Nutrition: vitamins and minerals

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Introduction

Both vitamins and minerals are essential in the diet in small quantities.The term 'vitamin' was not coined until early in the 20th century, to describe those chemicals in food without which a pattern of deficiency symptoms (often called a deficiency syndrome) occurs. Minerals, also called mineral elements, are those elements other than carbon, hydrogen, oxygen and nitrogen that are found in the body.

This free course, *Nutrition: Vitamins and minerals*, looks at the two main groups of vitamins: the fat-soluble vitamins A, D, E and K, and the water-soluble vitamins, those of the B group (numbered B_1, B_2, etc.) and vitamin C. It also examines the major mineral elements, and the importance of fluid balance in the body.

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Learning Outcomes

After studying this course, you should be able to:

- Understand certain minerals are required in the body and that some minerals form essential structural components of tissues
- Understand that sodium, potassium, calcium and chloride ions are important in maintaining the correct composition of cells and of the tissue fluids around them (homeostasis)
- Understand that some minerals are essential components of important molecules such as hormones and enzymes
- Understand that the correct fluid balance is essential for normal functioning of the body
- Understand that tapwater, and not just mineral water, contains minerals.

1 Vitamins

1.1 Introduction to vitamins and why we need them

Before the 19th century, one of the hazards of long sea voyages was a condition called scurvy, whose symptoms were loss of hair and teeth, bleeding gums, very slow healing of wounds, and eventually death. Hundreds of sailors and explorers died from scurvy until a Scottish physician, James Lind, in the 1750s discovered that adding a daily portion of citrus fruit to the rations of those at sea could prevent the condition, whereas adding cider, vinegar or various other substances that he tested, could not. In those days, it was considered that a disease was caused by something bad in the diet, or in the air, but not by the absence of something good, so despite Lind's evidence, his ideas were not accepted by his fellow physicians. Additionally, he was unable to confirm his work by experiments on land since, although he tried to restrict the types of food eaten by a group of volunteers to attempt to produce scurvy in them, he was unable to do so, probably because it can take several months for the condition to develop, and in that time his volunteers occasionally cheated on their diet. However, though he died disillusioned, Lind had actually discovered the importance and source of vitamin C.

Before their detailed chemical structures were known, vitamins were named by being given a letter. They are generally still referred to by that letter, as well as by their chemical name; for example, vitamin C or ascorbic acid. There are two main groups of vitamins: fat-soluble vitamins and water-soluble vitamins. The body can store fat-soluble vitamins, but any excess water-soluble vitamins are easily removed from the body in the urine, so regular intake is necessary. Vitamins are, however, needed in only very small quantities.

The daily requirement of certain vitamins is much less than 1 mg (1mg is one-thousandth of a gram), and so is measured in micrograms per day, written as µg per day, where 1 µg is one-thousandth of a milligram. The values for the daily requirements of vitamins are regularly updated as more information becomes available. The values given in Table 1 are those recommended by the UK Government's Food Standards Agency early in 2005.

Table 1 Vitamins essential for human health, reference nutrient intake (RNI) values taken from the UK Food Standards Agency website, and the main dietary sources of these vitamins.

Name	RNI values for adults per day	Main dietary sources
Fat-soluble vitamins		
vitamin A	0.6 mg for women; 0.7 mg for men	liver, cheese, eggs, butter, oily fish (such as mackerel), milk, fortified* margarine, yoghurt
vitamin D	0.01 mg (10 µg) for certain groups, e.g. pregnant women, those who rarely go outside, etc.	oily fish, liver, eggs, margarine, some breakfast cereals, bread, powdered milk
vitamin E	3 mg for women; 4 mg for men	plant oils (such as soya,corn and olive oil), nuts, seeds, wheat germ, some green leafy vegetables

vitamin K	0.07 mg(70 µg), or 1 µg per kg of body weight	green leafy vegetables (such as broccoli and spinach), vegetable oils, cereals; small amounts can also be found in meat (such as pork),and dairy foods (such as cheese)
Water-soluble vitamins		
thiamin (vitamin B_1)	0.8 mg for women; 1 mg for men	pork, vegetables, milk, cheese, peas, fresh and dried fruit, eggs, wholegrain breads, some fortified* breakfast cereals
riboflavin (vitamin B_2)	1.1 mg for women; 1.3 mg for men	milk, eggs, fortified* breakfast cereals, rice, mushrooms.
niacin (vitamin B_3)	13 mg for women; 17 mg for men	beef, pork, chicken, wheat flour, maize flour, eggs, milk
vitamin B_6 (pyridoxine)	1.2 mg for women; 1.4 mg for men	liver, pork, chicken, turkey, cod, bread, whole cereals (such as oatmeal, wheatgerm and rice), eggs, vegetables, soyabeans, peanuts, milk, potatoes, breakfast cereals
folate (folic acid, vitamin B_9)	0.2 mg, but 0.4 mg extra for women who are, or plan to be, pregnant	broccoli, sprouts, spinach, peas, chickpeas, potatoes, yeast extract, brown rice, some fruit (such as oranges and bananas),breakfast cereals, some bread
vitamin B_{12} (cobalamin)	0.0015 mg (1.5 µg)	meat (particularly liver), salmon, cod, milk, cheese, eggs, yeast extract, some breakfast cereals
pantothenic acid (vitamin B_5)	none given – should be sufficient in normal diet	chicken, beef, potatoes, porridge, tomatoes, liver, kidneys, eggs, broccoli, wholegrains (such as brown rice and wholemeal bread), some breakfast cereals
biotin (vitamin H)	0.01–0.2 mg	meat (such as kidney and liver), eggs and some fruit and vegetables, especially dried mixed fruit
vitamin C (ascorbic acid)	40 mg	wide variety of fruit and vegetables, especially peppers, broccoli, sprouts, sweet potatoes, cranberries, citrus fruits, kiwi fruit

*'Fortified' indicates that the vitamin has been added during manufacture of the food product.

Activity 1

Use Table 1 to answer the following questions.

1. Which vitamin is needed in the greatest daily amount and how much of that vitamin is needed?
2. Which other vitamins are needed by men in amounts of more than 1 mg per day?
3. Which vitamins are needed in amounts of 100 µg or less per day?

Answer

1. Vitamin C is needed in the greatest amount, namely 40 mg per day.
2. The other vitamins needed by men in quantities of more than 1 mg per day are vitamin E and the B vitamins, i.e. thiamin, riboflavin, niacin and vitamin B_6
3. 100 µg is 0.1mg, so vitamins needed in less than this quantity are vitamin D (10 µg for certain groups of people), vitamin K (about 70 µg), vitamin B_{12} (1.5 µg) and biotin (between 10 µg and 200 µg neeeded).

Activity 2

On a breakfast cereal packet, the nutrition information states that a 40 g serving of the cereal, with 125 g semi-skimmed milk, provides the following vitamins:

Vitamins	Amount per serving	% RDA
thiamin (B_1)	0.4 mg	30
riboflavin (B_2)	0.6 mg	40
niacin	4.6 mg	25
vitamin B_6	0.6 mg	30
folic acid	110 µg	55
vitamin B_{12}	0.75 µg	75

1. What is meant by % RDA in the heading of the third column here?
2. What is the RDA of thiamin in mg? How does this value compare with the information in Table 1 ? Suggest possible reasons for any difference.
3. Based on the information in Table 1, which of these vitamins are likely to be present only in the cereal, which only in the milk and which could be present in both?

Answer

1. RDA is the recommended daily allowance, so the values in the third column are the percentage of that amount that would be obtained from a bowl of this cereal with milk.
2. Knowing that 0.4 mg of thiamin represents 30% of the RDA, then the task is to calculate 100% of the RDA.

   If 30% RDA = 0.4 mg, then 1% is 0.4 divided by 30 mg and 100% is 0.4 divided by 30 x 100 mg = 1.3 mg. So the RDA of thiamin is 1.3 mg.

   Table 1 gives an RNI value for thiamin of 0.8 mg for women and 1 mg for men, so the value quoted on the cereal packet is significantly greater. The reasons for the discrepancies are unclear. It could be that the recommended daily amount of thiamin has been reduced recently, and the cereal packet information has not been updated. It may be that the cereal manufacturer is using USA rather than UK values, which may be different. Or it may be a simple error in a calculation somewhere.

If you did similar calculations for the other vitamins, you would discover similar discrepancies, though sometimes the RDA values on the cereal packet are greater and sometimes smaller than the values in Table 1. This example illustrates the problems with numerical, and other, information in the nutrition area. It is often very difficult to know how much reliance to place on a particular set of figures, or on particular information.

3. Thiamin, riboflavin, vitamin B_6 and vitamin B_{12} are likely to be present in both the cereal and the milk. Folic acid is probably present only in the cereal. Niacin appears to be present only in the milk.

Activity 3

Looking down the main dietary sources of the vitamins in Table 1, which one food contains the most vitamins? Which vitamins does this food *not* contain? Suggest an explanation for why this food is so rich in vitamins.

Answer

Eggs appear as a source of 9 of the 13 vitamins. Only vitamins E, K, folate (vitamin B_9) and C are absent. Eggs are the food source for the developing chick and, as such, must contain all the substances needed to build its body, amongst which are the vitamins. For similar reasons, milk is also rich in vitamins.

The following sections consider in turn the fat-soluble vitamins and the water-soluble ones. Vitamins have complex chemical structures, and so, apart from a brief look at vitamin A, we will not be dealing with their chemistry here.

1.2 Vitamin A

Activity 4

Look back at Table 1 and identify the foods that contain vitamin A. On the basis of this information, try to predict where vitamin A is stored in the human body.

Answer

Vitamin A is found in liver. If it is stored in the liver of other animals that we eat, then it would be reasonable to suggest that it might be stored in human liver, which indeed it is. Since vitamin A is a fat-soluble vitamin, you might also predict that it would be stored in adipose tissue, which, to a lesser extent, it is too.

Vitamin A is toxic if taken in very large quantities and poisoning has occurred in Arctic explorers who have eaten polar bear liver, which is particularly rich in vitamin A. The concentration of vitamin A in lamb and calf liver has increased substantially in the last 20 years due to supplements to their feed. Pregnant women are advised to restrict their intake of liver and pâté made from liver, since there is some evidence that high doses of vitamin A can cause birth defects. However, vitamin A is an essential part of the human diet and severe health problems occur if there is a deficiency. Since dairy products, such as butter, are a good source of vitamin A, all types of margarine and similar spreads are now required by law to have vitamin A added to them, as you will see on their labels. Vitamin A, which is actually a group of interrelated substances (retinol, retinal and retinoic acid), can be synthesised in the body from β-carotene, found in dark-green leafy vegetables such as cabbage, sprouts, broccoli and spinach, and in carrots. Cooking the vegetables does not damage the β-carotene molecules and in fact β-carotene is more easily absorbed into the body from cooked carrots. The structure of β-carotene, retinol and retinal are shown in Figure 1.

