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Calcium intake, calcium bioavailability and bone health

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Calcium accounts for 1–2 % of adult human body weight. Over 99 % of total body Ca 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 Ca. Dietary Ca intake has an important impact on bone metabolism and bone health. Chronic Ca deficiency resulting from inadequate intake or poor intestinal absorption is one of several important causes of reduced bone mass and osteoporosis. It is vital, therefore, that adequate dietary Ca is consumed at all stages of life – in early life so that the genetically programmed peak bone mass can be reached and in later adulthood so that the skeletal mass can be maintained and age-related bone loss minimised. Unfortunately, there is wide variation in the estimates of daily Ca requirements made by different expert authorities. Furthermore, there is evidence that many individuals are not consuming these recommended levels. The consequence of this for bone health will be discussed in the present review. Besides the amount of Ca in the diet, the absorption of dietary Ca in foods is also a critical factor in determining the availability of Ca for bone development and maintenance. Thus, there is a need to identify food components and/or functional food ingredients that may positively influence Ca absorption in order to ensure that Ca bioavailability from foods can be optimised. This approach may be of particular value in individuals who fail to achieve the dietary recommended level of Ca.

Calcium intake: Calcium absorption

Introduction

Osteoporosis is a global health problem that will take on increasing significance as people live longer and the world's population continues to increase in number. Dietary composition is an important determinant of the bone mineral density in the growth period, and of the magnitude of the age-related bone mineral loss, in particular among postmenopausal women (Michaelsen *et al.* 1994). Calcium, in particular, plays an important role in skeletal health (European Commission, 1998). A sufficient intake of Ca and vitamin D can reduce the risk of fractures in postmenopausal women, and it is likely that a low Ca intake may affect peak bone mass negatively (Michaelsen *et al.* 1994). Nonetheless, dietary Ca intakes are below recommended levels in many EU member states (European Commission, 1998), with consequences for bone health and risk of osteoporosis in these populations. The present review will define the principal disease of bone mass (i.e. osteoporosis) as well as considering its epidemiology and risk factors. The review will then focus on the importance of dietary Ca in bone health, with particular emphasis on the role of Ca intake and Ca bioavailability in maintaining optimal skeletal health.

Definition of osteoporosis and osteopenia

Osteoporosis is defined as a systemic skeletal disease characterised by low bone mass and microarchitectural deterioration of bone tissue, with a consequent increase in bone fragility and susceptibility to fracture (Consensus Development Conference, 1993). Osteopenia is sometimes referred to as borderline low density because there is a loss of bone density, but less than is seen with osteoporosis. For the purposes of clinical diagnosis, a Working Party of the World Health Organisation has redefined osteoporosis and osteopenia according to bone mass, at least for women. Their diagnostic criteria for osteoporosis and osteopenia, based on bone mineral content (BMC) or bone mineral density (BMD) include: normal, within 1 standard deviation (SD) of young adult reference mean for the population; osteopenia, between −1 and −2·5 SD of the young adult mean; osteoporosis, more than −2·5 SD below the young adult mean, and established osteoporo-

Abbreviations: CPP, casein phosphopeptides; NDO, non-digestible oligosaccharide; PBM, peak bone mass; PTH, parathyroid hormone.

Note: For the definition of the terms inulin and oligofructose please refer to the introductory paper (p. S139) and its footnote.

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sis as the same mass definition but associated with a fragility fracture (World Health Organisation, 1994). Fragility fractures are the hallmark of osteoporosis and are particularly common in the spine, hip and distal forearm, although they can occur throughout the skeleton.

