Viva! HEALTH

Break Free

How to build healthy bones and what really matters in the prevention of osteoporosis.

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Break Free How to build healthy bones and what really matters in the prevention of osteoporosis

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Contents

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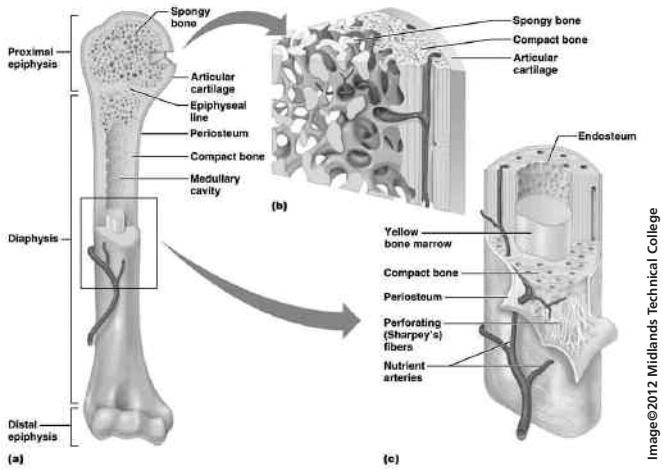
Viva! Health is the science-based section of the charity Viva!. We promote human health through the promotion of a plant based diet. Viva! Health monitors and interprets research that links diet to health – explaining in simple terms how what we eat affects us, in both positive and negative ways. Viva! Health communicates with the media, the public, health professionals, schools and food manufacturers to provide accurate information to help people make informed choices.

Living skeleton

The human skeleton is a very complex structure made up of more than 200 bones held together and supplemented by ligaments, tendons and cartilage. It serves as scaffolding that supports and protects organs, anchors muscles and stores minerals such as calcium and phosphorus. Red bone marrow in certain bones also produces blood cells. The human skeleton is far from being just an inanimate framework, it's a living network of cells, protein fibres, minerals and blood vessels.



Bone mass itself is made of two basic matters – the flexible and tough protein (collagen) scaffolding and the hard but fragile mineral matter (around 65 per cent of bone) that consists mostly of calcium phosphate.

Bone formation requires adequate supplies of energy, amino acids (protein), bone-forming minerals (calcium, phosphorus, magnesium, zinc) and other ions (eg copper, boron) and vitamins (eg vitamins C, D, K) that are involved in bone and cartilage metabolism (Prentice *et al*., 2006).

Bone growth and remodelling

Bones grow very fast immediately after birth, the growth then slows down rapidly and increases again later in infancy. At this stage bone growth is faster in arms and legs than in the trunk and remains so until puberty. With the beginning of sex hormone production at puberty, trunk bone growth accelerates while that of the long bones slows down (Prentice *et al*., 2006).

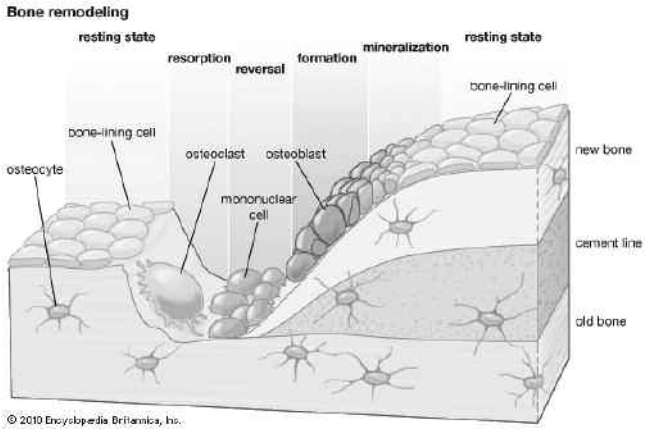
Long-term studies of changes in bone mass during growth have confirmed that in girls, the greatest increases in bone mass occur between the ages of 12–15 years, compared with 14–17 years in boys (Theintz *et al*., 1992, Weaver, 2002). The rate of change in bone mass then slows dramatically by the age of 16–18 years in women and 17–20 years in men (Davies *et al*., 2005) and by the age of 20, the bones stop growing.

As bones grow, wear away or suffer minor damage as a result of physical activity, they are continuously repaired – damaged or worn out parts are decomposed and carried away while new cells fill in the gap and build the appropriate structure around themselves. This maintenance occurs throughout life, although the repair rate tends to gradually decrease with age. The cells removing the old or damaged bone are called osteoclasts and the bone-forming cells are called osteoblasts. Once an osteoblast is embedded in the bone, it becomes an osteocyte.

The human body has only a limited ability to produce new osteoblasts (cells forming new bone) and with aging, bone formation (ie the ability to produce new bone tissue for bone repair) decreases due to reduction in osteoblast number and activity (Eaton, 2006; Marie, 2010). It is therefore important not to make the body use osteoblasts unnecessarily and the only way this can be achieved is through diet as is described later on.

Normal bone mineralisation (deposition of the mineral matter in the collagen fibre scaffolding) is the result of two dynamic processes: modelling and remodelling.

Modelling allows for deposition of new bone mass in specific areas in the bones and it is the process by which bones grow wider and longer. This process is unique to growing skeletons.



Remodelling is a different process as it occurs throughout life and consists of two opposing processes: resorption and formation. Bone resorption is initiated by osteoclasts and has three functions:

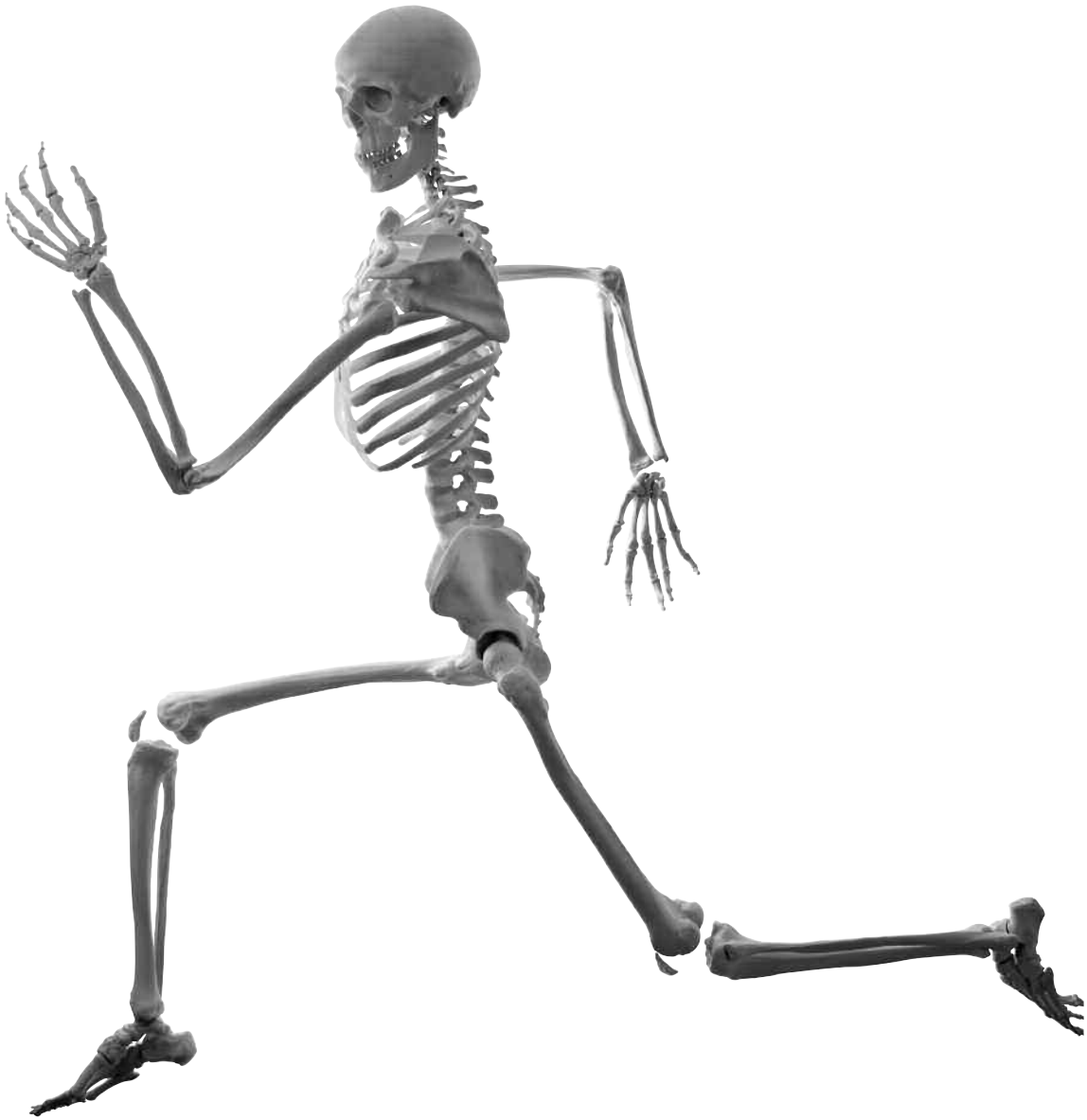
- maintain normal skeletal mass
- repair microdamage to the skeleton
- participate in calcium homeostasis (keeping calcium levels in the body at ideal concentrations)

This process is followed by bone formation, during which osteoblasts fill the resorption cavity and form a pre-bone mass, which is later mineralised into new bone.

Peak bone mass is achieved sometime in early adulthood, usually in the third decade (Davies *et al*., 2005; Henwood and Binkovitz, 2009) after which bone formation slowly starts lagging behind bone resorption which can lead to decreasing bone density. This is a natural process that does not inevitably lead to osteoporosis.

The bone mineral (hydroxyapatite) consists mainly of calcium and phosphate. Calcium content in bones is tightly linked to calcium levels in the blood and calcium is being continuously exchanged between the two systems. This mechanism is finely regulated by complex interplay amongst the skeleton, intestines, kidneys, and parathyroid glands.

Ninety nine per cent of the body's calcium and 80 per cent of phosphate are in the skeleton and therefore any effect of food, lifestyle or medication on calcium balance in the body is synonymous with an effect on bone mineral density (Bonjour, 2011; Prentice, 1997; Prentice *et al*., 2003, Prentice *et al*., 2006). Any factor that disturbs the balance between bone resorption and formation or calcium absorption has the potential to cause increased bone loss (which can result in osteopenia or osteoporosis), regardless of patient age.



Hormone cascade

One of the main hormones regulating calcium metabolism is parathyroid hormone (PTH) which is secreted by the four parathyroid glands hidden behind the thyroid. This hormone directly affects the skeleton and kidneys and indirectly affects the small intestine so that calcium levels in the body can be maintained in the normal range.

When calcium levels in the blood fall, PTH levels rise and promote calcium release from the bones. PTH indirectly activates osteoclasts which then decompose top layers of the bone and by this process calcium is released into the blood.

In the kidneys, PTH has two distinct actions:

1) **Promoting calcium reabsorption and phosphorus excretion**
2) **Facilitating the conversion of inactive vitamin D to its active form**

In turn, active vitamin D is necessary for active absorption of calcium from the small intestine. Therefore, the overall effect of PTH secretion is an increase in calcium levels in the blood and a decrease in phosphorus levels. On the other side, when calcium levels are too high, secretion of PTH is suppressed which leads to an increase in calcium excretion in urine (Henwood and Binkovitz, 2009).

Calcitonin, a hormone produced by the thyroid, counteracts the actions of PTH to maintain calcium balance. Calcitonin lowers calcium levels in the blood and it does so in three ways:

1) **Inhibits calcium absorption by the small intestine**
2) **Inhibits osteoclast activity in bones**
3) **Inhibits reabsorption of calcium in the kidneys allowing it to be secreted in the urine**

PTH and calcitonin regulate calcium levels in the body but there are other hormones that influence the skeleton, particularly during development.

Throughout childhood, growth hormone (GH) and insulin-like growth factor 1 (IGF-1) strongly influence bone mass accrual, both before and after the attainment of final height (Boot *et al.*, 1997; Shalet *et al.*, 2003). Levels of GH and IGF-1 increase dramatically during puberty, supported by the rising levels of sex hormones (Weaver, 2002).