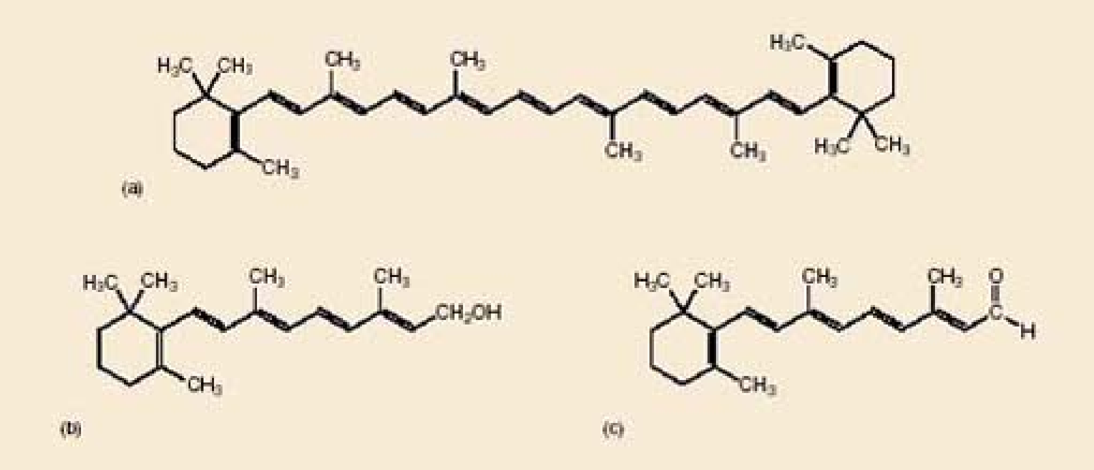


Figure 1 Chemical structure of (a) β-carotene, (b) retinol and (c) retinal. Note that for ease of comparison, the carbon atoms, with their associated hydrogen atoms, have been omitted from the chains and the rings.

Activity 5

Look carefully at the three molecules and identify the relationship between retinol and β-carotene and the difference between retinal and retinol.

Answer

If a β-carotene molecule (a) is split in the middle and a molecule of water (H_2O) added to each cut end, then two molecules of retinol (b) are produced. Retinol is the same as retinal (c) except that two hydrogen atoms have been removed from the end of the molecule to give a —CHO group, rather than a —CH_2OH group

Retinal is found in the cells of the eye where it plays a vital part in the perception of light and this is the reason why the 'old wives' tale' that carrots help you to see in the dark is, in fact, true. The speed at which the human eye adapts to seeing in the dark depends on the amount of vitamin A available in the body, known as the vitamin A status. A 'dark adaptation test' can be used as a measure of vitamin A status. Vitamin A deficiency is a major public health problem in the developing world, causing blindness in a quarter of a million people each year. Vitamin A supplements are successful in preventing blindness from this cause.

Vitamin A also assists in keeping the epithelial cells of the body moist and healthy. As well as lining the whole of the digestive tract, epithelial cells cover the surfaces of the glands around the eyes and line the lungs (and are found elsewhere too). Xerophthalmia or dry-eye is a classic sign of vitamin A deficiency. Tear production is reduced and the eyes become susceptible to infections such as conjunctivitis. Children who are vitamin A-deficient are more susceptible to respiratory infections and measles. Vitamin A is involved in normal growth and bone formation and it plays a part in the production of red blood cells and therefore the prevention of anaemia.

In order to understand another important role of vitamin A, and other vitamins, as antioxidants, you need to know a little more about the internal structure of atoms. Atoms sometimes carry a positive or a negative (+ or−) charge. These charges arise because atoms are made up of positively charged particles called protons and negatively charged particles called electrons. The protons, along with uncharged particles called neutrons, reside in the core of the atom as part of the atomic nucleus. For the purpose of this simple description, you can think of the electrons as tiny spheres that are in orbit around the nucleus. Normally, the numbers of protons and electrons in any particular atom are the same, so the positive and negative charges are balanced, and overall the atom has no charge. However, if an atom gains an electron, it has one extra negative charge (since it now has one more electron than it has protons), and so we would write a − sign beside it, and if it loses an electron, it has a positive charge (since it now has one more proton than it has electrons), and we would write + beside it. When atoms bond together, they can share pairs of electrons, one from each atom, so when we have been talking about a bond between two atoms (the atoms 'holding hands'), we have actually been referring to these electron pairs.

However, sometimes a molecule can be formed in which there is an atom with a single free electron, and this type of molecule is called a free radical. Free radicals are extremely reactive and the problem is that as they react, they create more and more free radicals in a runaway chain reaction. This process happening within cells involves atoms in molecules such as DNA that are vital to the cell's functioning, and it can have serious health consequences. The precise way in which free radicals cause the damage attributed to them is not fully understood, but they are implicated in many human diseases and disorders. Many pollutants generate free radicals, as does smoking, and free radicals are probably the link between exposure to toxins and the development of cancer.

Certain molecules have the ability to donate electrons to free radicals, while not themselves being destroyed or becoming free radicals. Thus they can safely interact with free radicals and terminate the chain reactions before vital cell components are damaged or destroyed. Such molecules are known as antioxidants, and vitamin A is one of the important antioxidants in the body.

1.3 Vitamin D

The main role of vitamin D is to facilitate the uptake of calcium from food, through the lining of the small intestine into the blood. It also controls the deposition of calcium in the bones during growth and maintains adult bone structure. If vitamin D is deficient, with less calcium available, the skeleton fails to develop normally. The most obvious symptom is the bowing of the leg bones in children, producing the condition called rickets (see Figure 2). Children with vitamin D deficiency grow more slowly and may become smaller adults which, in women, has serious consequences because the pelvis may end up so small that giving birth normally is impossible. Vitamin D deficiency in adults is called osteomalacia. Rickets and osteomalacia were relatively common in Europe during the 19th century, especially in urban slums.

Figure 2 A young child with rickets photographed in the late 1980s; without sufficient vitamin D, calcium is not properly absorbed in the gut so the growing bones cannot harden normally. The abnormally flexible bones bend under the child's weight, producing the characteristic bowed legs.

Activity 6

Given that vitamin D is a fat-soluble vitamin, predict which foods are likely to contain it.

Answer

You would expect to find vitamin D in those foods that contain significant amounts of fat, such as dairy products and, by analogy with vitamin A, probably liver too.

If you look back at Table 1 you will find oily fish on the list and you may know that a generation or two ago, a regular dose of cod liver oil was given to children to prevent rickets. Levels of vitamin D in dairy products vary throughout the year but it is now added to margarine and many low-fat spreads, providing an all-year-round supply. Breakfast cereals, yoghurts and food for babies and infants are often also ‘fortified’ with vitamin D.

However, there is some debate as to whether vitamin D should actually be classified as a vitamin, since it does not fit completely with the usual definition, which is that vitamins are obtained from the diet. It is not essential to obtain vitamin D in the diet. It can be synthesised below the surface of the skin in the presence of ultraviolet (UV-B) light. However, in the UK, there is insufficient UV-B in sunlight between October and March for synthesis to occur, although most people probably make and store enough in the body during the summer months to last through the winter.

Activity 7

Which groups of people would be most at risk if their diet contained insufficient vitamin D?

Answer

You might have thought of: people who are housebound during the summer; people who live in areas of high air pollution; those who never expose their skin to sunlight or only do so when wearing high factor (UV-B blocking) sunscreens; and people with dark skin which prevents the UV light from penetrating far enough into the skin for vitamin D synthesis.

In fact, the beneficial effect of sunlight, in playing a part in vitamin D synthesis, has to be balanced with the detrimental effect, its role in causing skin cancers. It appears that an exposure to sunlight of about 30 minutes per day (avoiding the part of the day when sunlight is strongest) is an appropriate balance between the harmful and beneficial effects. Although rickets has largely been eliminated in the UK, due to the addition of vitamin D to food especially for infants and children, the condition has reappeared in Asian communities in the UK, especially in the more northern parts of the country.

Activity 8

List the factors, relating to both dietary intake and production of vitamin D, that may be the cause of vitamin D deficiency in Asian communities.

Answer

Some of the factors are:

- darker skin colour, so that more exposure to sunlight is required to stimulate vitamin D production
- less sunlight in northern parts of the UK than in the south, or than would be found in the Asian countries from where this population group originated
- for cultural reasons, spending less time out of doors than white UK residents, (such habits are especially common among Asian women)
- the wearing of clothes that cover more of the body surface than those of white UK residents, so exposing less skin to sunlight
- a diet containing less dairy products than a typical UK diet; a strict vegetarian diet is particularly low in vitamin D.

1.4 Vitamin E

Vitamin E is not a single compound, but consists of a group of eight closely related chemicals, of which the most important, responsible for about 90% of its activity in the body is alpha-tocopherol. Since, like vitamins A and D, vitamin E is fat-soluble, it occurs in fat-rich foods. The main sources in the UK diet are from plant oils such as soya, corn and olive oil. Other good sources include nuts and seeds, and wheatgerm (the part of the wheat grain that will develop into the new plant) and some green leafy vegetables. It is added to some margarines and spreads.

The main role of vitamin E in the body is as an antioxidant.

Activity 9

Fill in the blanks in the following short paragraph. You may need to look again at the end of the section on Vitamin A.

Some chemical reactions in the body produce harmful substances called________ that contain single_________and become involved in chain reactions in the cells, which can be damaging to the body.______________________like vitamin-s______and____neutralise the harmful substances and prevent further damage.

Answer

Some chemical reactions in the body produce harmful substances called **free radicals** that contain single **electrons** and become involved in chain reactions in the cells, which can be damaging to the body. **Antioxidants** like vitamins **A** and **E** neutralise the harmful substances and prevent further damage.

Vitamin E is particularly important in maintaining cell membranes in a healthy state. Its presence appears to be particularly significant in the lungs, red blood cells, heart and brain, though deficiencies are rare and few human conditions can be specifically related to its absence. However, fewer cases of heart disease and cancer occur in people whose vitamin E intake is adequate. There is, as yet, no clear evidence that taking in additional vitamin E gives additional protection against these conditions and supplements are not advised.

1.5 Vitamin K

Like vitamin E, vitamin K is fat-soluble and composed of a series of related compounds. Vitamin K is widely distributed in the diet (see Table 1) and it is absorbed from the small intestine with the assistance of bile acids. Vitamin K is also manufactured by the bacteria that inhabit the human large intestine and appears to be absorbed there too. The main role of vitamin K is in blood clotting. This process requires the presence of a number of different chemicals, called clotting factors, in the blood. A number of these (including prothrombin and Factors VII, IX and X) require vitamin K in their synthesis. Deficiency could therefore result in an increasing tendency to bleed. Vitamin K also plays a role in the formation of bone and supplements can be effective in increasing bone density in osteoporosis.