Epidemiology of osteoporosis

Osteoporotic fractures constitute a major public health problem. Currently, in the US alone, 10 million individuals already have osteoporosis, and a further 18 million more have low bone mass, placing them at increased risk for this disorder (National Institutes of Health, 2000). One in eight EU citizens over the age of 50 years will fracture their spine this year (European Commission, 1998). The estimated remaining lifetime risk of fractures in Caucasian women at the age of 50 years, based on incidence rates in North America is 17·5 %, 15·6 % and 16 % for hip, spine and forearm respectively; the remaining lifetime risk for any fragility fracture approaches 40 % in women and 13 % in men (Melton *et al.* 1992). Similar rates have been reported from parts of Europe, although there is a marked variation in the incidence of fractures between countries and regions (Johnell *et al.* 1992) and even within countries (Elffors *et al.* 1994). Hip fractures in particular are associated with significant morbidity, necessitating hospital admission for an average of 20–30 days (Johnell *et al.* 1992). Osteoporosis patients currently occupy 500 000 hospital bed nights per year in the European Community (European Commission, 1998). Moreover, they have an overall mortality of 15–30 % (Browner *et al.* 1996), the majority of excess deaths occurring within the first 6 months after the fracture. Vertebral fractures are also associated with reduced survival (Copper *et al.* 1993), probably due to clustering of comorbidity which predisposes independently to osteoporosis and premature death. Fractures can also have a profound impact on quality of life, as evidenced by the finding that 80 % of women older than 75 years preferred death to a bad hip fracture resulting in nursing home placement (National Institutes of Health, 2000). Fear, anxiety, and depression are frequently reported in women with established osteoporosis and are likely to be under-addressed when considering the overall impact of this condition (National Institutes of Health, 2000).

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 (Compston, 1993). This is of particular concern as it is projected that the number of elderly (80 years and older, in whom the incidence of osteoporotic fracture is greatest) in the EU population will grow from 8·9 million and 4·5 million women and men, respectively, in 1995 to 26·4 million and 17·4 million women and men, respectively, in the year 2050 (European Commission, 1998). Because of the increase in incidence rates of osteoporotic fractures with age, the above demographic changes and increasing life expectancy will have a huge impact on the number of fractures that can be expected to occur. For example, the number of hip fractures occurring each year in the EU alone is estimated to rise from current figures of 414 000 to 972 000 by the year 2050, representing an increase of 135 % (European Commission, 1998). The increase in the number of vertebral fractures occurring each year is not expected to be of the same magnitude as for hip fractures; thus the estimated increase is from current figures of 237 000 to 373 000 by the year 2050, representing a rise of 57 % (European Commission, 1998).

From an economic perspective, the expenses of hospital care and rehabilitation associated with osteoporotic fractures are a considerable fiscal drain for the health care system, exceeding those of other highly prevalent pathologies of the elderly, such as myocardial infarction (Schurch *et al.* 1996). Osteoporosis costs national treasuries over 3500 million ECU annually in hospital health care alone (European Commission, 1998).

Risk factors for osteoporosis

Low bone mineral mass is the main factor underlying osteoporotic fracture (Prentice, 1997). Bone mass in later life depends on the peak bone mass (PBM) achieved during growth and the rate of subsequent age-related bone loss. Bone mineral is laid down throughout childhood, with the most rapid increase occurring during puberty. The deposition continues, at a slower rate, after growth in height has stopped (British Nutrition Foundation, 1989). PBM is achieved in early life (20–35 years), although the exact timing is not certain and may vary between different regions of the skeleton (Teegarden *et al.* 1995; Institute of Medicine, 1997). From the age of 20 years until approximately 40 years, bone mass is stable in both sexes (Reid & New, 1997). At older ages, bone is gradually lost from the skeleton in both men and women (Prentice, 1997). For women, there is also a period of about 10–15 years when bone loss (especially at trabecular-rich sites such as the spine or wrist) is accelerated due to oestrogen withdrawal at the menopause, when more than one-third of bone is lost from the skeleton (Compston, 1993). This accelerated rate of loss seen in women, when associated with a low attainment of PBM, leads to excessive risk of future fracture (Reid & New, 1997).

Bone is a living, dynamic tissue, and is constantly undergoing breakdown and formation as part of the natural process of renewal and repair (Prentice, 1997). Development of maximal bone mass during growth and reduction of loss of bone later in life are the two main strategies of preventing osteoporosis (Weaver, 2000). Consequently, any factor that influences the development of PBM or the loss of bone in middle age will affect later fracture risk. Several factors are thought to influence bone mass. These can be broadly grouped into factors that cannot be modified, such as gender, age, body (frame) size, genetics and ethnicity, and those factors that can be modified, such as hormonal status (especially sex and calciotropic hormone status), lifestyle factors including physical activity levels, smoking and alcohol consumption patterns, and diet. The interaction of these genetic, hormonal, environmental and nutritional factors influences both the development of bone to PBM at maturity and its subsequent loss. It has been suggested that genetic factors probably account for

up to 80 % of the bone mass variation in the population (Morrison *et al.* 1994). While diet and lifestyle factors, such as physical activity, may have a smaller influence than genetics on bone mass, these factors are nonetheless important since they are modulators for the achievement of maximum genetic potential peak bone mass as well as the subsequent rate of bone loss and, unlike genotype, they can be modified (Cashman & Flynn, 1998).