Before the age of 50, sex hormone levels begin to decline (in women more significantly than in men) and the decrease in oestrogen (women) or testosterone (in men) causes a higher rate of bone resorption creating an imbalance in bone resorption relative to bone formation. This may lead to osteoporosis, a common skeletal disease characterised by reduced bone mass, deterioration of bone microarchitecture and increased susceptibility to fractures (Marie, 2010). The oestrogen decline caused by the menopause in women is much more dramatic and has a more profound effect than the testosterone decline in men, therefore women are at a higher risk of developing osteoporosis.

Both the development of peak bone mass in the younger population and the rate of bone loss in older adults are determined by a combination of genetic, hormonal, mechanical and nutrition factors (New, 2002).

Here is a typical bone accrual and loss curve (New, 2002):

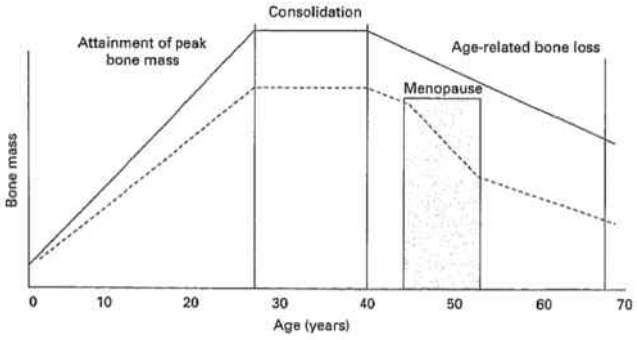


Fig. 2. Alterations in skeletal mass in men (–) and women (- - -) throughout the life cycle.

Osteoporosis

Osteoporosis is a disease that affects millions of people around the world. In the UK, almost three million people have it (National Osteoporosis Society, 2012).

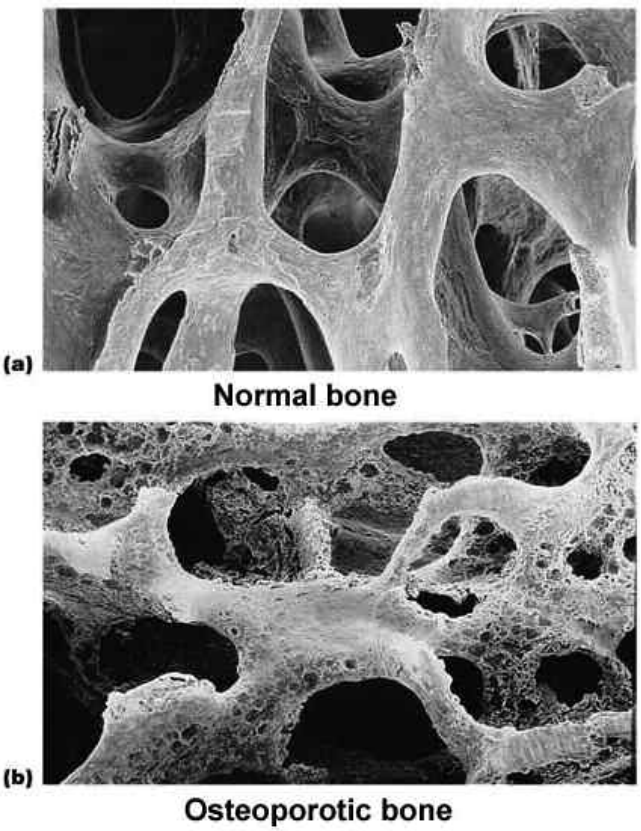
Osteoporosis is a bone disease with two predominant characteristics:

1. Low bone density
2. Structural deterioration of bone tissue

Both these factors lead to an increased bone fragility and a consequent increase in fracture risk (New, 2002; Ashwell *et al*., 2008). Fragility fractures are fractures caused by minimal trauma, such as a fall from a standing position. In children, such fractures are most common in the lower forearm, and in older individuals at the wrist, spine and hip, but osteoporotic fractures can occur anywhere in the skeleton. There are about 300,000 fragility fractures every year in the UK (National Osteoporosis Society, 2012).

Osteoporotic fractures are a major cause of poor health and disability in the elderly and, in the case of hip fractures, can lead to premature death. In the UK, 1,150 people are dying every month as a result of hip fractures (National Osteoporosis Society, 2012). People who were not in very good health or were underweight before falling are most likely to die from a hip fracture – this type of injury takes a heavy toll on an elderly body and a frail person is least likely to recover. When people die quite soon after the fall or following surgery, it is often because of complications such as infection or pneumonia. If the person is unable to call for help immediately after the fall, they can develop hypothermia and dehydration, or may suffer blood loss, which increases the risk of death. Hip fractures result in severely reduced mobility, which can also cause, or exacerbate, cardiovascular disease and can also lead to potentially fatal blood clots.

Hip fracture numbers in the UK are projected to increase to 117,000 per year in 2016 (Dennison *et al*., 2005) and 120,000 by 2020 (Ashwell *et al*., 2008). The incidence of vertebral and hip fractures increases exponentially with advancing age while that of wrist fractures levels off after the age of 60 years. Ninety per cent of hip fractures occur in those aged 65 years and over, and a quarter of these are in men (Ashwell *et al*., 2008).



Poor bone health also comes with a skyrocketing price tag – combined cost of hospital and social care for patients with a hip fracture amounts to more than £2.3 billion per year in the UK – that's approximately £6 million a day (National Osteoporosis Society, 2012).

Osteoporosis and hip fractures around the world

In the UK, one in two women and one in five men over the age of 50 will suffer a fracture (van Staa *et al*., 2001). The risk is similarly high in many Western countries. Contrary to the popular belief that osteoporosis is a disease caused by calcium deficiency, populations that consume the most cows' milk and other dairy products have the highest rates of osteoporosis and hip fracture in later life (Abelow *et al*., 1992; Lanou and Castleman, 2009). The average consumption of dairy products per person per week in the UK is (DairyCo, 2012): 1.5 litres of milk, 200 grams of yoghurt, 120 grams of cheese, 65 grams of cream and butter. The figures do not include desserts and ice-cream. How does it happen that with dairy product consumption of more than 270 grams per day (the actual figure is likely be higher because the average value does not exclude small children, lactose intolerant and people avoiding dairy) providing more than enough

calcium, the British population has one of the highest osteoporosis and hip fracture rates?

The latest figures (Kanis *et al*., 2012) from 63 countries show that there is a greater than 10-fold variation in hip fracture risk between countries (see the graph below). In the countries where the consumption of dairy and meat is relatively low, the rates of osteoporosis and/or hip fractures are also low and vice versa. The authors also noted that while the USA's numbers are in the 'middle' risk group, if the US population was categorised according to ethnicity, white Americans would be in the high risk group, while Hispanic, Asian and Black populations would be at the lower risk level. Among people of Hispanic, Asian and Black heritage, lactose intolerance is much more common so many cannot consume dairy products.

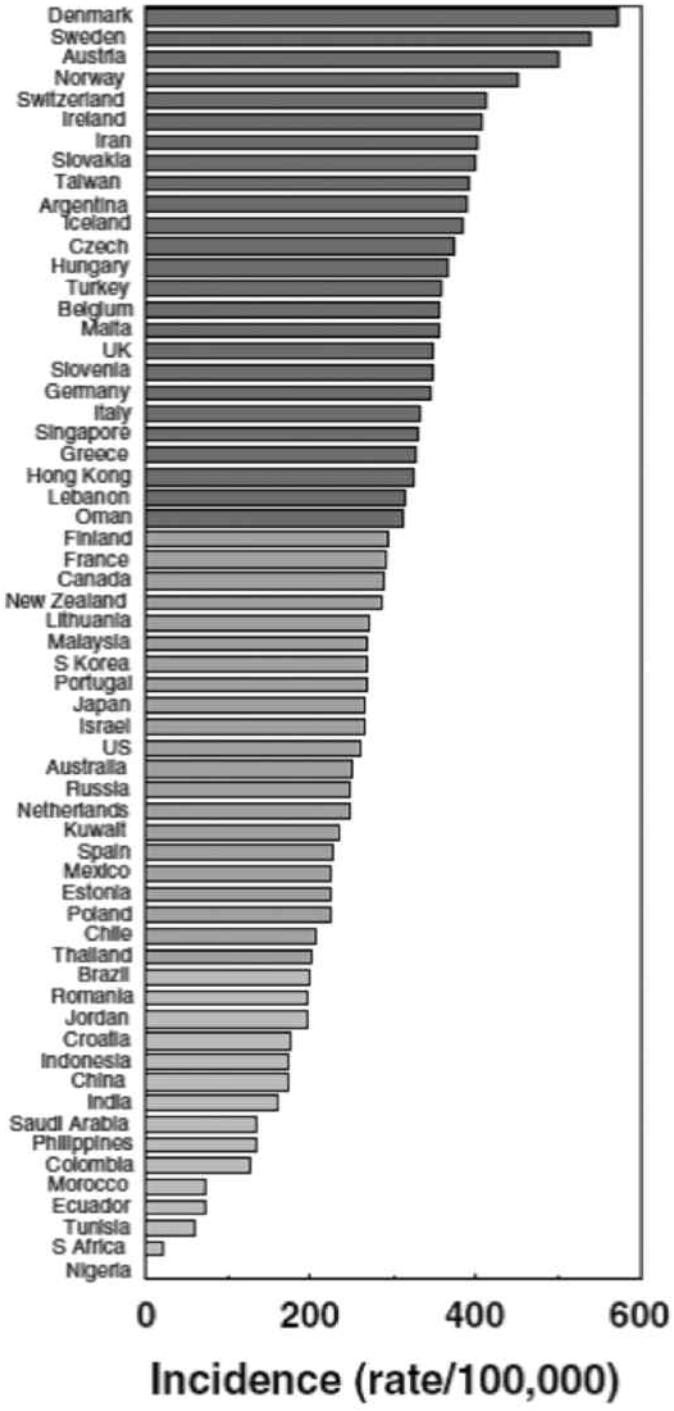
Anderson (1999) proposes that the lower hip fracture rates in Asian women (despite the lower intake of calcium and lower lifetime exposure to oestrogens due to later onset of menstrual cycle) can be explained by a combination of their dietary and lifestyle factors:

- greater physical activity
- a diet with less animal protein and more phytoestrogens (from soya products)
- greater exposure to ultraviolet light and thus enhanced vitamin D production in the skin

Osteoporosis – who is at risk?

In general, white people are at greater risk than persons of Latin American or African heritage but many risk factors are associated with osteoporosis. The following are among the most common:

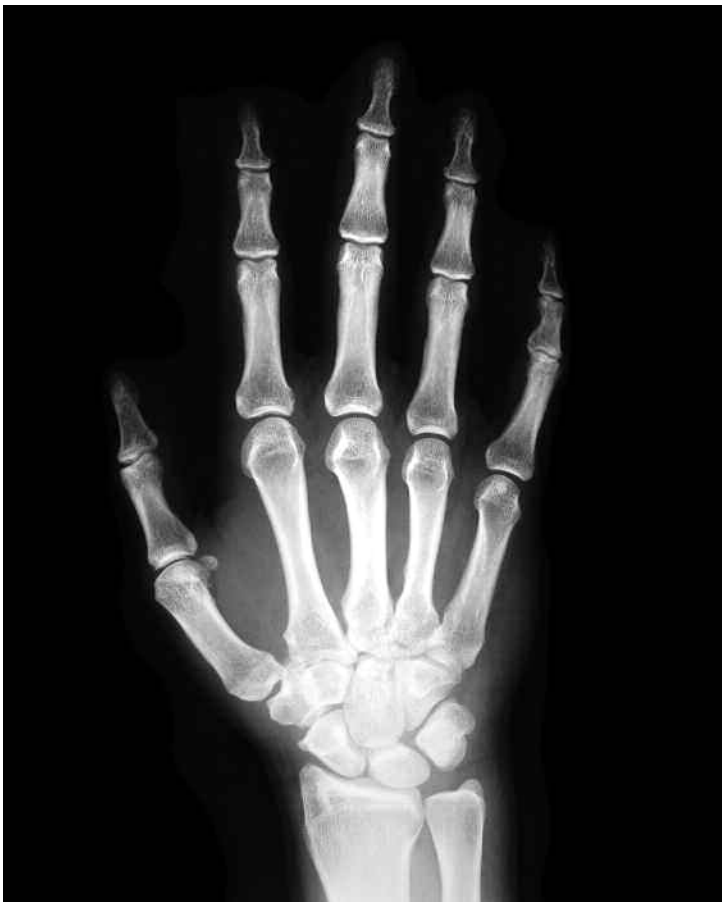
- Age – in postmenopausal women, fracture risk increases with age. Both men and women aged 70 and older have an increased risk of fracture.
- Female gender – osteoporosis is more common in women than in men, tends to occur earlier and be more severe.
- Weight – low body weight or being underweight can contribute to lower bone mineral density.
- Sedentary lifestyle – due to a lack of stimulation for the bones.
- Genetic factors – having a relative with osteoporosis might mean an increased risk but lifestyle choices can determine whether the disease will develop or not.
- Previous fracture.
- Smoking – smokers tend to have lower bone density.
- Glucocorticoid, cyclosporine and methotrexate treatment – these medications are known to have a negative effect on bone density.
- High alcohol consumption – however, low to moderate alcohol intake could be protective.
- Elevated blood homocysteine concentration is associated with elevated risk – this can be easily avoided with regular vitamin B12 intake.
- Having no children – women who never had children tend to have a higher risk.
- Early onset of menopause.