Activity 10

How might a course of antibiotics affect the levels of vitamin K in the blood?

Answer

Antibiotics kill bacteria, so, as well as destroying those that are causing the infection for which the antibiotics have been prescribed, they also kill many of the useful bacteria in the gut. Since these bacteria synthesise vitamin K, their absence could lead to reduced vitamin K uptake from the gut into the blood for a few days until the normal population of bacteria in the gut is re-established.

There is a rare condition called vitamin K deficiency bleeding which occurs in about 1 in 10 000 babies in the first few weeks of life. Many babies who have this condition die or sustain significant brain damage due to bleeding into the brain. The condition occurs almost exclusively in breastfed babies, since human milk contains very little vitamin K, whereas it is added to formula milk. It is almost completely preventable by giving a single injection of vitamin K soon after birth, and such an injection has been given routinely to UK babies since the 1960s. However, two papers in the early 1990s suggested an association between the vitamin K injection and a very slight increase in the incidence of childhood leukaemia. This discovery led, in some countries, to vitamin K being offered as an oral dose instead. However, vitamin K by mouth was less effective than the injection at preventing vitamin K deficiency bleeding, which still occurred in 1 in 100 000 babies. Other research has not supported the link between vitamin K and leukaemia and a study published in 2004, which looked at 4000 cases of childhood cancers, found no association with the injections of vitamin K. In the UK now, new mothers may be given the choice of a vitamin K injection or a course of oral doses for their newborn baby.

Activity 11

List the vitamins that we have covered so far in this course. Which group remain?

Answer

So far we have covered vitamins A, D, E and K – the fat-soluble vitamins. The group that remains is the water-soluble group of vitamins, vitamins B and C.

1.6 Vitamin B

Vitamin B, often called the vitamin B complex, consists of a whole range of different compounds, some of which have similar functions and work together. However, unlike the families of compounds forming vitamins E and K, the B vitamins are sufficiently different from one another to be given individual names or numbers, and to be listed separately on many food labels. Except for vitamin B_{12}, the body can only store limited amounts of B vitamins and because they are all water-soluble, any excess is excreted in the urine. Their water-solubility also means that B vitamins are easily lost in cooking, and they can also be destroyed by light and exposure to air.

1.6.1 **Thiamin (or thiamine, also known as vitamin B_1)**

The deficiency disease beriberi has been known for thousands of years. The name literally means ‘I can't, I can't’ in Sinhalese (a major language in Sri Lanka), and reflects the crippling effect on its victims, who suffer from neurological symptoms, including pain, fatigue and paralysis, and cardiovascular disease. The disease was most common in southeast Asia, where white or ‘polished’ rice was a major part of the diet. The main source of thiamin is in the outer layers of the grain, the bran, which is removed during milling to produce white rice grain and white rice flour. Thiamin is added to white flour in the UK and many breakfast cereals are also enriched in thiamin. It is present in seeds, nuts and in beans and in smaller quantities in other foods such as meat, milk and potatoes. Since potatoes are eaten frequently in the UK diet, they can form a useful source, though thiamin is gradually destroyed by boiling water and it is estimated that 20% of the possible dietary intake is lost in cooking.

Thiamin is essential in many of the metabolic pathways in the body, especially in the processing of carbohydrate to provide energy. Since the nervous system relies almost exclusively on carbohydrate (glucose) for its energy, it is not surprising that the symptoms of deficiency are seen there. Because, as a water-soluble vitamin, little thiamin can be stored in the body, symptoms appear in less than a month on a diet in which it is completely absent. The early symptoms can, however, be rapidly corrected by regular intake of thiamin.

There are two forms of beriberi, known as the ‘wet’ and ‘dry’ forms. In ‘wet’ beriberi, there is swelling of the limbs, increased heart rate, lung congestion and an enlarged heart, all symptoms of heart failure, which can ultimately be fatal. The symptoms of ‘dry’ beriberi include pain, tingling and loss of sensation in the hands and feet, muscle wasting and gradual loss of function and paralysis of the legs, brain damage and eventually death. Nowadays, with better nutritional information and the addition of thiamin to many foods, beriberi is rarely seen, except in people with alcoholism, who mainly have the ‘dry’ form, in a condition called Wernicke-Korsakoff syndrome. Chronic alcoholism is often associated with poor nutrition and therefore a low intake of thiamin. Additionally, alcohol appears to interfere with thiamin absorption from the gut. The symptoms of Wernicke-Korsakoff syndrome begin with peripheral nerve damage (loss of feeling in hands and feet), then damage to the central nervous system and finally a confused mental state, or psychosis, which affects mood, language and thinking.

Because of its involvement in carbohydrate metabolism, additional thiamin may be needed during pregnancy, lactation and also in cancer patients and in people on kidney dialysis. It has been suggested that additional thiamin could be beneficial to performance in certain sports, but experiments so far have produced no evidence to support this idea.

1.6.2 **Riboflavin (vitamin B_2)**

Riboflavin or vitamin B_2, which was originally known as vitamin G, is found in a wide variety of foods, including milk and dairy products. It is more stable to heat than some of the other B vitamins, but is destroyed by exposure to sunlight. Milk in a glass bottle exposed to sun, loses 10% of its riboflavin per hour. Riboflavin plays a crucial role in the metabolism of carbohydrates and proteins and is involved in many other metabolic reactions in the body.

Although riboflavin deficiency does occur in some parts of the world, it is usually associated with deficiencies in other B vitamins and a specific deficiency syndrome is hard to identify. The clearest signs of deficiency are in the mouth, with cracks and inflammation at the corners, sore and ulcerated lips and a painful tongue. Others signs are detected in the eyes, with increased sensitivity to light and burning and itching sensations.

1.6.3 **Niacin (vitamin B_3)**

Niacin, which comprises two compounds, nicotinic acid and nicotinamide, also occurs widely in food and is added to many breakfast cereals. It is easily absorbed into the blood from the digestive system and plays a vital role in energy production in cells. It appears to reduce the levels of low density lipoproteins or LDLs in the blood and increase high density lipoproteins or HDLs, perhaps by affecting the proteins that carry the fats. This is important because LDLs are a way of transporting cholesterol around in the blood. Cells that need cholesterol take it up from LDLs. If cells contain excess cholesterol, it is returned to the blood packaged into HDLs. The higher the ratio of HDL to LDL in the blood, the lower the risk of developing heart disease. Thus, if niacin increases HDLs and reduces LDLs, this should give some protection against heart disease.

The deficiency disease associated with lack of niacin is pellagra. Its symptoms are the four Ds – diarrhoea, dermatitis, dementia and death, normally experienced in that order! The term 'pellagra' was first used in 1771 to describe the disease that was endemic at that time in poor populations in southern Europe. 'Pellagra' is from the Italian words *pelle* meaning 'skin' and *agro* meaning 'sour' and refers to the thickened, roughened skin, or dermatitis, which is characteristic of the disease.

It was noticed that people with pellagra subsisted on a diet that was based on maize and contained very little meat. By 1900, the disease had spread to France, Egypt and England, and in 1902 it was first reported in America. For the next 20 years, it reached epidemic proportions in the southern USA. Again, poverty and the consumption of large quantities of maize (corn) appeared to be the risk factors. Although it was soon realised that the deficiency disease could be prevented by the inclusion of meat in the diet, it was not until the late 1930s that the explanation of the link with eating a lot of maize was understood.

This link involves a molecule called tryptophan. Tryptophan is an amino acid, one of the molecules that make up proteins, and is commonly found in animal proteins. Niacin can be synthesised in the body from tryptophan. In fact, in the average UK diet, there is probably sufficient protein to satisfy all the niacin requirement of the body, and dietary niacin is therefore not essential. However, maize contains so little tryptophan that there is insufficient for the body to convert to niacin. Additionally, any niacin present in the maize itself is so tightly bound to molecules in the maize which are not digested, that it cannot be absorbed by the body. In the indigenous populations of Mexico and Central America, who also subsist on a diet of maize, there have been almost no occurrences of pellagra. It seems that their tradition of soaking the maize in an alkaline solution of lime before cooking it, releases the bound niacin, freeing it for absorption by the body. Poor peasants of the Deccan Plateau of India, however, do suffer from pellagra, although their staple carbohydrate is millet (sorghum) rather than maize. This grain contains sufficient tryptophan but it also contains very high levels of leucine, another amino acid that has been found to prevent niacin synthesis in the body, so symptoms of its deficiency occur. People with HIV infection can also suffer from a pellagra-like condition, since the infection causes the tryptophan levels in their blood to be very low. High doses of niacin can reverse the pellagra condition.

1.6.4 **Vitamin B_6 (pyridoxine)**

Vitamin B_6 is composed of pyridoxine and two closely related compounds. It is found in small quantities in many foods, though it can be destroyed in the cooking process. No clear deficiency disease has been recognised in humans as being directly caused by lack of this vitamin, since it is often found in conjunction with other B vitamins and their absence has greater effects. Its main role is in the conversion of some amino acids into other ones, depending on the requirements of the body. It also plays a role in fat metabolism (in the conversion of linoleic acid to arachidonic acid) and in carbohydrate metabolism. Thus, deficiency causes generalised problems such as anaemia, dermatitis and neuromuscular problems such as headaches, aching muscles and difficulty in walking. There is some evidence that low doses of vitamin B_6 can be helpful in improving the symptoms of premenstrual syndrome (PMS), even when there is no evidence of deficiency in the diet.

1.6.5 **Folate (folic acid, vitamin B_9)**

Folate is a generic name for a group of related compounds. The name 'folate' was based on the word 'foliage', after it was identified in a crude extract from spinach, though it is also found in liver, other green vegetables, oranges and potatoes and it is often added to breakfast cereals (usually listed as folic acid). Folate is less sensitive to heat than many of the B vitamins, though it is destroyed if food is reheated or kept hot for long periods. Folate is involved in amino acid metabolism, but its crucial role is in cell division, since it is used in DNA synthesis. So deficiency of folate has its major effect on dividing cells, especially those in the bone marrow (which produces red blood cells) and those lining the digestive system. Failure of normal cell division in the cells lining the digestive system can lead to loss of appetite, nausea and diarrhoea, and soreness in the mouth. Failure of normal cell division in the bone marrow leads to a type of anaemia called megaloblastic anaemia, where large, immature blood cells which do not have the normal oxygen-carrying capacity, are released into the circulation. After iron deficiency, folate deficiency is the next most common cause of anaemia.