Calcium and bone health

A large number of macro- and micronutrients have been proposed as possible determinants of bone health and osteoporosis risk. Of the bone-building nutrients, Ca is the most likely to be inadequate in terms of dietary intake (Weaver, 2000). Therefore, the remainder of the present review focuses only on the impact of Ca (in particular, Ca intake and Ca bioavailability) on bone health.

The adult human body contains about 1200 g of Ca, which amounts to about 1–2 % of body weight. Of this, 99 % is found in mineralised tissues, such as bones and teeth, where it is present as Ca phosphate (together with a small component of Ca carbonate), providing rigidity and structure (Nordin, 1997). The remaining 1 %, found in blood, extracellular fluid (ECF), muscle, and other tissues, plays a role in mediating vascular contraction and vasodilation, muscle contraction, nerve transmission and glandular secretion (Institute of Medicine, 1997).

Calcium is under close homeostatic control with processes such as absorption, excretion and secretion and storage in bone being involved in maintaining the concentration of ionised Ca in the plasma within a tightly regulated range (1·1–1·3 mmol/l; British Nutrition Foundation, 1989). This tight regulation of plasma Ca concentration is achieved through a complex physiological system comprising the interaction of the calcitropic hormones, such as parathyroid hormone (PTH), 1,25 dihydroxycholecalciferol (1,25 $(OH)_2D_3$) and calcitonin, with specific target tissues (kidney, bone and intestine) which serve to increase or to decrease the entry of Ca into the extracellular space. Only in extreme circumstances, such as severe malnutrition or hyperparathyroidism, is the serum ionised Ca concentration below or above the normal range. The secretion of these hormones is governed wholly, or in part, by the plasma concentration of ionised Ca, thus forming a negative feedback system. PTH and 1,25 $(OH)_2D_3$ are secreted when plasma Ca is low, while calcitonin is secreted when plasma Ca is high (British Nutrition Foundation, 1989).

Calcium is required for normal growth and development of the skeleton (National Research Council, 1989*a*; Nordin, 1997). During skeletal growth and maturation, i.e. until the age of the early twenties in humans, Ca accumulates in the skeleton at an average rate of 150 mg per day. During maturity, the body – and therefore the skeleton – is more or less in Ca equilibrium. From the age of about 50 in men and from the menopause in women, bone balance becomes negative and bone is lost from all skeletal sites. This bone loss is associated with a marked rise in fracture rates in both sexes, but particularly in women. Adequate Ca intake is critical to achieving optimal peak bone mass and modifies the rate of bone loss associated with ageing (National Institutes of Health, 1994).

In recent years, convincing evidence has emerged with respect to effects of dietary Ca on bone health in all age groups (European Commission, 1998). Intervention and cross-sectional studies have reported a positive effect of Ca on bone mass in children and adolescents (Kanders *et al.* 1988; Johnston *et al.* 1992; Dawson-Hughes, 1996). Välimäki *et al.* (1994) reported that dietary Ca intake in childhood and adolescence was positively related to bone mineral density in young women. A meta-analysis of thirty-three studies concluded that there was an overall association between Ca intake and bone mass in premenopausal women (Welten *et al.* 1995). There is considerable evidence that increasing Ca intake above that usually consumed in the diet may have benefits for the development and maintenance of bone, and may reduce the risk of osteoporosis in later life (Flynn & Cashman, 1999). The findings of many of these controlled Ca intervention trials have been reviewed (Dawson-Hughes, 1991; Institute of Medicine, 1997; Prentice, 1997; Department of Health, 1998).