- Calcium or vitamin D deficiency.
- Low peak bone density achieved in young adulthood.
- Ovarian hormone deficiency (oestrogens).

How to measure bone mass?

The most commonly used technique is to measure bone mineral density (BMD). BMD represents the mass of bone mineral per unit bone area scanned (g/cm2). A method called DEXA or DXA (dual-energy X-ray absorptiometry) is usually used to measure BMD. However, while DEXA provides an assessment of bone mass, it doesn't assess the architecture of bone which is a very important factor in terms of bone health (Murphy and Carroll, 2003).



Moreover, the measures are not equivalent across different BMD measuring techniques and comparisons cannot be made between them. Even comparing measurements using the same technique but on instruments developed by different manufacturers can be a problem because of the use of different calibration methods and materials. For example, DEXA measurements can differ by ten to 20 per cent between instruments made by different manufacturers (Prentice *et al*., 2006).
It is also important to consider bone remodelling when assessing bone mass or bone mineral density. Bone remodelling (turnover) is the continual process by which the skeleton is renewed through the breakdown (resorption) of existing bone and the formation of new bone. Remodelling causes a temporary deficit of bone tissue. Any intervention that alters the balance between resorption and new bone formation produces a temporary lag while the system readjusts. This readjustment process can lead to an increase or decrease in bone mineral density depending on whether resorption is temporarily increased or decreased relative to bone formation. This together with the fact that bone scanning techniques provide a static measure of the skeleton at one specific moment can lead to inaccurate results and momentary changes in bone density can be interpreted as a long-term situation (Murphy and Carroll, 2003; Prentice *et al*., 2004).

This raises a question – should we rely on measurements of our bone density to tell us how healthy our bones are? We can be seriously misled if we do. The best possible approach is doing everything we can to keep our bones healthy such as eating a healthy diet, engage in regular weight-bearing activity and spend at least 20 minutes a day outside (to allow our skin to produce vitamin D).

Why do bones become porous?

Contrary to popular belief, osteoporosis is not a disease caused by a lack of calcium in the diet, neither is it an inevitable part of aging.

There are several key players in the development of osteoporosis:

- High animal protein intake
- Lack of other nutrients
- Lack of physical activity
- Hormonal imbalances (mainly lack of oestrogens in women, as described earlier)

Even though bone health is partly dependent on genetics, diet and lifestyle are the determining factors in the development of osteoporosis.

Fine acid-alkali balance

The human body is a fine-tuned organism that works best only under certain conditions and is very sensitive to any changes in the inner environment. One of the most important characteristics of the body is a stable acid-alkaline balance in the blood. The acidity or alkalinity of any solution is measured by pH – the hydrogen ion concentration. The more hydrogen ions are in a solution, the more acidic the solution is. The scale of the pH is zero to 14. The neutral pH is considered to be seven, pH below seven means the solution is acidic (the lower the number the more acidic) and above seven means it is alkaline (the higher the number the more alkaline).

The pH of the blood has to be maintained between 7.35 and 7.45. The body immediately corrects the balance if any changes to this pH value occur as acid-base homeostasis (stable and fine balanced ratio) in the body is critical to health and survival.

There are three specific mechanisms maintaining the pH (New, 2002):

1) Buffer systems
2) Exhalation of carbon dioxide (CO2)
3) Kidney excretion

Diet influences the acid–base balance in the body and dietary data can be used as an estimate for endogenous acid production – ie the amount of acid produced in the body as a result of metabolism of the food eaten (Alexy *et al*., 2007).

Everything we eat or drink is either acid or alkali forming. When acid is formed, the body needs to employ one of its buffer systems – the skeleton – to neutralise the acid by releasing calcium. Decrease in pH (caused by acid overload of the body) directly enhances the activity of osteoclasts (the bone decomposing cells) which leads to calcium being released in the blood (New, 2002). This process is independent of hormonal status. Both calcium and acid are then excreted in urine and only a fraction of calcium can be returned back to the bones (Ashwell *et al*., 2008; Eaton, 2006; Hannan *et al*., 2000; Itoh *et al*., 1998).

It is almost impossible to eat only alkaline foods and maintain a healthy diet but as it's shown later on, aiming for 70:30 ratio of alkalising versus acidifying foods is the best balance.

One way to measure the effect of food on the body is by assessing the protein and mineral content of the food – some minerals are alkalising while others are acidifying. The most commonly used measurement is called PRAL (potential renal acid load) and the main minerals taken into consideration are magnesium, potassium, calcium and phosphorus.

Another way of measuring the effect of the food is by testing the pH of the urine, saliva and the blood after eating a particular food.

Protein matters

Some dietary factors contribute to dietary acid load more than others. Sulphur from sulphur amino acids (protein building blocks) is the main contributor because it is metabolised into sulphuric acid. Sulphur amino acids are highest in animal protein and therefore diets high in animal protein are likely to produce considerable amounts of acid in the body. Another contributor is phosphorus, which is mainly supplied by meat and dairy products. Potassium and magnesium, mainly contained in plant foods, and calcium, being present both in plant foods and dairy products, are determinants of alkaline load (Alexy *et al*., 2007).

When Mazess and Mather (1974) studied an Inuit population, one of the most outstanding discoveries was that after the age of 40, Inuits had a bone mass deficit of between ten to 15 per cent compared to the average American population. The bone loss and fast progression of osteoporosis was attributed to a diet very high in animal protein and phosphorus and low in alkalising salts.

In a series of experiments, Remer and Manz (1994) studied the impact of diets with varying proportions of animal protein and fruits and vegetables on the amount of acid produced in the body. They found that with increasing amounts of animal protein, the acid production rises significantly and that an average Western diet produces enough acid to have a permanent acidifying effect on the body. They recommended a higher intake of alkalising foods such as fruits and vegetables and warned against high protein diets.

Although the concept has been debated for decades, the hypothesis that animal protein is the main dietary

factor responsible for producing an acidic environment in the body leading to brittle bones gained more attention in 1992 when a study by Abelow *et al*. from Yale University was published. They analysed data from 34 surveys and 16 countries and found that 70 per cent of the fracture rates were attributable to the consumption of animal protein. The impact of acid–alkali balance on health, especially of bone (New *et al*., 2004; Alexy *et al*., 2005) and kidney (Reddy *et al*., 2002) is now widely accepted.

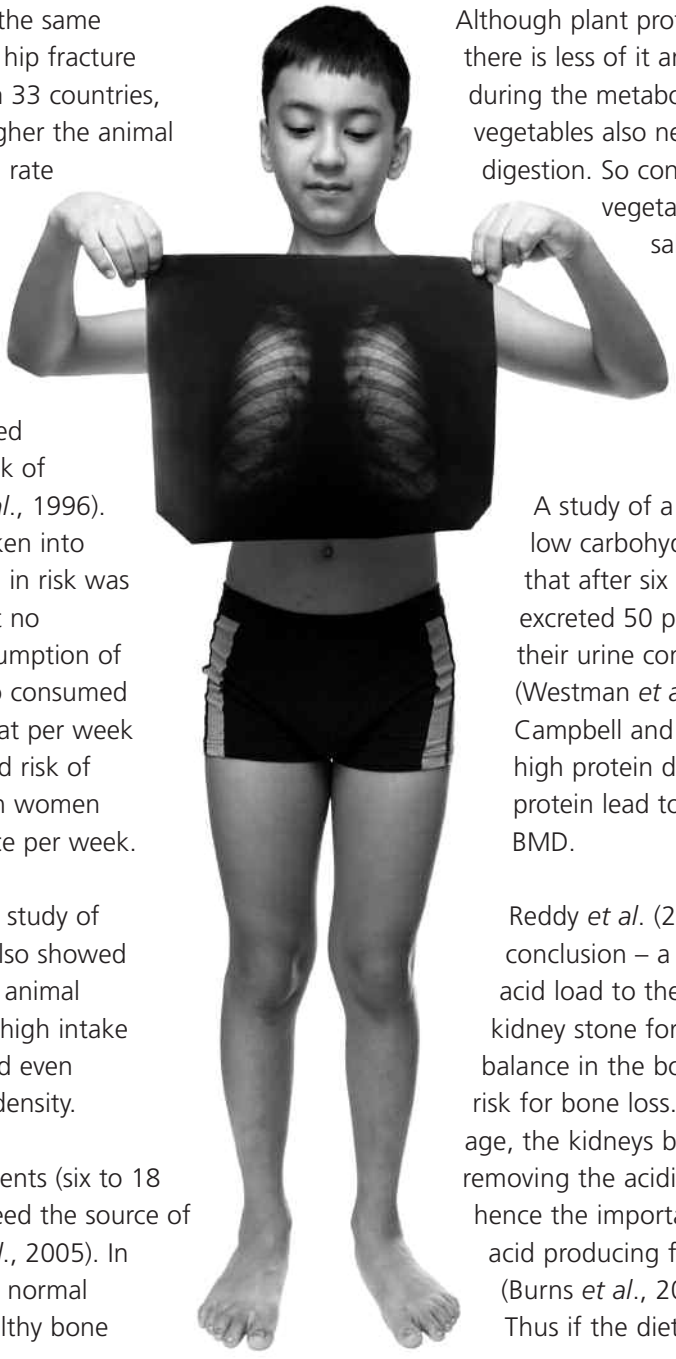
When the hypothesis was tested in a seven-year study of 1,035 women (Sellmeyer *et al*., 2001), it was found that women with diets high in animal and low in plant protein had an almost four times higher rate of bone loss and their risk of hip fracture was 3.7 times that of women who consumed the least animal protein. Frassetto *et al*. (2000) came to the same conclusion – in their analysis of hip fracture incidence and dietary data from 33 countries, they clearly showed that the higher the animal protein intake is, the higher the rate of hip fractures.

Another large study of more than 120,000 women lasting 12 years showed that high protein consumption (more than 95g per day) was associated with a significantly increased risk of forearm fracture (Feskanich *et al*., 1996). When types of protein were taken into consideration, a similar increase in risk was observed for animal protein but no association was found for consumption of vegetable protein. Women who consumed five or more servings of red meat per week also had a significantly increased risk of forearm fracture compared with women who ate red meat less than once per week.

Findings from yet another large study of women (Weikert *et al*., 2005) also showed a clear division – high intake of animal protein caused bone loss while high intake of vegetable protein did not and even contributed to increased bone density.

A study of children and adolescents (six to 18 years old) showed that it is indeed the source of protein that matters (Alexy *et al*., 2005). In this study, protein intake within normal ranges was associated with healthy bone mass increase. Nevertheless, in children whose diet had higher acid load, bone mass and cortical bone density (close to the bone surface) was significantly lower. Apart from recommending increasing the fruit and vegetable intake, this study also showed that long-term calcium intake had no significant effect on any bone health variable.

Another recent study focusing on children and bone mass accrual (Zheng *et al*., 2010) showed that when protein intake was considered according to animal or plant food sources, protein from animal foods, particularly meat, had significant negative effects on bone mass accrual. It was concluded that higher protein intake, especially from animal foods, appeared to have a negative effect on bone mass in adolescents.