Due to the huge amount of cell division that goes on in the first few months of pregnancy, pregnant women need as much as five times more folate than the normal daily requirement. Up to 25% of women would show changes in their bone marrow that are characteristic of folate deficiency if they did not increase their intake. Folate also appears to be important around the time of conception. For this reason, women planning to become pregnant are now encouraged to take folate supplements for about three months before conception and for the first three months of pregnancy. There appears to be a link between lack of folate and neural tube defects such as spina bifida, where the spinal cord does not develop correctly in the early fetus. Several studies have shown that giving folate supplements to women who have previously given birth to a child with a neural tube defect can reduce the risk of the same problem arising in a subsequent pregnancy by almost 75%.

There is some evidence that folate deficiency is also linked with increased risk of cardiovascular disease and with cancer, but more work is needed in both these areas. Alcohol affects the uptake of folate from the digestive system into the blood; so alcoholics are at risk of folate deficiency for this reason as well as because their diet may be lacking in folate. Other population groups who do not have a balanced diet, due to poverty, poor food choices, or illness, may also be at risk. Some commonly used drugs, including aspirin, indigestion remedies and the contraceptive pill, together with some antibiotics and anti-epilepsy drugs, may affect folate uptake too, and smokers may need additional folate. Chemotherapy drugs used in cancer treatment can also cause folate deficiency. In fact, folate deficiency is probably the most common vitamin deficiency seen in the developed world.

1.6.6 **Vitamin B_{12} (cobalamin)**

Vitamin B_{12} is yet another group of compounds, this time with an atom of the metal called cobalt (present in only trace quantities in the body) in their structure, hence the alternative name 'cobalamin'. Vitamin B_{12} works alongside folate and if levels of it are low, folate deficiency symptoms occur too. It is stored in the liver and in general the body does not appear to need a regular intake. Many people have enough B_{12} stored in their liver to last for up to 30 years. Unlike most vitamins, vitamin B_{12} is found only in foods obtained from animals. In ruminant animals such as cattle and sheep, the bacteria in their stomachs synthesise vitamin B_{12}, hence its presence in their meat, milk and dairy products. They too store it in their liver and hence eating liver is a rich source of the vitamin. Vegetarians are likely to take in sufficient vitamin B_{12} due to contamination of their food by yeasts and bacteria, but strict vegans may need to supplement their diet to ensure sufficient intake. If the diet contains excess amounts of vitamin C, this can bind to vitamin B_{12} and limit its availability. Vitamin B_{12} is essential for the formation of the protective coating of myelin, which is found around some nerve fibres (neurons) and so its deficiency can lead to malfunction of the nerves and eventual paralysis and dementia. Like folate, vitamin B_{12} is also vital for cell division, especially in the bone marrow, since it also plays a role in DNA synthesis.

Activity 12

Using your learning about folate and cell division, what condition might you expect to see in a person with vitamin B_{12} deficiency?

Answer

Since red blood cells are produced in the bone marrow, you would expect some type of anaemia to develop.

Deficiency of vitamin B_{12} due to dietary insufficiency is uncommon, but this vitamin can be deficient due to a condition that prevents its normal absorption. Because the B_{12} molecule is particularly large, in order to be absorbed by the body it has to be linked to a protein known as 'intrinsic factor', which is produced by the lining of the stomach. The combined 'complex' is then absorbed into the blood when the food reaches the small intestine. If the cells that produce intrinsic factor are destroyed, or the intrinsic factor is inactivated, vitamin B_{12} cannot be absorbed. This situation may occur due to an autoimmune disease in which the body produces antibodies against the cells that produce the intrinsic factor or against the intrinsic factor itself. Women are more commonly affected than men and this type of autoimmunity tends to run in families. The intrinsic factor-producing cells can also fail to function efficiently in a patient with ulcers, stomach cancer or other conditions such as Crohn's disease that affect the digestive system. The condition that results in all these cases is called pernicious anaemia, for which the treatment is regular injections of vitamin B_{12}.

Activity 13

Before the availability of injectable vitamin B_{12}, the treatment for pernicious anaemia was to feed the patient large quantities of raw liver every day. Why would this treatment be only partly effective?

Answer

The cause of pernicious anaemia is a failure in the absorption of vitamin B_{12} from the food, due to the lack of intrinsic factor to which it binds. Taking in large quantities of liver would increase the amount of B_{12} ingested, since liver is a rich source, but would not help the underlying lack of intrinsic factor. Presumably enough would be absorbed directly, without the binding factor, to have some effect in alleviating the anaemia.

1.6.7 **Pantothenic acid (vitamin B_5)**

The name 'pantothenic acid' is derived from the Greek *pantothen* which means 'from all sides', indicating that it is widely distributed in the diet. It plays a vital role in metabolism, particularly in the production of energy in cells. Naturally occurring pantothenic acid deficiency is very rare, since it is so widespread in the diet. However, during World War II, prisoners in the Philippines, Burma and Japan suffering from severe malnutrition did experience numbness, tingling and painful burning in their feet, which was relieved specifically by pantothenic acid. In mice and rats, pantothenic acid deficiency led to their fur turning grey, and on the basis of this finding, pantothenic acid has been added to some shampoos, in the hope that it might prevent grey hair in humans. There is as yet no evidence that it does.

1.6.8 **Biotin (vitamin H)**

Although biotin is usually considered to be a member of the B vitamin complex, it is also sometimes known as vitamin H. Like pantothenic acid, it plays a major role in metabolism. Deficiency is not normally seen, though it can be induced in rats and people by them eating large quantities of raw egg white. This binds biotin and prevents it being absorbed. Various symptoms result, including hair loss, dermatitis, depression and lethargy.

1.7 Vitamin C (ascorbic acid)

You may already have some knowledge about vitamin C. Try answering this question first.

Activity 14

What is the condition that results from vitamin C deficiency and what are its symptoms?

Answer

You will probably remember from the start of this course that scurvy is the deficiency disease associated with lack of vitamin C and that its symptoms are loss of hair and teeth, bleeding gums, very slow healing of wounds and eventually death.

Vitamin C deficiency causes these symptoms because of its two important roles in the body. Firstly, it is used in the production of collagen, which is found in large quantities in bone, tendons, cartilage and skin, and in smaller amounts in other tissues. And secondly, it is important in enhancing the absorption of iron (which is needed for red blood cells) from vegetable sources.

Activity 15

Relate each of these roles of vitamin C to the symptoms of scurvy.

Answer

The symptoms of scurvy can all be largely explained by failure of collagen production, including loss of teeth, which are held in place by connective tissue in the gums. Bleeding gums and very slow healing of other wounds are also caused by lack of collagen, which is needed to hold cells together, including the cells forming the blood vessels, but the poor healing may also be due to the lack of oxygen reaching the tissues due to shortage of iron in the blood (anaemia).

Although we tend to think of scurvy as a disease of sailors long ago, it does still occur in refugee camps where the diet contains insufficient vitamin C, and among homeless people in the UK. Vitamin C is found in vegetables and fruit, especially blackcurrants and oranges. Potatoes are a good source too, though in the modern diet, more is probably obtained from fresh fruit and from fruit juices. Most mammals can synthesise their own vitamin C from glucose and so do not need it in their diet. However, along with humans and most other primates, guinea pigs lack this synthetic capacity. So some of the early research into vitamin C requirements was done on them, which is how ‘guinea pig’ came to mean a test subject in popular speech.

Vitamin C is very soluble in water. It is amongst the least stable of the vitamins and is rapidly destroyed by exposure to light and to air and by heating.

Activity 16

Suggest three ways in which you could maximise the amount of vitamin C retained in cooked vegetables.

Answer

You might have thought of some of the following: prepare the vegetables immediately before cooking, so exposing them to the air for the minimum time; cook them in the minimum amount of water (or steam them) for the minimum amount of time; keep the lid on the saucepan to prevent too much contact with the air; serve them immediately; use the cooking water in the meal if possible, since that may contain some of the vitamin C that has been leached out; and eat the vegetables immediately after cooking.

Vitamin C is readily absorbed from the digestive system and the total amount present in the body is typically about 2–3 g. Scurvy results when total body reserves fall below 300 mg. Vitamin C takes part in many of the body's metabolic processes and acts as an antioxidant (destroying free radicals). Vitamin C also appears to be beneficial to the immune system and there is evidence that moderate doses alleviate the symptoms of colds, though there is no convincing evidence that large doses can actually **prevent** colds. Many studies indicate that higher intake of vitamin C is linked with a lower risk of disease in general.

Activity 17

Studies show that smokers have less vitamin C in their bodies than non-smokers. Why might this be?

Answer

It may be because: (i) there is a lower intake – maybe the smoker has a cigarette after a meal, rather than a piece of fruit; (ii) there is poorer absorption in the gut; (iii) smoking generates more free radicals and the vitamin C is used up in destroying them.

Activity 18

Use Table 1, from the beginning of the course, to identify how much vitamin C is needed each day. If a person's diet contained no vitamin C, about how many days would it take for the level to fall low enough for symptoms of scurvy to appear?

Answer

Table 1 indicates that 40 mg of vitamin C are needed each day. Assume that the person has an average amount of 2.5 g, or 2500 mg of vitamin C in their body. For scurvy to develop, vitamin C reserves would need to fall below 300 mg, so 2500 mg - 300 mg = 2200 mg would need to be used and not replaced from the diet. At the rate of 40 mg per day, scurvy would appear after 2200 divided by 40 days = 55 days, i.e. in less than 2 months (assuming no vitamin C is available from the diet).

1.8 Test your learning

The following activities relate to the whole of this section about vitamins.

Activity 19

Use Table 1 to identify which vitamins are likely to be lost (a) when a piece of frozen beef is defrosted and the water, some of which comes from inside the meat, is thrown away and (b) when fat drips from meat during the roasting process.

Answer

(a) Any of the water-soluble vitamins could be lost in the water that drips from the thawed beef. The water-soluble vitamins found in beef are niacin (vitamin B_3) and some vitamin B_{12} and pantothenic acid (vitamin B_5).

(b) The fat-soluble vitamins could be lost in the fat that drips from the meat during cooking, but beef contains very few of the fat-soluble vitamins, just perhaps a small amount of vitamin K.

Activity 20

1. Which vitamins can be synthesised by cells in the body?
2. Which vitamins are groups of compounds?
3. Which three vitamins act as antioxidants? Are any of these synthesised in the body?

Answer

1. Vitamin D can be made in the skin, provided that it is exposed to sufficient sunlight. Vitamin A can be made from β-carotene in the diet, obtained from carrots and from dark green leafy vegetables. Niacin (vitamin B_3) can be made from the amino acid tryptophan.
2. Vitamins A, E and K are groups of compounds, as is the vitamin B complex, through the members of this group are given separate names.
3. Vitamins A, C and E are the vitamins that act as antioxidants. Vitamin A can be made from β-carotene (see above), but the others must be obtained through the diet.

