardless of individual and environmental circumstances. The EFSA expert panel recently proposed that the Dietary Reference Values (DRVs) for total water intake should include water from beverages of all kinds, including drinking and mineral water, and from food moisture (EFSA 2008). The EFSA expert panel met in September 2009 to discuss DRVs for water, following a consultation on this proposal and a set of draft DRVs for water that were published in April 2008. The draft DRVs are shown in Table 11.

Table 12 compares the draft EFSA DRVs for water with the adequate intakes defined by the Food and Nutrition Board of the IoM in the USA, and water

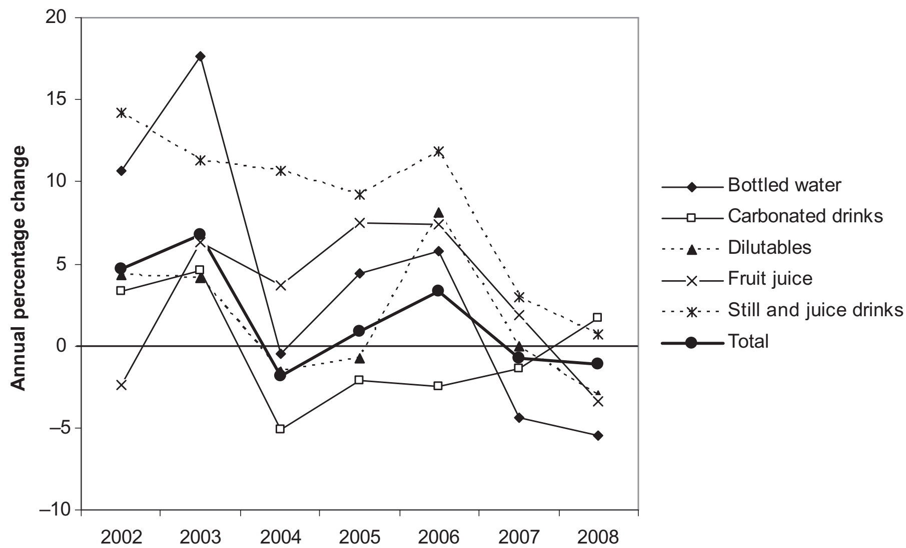

Figure 3 Annual percentage change of UK soft drinks consumption 2002–2008. Source: BSDA (2009).

Table 11 EFSA draft Dietary Reference Values for water (EFSA 2008)

	Adequate intakes*
Infants aged 0–6 months	100–190 ml/kg/day
Infants aged 6–12 months	800–1000 ml/day
Infants aged 12–24 months	1.1–1.2 l/day
Boys and girls aged 2–3 years	1.3 l/day
Boys and girls aged 4–8 years	1.6 l/day
Boys aged 9–13 years	2.1 l/day
Girls aged 9–13 years	1.9 l/day
Adolescent (14+ years) and adult females	2.0 l/day
Adolescent (14+ years) and adult males	2.5 l/day
Pregnant women	Require an extra 300 ml/day[†]
Lactating women	Require 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. Water losses incurred under extreme conditions of external temperature and physical exercise, which can be up to about 8.0 l/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.

[†]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. Assuming an increase of energy intake of 15% in the second trimester, equivalent, for example, to 300 kcal/day, an additional total water intake of 300 ml would be adequate. EFSA, European Food Safety Authority.

requirements defined by the World Health Organization (WHO). The IoM adequate intakes for water refer to total water intakes (including drinking water, water in beverages and water that has been part of food). The adequate intakes for total water are set to prevent deleterious effects of dehydration, which include metabolic and functional abnormalities. The WHO water requirements also refer to total water from drinking water, water from other beverages and water from food. Table 12 shows the recommended water intakes range from 2.5–3.7 l per day for adult men, and from 2.0–2.7 l per day for adult women. The draft EFSA recommendations (2.5 l per day for men, 2.0 l per day for women) are at the lower end of these ranges.

The UK's Food Standards Agency (FSA) recommends drinking 6–8 glasses (1.2 l) of fluid a day. If food supplies approximately 20% of our water intake (when we are relatively sedentary) (Grandjean & Campbell 2004), then the total water intake suggested by the FSA recommendations would be 1.5–2.0 l per day. This is quite low compared with the recommendations in Table 12.

Conclusions

- Water is essential for life, and maintaining optimum hydration is important for the body to function efficiently.
- It is not meaningful to give a specific recommendation regarding water requirements, as these vary widely depending on, for example, the age, gender, body mass, environmental conditions and the changing physical activity of the individual concerned.
- The body has several sensitive mechanisms for controlling the balance of body water and solutes, and in most cases, total body water remains stable.

Table 12 Recommended water intakes

	EFSA (2008) draft dietary reference values	IoM (2005) adequate intakes	WHO (2003; 2005) requirements
Infants 0–4 months			750 ml/day
Infants 0–6 months	100–190 ml/kg/day	700 ml/day	
Infants 6–12 months	800–1000 ml/day		
Infants 7–12 months		800 ml/day	
Infants 8–12 months			1.0 l/day
Infants 12–24 months	1.1–1.2 l/day		
Children 1–3 years		1.3 l/day	1.0 l/day
Children 2–3 years	1.3 l/day		
Children 4–8 years	1.6 l/day	1.7 l/day	
Children (boys) 9–13 years	2.1 l/day	2.4 l/day	
Children (girls) 9–13 years	1.9 l/day	2.1 l/day	
Adolescent boys 14–18 years		3.3 l/day	
Adolescent girls 14–18 years		2.3 l/day	
Adult (men) 19–30 years		3.7 l/day	
Adult (women) 19–30 years		2.7 l/day	
Adult (men) >19 years			2.9 l/day
Adult (women) >19 years			2.2 l/day
Adolescent (14+ years) and adult (men)	2.5 l/day		
Adolescent (14+ years) and adult (women)	2.0 l/day		
Pregnant women	2.3 l/day	3.0 l/day	4.8 l/day
Lactating women	2.7 l/day	3.8 l/day	5.5 l/day

- The most recent NDNS indicates that total beverage consumption in Britain in 2000/2001 was 1988 ml/day for males and 1585 ml/day for females.
- For most people in the UK, serious dehydration is unlikely, although some population groups may be at greater risk, particularly young people and the elderly. However, data on current fluid intakes and hydration status in the UK are limited and further research in this area would help to clarify whether the UK population are optimally hydrated.
- We can obtain water from both foods and drinks, and food typically supplies about 20% of dietary water. The water content of foods varies widely from less than 10% to over 95%.
- Drinking water can supply all our hydration needs, but many people prefer to drink a variety of beverages, which also supply water and may have other health effects, both positive and negative, as well as supplying essential nutrients.
- The body has sophisticated systems for getting rid of toxins, and it is not necessary to consume excess water or other substances to enhance this process.
- The FSA currently recommends consuming 6–8 glasses (1.2 l) of fluids per day, in addition to that provided from food. This can come from pure water and also other beverages. The recommended water intakes from EFSA, WHO and IoM are higher than this.
- Some beverages can be a significant source of calories.

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