Although plant protein also produces acid, there is less of it and alkaline salts produced during the metabolism of fruits and vegetables also neutralise the acidity during digestion. So consumption of fruits and vegetables that produce alkaline salts, such as carbonates and citrates, reduces the need for the bones to provide part of the buffer system (Burns *et al*., 2003).

A study of a high animal protein and low carbohydrate (Atkins) diet showed that after six months on the diet, people excreted 50 per cent more calcium in their urine compared to the starting point (Westman *et al*., 2002). Later on, Campbell and Tang (2010) warned that high protein diets emphasising animal protein lead to bone loss and decreased BMD.

Reddy *et al*. (2002) came to the same conclusion – a high protein diet increases acid load to the kidney, which may lead to kidney stone formation, decreases calcium balance in the body and thus increases the risk for bone loss. Moreover, with increasing age, the kidneys become less efficient at removing the acidic ions from the blood and hence the importance of consuming fewer acid producing foods becomes even greater (Burns *et al*., 2003; Frassetto *et al*., 2008). Thus if the diet continuously supplies the

body with acid and the kidneys are less able to remove these acidic substances from the blood, the alkalising bone minerals are used up faster than in a younger person, which results in increased losses of body calcium. Those effects may contribute to development of osteoporosis and kidney stones, loss of muscle mass, and age-related kidney insufficiency (Frassetto *et al*., 2008).

When particular types of food were tested, a significant positive correlation was found between acid production in the body and the weight consumed per day of milk, cheese, meat and cereal foods and a negative correlation was found with the weight of potatoes and fruit and vegetables (Prynne *et al*., 2004).

An extensive review by Lanou (2009) resulted in a conclusion that: 'bones are better served by attending to calcium balance and focusing efforts on increasing fruit and vegetable intakes, limiting animal protein, exercising regularly, getting adequate sunshine or supplemental vitamin D, and getting 500 mg Ca/d from plant sources.'

The accumulated data indicate that the adverse effect of protein, in particular animal protein, outweighs the positive effect of calcium intake on calcium balance (WHO/FAO, 2003). As shown above, acid generating food may lead to calcium losses from the skeleton and returning calcium back into the bones exhausts osteoblast (bone building cells) numbers. On the other hand, diet that is mostly alkaline and supplies lower doses of calcium gradually doesn't cause calcium loss from the bones (because it is not required for acid neutralisation) but allows the body to replenish calcium levels according to its needs.

Balancing act

The high alkaline salt content of many fruit and vegetables counteracts the effects of acid-generating foods such as meat, dairy and some cereals (see the chart on pages 25-27). Experiments with the administration of alkaline salts resulted in a decrease in urinary excretion of both calcium and phosphorus and an improvement in overall calcium balance. This was accompanied by a decrease in markers of bone resorption and an increase in markers of bone formation (Ashwell *et al*., 2008). Another study (Jehle *et al*., 2006) came to the same conclusion and stated that bone mass can be actually increased significantly by increasing daily alkali intake.

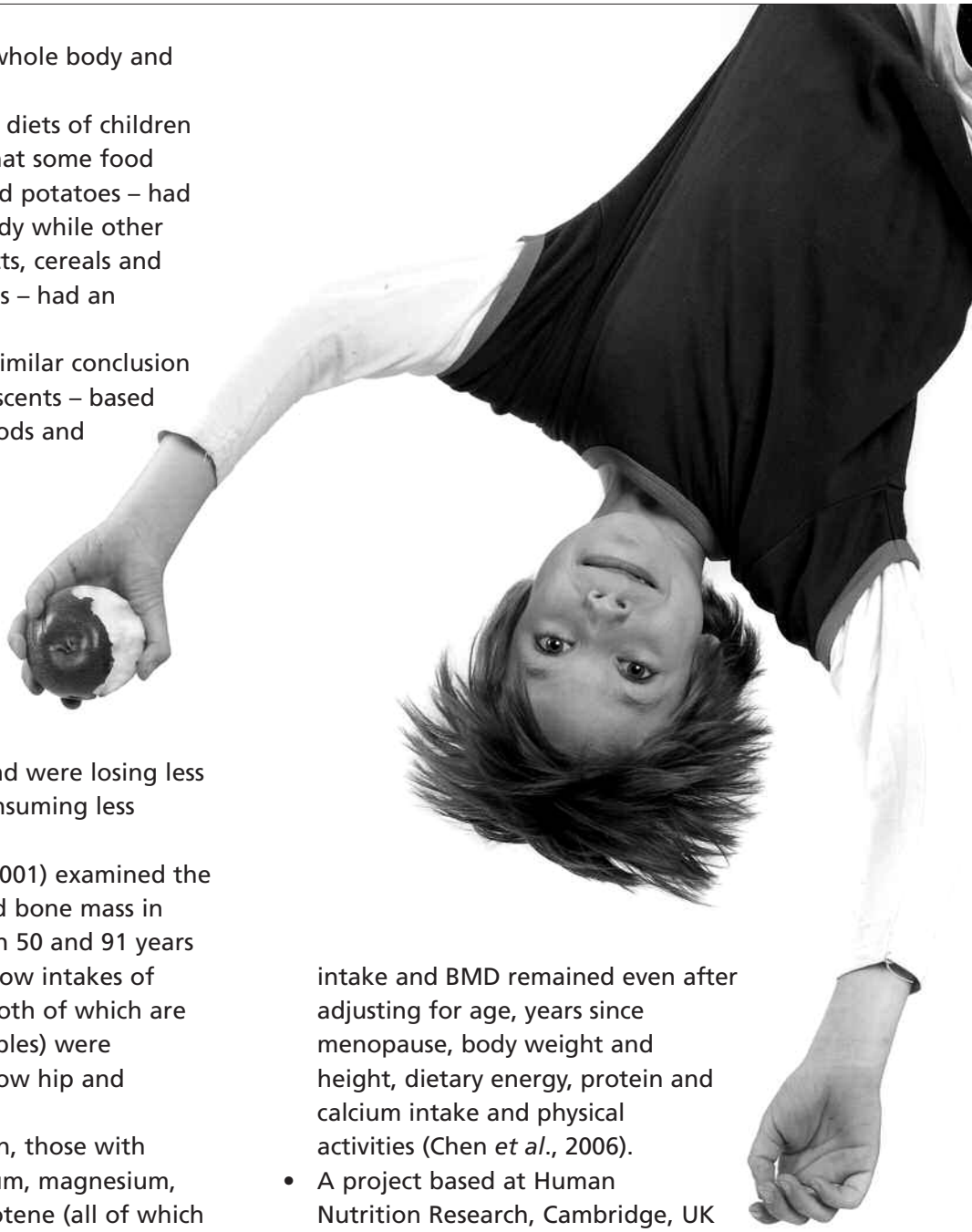
Apart from the high content of alkaline salts in fruit and vegetables their beneficial effect might be increased by other, as yet unidentified, dietary components in fruit and vegetables (Lanham-New, 2006).

A number of studies investigating the impact of diet on bone health have demonstrated the beneficial effect of fruit and vegetables on bone mass and bone metabolism in men and women across all age ranges:

- Chen *et al*. (2001) examined the association between diet and bone mineral density in a group of 668 early postmenopausal Chinese women. Results showed that higher intakes of fruit were positively associated with BMD at all three bone mass sites measured.
- Stone *et al*. (2001) studied the association between diet and bone health in a group of 1,075 elderly (over 65 years) men in the USA. Potassium and lutein (a pigment found in dark green vegetables) were found to be

significantly associated with whole body and hip bone mineral density.

- Alexy *et al*. (2007) focused on diets of children and adolescents and found that some food groups – fruits, vegetables and potatoes – had an alkalising effect on the body while other groups – cheese, dairy products, cereals and bread; meat and fish and eggs – had an acidifying impact.
- Chan *et al*. (2009) came to a similar conclusion when studying diets of adolescents – based on analyses of nutrients in foods and their effect on the body, they confirmed that meat intake had a strong acidifying effect on the body, while fruits, vegetables and pulses were alkalising.
- Adolescent girls consuming more than three servings of fruit and vegetables had healthier and better bones and were losing less calcium in urine than girls consuming less (Tylavsky *et al*., 2004).
- Another study (Miller *et al*., 2001) examined the relationship between diet and bone mass in North American men between 50 and 91 years old. The results showed that low intakes of magnesium and potassium (both of which are abundant in fruit and vegetables) were significantly associated with low hip and forearm bone mass.
- In a large study of 994 women, those with the lowest intakes of potassium, magnesium, fibre, vitamin C and beta-carotene (all of which are found in plant based foods) had significantly lower lumbar spine (lower back) and femoral neck (hip) bone mineral densities (New *et al*., 1997).
- A later study by the same team (New *et al*., 2000) confirmed the above and added one more factor – a high intake of fruit and vegetables in childhood as being important to bone health.
- Another population-based study examined the association of the intake of fruits and vegetables with bone mineral density in 670 postmenopausal Chinese women aged 48-63 years. Overall BMD was measured as well as BMD of lumbar spine and left hip. Analyses showed that the total intake of fruits and vegetables was significantly associated with greater BMD at all locations measured. This positive association between fruit and vegetable intake and BMD remained even after adjusting for age, years since menopause, body weight and height, dietary energy, protein and calcium intake and physical activities (Chen *et al*., 2006).
- A project based at Human Nutrition Research, Cambridge, UK analysed a series of studies examining the association between fruit and vegetable consumption and bone mineral status. Significant associations were observed between bone health markers (measurements of bone mineral density, bone resorption, loss of calcium in urine etc) and carotenoids (plant pigments) and vitamin E which suggested a positive effect of fruit and vegetable intake on bone health (Ashwell *et al*., 2008).



There is no doubt that an increased fruit and vegetable consumption has a positive effect on the calcium economy and markers of bone metabolism (New, 2003). The high potassium and magnesium content of fruits and vegetables, with their alkaline salts makes these foods extremely efficient dietary agents for inhibiting bone loss (Tucker *et al*., 2001).

Calcium and phosphorus

The two main minerals in the skeleton are calcium and phosphorus. For calcium and phosphorus to be absorbed and utilised efficiently it is important that both are present in the diet. Low calcium and high phosphorus intake and vice versa negatively influence the absorbability of the less abundant mineral (Bonjour, 2011; Weaver, 2002). Phosphorus is abundant in most diets and deficiencies are highly unlikely.

Over 99 per cent of total body calcium is found in the teeth and bones. Therefore, in addition to the obvious structural role of the skeleton, it also serves as a reservoir for calcium.

Available data suggest that absorption and utilisation of calcium for skeletal development are highly dependent on life stage. Absorption of calcium is highest in infancy (50 – 60 per cent), especially when infants are provided with human milk (Fomon and Nelson, 1993; Abrams *et al*., 1997). By adulthood, calcium absorption is on average about 30 per cent (Heaney *et al*., 1989; Jackman *et al*., 1997; Bronner and Abrams, 1998).

The calcium needs of full-term infants are met by their mothers' milk during the first six months of life. Infant formulas contain more calcium than human milk to compensate for the possibility that the calcium in formulas may not be absorbed as well as the calcium in human milk (Abrams, 2003).

The current recommended daily intakes of calcium for specific age groups are summarised in the table below.

It is highly questionable whether calcium intakes above the minimum amount required by the body can offer any benefit at all. As one of the studies of young women showed, while moderate exercise always has a beneficial effect on bones, calcium intake above 500mg a day (the intake of the studied women varied from 486 to 1958 mg a day) appeared to have little, if any effect (Lloyd *et al*., 2002).

This is supported by the findings of Prentice *et al*. (1993), who studied the bone mass of children and women in the Gambia. They suggested that calcium intakes of 300-500 mg a day have no apparent adverse effects on bone measurement variables. Aside from the different hereditary factors in ethnic groups, the main difference in lifestyle between Gambian and British subjects in this study was the amount of daily activities of walking, carrying of loads and other work chores. Harvard experts (Harvard School of Public Health, 2012) noticed the same: in countries such as India, Japan and Peru where average daily calcium intake is as low as 300 milligrams per day, the incidence of bone fractures is lower than in many western countries (including the UK). Apart from calcium intake these countries differ from the UK and USA in other important bone-health factors as well – such as level of physical activity and amount of sunlight – which could account for their low fracture rates.