Activity 21

Devise a table to show the similarities between the following pairs of vitamins: (a) riboflavin and niacin; (b) folate and vitamin B_{12}; (c) vitamins E and C.

Consider their sources, functions and signs of deficiency.

Answer

Table 3 The similarities between some pairs of vitamins

Vitamins	Sources	Functions	Signs of deficiency
(a) riboflavin and niacin	Both found in milk and eggs.	Both involved in cell metabolism.	Both affect the skin. Riboflavin deficiency causes cracks around the mouth, etc. and niacin deficiency causes dermatitis (one of the symptoms of pellagra).
(b) folate and vitamin B_{12}	Both found in yeast extract and breakfast cereals.	Both important in cell division.	Both deficiencies result in anaemia. Folate is linked to megaloblastic anaemia and vitamin B_{12} to pernicious anaemia.
(c) vitamins E and C_{12}	Both found in some vegetables.	Both act as antioxidants by destroying free radicals.	No clear symptoms related to vitamin E. Lack of Vitamin C causes scurvy.

Activity 22

A mother of three children under 5 is concerned that she is not giving them a balanced diet, since they mostly eat prepared convenience foods. What foods would you suggest that she introduces to their diet to boost their intake of vitamins?

Answer

A bowl of cereal with milk at breakfast time, together with eggs sometimes and fresh fruit regularly eaten at other meals would provide a good source of almost all the vitamins. Additionally, introducing some fresh, easy to prepare vegetables, such as broccoli, into their diet would be beneficial.

Activity 23

Have a look at labels on food packets, tins, etc., to see which have information about vitamins. Can you tell whether the food contains the vitamins naturally or whether they have been added by the manufacturer (fortified)?

1.9 Key points about vitamins

1. Vitamins A, D, E and K are fat-soluble; the remainder are water-soluble.
2. Adequate amounts of vitamins are required, many on a regular basis, though some can be stored.
3. A balanced diet should provide the necessary amounts of vitamins, but people on a restricted diet need to take particular care to ensure an adequate intake of all of them.
4. Deficiency diseases can occur when vitamins are absent or in short supply.
5. Water-soluble vitamins are easily lost during cooking, and are destroyed by exposure to air and light, so care is needed in food preparation to preserve them.

2 Minerals and fluids

2.1 Introduction to minerals and why we need them

Both vitamins and minerals are essential in the diet in small quantities and so they are often grouped together as micronutrients.

Activity 24

Which items in the diet are classified as macronutrients?

Answer

The macronutrients are proteins, fats and carbohydrates.

Minerals, also called mineral elements, are those elements other than carbon, hydrogen, oxygen and nitrogen, that are found in the body. These minerals are derived from the breakdown of the rocks of the Earth's crust which are then dissolved in water. So in a particular area, the minerals present in the local water depend on the underlying geology. Plants take up the water through their roots and, if those plants are used as food for people or animals, then the minerals enter their bodies. Animals are able to concentrate minerals in their tissues, so human foods of animal origin often contain a higher concentration than food obtained from plants. Minerals are also taken in through drinks. Minerals are needed in only small quantities in the diet, though some of them accumulate to a significant degree; for example, there is around 1 kg of calcium in the average human body. For most minerals, it is possible to identify their roles in the body, although some have, as yet, no known function.

2.2 Major minerals

The major mineral elements, defined here as those where 25 g or more is present in the body, are listed in Table 4.

Table 4 The major mineral elements required by the body. The recommended intakes (RNI) per day for a woman between the ages of 25 and 50 are listed. The approximate adult body content, functions and common food sources of the minerals are also shown.

Element (symbol)	RNI/g	Body content/ g	Functions	Main food sources
calcium (Ca)	0.7	1000	major structural component of bones and teeth; necessary for many enzymes, including those of blood clotting, muscle contraction and conduction of nerve impulses	milk, cheese, bread and flour (if fortified),cereals, green vegetables

chlorine (Cl)	2.5	100	major negative ion (as chloride,C1 $^{-}$) in body fluids; present in stomach secretions as hydrochloric acid (HCl)	main source is salt (sodium chloride, NaCl) used in food processing, cooking,and at the table
magnesium (Mg)	0.3	25	present in bone, inside cells and in body fluids; needed for some enzymes	milk, bread and other cereal products, potatoes and other vegetables
Phosphorus (P)	0.55	700	present in bones and teeth; essential for ATP and DNA and many other molecules	milk, cheese, bread and cereals, meat and meat products, nuts
potassium (K)	3.5	140	main positive ion inside cells; K^{+} also present in extracellular fluids; essential for conduction of nerve impulses, also for the maintenance of ion concentration gradients across cell membranes	widely distributed in vegetables, meat, milk, fruit and fruit juices
sodium (Na)	1.6	100	major positive ion in extracellular fluids; Na^{+} also present inside cells; essential for conduction of nerve impulses and active transport of small molecules across cell membranes (e.g. absorption from gut)	main source is salt (sodium chloride, NaCl) used in food processing, cooking, and at the table
sulfur (S)	no value set	150	present in proteins	protein-rich foods; meat, fish, eggs, milk, bread, cereals

Activity 25

You will see that Table 4 is arranged with the elements in alphabetical order.

1. If the table were to be arranged based on the recommended nutrient intake values, with the highest at the top, which two elements would appear at the top of the table?
2. If, alternatively, the elements which occurred in the largest amounts in the body were to be at the top, which two elements would be at the top, and which one would appear at the bottom?

Answer

1. The two elements with the highest reference nutrient intake (RNI) values are potassium (3.5 g) and chlorine (2.5 g).
2. The two elements that occur in the largest amounts in the body are calcium (1000 g or 1 kg) and phosphorus (700 g). The one in the list that occurs in the smallest amounts in magnesium (though there are many more elements that are present in even smaller quantities in the body as you will see later).

2.3 **Calcium (Ca)**

About 40% of the total mineral mass of bones is calcium, making it the most abundant mineral in the body. In bone, it is combined with phosphorus, as well as oxygen and hydrogen, in a mineral compound called hydroxyapatite. Calcium is also present in the fluids in the body, and there it occurs in the form of dissolved ions. An ion is an atom that carries a very small electrical charge, which can be either positive (+) or negative (−), depending on the ion.

You may recall from our study of Vitamin A that the charges are due to the loss or gain of electrons.

Activity 26

A calcium ion is written as Ca^{2+}. What does this indicate in terms of the number of its electrons compared with an atom of calcium?

Answer

A calcium atom must have lost 2 electrons to become Ca^{2+}, leaving it with two more protons in its nucleus than it has electrons around the outside, and thus an overall charge of +2.

Calcium ions, along with others, play an important role in the transmission of the electrical signals along the nerves of the body and in the brain, and in muscle contraction. Ions are also important in keeping the chemical composition constant inside cells and in the tissues around them. This process is one aspect of homeostasis, which is the maintenance of a stable internal environment in the body, by correcting any changes which occur to disturb that stable state. Calcium ions also play a role in blood clotting.

In the West, calcium is mainly obtained through milk and dairy products in the diet. Soya milk is usually enriched with calcium for vegetarians who do not consume dairy products. Calcium is present at a lower level in cereals and is added to most flour. It also occurs in green leafy vegetables and in those fish, like sardines, whose bones are eaten. Various compounds in food can bind to calcium and prevent it being released from the food so that it can be absorbed from the digestive system into the blood. For example, oxalates, which are present in spinach and rhubarb, may lock up the calcium in a compound called calcium oxalate. A meal containing these foods therefore provides the body with less calcium than would be expected. In general it appears that only about 30% of the calcium in food is actually absorbed into the blood; the rest is lost in the faeces.

Activity 27

Which vitamin is involved in the uptake of calcium from the digestive system and what are the deficiency diseases associated with this vitamin in adults and children? Which other vitamin plays a part in the formation of bone?

Answer

Vitamin D is involved in calcium uptake and the deficiency disease in adults is osteomalacia and in children, rickets (see section on Vitamin D). Vitamin K also has a role in bone formation (see section on Vitamin K).

With the natural ageing process, the amount of calcium present in the bones declines, especially in women for the first two to three years after the menopause. When this process has continued to the extent that the bones become fragile and easily broken, the condition is called osteoporosis. Inactivity and changes in some hormone levels, and certain drugs such as steroids, can increase the risk of osteoporosis. In 2000, there were 90 000 cases in the UK of fractures associated with osteoporosis, so it is a significant cause of illness (morbidity) and mortality in the population. The best method of prevention appears to be to achieve the maximum amount of bone mass (known as the peak bone mass, PBM) by the age of 20–25. Although bone composition is largely genetically controlled, various factors under the control of the individual can play an important role in teenagers and young adults, such as:

- Taking exercise. Increased muscle development leads to increased bone mass.
- Ensuring an adequate calcium intake, maybe as high as 1.3 g per day, i.e. significantly above the RNI value.
- Maintaining a normal BMI. Underweight female teenagers are particularly at risk, since a low BMI leads to lower bone mass. It also leads to amenorrhoea (ceasing of the normal menstrual cycle), when steroid hormones, such as oestrogen, are at lower levels than normal, and this also affects normal bone growth.
- Ensuring adequate vitamin D and K intake, as already mentioned.
- Vitamin C is important for collagen synthesis, and collagen forms part of the structural framework of bones, so adequate vitamin C intake is important too.
- Alcohol intake and cigarette smoking are linked with relatively lower bone mass.

In fact, many of these same factors apply to the maintenance of bone mass throughout life.

2.4 Phosphorus (P), magnesium (Mg) and sulphur (S)

2.4.1 Phosphorus (P)

Like calcium, phosphorus is important in the structure of bones and teeth. It is vital in the body as part of the molecules ATP and DNA, and is also a component of phospholipids, lipoproteins and many other proteins too. Phosphorus can occur, combined with oxygen, in phosphate ions and in this form it plays an important role in switching on and off metabolic pathways in cells. Phosphorus is widely available in the diet, from both plant and animal sources, such as meat, fish, eggs and dairy products, cereals and nuts. It is also added to many prepared foods such as bread and cakes, processed meats and soft drinks. Since the body absorbs phosphorus more efficiently than calcium, intake is usually sufficient for the body's needs, but deficiency could lead to rickets and osteomalacia, as with calcium deficiency.

2.4.2 **Magnesium (Mg)**

Magnesium is also present in bone in the body and in the soft tissues, although in much lower quantities than calcium. It is important in the activity of more than 300 enzyme systems, in particular those using ATP. It is involved in the synthesis of proteins and in many other reactions in the body. In plants, magnesium is part of the chlorophyll molecule, so it is present in green vegetables and is found widely elsewhere in the diet, so intake is normally adequate. In some areas, there are low levels of magnesium in the drinking water, due to the lack of magnesium compounds in the underlying rocks. In such areas, surveys show that coronary heart disease is more common, though no clear causative link between magnesium and coronary heart disease has yet been found.