A number of studies of Ca supplementation in children and adolescents, typically of one to two years duration, have shown that increased Ca intake is associated with a higher rate of accrual of bone mass (as measured by BMC or BMD) of approximately 1–5 %, depending on the skeletal site (Johnston *et al.* 1992; Lloyd *et al.* 1993; Andon *et al.* 1994; Lee *et al.* 1994; 1996; Bonjour *et al.* 1997; Cadogan *et al.* 1997; Dibba *et al.* 1998; 1999). There is strong consistency in the results of these studies despite the differences in ages of subjects, forms of Ca used (e.g. as supplements, dairy products or Ca enriched foods) and in habitual Ca intake. There is still considerable debate on the meaning of these effects of Ca on bone. For example, some researchers argue that the increase in bone mass is due to a decrease in bone turnover and is transient and reversible (Department of Health, 1998). In the absence of longitudinal studies of sufficient duration it is not clear whether additional Ca consumed throughout early life results in increased PBM in adulthood. This question is of great significance since PBM in adulthood is predictive of bone mass, and therefore osteoporosis risk, in later life (Hansen *et al.* 1991).

Studies of Ca supplementation in postmenopausal women, typically of one to two years duration, have shown that Ca cannot prevent bone loss but can reduce the rate of bone loss to some extent. These studies reveal that the effectiveness of Ca varies by skeletal site, by menopausal age, and with usual Ca intakes of the study subjects (Institute of Medicine, 1997). For example, supplementation studies indicate that an increase in Ca intake for women during the first 5 years of menopause (the period of most rapid bone loss) is not effective in retarding bone loss from trabecular regions of the skeleton, including those most vulnerable to osteoporotic fracture (Riis *et al.* 1987; Dawson-Hughes *et al.* 1990; Elders *et al.* 1994). However, reductions in cortical bone loss due to Ca supplementation are observed during this period (Polley *et al.* 1987; Riis *et al.* 1987; Smith *et al.* 1989; Dawson-Hughes *et al.* 1990; Elders *et al.* 1994).

Women who are more than 5 years past menopause tend to be more responsive to supplemental Ca (Nelson *et al.* 1991; Reid *et al.* 1993; Chevalley *et al.* 1994; Prince *et al.* 1995), and those with very low Ca intakes generally gain more from Ca supplementation than do women with higher usual Ca intakes (Dawson-Hughes *et al.* 1990; Elders *et al.* 1994). Trials in women with the highest usual Ca intakes demonstrate that increasing Ca intake above 750 mg (Reid *et al.* 1995), 800 mg (Prince *et al.* 1995), or 1000 mg (Riis *et al.* 1987) reduces loss of bone mineral from cortical-rich sites, such as the proximal radius, femoral neck, and total body. Increases in Ca intake have little effect on spinal-bone mineral in older women (Nelson *et al.* 1991; Chevalley *et al.* 1994; Prince *et al.* 1995).

There is still considerable debate on the significance of the reduction in the rate of bone loss observed in these Ca supplementation studies. A meta-analysis of Ca supplementation trials (Mackerras & Lumley, 1997) confirmed that Ca supplementation reduces bone loss, but the effects were only significant in the first year of supplementation. Although osteoporosis is usually defined in terms of reduced bone mass, it is the end result, i.e. the greater tendency to sustain fractures, which is of major concern. There have been only a few studies on the effect of Ca supplementation on fracture rates in postmenopausal women. A reduction in vertebral fractures with Ca supplementation was observed in two studies in which habitual Ca intakes were low (450–620 mg, Chevalley *et al.* 1994).

Studies of combined supplementation with Ca and vitamin D for 1·5–3 years have shown impressive reductions in hip-fracture incidence in elderly women (mean age 84 years) (Chapuy *et al.* 1992; 1994). More recently, Dawson-Hughes *et al.* (1997) showed that combined supplementation with Ca and vitamin D for 3 years significantly reduced non-vertebral fracture rates in men and women (mean age 71 years). Correction of poor vitamin D status and reduction in serum PTH levels appear to be central to the mechanism of this effect (Prentice, 1997).

The effect of Ca supplementation on bone turnover in the aforementioned studies is due to the increased Ca intake increasing plasma Ca, leading to a suppression of plasma PTH and, consequently, the renal production 1,25 $(OH)_2D_3$. Reduced serum levels of PTH and 1,25 $(OH)_2D_3$ reduce the stimulus for osteoclastic bone resorption (Rubinacci *et al.*1996).