A review of 15 studies on calcium intake and the risk of hip fractures (Bischoff-Ferrari *et al*., 2007) suggests that neither total calcium intake nor calcium supplementation is significantly associated with decreased hip fracture risk in women or men. As for calcium supplementation, the authors suggested that it might indeed increase the risk. The Harvard Nurses' Health study examined whether higher intakes of milk can reduce the risk of osteoporotic fractures. The study observed over 75,000 women for 12 years and concluded that a report increasing milk consumption did not confer a protective effect against hip or forearm fracture. In fact the 1997 study found that an increased calcium intake from dairy foods was associated with a higher risk of fracture. They concluded that their results do not support the hypothesis that higher consumption of milk or other food sources of calcium by adult

Recommended dietary intake of calcium

(Department of Health, 1991)

Age	Recommended intake (mg/day)
0 to 12 months	525
1-3 years	350
4-6 years	450
7-10 years	550
Males	
11-18 years	1,000
Over 19 years	700
Females	
11-18 years	800
Over 19 years	700
During lactation	The above + 550

women protects against hip or forearm fractures (Feskanich *et al*., 1997). In a 2003 follow-up of the Nurses' Health Study, the increased risk associated with dairy was not reported but they still found that higher daily intakes of cow's milk did not reduce the risk of hip fracture. In other words, there was still no evidence of a protective effect of dairy against fracture risk (Feskanich *et al*., 2003). Interestingly, a lower risk of hip fracture was found among those with higher vitamin D intakes.

The latest study of this type brought very similar results (Warensjö *et al*., 2011). Over 60,000 women were followed for up to 19 years and when the data were analysed, it was found that calcium intake above 750 mg didn't offer any protection from fractures and high calcium intakes increased the risk of hip fractures.

When it comes to calcium intakes in children, the situation is similar. An analysis of 19 studies investigating the relationship between calcium supplementation and the risk of fractures in children (Winzenberg *et al*., 2006) showed that calcium supplementation in children is unlikely to result in a decrease in the risk of fracture in childhood or in later life.

And another review published around the same time (Lanou *et al*., 2005) analysed 58 studies examining whether high calcium intake as such or high dairy intake improves bone health in children. The authors concluded that neither increased consumption of dairy products nor total dietary calcium consumption had shown even a modestly consistent benefit for child or young adult bone health.

Excessive calcium intake can be very detrimental for bones and can be in fact one of the two main causes of osteoporosis (the other being excessive acid generating food, described earlier). The only foods excessively high in calcium are dairy products which also always contain animal protein.

As described above, when animal protein is digested, its building blocks – amino acids – are metabolised and some of them in particular (sulphur containing amino acids) generate sulphuric acid which needs to be neutralised immediately. This exhausts readily available calcium very quickly and can lead to calcium leaching from the bones.

Even though dairy products contain high amounts of calcium, it is absorbed more slowly and therefore the body cannot use the calcium from dairy products to counteract the acid-generating protein from the same food. Later on, when calcium from the particular dairy product is absorbed, the calcium level in the blood becomes too high because of the calcium previously released from bones. Some of the excess calcium is deposited back in the bones, some is excreted in the urine (excess calcium supresses PTH which causes increase in urinary excretion of calcium) and some can be deposited in other tissues (eg kidneys) which can eventually cause problems such as kidney stones. Not all calcium can be deposited back in the bones because the decrease in calcium levels in the blood needs to be fast and also the bones can only store a certain amount of calcium. A high-calcium diet can temporarily increase the BMD but only to a certain extent and it cannot be sustained in the long term.

Depositing calcium back in the bones requires osteoblast activity as osteoblasts are the only cells that are able to incorporate calcium into the bone. As several studies (eg Kassem *et al*., 1997; Mueller and Glowacki, 2001) have shown, the potential of human bone marrow to produce osteoblasts is limited and decreases with age. Furthermore, 50 to 70 per cent of the composing osteoblasts die in the composition of new bone mass (Jilka *et al*., 1998). The more their activity is stimulated, the more they die. High calcium intake and an acidic diet causing calcium loss from the bones followed by repeated calcium deposition back into the bones results in a higher rate of exhausting the osteoblast capacity of the body. If high amounts of calcium are consumed on a regular basis, the replacement of osteoblasts may be increased all the time, thus resulting in an increased BMD. That is why the average BMD is higher in residents of countries where much milk is consumed.

However, since the number of times a cell can be replaced is limited, the osteoblast capacity will be exhausted or significantly impaired (Byers *et al*., 1997) sooner if high amounts of calcium are absorbed on a regular basis. Eventually, osteoblast replacement capacity is exhausted and since only osteoblasts can compose bone mass, too little new bone can be composed (Weinstein and Manolagas, 2000; Manolagas, 2000). In the meantime, old bone is constantly being decomposed anyway, to be replaced by new bone. When replacement cannot occur, porous holes will begin to appear. Osteoblast shortage then leads to premature bone loss and eventually to osteoporosis (Eaton, 2006).

Calcium intake from plant foods doesn't flood the system with excessive amounts of calcium but it provides a steady supply throughout the day so the

Calcium content of selected plant foods (FSA, 2002):

Food	Mg calcium/ 100g food
Oats (oat flakes)	52
Brown rice – boiled	4
Basmati rice – boiled	18
Wholemeal spaghetti – boiled	11
Wheatgerm	55
Wholemeal bread	106-186
Granary bread	209
Bran flakes	40
Muesli	110
Baked potatoes	11
Broad beans	56
Chickpeas – boiled	46
Green beans – boiled	56
Lentils – boiled	22
Kidney beans – canned	71
Soya beans – boiled	83
Tofu	510
(calcium-set; if not, the value is 150)	
Peas	35
Broccoli – raw	56
Broccoli – boiled	40
Cabbage – raw	52
Celery – raw	41
Kale – boiled	150
Okra – boiled	120
Peppers – raw	30
Spinach – boiled	160
Sweet potatoes – boiled	23
Watercress	170
Beanburger	69
Nutroast	77
Vegetable kiev	105
Cinnamon	1230
Mixed herbs (dried)	1653
Rosemary	1280
Thyme	1890
Dried apricots	73
Currants	93
Figs – dried	250
Cantaloupe melon	20
Olives	61
Oranges	47
Pineapple	18
Raisins	46
Raspberries	25
Satsumas	31
Almonds	240
Brazil nuts	170
Hazelnuts	140
Pecans	61
Sesame seeds	670
Tahini (sesame seed paste)	680
Sunflower seeds	110
Tortilla chips	150

Cows' and soya milk calcium content (FSA, 2002; Provamel, 2012; Alpro, 2012):

Type of milk	Mg calcium/ 100g food
Whole milk	118
Semi-skimmed milk	120
Soya milk – Provamel, calcium enriched	120
Soya milk – Alpro original	120

body can utilise it for immediate needs and keep the blood levels steady without depositing any excesses and without unnecessary bone turnover. When small amounts of calcium are being absorbed into the blood, hormone regulation is more precise and efficient. On the other hand, in the case of excess calcium in the blood, more hormones are being produced than necessary which leads to overstimulation of both bone decomposition and assimilation.

As long as a varied diet with plenty of vegetables, fruit, nuts and seeds and pulses is consumed, enough calcium is being supplied to the body. Good sources of calcium are: sesame and other seeds, tofu (calcium-set), pulses, almonds and Brazil nuts, green leafy vegetables (including broccoli), figs, cinnamon, oregano and parsley.

It is not advisable to take calcium supplements because as shown above and below, the body can get enough calcium from food, high calcium intake can be detrimental for bones and, as many studies show, calcium supplementation does not offer any health benefits.

Apart from adverse effects of excess calcium on bones, people consuming too many calcium-rich dairy foods (eg hard cheese containing 700-840mg per 100g) or taking supplements and getting too much calcium, are increasing their risk for kidney stones and calcification of tissues (Institute of Medicine, 2011). In this case, calcification means that calcium is deposited in the wrong places such as soft tissues. Calcium deposits cause pain, interfere with the normal functioning of the tissue and, if they are in arteries, can increase the risk of heart attack.

Once intake surpasses 2,000 milligrams per day for calcium (for any individual), the risk of harm increases. As people take more supplements and eat more foods that have been fortified with calcium, it becomes more likely that they consume high amounts of these nutrients. And as Dr Thomas Levy (2001) says: 'One of the clearest examples of toxic accumulation is seen with most common forms of calcium supplementation. There is a lot of calcium in most diets and even a relatively small amount of calcium supplementation, taken on a regular basis, can result in undesirable, rocklike, nonbiologic deposits of calcium in the tissues.'

Other nutrients necessary for bone health

Calcium and protein are essential for good bone health but they are not the only important nutrients. The body needs many substances to work properly and to build and maintain strong bones. The main ones are described below.

Vitamin D

Vitamin D is critically important for the development, growth and maintenance of a healthy skeleton from birth until death. The main function of vitamin D is to maintain calcium levels in the body within the normal range.

Vitamin D increases the efficiency of the intestinal absorption of dietary calcium and phosphate and it is necessary for the transcellular transport of calcium (Weaver, 2002; Holick, 2003). When the diet is low in calcium, vitamin D communicates to osteoclasts (bone decomposing cells) which then break down bone tissue to dissolve the calcium stored in the bone (Holick, 2003).

Ninety to 100 per cent of most human being's vitamin D requirement comes from exposure to sunlight (Holick, 2003). It is the UVB portion of the solar spectrum that is responsible for the production of previtamin D3 in human skin. Thus, any alteration in the amount of UVB light reaching the skin can dramatically affect the skin production of vitamin D3. Increased skin pigmentation can reduce the production of vitamin D3 by as much as 50-fold. The application of a sunscreen with a sun protection factor (SPF) of only 8 reduces the UVB penetration into the skin by over 95 per cent, thereby reducing the production of previtamin D3 by the same amount. A sunscreen with SPF 15 absorbs 99 per cent of the incident UVB radiation, and, thus, when applied properly will decrease the synthesis of vitamin D3 in the skin by 99 per cent (Holick and Chen, 2008). It is therefore advisable to apply sunscreen only after ten to 15 minutes in the sun.

An increase in the angle of the sun results in more of the UVB light being absorbed by the ozone layer. This is the explanation for why during the winter less vitamin D3 is produced in the skin. Time of day, season of the year, latitude and altitude all markedly affect the cutaneous production of vitamin D (Holick, 2003).

Aging can markedly reduce the skin's capacity to produce vitamin D. However, despite the up to fourfold reduction in vitamin D production in a 70-year-old compared to a

20-year-old, the skin has such a high capacity to make this vitamin that even elderly people exposed to sunlight will produce an adequate amount of vitamin D to satisfy their vitamin D requirement (Holick, 2003).

Vitamin D is metabolised in the liver and then in the kidneys to its active form. It is also recognised that many other tissues in the body, including white blood cells, brain, colon, prostate, breast, and others, have the enzymatic machinery to locally metabolise the vitamin. Vitamin D produced by the kidneys enters the circulation and travels to its major target tissues – the intestine and bone – where it interacts with its vitamin D receptors to enhance intestinal calcium absorption and mobilise osteoclast activity which leads to calcium being released into the bloodstream (Holick and Chen, 2008).

Vitamin D supplementation needs to be exercised with caution – when intakes of vitamin D surpass 4,000 IUs per day, the risk for harm begins to increase. Very high levels of vitamin D (above 10,000 IUs per day) are known to cause kidney and tissue damage and are therefore toxic (Institute of Medicine, 2011).

Moreover, there is no evidence that calcium and vitamin D supplementation alone can prevent fractures (Grant *et al*., 2005; Porthouse *et al*., 2005). If there is a concern about a lack of vitamin D, supplementing the diet with it is recommended but unless the whole diet and lifestyle is 'bone friendly', vitamin D itself cannot ensure healthy bones.

Vitamin K

As recent research of bone health suggests (Burns *et al*., 2003; Ashwell *et al*., 2008), vitamin K is increasingly being recognised as an important nutrient for bone health. Vitamin K mediates metabolic reactions of several bone proteins essential for bone formation.