2.4.3 **Sulfur (S)**

Most proteins contain about 1% sulfur, which occurs in the side-chains (R groups) of two of the protein-forming amino acids, methionine and cysteine.

Cysteine is particularly important in proteins such as collagen (found in bone, tendons, cartilage and skin) and keratin (found in hair and nails, as well as skin).

Activity 28

What is the common feature of these two proteins that may be linked to the presence of cysteine in them?

Answer

Collagen and keratin are both found in parts of the body that are relatively tough and strong. They are known as ‘structural proteins’. Links between the sulfur atoms of the cysteines in adjacent protein (polypeptide) molecules link the molecules firmly together, providing that strength.

After injury, there is a particular need for sulfur to repair and build new structural proteins. However, a diet containing sufficient protein almost certainly provides sufficient sulfur for the body. Sulfur is also found in the vitamins biotin and thiamin and in some enzymes that play important roles in metabolism.

2.5 **Sodium (Na), chlorine (Cl) and potassium (K)**

The element sodium is a soft silvery metal and the element chlorine is a greenish gas that is poisonous to humans and many other animals. Yet when these two elements are combined together in a compound called sodium chloride, the properties are quite different. Sodium chloride in its solid form is composed of white crystals and we call it salt. When salt dissolves in water, the constituent sodium ions, Na^+, and chloride ions, Cl^-, become separated. Both of these ions are common in the body, sometimes to the extent that body fluids such as sweat taste quite salty. It is important to normal body functioning that the concentrations of sodium and chloride ions, together with potassium ions (K^+), in the blood and in the fluid around cells, are regulated within quite tight limits, however much or little is present in the diet. The ions are also essential for transmission of impulses along nerves and for muscle contraction.

Activity 29

What is the name of the process by which the correct balance of ions is maintained within and around cells?

Answer

It is called homeostasis (see section on calcium).

In the UK, most people take in more sodium per day than is needed, mostly due to salt which is added to food either during the cooking process – particularly in manufactured foods, including bread – or at the table, to improve the taste of the food. There is no way of storing the ions and so the excess must be removed from the body by the kidneys in urine. It is particularly important that babies do not take in too much salt, since their kidneys are not fully developed and they are unable to remove excess from their bodies. If, when they start on solid food, they are given food with the normal adult quantity of salt, they can suffer kidney, liver and brain damage. As people get older, a small increase in salt intake has a greater effect on blood pressure than it does in younger people. The UK Government's guideline advice is that the intake of salt in adults should be no more than 5 g per day for women and 7 g for men. The average adult intake is currently around 9 g per day.

When levels of sodium are too high, the body retains too much water and the volume of body fluids increases, increasing the blood pressure (hypertension). High blood pressure is linked with a higher risk of cardiovascular disease and strokes. Reducing the salt intake does, over a number of weeks, lead to a blood pressure reduction. Since there appear to be no adverse consequences of a reduction in salt intake, such a reduction in the diet of all adults is to be recommended. However, this dietary change is not easy to achieve, since people become accustomed to the taste of a particular level of salt in food and taste buds need time to adapt to less. Additionally, food labels often give the sodium content of food, rather than the salt content.

Activity 30

The mass of a chlorine atom is about one and a half times that of a sodium atom. Knowing that salt is made up of equal numbers of sodium and chorine atoms, how many times greater would the salt content of a food be than the sodium content?

Answer

If you assume 1 unit for the mass of a sodium atom and 1.5 units for the mass of a chlorine atom, then the mass of sodium chloride is 2.5 units. So the salt content would be two and a half (2.5) times higher than the sodium content.

Activity 31

100 g of a particular breakfast cereal contains 0.3 g sodium while 100 g of a chicken curry ready-made meal contains 0.4 g sodium.

1. Calculate the amount of salt present in 100 g of each of these foods.
2. The average portion size of the cereal is 40 g while the ready-made meal, suitable for one person, is 450 g. How much salt would be taken in by eating a portion of each of them?

3. How does this total amount compare with the advised daily salt intake for a woman?

Answer

1. Since the salt content is 2.5 times higher than the sodium content, 100 g of the cereal contains 0.3 x 2.5 g salt = 0.75 g salt, while 100 g of the ready-made meal contains 0.4 x 2.5 g salt = 1 g of salt.
2. Since 100 g of the cereal contains 0.75 g salt, 1 g of cereal contains 0.75 divided by 100 g of salt and so a 40 g portion contains 40 x 0.75 divided by 100 g salt = 0.3 g salt. And similarly, since 100 g of the ready-made meal contains 1 g of salt, 1 g of the meal contains 1 divided by 100 g of salt and the whole of the 450 g portion would contain 450 x 1 divided by 100 g salt = 4.5 g salt.
3. The advised daily intake for a woman is 5 g per day. The ready-made meal contains 90% (4.5 g divided by 5 g x 100% = 90%) of this quantity, while a portion of the cereal contains only 6% (0.3 g divided by 5 g x 100% = 6%). However, a bowl of cereal for breakfast and the chicken curry later in the day, would provide almost all of the woman's recommended salt intake for the day.

Like sodium ions and chloride ions, potassium ions are also widely distributed in foods and intakes are thought to be similar to those of sodium. However, potassium appears to have quite the opposite effect on blood pressure to sodium; the higher the potassium intake, the lower the blood pressure. Studies indicate that higher potassium levels allow the body to deal more effectively with excess sodium. Since fruit such as bananas, and vegetables, are good sources of potassium, more fruit and vegetables in the diet can have a beneficial effect on blood pressure.

2.6 Trace elements

The trace elements (also known as minor minerals or microminerals) are those that occur in quantities of less than about 5 g in the body. The more important ones are listed in Table 5, though not all of them will be considered here.

Table 5 Some trace elements needed by the human body. The functions and common food sources of the trace elements are shown.

Element (symbol)	Functions	Main food sources
chromium (Cr)	found in all tissues, may be involved in blood glucose regulation	liver, cereals, beer, yeast
cobalt (Co)	required for formation of red blood cells	liver and other meat
copper (Cu)	component of many enzymes; necessary for haemoglobin formation	green vegetables, fish, liver
fluorine (F)	prevents tooth decay	tea, seafood
iodine (I)	essential constituent of thyroid hormones	milk, seafood, iodised salt
iron (Fe)	essential component of haemoglobin in red blood cells	meat and offal, bread and flour, potatoes and other vegetables

manganese (Mn)	essential component of some enzymes	cereals, pulses, nuts
molybdenum (Mo)	essential component of some enzymes	kidney, cereals, vegetables, fruit
selenium (Se)	essential component of some enzymes; associated with Vitamin E activity	cereals, meat, fish, eggs, Brazil nuts
Zinc (Zn)	essential component of many enzymes and other proteins; required for steroid and thyroid hormone activity	meat and meat products, milk and cheese, bread flour and cereal products, peanuts

2.7 **Fluorine (F)**

Fluoride ions (F^-) are rare in foods, though some are found in tea and in seafood. However, fluoride does occur naturally in some water supplies, derived from the rocks through which the water flows. Its only role in the body appears to be to help to protect teeth from decay.

The stages of tooth decay are as follows:

- bacteria live in saliva on teeth (form plaque)
- produce lactic acid → dissolves calcium salts in tooth enamel
- produce protein-digesting enzymes → destroy enamel protein
- eventually enamel surface of tooth is breached
- underlying softer dentine is attacked
- cavities form in the teeth.

Activity 32

The main structural chemical in the enamel of teeth is the same as that in bone. Look back to the section on calcium to identify the chemical and its important component elements.

Answer

It is called hydroxyapatite, and contains the minerals calcium and phosphorus, as well as oxygen and hydrogen.

Acid dissolves the hydroxyapatite, a process called demineralisation. Once the acid has been neutralised by the saliva, the minerals can be restored to the tooth surface in a process called remineralisation. However, too many sugary foods mean that there is insufficient time for this remineralisation to occur completely and the tooth begins to decay. It is thought that fluoride helps to prevent this decay in several different ways:

1. As the enamel is developing in children's teeth, if fluoride is present, it replaces the OH (hydroxy-) part of hydroxyapatite, forming fluoroapatite, which is harder and more resistant to decay.
2. When the remineralisation process is occurring in the presence of fluoride, again the newly formed enamel is stronger.
3. Fluoride becomes concentrated inside the plaque bacteria, which reduces their ability to produce acid, so less demineralisation of the teeth occurs.

4. There is some evidence that children who grow up in areas where fluoride is present in the water have shallower grooves in the biting surfaces of their teeth, thus reducing the places where bacteria can lodge to form plaque.

It seems likely that the remineralisation effect (2) is the most important and so the control of sugars in the diet and the regular use of fluoride toothpaste, to supplement fluoride in the water, are the best preventative measures.

For the protection of teeth, the optimal level of fluoride in drinking water is 1 gram of fluoride per million grams of water (abbreviated to 1 part per million or 1 p.p.m.). In areas where fluoride levels are naturally low, this mineral can be added to the water supply, as it is in some areas of the UK. However, there is some controversy about this measure due to concerns that fluoride could be in some way harmful to health, although there is no scientific evidence to support that claim. The only adverse effect of fluoride appears to be that when fluoride intake is too high, children's teeth can become mottled with opaque white patches (dental fluorosis). The teeth remain functionally normal and resistant to decay and only their appearance is affected.

2.8 **Iodine (I)**

Iodide ions (I^-) derived, like all mineral elements, from the breakdown of rocks, is present in some soils, but much of it has been dissolved out by water over millions of years and washed down into the sea. It is concentrated by some marine organisms, and so can occur at quite high concentrations in edible seaweed, and in fish and other seafood. Thus people living near coasts often have sufficient iodine in their diet, whereas those living in mountainous areas, such as the Himalayas and Andes, where most of the iodine has been removed from the soil by millennia of high rain and snowfall, can suffer from iodine deficiency.

Iodine is an essential component of thyroid hormones, produced by the thyroid gland at the base of the neck. These hormones play a vital part in the regulation of metabolic processes, especially growth and energy expenditure. If there is insufficient iodine for the production of normal amounts of these hormones, the thyroid gland enlarges as the cells attempt to boost their hormone production. Ultimately, the swollen thyroid produces an enlargement of the throat called a goitre (Figure 3). Not only does the swelling impede breathing and swallowing, but the lack of sufficient thyroid hormones also leads to weight gain, lethargy, intolerance to cold, increased blood cholesterol, mental slowness and reduced heart function.

Figure 3 The condition of goitre where the thyroid gland enlarges due to an inadequate intake of iodine.