Low levels of vitamin K have been linked with low bone density and supplementation with vitamin K shows improvements in biochemical measures of bone health (Weber, 2001). A report from the Nurses' Health Study suggests that women who consume at least 110 micrograms of vitamin K a day are 30 per cent less likely to break a hip than women who get less than that (Feskanich *et al*., 1999). Among the nurses, eating a serving of lettuce or other green, leafy vegetable a day cut the risk of hip fracture in half when compared with eating one serving a week. Data from another large study also show an association between high vitamin K intake and reduced risk of hip fracture in men and women and increased bone mineral density in women (Booth *et al*., 2000; Booth *et al*., 2003). Consuming one or more servings per day of broccoli, Brussels sprouts, dark green lettuce, collard greens, or kale should be enough to meet the daily recommended target of 120 micrograms per day for men and 90 micrograms per day for women (Harvard School of Public Health, 2012).

Good sources of vitamin K include parsley, kale, spinach, Brussels sprouts, Swiss chard, green beans, asparagus, broccoli, kale, collard greens, thyme, romaine lettuce, sage, oregano, cabbage, celery, sea vegetables, cucumber, leeks, cauliflower, tomatoes and blueberries.

Vitamin C

Vitamin C is required for the formation of bone protein collagen and is therefore necessary for bone formation. Scurvy is a disease caused by vitamin C deficiency – the body cannot manufacture collagen in the absence of vitamin C which means bones cannot be repaired and maintained.

Dietary sources of vitamin C are fresh fruit (particularly citrus fruit and berries) and vegetables (particularly green leafy vegetables, peppers), potatoes and sweet potatoes.

Vitamin A

Vitamin A is in fact a family of compounds that play an important role in many bodily processes including bone growth. However, too much vitamin A has been linked to bone loss and an increase in the risk of hip fracture (National Institute of Arthritis and Musculoskeletal and Skin Diseases, 2012). Too much vitamin A may also interfere with vitamin D, which plays an important role in preserving bone.

Retinol is the form of vitamin A that causes concern. It is found only in foods of animal origin and it is relatively easy to get too much of it in a diet based on animal products and/or from supplements.

Beta-carotene, on the other hand, is a plant form of vitamin A and is considered to be safe and has not been linked to adverse effects in bone or elsewhere in the body. Quality sources of beta-carotene are brightly coloured fruits and vegetables, for example carrots, sweet potatoes, apricots, green vegetables, pumpkins, tomatoes, apples, peaches, etc.

The B vitamins

The B group vitamins are important for bone health. Vitamin B12 especially has been highlighted, as low levels are associated with an increased bone loss (Glenville, 2005).

Folic acid along with vitamin B6 and B12 help control a substance called homocysteine. Homocysteine is a by-product of the breakdown of methionine – one of the sulphur amino acids mentioned earlier. It is broken down and excreted by the body under normal circumstances but diets high in animal protein produce more of this substance and therefore the need for the B vitamins is higher too. High levels of homocysteine interfere with the correct linking of collagen fibres in the bone.

The best sources of B vitamins are wholegrains (eg oats, brown rice, wholegrain bread), nuts and seeds, green leafy vegetables, avocado, mushrooms, beans and lentils. Vitamin B12 is best taken as a supplement as there aren't many good food sources and also the body's ability to absorb it from food decreases with age.

Magnesium and potassium

Magnesium and potassium are two electrolyte minerals that contribute to an alkaline environment and help protect bone. Both are also essential for many vital reactions in the body.

Magnesium is as important as calcium for bone health, it helps maintain and repair bone, yet it is not mentioned very often as a nutrient necessary for strong bones (Glenville, 2005).

One of the studies that showed the clear link between these elements and bone health concluded that alkaline producing dietary components, specifically potassium, magnesium and fruit and vegetables, contribute to maintenance of healthy bones (Tucker *et al.*, 1999).

Good sources of magnesium in the diet are dark green leafy vegetables, apples, nuts and seeds, wholegrains, avocados, figs, bananas, apricots and lemons.

Iron

Iron is essential for bones because it is involved in a chain of reactions leading to the manufacture of bone protein – collagen.

Foods such as beans, lentils, peas, broccoli, cabbage, wholegrains, seeds, dried apricots, prunes and figs are good sources.

Boron

Boron is essential for the conversion of vitamin D into its active form and vitamin D is necessary for calcium absorption. It is therefore another essential mineral for healthy bones.

Boron is plentiful in green leafy vegetables, fruit, nuts and pulses (beans, chickpeas, etc).

Sodium

Dietary salt has been considered detrimental to bone because high salt intake increases calcium losses in urine. Low salt intake is generally recommended for a number of reasons, of which the main is high blood pressure (high salt intake contributes to high blood pressure) but it is certainly advisable also with regard to bone health.

Copper

Copper is vital for bone and cartilage protein (collagen and elastin) formation. It is widely available from plant foods but the best sources are pulses and nuts and seeds.

Zinc

Zinc stimulates bone growth and repair and is essential for metabolic reactions in bones. Apart from that, zinc is necessary for hundreds of other vital reactions in the body and is needed for the production of enzymes and hormones.

Good dietary sources include wholegrains, nuts and seeds (especially pumpkin seeds), pulses and green leafy vegetables.

Silicon

Cartilage and bone contain silicon in much higher concentrations than muscle, mainly as an integral part of proteins and bone building cells.

Major dietary sources of silicon include wholegrain cereals, some fruits and vegetables and beer. Processed (white) cereal products are stripped of most of their mineral content, including silicon, so those are not an appropriate source.

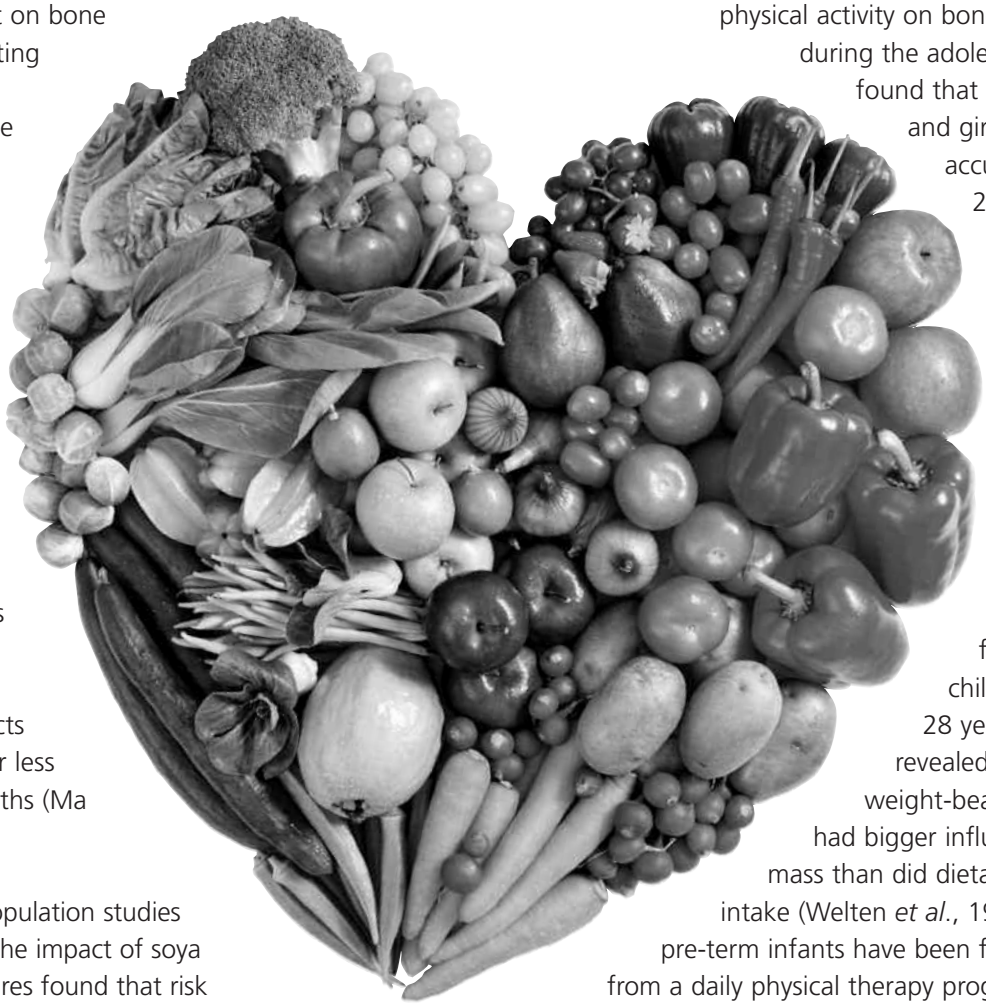
Isoflavones

Isoflavones are plant substances (most commonly found in soya foods), which can act as very mild oestrogens in the body. Nevertheless, the oestrogen effects of isoflavones are much less powerful than those of oestrogens (the effectiveness represents around 1/1000 of the oestrogen effect). Isoflavones bind to the same receptors in the body as oestrogens and this is why

isoflavones have a balancing effect when the levels of oestrogens are low, such as during the menopause, and can ease menopause symptoms. Isoflavones can also reduce the effect of oestrogens when the hormone levels are high, and then essentially reduce the risk of oestrogen linked cancers.

Short-term (Arjmandi and Smith, 2002) as well as long-term (Kuhnle *et al*., 2011; Marini *et al*., 2007) studies suggest that isoflavones (from soya foods) positively influence bone formation in postmenopausal women and are generally beneficial for bone health.

In a recent analysis of ten controlled trials, soya isoflavones demonstrated a significant beneficial effect on bone health, attenuating bone loss and stimulating bone formation (Ma *et al*., 2008a). The authors suggested that the best results are seen in people who consume soya for more than six months. However, as another analysis of nine trials showed, these favourable effects occur even after less than three months (Ma *et al*., 2008b).



Another two population studies that evaluated the impact of soya intake on fractures found that risk was reduced by approximately one-third when women in the highest soya intake group were compared to women in the lowest (Koh *et al*., 2009; Zhang *et al*., 2005).

Lifestyle factors

Exercise

Exercise has a positive effect on bone mass from childhood, through adolescence to old age. The importance of exercise for the attainment of peak bone mass in children and adolescents is well documented and is considered to be the most important environmental factor for bone development (Anderson, 2001). Bone adapts to the loads applied to it and therefore weight-bearing exercise (walking, running, dancing, ball games, etc.) leads to an increase in bone density (Weaver, 2002; Anderson, 2001).

Although effective at any age, exercise initiated during childhood or early teenage years appears to be the most beneficial for improving bone mass (Anderson, 2001; Davies *et al*., 2005; Weaver, 2002). A study analysing six years of data investigating the influence of physical activity on bone mineral density during the adolescent years found that teenage boys and girls who exercised accumulated ten to 20 per cent greater bone mass over a two year period than children who were not active (Bailey *et al*., 1999).

Findings from another study following Dutch children from 13 to 28 years of age revealed that regular weight-bearing exercise had bigger influence on bone mass than did dietary calcium intake (Welten *et al*., 1994). And even pre-term infants have been found to benefit from a daily physical therapy program aimed at increasing bone mineralisation and growth (Moyer-Mileur *et al*., 2000).

However, it is important to engage in a regular physical activity, preferably weight-bearing (such as walking, running, dancing, playing ball games, yoga, gardening, etc), throughout life as the effects are relatively short-term. One of long-term studies (Karlsson *et al*., 2000) showed that fracture incidence in elderly former football players was no different from control subjects. Although their bone mineral density was higher in the

years following retirement from their football career, lack of exercise resulted in an accelerated loss of bone density, such that those who had been retired for over 35 years and aged over 60 years had no significant residual benefit in bone mineral density.

Lack of physical activity is a recognised factor contributing to bone loss, especially in older people whose bone formation is already compromised (Marie, 2010). On the other hand, the health benefits of exercise have been demonstrated in both sexes up to the age of 90 years (Malbut *et al*., 2002).

In osteoporosis patients, moderate weight-bearing exercise alone has been shown not only to significantly increase bone mineral density but also to reduce pain experienced by many (Andgin and Erden, 2009; Lirani-Galvão and Lazaretti-Castro, 2010). Moreover, physical activity helps in another way – it helps to improve balance and muscle strength and therefore decreases the likelihood of falls (Lirani-Galvão and Lazaretti-Castro, 2010).

Many studies (as reviewed by Murphy and Carroll, 2003) suggest that regular physical activity increases bone mineral density and can prevent osteoporosis. The exercise response is not the same for everyone though – the greatest gains are seen in those who are least active and the effect is smaller in comparison in those who are already active.

Although physical activity is beneficial for bone health, there is a threshold – excessive exercising leading to amenorrhea (absence of a menstrual period) in women in reproductive age is extremely detrimental to bone in the long-term because it affects hormone balance, especially oestrogens (a decrease in oestrogen levels can lead to increased bone loss), and can cause irreversible damage (New, 2002).

Eating disorders

Eating disorders resulting in being underweight and undernourishment are extremely dangerous for bone health. If amenorrhea occurs (absence of a menstrual period) caused by a drop in oestrogen production, the damage to the bone (loss of bone mass) can be irreversible (Weaver, 2002). Oestrogen deficiency during puberty may cause increased bone resorption and reduced peak bone mass. Although bone density can be increased again during and after recovery, it usually doesn't reach peak levels.

Osteoporosis associated with anorexia is more severe than

with other causes of oestrogen deficiency. In one study, risk of fractures in individuals with anorexia was sevenfold that of age-matched women (Rigotti *et al*., 1991).

Smoking

Smoking is a risk factor for poor bone health because it accelerates bone loss and reduces calcium absorption (Krall and Dawson-Hughes, 1999). Women who smoked about one pack of cigarettes a day in the long term, had lower BMD at all measured sites (Ilich *et al*., 2002).

The effect is strongest in women, with a twofold risk of fracture for current smokers compared with current nonsmokers (Burns *et al*., 2003).

Alcohol

Moderate alcohol consumption (one drink a day) seems to be beneficial for bones (Ilich *et al*., 2002).

One study examined bone status by type of alcohol. BMD was 6 to 8 per cent greater among postmenopausal women consuming around two drinks per day of wine relative to non-drinkers, and 6 per cent greater among men drinking one to two beers per day relative to non-drinkers (Tucker *et al*., 2009).

In contrast, men consuming more than two drinks per day of distilled spirits had the lowest BMD compared to those with lower alcohol intake.

Current osteoporosis therapies

Current therapies emphasise the use of antiresorptive agents, such as oestrogen (hormone replacement therapy), calcitonin and bisphosphonates.

These therapies are associated with certain risks and side effects making compliance an obstacle (Arjmandi and Smith, 2002; Lanou and Castleman, 2009). In general, none of the therapies can cure osteoporosis, they only slow down bone loss and some of them can mildly stimulate bone formation.

Drug	How it works	Side effects
Biphosphonates (the most commonly used drugs in treatment of osteoporosis): a group of drugs that include alendronate, risedronate and etidronate	They reduce the speed of bone loss (slow down bone decomposition by osteoclasts).	Bisphosphonate tablets have to be taken on an empty stomach whilst the patient is standing or sitting up and with plenty of water because they can cause irritation of the oesophagus. This can lead to indigestion-type symptoms such as heartburn or difficulty swallowing and other side-effects may include diarrhoea or constipation. Rare side effects include itchy rashes or photosensitivity, a sore mouth, flu-like symptoms, bone and/or muscle pain, headaches. There is also another very rare side-effect: osteonecrosis of the jaw which is a condition where an area of bone is exposed through lesions in the gum that don't heal and a small amount of bone dies. There's also a very small increase in the occurrence of cancer of the oesophagus (gullet) in people taking bisphosphonates by mouth for more than 3–5 years. Patients may be taken off the treatment after 5 years to further lessen the risk.
Strontium ranelate (an alternative for osteoporosis patients for whom a bisphosphonate is not suitable or is not tolerated)	It reduces the speed of bone loss.	Some people experience side-effects such as diarrhoea, nausea and vomiting or rashes. There is a small risk of developing deep vein thrombosis.
Raloxifene (usually prescribed for women who have already had a fragility fracture in the spine)	It mimicks the natural effects of oestrogen which slows down the increased breakdown of bone that happens during and after the menopause.	Some women experience hot flushes, leg carmps and flu-like symptoms. There is a small risk of developing a deep vein thrombosis in some people who take raloxifene.

Parathyroid hormone (PTH) or Teriparatide (sometimes suggested for people who have already had a fragility fracture and are at a high risk of further spinal fractures)	Parathyroid hormone is naturally produced by parathyroid glands (four small glands adjacent to the thyroid gland in the neck). It helps regulate calcium levels in the blood. Teriparatide is a synthetic hormone, very similar to PTH. It's effective but expensive, and so it's usually reserved for severe cases.	Gastrointestinal side-effects may occur – eg nausea or acid reflux symptoms. It can also cause palpitations, dizziness, headache, fatigue, depression, slight irritation at the injection site and occasional bone pain.
Calcitonin (due to the safety concerns when used in long-term periods prescribed only rarely to patients who do not tolerate bisphosphonates)	It is a naturally occurring hormone which helps regulate calcium levels in the body and is involved in the process of bone building. It slows the rate of bone thinning and it also relieves pain caused by collapsing vertebrae (spinal compression fracture).	Possible side-effects include nausea, vomiting, diarrhoea, abdominal pain, flushing, dizziness, headache, musculoskeletal pain and taste disturbance. Long-term use has been also linked to a small increased risk of cancer, which is why it's only available for short-term use.
Hormone replacement therapy (HRT)	Compensates for the lack of oestrogen in women and therefore slows down bone loss (a natural effect of oestrogens). It can be also used for men whose levels of testosterone drop significantly (very rarely).	There is a small increased risk of breast and ovarian cancer, deep vein thrombosis, heart attacks, strokes and memory impairment if used in the long term.
Denosumab (recommended for postmenopausal women who can't take bisphosphonates and also in men who develop osteoporosis as a result of treatment of prostate cancer which reduces testosterone levels)	It blocks osteoclasts, the cells that break down bone and therefore decreases bone loss.	Some people may experience numbness in fingers or toes, spasms or twitches, irritability, confusion, irregularities in heart rate, nausea, vomiting and muscle pain. Back, arm and leg pain may occur as well as urinary tract infections, increased cholesterol levels, constipation and rashes. Osteonecrosis of the jaw is a very rare adverse effect.

As mentioned above, the osteoporosis drugs only help to slow down bone loss, they don't treat the condition. Therefore it's very important to adjust the diet so the body can have the best possible conditions for improving bone strength. The drugs might help to a certain extent but if the diet is constantly acidifying the body, there won't be any improvements.

Viva! Health's Break Free Diet

Although the intake of essential nutrients is necessary for healthy bones, it is diet as a whole that matters most. It is perfectly possible to eat all the important nutrients and have poor bone health if the beneficial effect of the bone-friendly nutrients is outweighed by bone-deteriorating components of food.

And because osteoporosis develops from a gradual loss of bone mineral that is thought to begin as early as 25–30 years of age (Tenenhouse *et al*., 2000), it is important to maintain a healthy lifestyle from a young age. However, the Break Free diet helps people at any age, with or without osteoporosis.

Concerns have been voiced about poor diets of children and adolescents in the UK negatively influencing growth or general health (Gregory *et al*., 2000). There have also been warnings that the main sources of nutrients may not be the most appropriate (Prynne *et al*., 2004), that food group recommendations are not being met (eg 5-a-day fruit and vegetable intake; Gregory *et al*., 2000) and that recent or anticipated changes in eating and lifestyle habits may compromise nutritional adequacy further (Prentice *et al*., 2006).

The UK has very high rates of osteoporosis and hip fractures despite the ever-present promotion and high consumption of dairy products that are meant to be 'the' food for healthy bones. There is a wealth of scientific evidence showing that not only are dairy products not beneficial for healthy bones but with their animal protein and high calcium content, they can be actually harmful. Many studies and authors agree that the best approach to a bone-friendly diet emphasises plant foods and steers away from animal protein.

One of these studies (Tucker *et al*., 2002) identified the best diet patterns: men consuming a diet high in fruit, vegetables and breakfast cereal had significantly greater BMD than men consuming other diet patterns, such as those high in meat or baked products and sweets. Women who reported a pattern high in sweets (20 per cent of energy intake) consistently had the lowest BMD relative to all other patterns; whereas women who consumed high amounts of fruit and vegetables had higher BMD. Not surprisingly, the fruit and vegetable group had the highest intakes of magnesium, potassium, vitamin C and vitamin K.

Everitt *et al*. (2006) say: 'On the basis of current research, the best diet to delay age-related disease onset is one low in calories and saturated fat and high in wholegrain cereals, legumes, fruits and vegetables, and which maintains a lean body weight. Such a diet should become a key component of healthy aging, delaying age-related diseases [including osteoporosis] and perhaps intervening in the aging process itself. Furthermore, there are studies suggesting that nutrition in childhood and even in the foetus may influence the later development of aging diseases and lifespan.'

Alkaline diet for strong and healthy bones

In addition to the growing body of scientific evidence which shows a strong connection between dietary acid load and bone health explained earlier, other investigations are uncovering links between an acid-heavy diet and obesity, cardiovascular disease, as well as overall health and well-being (Berardi *et al*., 2008).

The common factor among these may be the stress hormone cortisol. Researchers have shown that the typical acid-heavy Western diet promotes cortisol production (Remer *et al*., 2008), and this elevation in cortisol can be attenuated when the acidic diet is neutralised through a low-acid diet or bicarbonate supplementation (Maurer *et al*., 2003). Since elevated cortisol has been associated with obesity, cardiovascular disease and mental health, alkaline diet, or neutralisation of an acidic diet, might not only protect bones but also promote lean body and a positive mental outlook (Berardi *et al*., 2008).

In many studies, the acid potential is usually associated with protein intake and the alkaline potential with intakes of calcium, phosphorus, potassium, magnesium, vitamins C and K, all of which are abundant in plant foods (Chan *et al*., 2009). It is important to note that even though high protein intakes are considered harmful for the bones, intakes that are too low can be detrimental too (Hannan *et al*., 2000). However, if the recommendations below are observed, this shouldn't be an issue.

The most effective alkalising substances in food are potassium and bicarbonate (Lanham-New, 2008). There

are few foods that are good sources of both of them in the Western diet but only fruits and vegetables are suppliers of a potassium-rich, bicarbonate-rich combination which makes them ideal foods.

The ratio of alkalising to acidifying foods in a diet should be 70:30 for the maintenance of healthy bones and 80:20 in cases where osteoporosis has already developed. The table below shows the effect of particular foods on the body. Although the pH of a certain food can be acid, the overall effect on the body may be alkalising and vice versa; the table only states the effect on the body.