Iodine deficiency has its greatest impact during pregnancy, since it has major effects on the developing brain and physical growth of the fetus. In the worst case, the child suffers from cretinism, in which there is mental retardation, stunted growth, apathy, and impairment of movement, speech and hearing. However, even minor iodine deficiency can lower a child's IQ by between 10 and 15 points, which, if it occurs in a large percentage of the population, can severely hamper the economic development of a country. Iodine deficiency is regarded as the greatest cause of preventable brain damage, putting almost a thousand million children at risk worldwide. A UN initiative aims to eliminate the problem by adding iodine to salt, since salt is consumed by almost everyone in the world, regardless of culture or socioeconomic group. In the UK, cows'; milk is a major source of iodine due to the use of iodine-containing supplements in cattle food.

Nuclear accidents can release radioactive isotopes of iodine into the environment, which can then contaminate water and food supplies. The iodine settles onto the grass in pasture land, and is then eaten by cattle, and appears in their milk – a major way in which it is taken in by people. Radioactive iodine can become concentrated in the thyroid gland and cause thyroid cancers. If a large amount of normal (non-radioactive) iodine is taken in, it can displace the radioactive iodine (which is then excreted) and reduce the chances of cancer developing. This non-toxic iodine can be supplied to those at risk in the form of potassium iodide tablets. After the explosion at the nuclear power plant at Chernobyl in 1986, such tablets were supplied to 10.5 million adults and 7 million children thought to be at risk.

2.9 **Iron (Fe)**

The ability of blood to carry oxygen is due to the presence of the red pigment, haemoglobin, present in red blood cells. Haemoglobin is a protein formed from four polypeptide chains called globins, in the centre of each of which is a small non-protein part called a haem group (*haima* is Greek for 'blood'). Each of the haem groups has an iron atom within it (Figure 4).

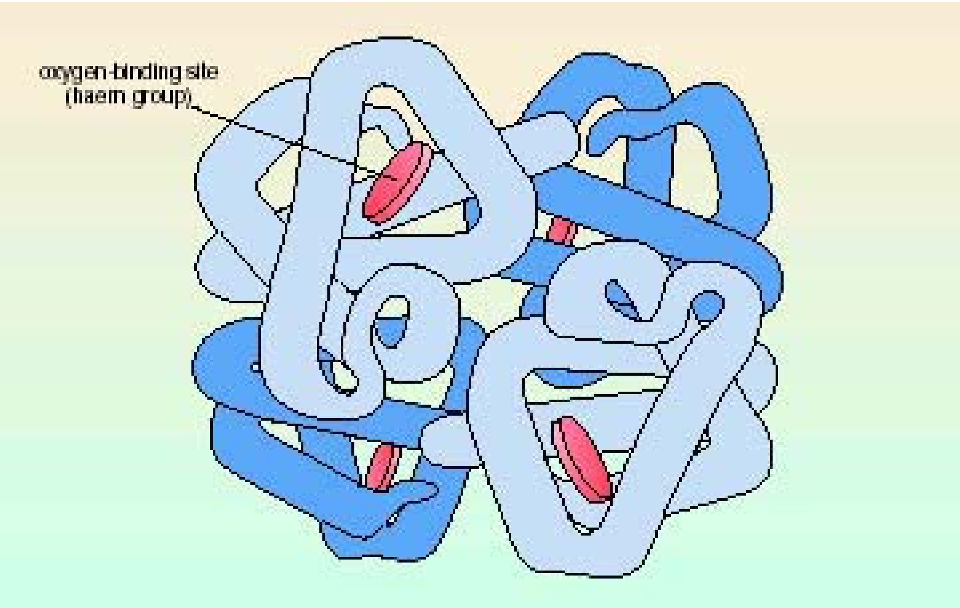


Figure 4 Schematic diagram showing the structure of the haemoglobin molecule, with four globin chains and a haem group within each.

The majority of iron in the body is in the form of haemoglobin. The total amount present depends on a number of factors, including gender and body weight, as well as general health.

Activity 33

1. If a woman weighing 60 kg has 40 mg of iron for each kilogram of body weight (mass), how much iron will her body contain?
2. If two-thirds of the iron in the body is contained in haemoglobin molecules, how many grams of iron will be in the woman's haemoglobin?

Answer

1. The total amount of iron in her body is 60 x 40 mg = 2400 mg = 2.4 g. This quantity is significantly less than the average amount of iron in the human body which is usually given as 4 g. Women of reproductive age are often short of iron due to menstrual losses or to the needs of pregnancy.
2. If two-thirds of this quantity is in the haemoglobin, then the amount of iron in the haemoglobin is 2.4 g x 2 divided by 3 = 1.6 g, i.e. just over one and a half grams.

Iron is also found in another molecule, that also binds to oxygen, called myoglobin. A myoglobin molecule is very similar to a quarter of a haemoglobin molecule, i.e. one globin chain with its associated haem. The red colour in the meat that we eat (the muscles of animals) is due to myoglobin. There are several types of fibres in muscles, including red fibres and white fibres, and whether the meat has a light or dark colour depends on the amount of each type present. Red muscle fibres predominate in those muscles that sustain long periods of activity. Fat may be stored around these muscles as an energy source, and the oxygen needed to combine with the fat to provide energy when the muscles are active is obtained from myoglobin. The myoglobin constantly replenishes its oxygen by picking it up from the haemoglobin in the blood. So these muscle fibres are high in myoglobin, which gives them their red colour. White fibres are found in muscles that are only required to be active for a short time. They use glucose from the blood as an energy source, and so there is little fat around the muscles. Less oxygen is needed to combine with glucose, and so less myoglobin is present and the muscles are lighter in colour.

Activity 34

Where do you find red meat and white meat in a cooked chicken? Can you relate this distribution to the requirement for myoglobin?

Answer

Chickens have red meat on the legs and white meat on the breast. Since the legs are used almost continuously for standing and walking, you would expect more myoglobin to be present and therefore the meat would be red. The breast muscles are used for flight and, since flights are rare and short in chickens, the myoglobin levels are low and so the breast meat is much paler. In birds that fly more, such as wild ducks, the breast meat is much darker in colour.

Liver is another type of meat that is very rich in iron, since the liver is where all mammals, including ourselves, store their iron, bound to a protein called ferritin. Cereals contain iron, though it is usually bound to a substance called phytate which is also found in nuts and some vegetables, and which also binds to calcium and zinc. Being bound in this way means that the iron from vegetables and cereals is less easily absorbed than the iron from animal products. However, phytate is removed by milling and then white bread flour is fortified with iron to ensure that bread is a useful source of the mineral. Various other substances in the diet can also bind iron and therefore prevent its absorption, while others, including vitamin C, can enhance the amount that is absorbed. The complex interaction with other foods makes it extremely difficult to predict just how much iron will be absorbed into the body from a particular meal. The average amount of iron in the diet is about the same as the RNI, which hides the fact that many individuals, especially women, are deficient in iron.

Red blood cells do not have a nucleus and so, without a set of chromosomes, they are unable to make new components or repair any damage. Since they spend a lot of their time being squeezed through tiny blood capillaries, often not much wider than themselves, they are easily damaged and this results in their limited lifespan of about 120 days. So, there is a huge daily turnover of red blood cells. In fact, every second, one and a half million (1 500 000) red blood cells are destroyed, and the same number of new ones are produced. If the iron was not recycled from the red cells that are destroyed, 240 mg of iron would be needed every day. Red cells are broken down mostly in the liver (and spleen), where the iron is stored attached to ferritin, as mentioned earlier, and new red cells are made in the bone marrow. So there is a requirement for iron to be transported in the blood between these sites, which it does attached to a protein called transferrin. Small amounts of the storage protein, ferritin, are present in the blood and a fall in ferritin level is the first sign of iron deficiency. If the deficiency persists, the red cells that are produced are smaller and contain less haemoglobin than normal and gradually the person develops the symptoms of anaemia, with tiredness and lack of appetite. It is thought that anaemia may affect one-tenth of the world population. A change in diet or taking iron supplements should correct the condition.

2.10 **Selenium (Se)**

Selenium is found in the body in an important group of enzymes (glutathione peroxidases) which have important antioxidant properties and work in conjunction with vitamins C and E to destroy free radicals in cells. Some studies have shown that a higher selenium level is linked to a lower risk of breast, prostate and colon cancer, which may in part be due to selenium's antioxidant function. Other selenium-containing proteins help to regulate thyroid function and play a role in the immune system.

The selenium content of foods depends partly on the protein level, since selenium is found attached to the amino acid cysteine in animal proteins and to methionine in plant proteins.

However, the level in food also depends on the selenium content of the soil where the plants are grown or the animals are raised. Levels are low where soils are acid and there is heavy rainfall. Soils in some parts of China and Russia have very low amounts of selenium and selenium deficiency is often reported in those regions because most food in those areas is grown and eaten locally. Selenium is found in fish, meat and eggs and in bread, though the level depends on the source of the wheat. Much of the wheat from America and Canada contains sufficient selenium, but when bread-makers in the UK switched from Canadian to European wheat, the selenium levels in the wheat were found to be 10 to 50 times lower, resulting in a significant fall in the daily intake of selenium in the UK. At least one bread manufacturer subsequently added selenium to their products. An alternative solution is to encourage farmers to use fertilizer containing added selenium, on their land. In the UK, Brazil nuts are the richest dietary source of selenium and if eaten in large quantities, could result in excess intake.

Selenium deficiency may contribute to the development of arthritis, coronary heart disease, thyroid malfunction, and to a weakened immune system. Evidence suggests that selenium deficiency does not usually cause illness by itself, but makes the body more susceptible to illnesses caused by other nutritional, biochemical or infectious stresses. Keshan Disease, named after the area of China where it was originally found, is a specific disease associated with selenium deficiency, resulting in an enlarged heart and poor heart function in children. It was first described in the early 1930s, though now has largely been eliminated due to a more varied intake of food.

2.11 **Zinc (Zn)**

Zinc is involved in many metabolic processes in the body, due to its importance in the functioning of more than 100 enzymes. These control, amongst other things, metabolism of foods, production of energy, cell division and protein synthesis. The body contains 2 to 3 g of zinc in total. Zinc is most commonly found in protein-rich foods, such as meat, and also in peanuts and pulses (peas and beans). Generally sufficient is available in Western diets, although there is some concern that amounts are declining due to increased processing of food and there may be insufficient reserves in some individuals to cope with increasing demands such as during periods of increased growth in children, during pregnancy and during wound healing after injury. Vegetarians who consume a variety of legumes and nuts will probably take in sufficient zinc, but other vegetarian diets may not contain enough, especially since zinc from plant sources is absorbed less readily than that from animal foods.

The clearest evidence of zinc deficiency was seen in the 1960s, when Iranian military officials noted that an unusual number of young men eligible for army duty were short in stature and showed delayed sexual maturation, as well as a number of other symptoms. Earlier research had shown that similar symptoms developed in animals if they were deprived of zinc in the diet. When the zinc levels of the army recruits were tested, they were found to be particularly low. Their normal diet was based almost exclusively on cereals, which although they do contain zinc, also contain chemicals called phytates (see the section on iron) which prevent the zinc from being absorbed. Furthermore, many of the young men indulged in the strange habit of geophagia, or clay eating. Clay binds to zinc in the digestive system and slows down its absorption. After treatment with a well-balanced diet containing adequate amounts of zinc for a year, pubic hair appeared, sexual organs increased in size, and growth in height was resumed, so confirming the vital role of zinc.

Signs of mild zinc deficiency are less dramatic and there is no specific deficiency disease associated with zinc. Instead many general signs appear such as poor appetite, a decrease in the sense of taste and smell, weight loss, poor night vision, delayed healing of wounds and repeated infections. About 25% of people who have an impairment in taste and or smell are suffering from zinc deficiency. Half of people with anorexia nervosa also appear to have a zinc deficiency and there is some evidence that zinc supplements improve the condition. Zinc supplements are sometimes used to treat skin ulcers or bed sores, but they do not increase rates of wound healing when zinc levels are normal. Zinc and castor oil creams are used to prevent nappy rash in babies. There are also health risks if the intake of zinc is too high. Metal fume fever, also called brass-founders' ague or zinc shakes, is an industrial disease caused by inhaling zinc oxide fumes, which cause damage to the nervous system.

2.12 Fluid balance

Although a person can survive for several weeks without food, without fluids, someone can survive for only a few days. A loss of water equivalent to just 1% of body weight is enough to make someone feel thirsty and to have an effect on ability to concentrate. Such a loss has been shown in some studies in schools to result in a 10% decrease in the mental performance of children. A 4% loss results in dizziness and reduced muscle power. By the time there is a 6% loss, the heart is racing and sweating ceases and a 7% loss results in collapse and subsequent death, if the loss is not replaced.

2.12.1 **Fluid loss**

During an average day, a person in a temperate climate such as the UK, loses about 2.5 litres of water.

Activity 35

How is water lost from the body?

Answer

The main loss is through the production of urine. Some water is lost through the skin as sweat and some in the faeces. Water is also lost from the lungs in breathing; you know that breathing out onto a cold glass surface produces condensation, and in cold weather the water vapour in the breath condenses into visible droplets in the air.

Urine output is controlled by the kidneys and even in cases of quite severe dehydration, urine production continues, since it is needed to rid the body of the nitrogen-containing compound, urea, which is produced as a result of the breakdown of amino acids from proteins. In a dehydrated person, the output of urine can be as low as 0.5 litres per day and it will be a dark brown colour. A more normal output is 1.5 litres and a light yellow colour indicates that the body is well hydrated. Sweating is part of the system that regulates the body temperature. Heat from the body is used to evaporate sweat from the surface of the skin and so the evaporation has a cooling effect. A typical loss of water through sweating of about 0.5 litres per day can increase in hot weather and during exercise to up to 2 litres per *hour*. The losses from the lungs (0.4 litres daily) and in faeces (0.1 litres daily) are normally fairly constant. However, diarrhoea increases the loss from the digestive tract hugely and can quickly result in dangerous levels of dehydration if the fluid is not replaced. Diarrhoeal diseases are common where people live in overcrowded conditions without a clean water supply, and there are an estimated 10 million cases and 5000 deaths each day throughout the world. Since both water and ions are lost, the best treatment for diarrhoea is oral rehydration, using sachets of commercially prepared rehydration mixture or a home-made solution containing eight teaspoons of sugar (to provide energy and to mask the taste of the salt) and one teaspoon of salt in a litre of water, together with some mashed banana or orange juice if available.

Activity 36

In addition to water, what are the main mineral ions present in this home-made rehydration solution?

Answer

Salt is sodium chloride, so the solution will contain sodium ions and chloride ions. Bananas and orange juice are good sources of potassium ions. All three ions are vital for the normal functioning of the body.

2.12.2 **Fluid gain**

In a normal diet, fluid is gained via food as well as in drinks. The amount of water in various foods is shown in Table 6. As well as plain water, most drinks, such as tea, coffee, juices and milk drinks, hydrate the body, but alcoholic drinks may not. Alcohol is a diuretic, a substance that increases the output of urine by the body. Calculations indicate that for each unit of alcohol taken in (1 unit=about 8 g alcohol), about 80 ml of extra water is lost from the body. If the unit of alcohol is taken in as a half pint of beer, then more fluid would have been taken in than was lost, so dehydration would not result. However, if the alcohol is taken in as wine or spirits, in a much smaller volume, then dehydration can result. Advice to alternate alcoholic and soft drinks, and to drink extra water at bedtime, is designed to offset the dehydration effect and go some way towards preventing a 'hangover' the next day. Caffeine, found in coffee and tea, is also a diuretic but over 300 mg a day is needed to have a diuretic effect and surveys in the UK find daily intakes well below this value. Individual fluid requirements vary but intakes of about 1 litre per day in food and 1.5 litres in drinks (nonalcoholic) are typical.

Table 6 The water content of some foods.

Food	Water/%
lettuce	95
carrots	90
boiled potatoes	80
grapes	80
lentil soup	78
grilled oily fish	65
cooked meat	60
potato chips	52

white bread	37
cheddar cheese	36
cake	15
cornflakes	3
semi-sweet biscuits	2.5

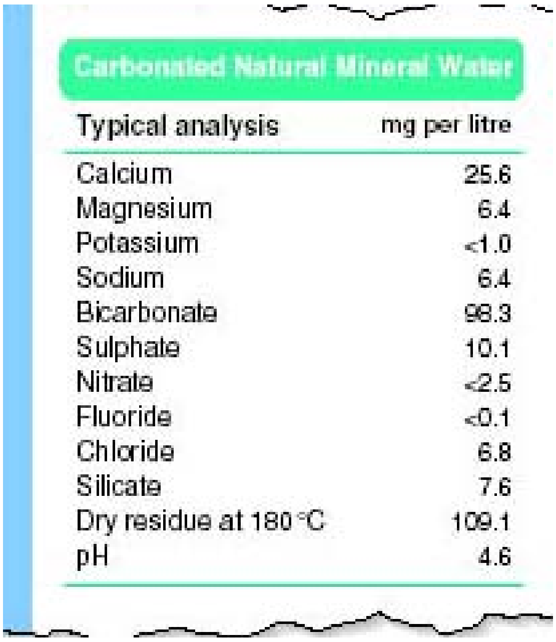
Water is also produced in the body. When proteins are synthesised by linking together amino acids, a water molecule is produced for every peptide bond made. When fatty acids are joined to glycerol to make a fat (triacylglycerol), water molecules are also generated. And finally, linking monosaccharides together to make carbohydrates also generates water. Overall, about a quarter of a litre (0.25 litre) of water per day is gained by the body from such metabolic processes.

Many people now drink mineral water, often carrying a bottle with them. Mineral water is thought to be 'better' in some way than drinking tapwater. In fact, tapwater contains adequate minerals too. Currently in the UK, water companies must satisfy the requirements of the Water Supply (Water Quality) Regulations 1989, which give prescribed concentration values (upper limits) for 57 different parameters. The limits for a few of them are given in Table 7.

Table 7 The legal upper limits of some dissolved mineral ions in drinking water in the UK.

	Upper limits/mg per litre
calcium (Ca^{2+})	250
magnesium (Mg^{2+})	50
potassium (K^{+})	12
sodium (Na^{+})	150
chloride (Cl^{-})	400
sulphate (SO_4^{2-})	250
nitrate (NO_3^{-})	50
dry residue	1500

The regulations also specify a range for the pH of 5.5–5.9 for tapwater. pH is a measure of the acidity or alkalinity of the water, with 7 being neutral, values below 7 being acidic and those above 7 being alkaline. The dry residue is the amount of material left when a sample of the water is boiled to dryness.



Carbonated Natural Mineral Water	
Typical analysis	mg per litre
Calcium	25.6
Magnesium	6.4
Potassium	<1.0
Sodium	6.4
Bicarbonate	98.3
Sulphate	10.1
Nitrate	<2.5
Fluoride	<0.1
Chloride	6.8
Silicate	7.6
Dry residue at 180 °C	109.1
pH	4.6

Figure 5 Part of the label from a bottle of mineral water.

Activity 37

Compare the values in Table 7 with those from the label on a bottle of 'carbonated natural mineral water' (Figure 5). Comment on the comparisons.

Answer

The values for mineral water are all far below the limits given and, in fact, mineral water appears to be rather low in minerals, compared with the limits permissible in drinking water. The bicarbonate in the mineral water is produced by the dissolved carbon dioxide and this also lowers the pH value.

Tapwater and mineral water may, of course, come from exactly the same source. However, some tapwater is obtained from sources that are at risk of contamination from microbes, and in the UK, tapwater is therefore filtered and pretreated with chlorine and other chemicals to make it safe to drink. Bottled water that is labelled as 'natural mineral water' is extracted from the ground, and is bottled at source without any treatment. If the water is sparkling when it comes from the ground it is labelled as 'naturally carbonated natural mineral water'. If the carbon dioxide is added at the bottling plant, it must be labelled 'carbonated (or sparkling) natural mineral water'. Water labelled as 'spring water' must be obtained from an underground source, be bottled at source and be micro-biologically safe without any treatment. However, certain other treatments, such as the chemical removal of minerals whose levels are too high, are permitted. 'Table water', on the other hand, need comply only with regulations on water quality for tapwater and can be bottled anywhere.

2.13 Key points about minerals

1. Certain minerals are required in the body.

2. Some minerals form essential structural components of tissues. For example, calcium, phosphorus and magnesium compounds are major components of bones and teeth. Fluoride is also important in protecting teeth from decay.
3. Sodium, potassium, calcium and chloride ions are important in maintaining the correct composition of cells and of the tissue fluids around them (homeostasis). These same ions are also involved in communication between cells, in particular the rapid transfer of signals along nerve cells and in the brain. They also play a part in muscle contraction.
4. Some minerals are essential components of important molecules such as hormones and enzymes. For example, the hormones produced by the thyroid gland contain iodine and many enzymes need magnesium, selenium or zinc to function. Sulfur is an essential component of some amino acids and iron is incorporated into haemoglobin and related proteins.
5. The correct fluid balance is also essential for normal functioning of the body.
6. Tapwater, and not just mineral water, contains minerals.

Conclusion

This free course provided an introduction to studying Science. It took you through a series of exercises designed to develop your approach to study and learning at a distance and helped to improve your confidence as an independent learner.

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