Effect of foods on the body's pH

(data compiled from a combination of resources – for references see 'Acid-alkaline chart references' at the end of this report).

	highly acidic	moderately acidic	mildly acidic	mildly alkaline	moderately alkaline	highly alkaline
vegetables	pickled vegetables	sauerkraut corn	overcooked vegetables (all kinds) mushrooms	asparagus artichokes aubergine carrot courgette mustard greens new potatoes olives parsnip pumpkin rhubarb seaweed squash sundried tomato swede sweet potatoes turnip	avocado Brussels sprouts cabbage cauliflower endive ginger horseradish leeks lettuce okra onion peas peppers potatoes savoy cabbage radishes spinach tomato watercress	alfaalfa grass barley grass beetroot broccoli celery cucumber green beans garlic kale sorrel sprouts wheatgrass
fruit		preserved/ canned fruit	blackcurrants blackberries clementines gooseberries plums prunes	apple apricot (fresh or dried) banana blueberries cantaloupe melon cherries dates (fresh or dried) figs (fresh or unsweetened dried)	lemon lime	

				grapes grapefruit kiwi mango nectarine orange papaya peach pear pineapple pomegranate raisins raspberries sour cherries strawberries tangerine watermelon		
pulses		dairy-free cheese	hummus tempeh chickpeas kidney beans black beans	lentils tofu dried soya protein products mung beans	white beans butter beans soya beans peas	sprouted beans and lentils
nuts and seeds		peanuts peanut butter pistachios walnuts	cashews hazelnuts macadamia nuts pecans pumpkin seeds sunflower seeds	Brazil nuts pine nuts (raw)	almonds almond butter flax seeds fresh coconut pumpkin seeds sesame seeds	
cereals	biscuits and cookies cakes	corn tortillas crackers pasta processed morning cereal (eg cornflakes, processed chocolate cereal) sourdough bread white bread	amaranth barley basmati rice brown rice buckwheat pasta (soba noodles) bulghur/bulgar wheat couscous oats popcorn rye bread seitan (wheat protein) wheat wholemeal bread	buckwheat kamut millet spelt wild rice	quinoa	sprouted grains

beverages	beer coffee spirits sweetened fruit juice tea (black)	wine	coffee substitutes (barley, rye, etc.) fresh fruit juice rice milk	almond milk green tea soya milk	coconut milk ginger tea herbal tea	coconut water
spices and herbs				basil caraway seeds comfrey cumin seeds fennel seeds thyme	cinnamon coriander curry oregano	cayenne pepper chives
oils and fats		butter	margarine rapeseed oil sunflower oil	avocado oil coconut oil flaxseed oil olive oil sesame oil		
condiments	vinegar yeast	ketchup mayonnaise mustard soya sauce	miso			Himalayan salt sea salt wasabi
sweets	artificial sweeteners cane sugar fructose honey jam white sugar	barley malt syrup brown rice syrup chocolate halva molasses	agave syrup maple syrup			
dairy and eggs	eggs goat cheese hard cheese ice-cream	butter cheese egg whites milk yoghurt (sweetened)	cream yoghurt	buttermilk		
meat and fish	beef chicken lobster ocean fish pork sardines (canned) tuna (canned) veal wild salmon	chicken duck freshwater fish liver organ meats oysters				

Viva! Health's Break Free Diet for Healthy Bones & Teeth

No. of Servings (per day)	Foods	Healthy Portion Size	To Provide
At least 8	**Fruits:** Apples, pears, peaches, oranges, kiwi fruit, bananas, raisins, berries, etc. Eaten whole or in smoothies (juices are more acidifying because they don't contain fibre and provide fruit sugar more readily than whole fruit) **And Vegetables:** Broccoli, cauliflower, spinach, kale, leeks, carrots, peppers, tomatoes, squash, green beans, sweet potatoes, celery, lettuce, cabbage, Brussels sprouts, etc	**Fresh fruit**: 1 medium piece (the size of a tennis ball) **Dried fruit**: 1-1 ½ tablespoons or 1 golf ball **Green or root vegetables**: 2-3 tablespoons or ½ tennis ball **Salad vegetables**: 1 large cereal bowl or 80g	Folate (folic acid), Calcium, Vitamin A, Vitamin C, Fibre, Iron, Antioxidants
3-4	**Whole grains**: Millet, quinoa, brown and wild rice, spelt, buckwheat, wholegrain bread, muesli, wholegrain pasta, etc	**Cooked grains**: 2-3 heaped tablespoons or ½ cup **Breakfast cereal**: 25g or 1 regular sized cereal bowl **Muesli**: 45g or a small sized bowl **Cooked wholemeal pasta**: 1 cup as side dish or 2 cups as main dish **Wholemeal or rye bread**: 2 slices	Energy, Fibre, B Vitamins, Calcium, Iron, Protein
3-4	**Pulses:** Beans (pinto, white, butter, black-eyed, soya), lentils, peas, chickpeas, tofu and soya and bean products (burgers, sausages, mock meat, etc) **Nuts or seeds** Almonds, Brazil nuts, pumpkin seeds, sesame seeds, flaxseed, etc	½ cup (cooked) 2 tablespoons	Protein, Energy, Fibre, Iron, Calcium, other minerals
Small amounts	**Vegetable oil** Flaxseed, hemp seed oil, used cold; olive oil or rape seed oil for cooking **Margarine**	1 teaspoon per portion	Energy, Vitamin E (oils), Vitamin A & D (fortified margarine), Essential omega-3 and omega-6 Fats (flaxseed, soya, walnut, hemp)
At least 1	**B12 Fortified Foods** eg fortified soya milk, Vitamin B12 fortified breakfast cereal, yeast extract (eg Marmite) **Or B12 supplement**		Vitamin B12

1-2 litres of water per day (at least eight glasses) should also be consumed as part of a healthy, balanced diet. Tea, especially herbal teas, can be counted as water.

Combination is the key

The effect of foods on the body is always combined, therefore the foods in the mildly and moderately acidic category can be combined with alkaline foods to achieve the desired overall effect. Or simply the proportions of ingredients can be changed so a more alkaline effect is achieved (for example lower ratio of pasta to tomato sauce with vegetables and lentils or tofu).

All nutrients necessary for healthy bones are available from all the plant foods categorised as mildly acidic to highly alkaline. Animal foods always contain acid forming substances and lack essential nutrients necessary for long-term health (such as magnesium, potassium, beta-carotene, vitamin C, etc). They are not only a detrimental influence on bone health but they are also completely unnecessary in the diet.

A healthy diet to achieve strong and healthy bones should be based on the food groups on page 27.

To ensure sufficient intake of essential omega-3 fats, natural sources should be made part of a daily diet – flaxseed (linseed) or hempseed and their oils and rapeseed oil.

An alkaline diet based on the above foods and principles provides the body with all the essential nutrients but there is still a need for one vitamin to be taken as a supplement. Vitamin B12 can be taken either in the form of food supplements or enriched foods, such as soya milk or margarines.

Healthy bones, healthy teeth

Tooth decay is caused by bacteria such as *Streptococcus mutans* and *Lactobacillus* that live within dental plaque. These bacteria produce acids when carbohydrates, especially sugar, are eaten. When enough acid is produced so that the pH decreases below 5.5 (Cury and Tenuta, 2008), the acid dissolves the main component of tooth enamel (carbonated hydroxyapatite) which can eventually lead to tooth decay. When the pH rises again, the mineral loss can be reversed and damage compensated for from ions dissolved in the saliva.

Just like in bones, if the speed of tooth damage exceeds the speed of repair, small cavities can occur. This process lasts for months or even years.

Sugars and sugary foods produce acid in the whole body and are therefore an undesirable component of a diet anyway. An alkaline diet together with regular tooth brushing (twice a day) is therefore the key to healthy teeth.

Osteoporosis: help in a nutshell

The Break Free Diet is a diet aimed at achieving healthy bones at any age and health condition, it is suitable for children, adults and people with osteoporosis. The only difference is in the ratio – people who suffer from osteoporosis should follow the 80:20 recommendation for alkalising versus acidifying foods while healthy individuals can follow 70:30 ratio.

Moderate weight-bearing activity is necessary to complement the diet and even though it might be more difficult to be active for osteoporosis patients, every move and every minute of mild exercise matters. Even washing-up or cooking is a weight-bearing activity and stimulates bones. Not only can exercise help strengthen the bones but it can also reduce pain that many people with osteoporosis experience (Angin and Erden, 2009) and because it improves muscle coordination, it also helps to lower the risk of falls.

Osteoporosis drugs might be necessary in some cases but they are not a cure, can have an array of side effects and cannot achieve a substantial improvement without dietary and lifestyle adjustments. Taking calcium supplements is not advisable as long as a healthy alkaline Break Free diet is followed.

Summary

Building and maintaining healthy bones requires a steady supply of many nutrients. All these nutrients are readily available from plant-based foods and in the right proportions for the body to make the best use of them. Population as well as clinical studies show that a diet based on alkalising plant foods is beneficial not only for bone but for overall health and well-being.

Increased calcium consumption can temporarily increase bone density but this is not sustainable in the long term and the body's limited capacity for incorporating calcium in the bones is being exhausted in the process. Foods that acidify the body directly contribute to bone destruction and add to the gradual exhaustion of bone-repairing cells (osteoblasts). It is crucial not to cause unnecessary damage for the skeleton to stay strong until, and throughout, old age.

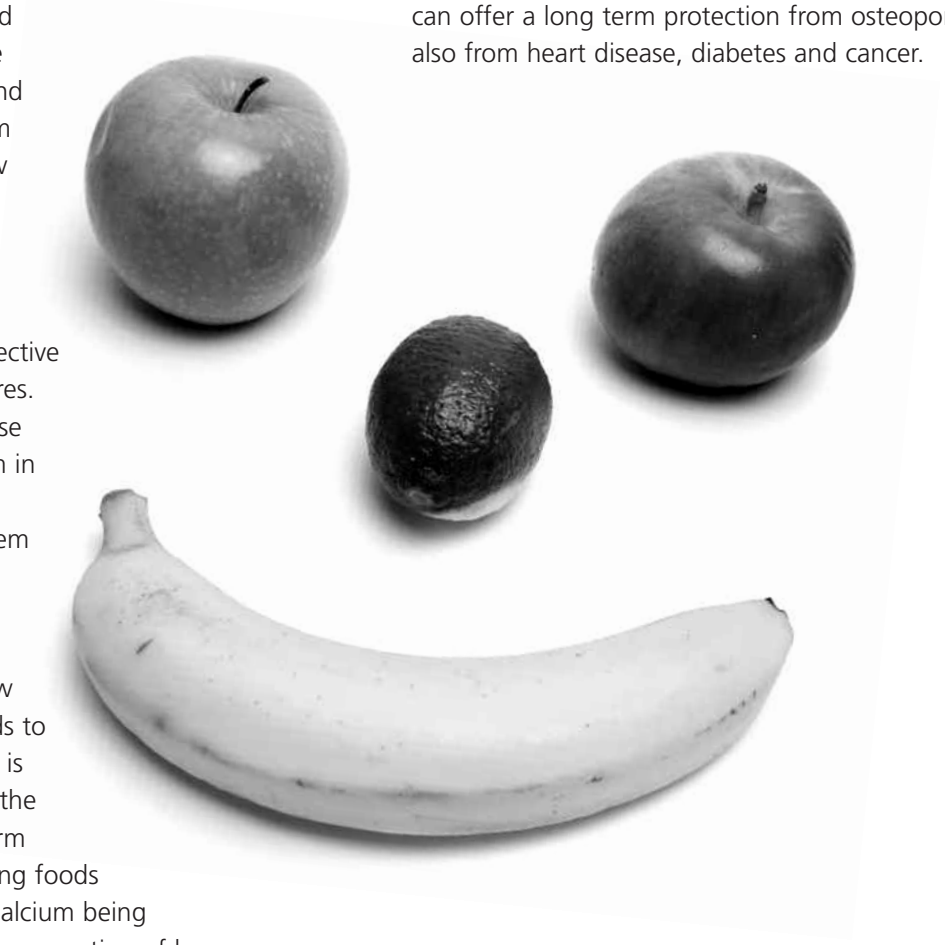
Countries where dairy and meat consumption is high have consistently high rates of osteoporosis. On the other hand, countries where the consumption of these acidifying foods is lower and physical activity higher have low rates of hip fractures and osteoporosis despite calcium intake being considered low by British standards.

A number of studies show that calcium and vitamin D supplementation is not effective in the prevention of fractures. Osteoporosis is not a disease caused by a lack of calcium in the diet, therefore adding more calcium into the system cannot help. Osteoporosis develops when the rate of bone loss is consistently higher than the rate of new bone formation which leads to a bone density deficit. This is caused by acids formed in the body as a result of long-term consumption of acid-forming foods which are responsible for calcium being leached from the bones. Consumption of large amounts of calcium does not simply return the calcium into the bones and can even worsen bone health in the long-term, exhausting the numbers and the capacity of osteoblasts to form new bone.

Many studies and analyses came to the conclusion that it is a diet high in alkalising plant foods coupled with regular weight-bearing exercise that matters in bone development and preserving bone mineral density.

Dairy foods do not have any beneficial effect on bones or teeth. Even the World Health Organisation's recommendations for preventing osteoporosis (Joint FAO and WHO report, 2003) acknowledge this 'calcium paradox' – that countries with the highest intakes of dairy have the highest rates of osteoporosis.

Viva! Health's Break Free diet, a healthy diet based on fruit and vegetables, nuts, seeds, pulses and wholegrains is the best for diet for building healthy bones and offers everything human body needs. Aiming at 70 per cent of the diet being composed of alkalising and 30 per cent acidifying foods is ideal and can offer a long term protection from osteoporosis but also from heart disease, diabetes and cancer.



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