Consequences of inadequate calcium intakes

Because of the small metabolic pool of Ca (less than 0·1 % in the ECF compartment) relative to the large skeletal reserve, for all practical purposes metabolic Ca deficiency probably never exists, at least not as a nutritional disorder. An inadequate intake or poor intestinal absorption of Ca causes the circulating ionised Ca concentration to decline acutely, which triggers an increase in PTH synthesis and release. PTH acts on three target organs to restore the circulating Ca concentration to normal. At the kidney, PTH promotes the reabsorption of Ca in the distal tubule. PTH affects the intestine indirectly by stimulating the production of 1,25 $(OH)_2D_3$, which in turn leads to increased Ca absorption. PTH also induces bone resorption, thereby releasing Ca into blood. Due to the action of PTH and 1,25 $(OH)_2D_3$ on the target tissues, plasma Ca levels are restored within minutes to hours (Cashman & Flynn, 1998; Flynn & Cashman, 1999).

If, on the other hand, there is a chronic Ca deficiency resulting from a continual inadequate intake or poor intestinal absorption of Ca, circulating Ca concentration is maintained largely at the expense of skeletal mass, i.e. from an increased rate of bone resorption. This PTH-mediated increase in bone resorption is one of several important causes of reduced bone mass and osteoporosis (National Research Council, 1989*b*; National Institutes of Health, 1994; Institute of Medicine, 1997). The cumulative effect of Ca depletion on the skeleton over many years contributes to the increasing frequency of osteoporotic fractures with age (Flynn & Cashman, 1999).

Calcium requirements and recommendations, and prevalence of calcium deficiency

Given the high proportion of body Ca which is present in bone and the importance of bone as the major reservoir for Ca, development and maintenance of bone is the major determinant of Ca needs. Thus, unlike other nutrients, the requirement for Ca relates not to the maintenance of the metabolic function of the nutrient but to the maintenance of an optimal reserve and the support of the reserve's function (i.e. providing internal structural rigidity needed for locomotion and gravity resisting activity, Heaney, 1997).

Calcium is stored in skeletal tissue as Ca phosphate crystals embedded in a protein matrix. This composite is laid down as a result of cell-based activity, which, in turn, is determined by the combined effects of genetics and mechanical usage, as well as Ca availability. Calcium is a threshold nutrient, i.e. at sub-optimal intakes the ability of the organism to store Ca as bone tissue is limited by the intake of Ca, but increasing Ca intake above that required as optimal for genetic or mechanical purposes further increases are not stored (Heaney, 1997). Thus, Ca can only be stored as bone and increasing Ca intake beyond that which produces optimal bone mass will not result in more bone.

Calcium requirements vary throughout an individual's life, with greater needs during the periods of rapid growth in childhood and adolescence, during pregnancy and lactation, and in later life. There are important genetic and environmental influences of Ca requirements. Genetic influences include such factors as bone architecture and geometry and responsiveness of bone to hormones which mediate the function of bone as the body's Ca reserve (Heaney, 1997). Environmental influences include factors such as dietary constituents and the degree of mechanical loading imposed on the skeleton in everyday life. Because of their effects on urinary Ca losses, high intakes of both sodium and protein increase dietary Ca requirements (Shortt & Flynn, 1990; Massey & Whiting, 1996; Heaney, 1997).

There is considerable disagreement on human Ca

requirements, and this is reflected in the wide variation in estimates of daily Ca requirements made by different expert authorities. For example, expert committees in the US, UK and EU have established very different recommendations for Ca intake (European Commission, 1993; Institute of Medicine, 1997; Department of Health, 1998), see Table 1. Much of this divergence arises due to different interpretations of available human Ca balance data. The higher recommendations in the US derive from defining Ca requirements based on desirable Ca retention estimated from human Ca balance studies, i.e. that which results in the maximum skeletal Ca reserve (Institute of Medicine, 1997).

Low Ca status as reflected in reduced bone mass appears to be common in western countries. According to recent estimates obtained using WHO diagnostic criteria (based on bone mineral content), approximately 4–6 million older women and 1–2 million older men have osteoporosis in the US (Looker *et al.* 1997). Because life expectancy in western countries is increasing (it will soon average more than 80 years in the US and the EU), it is anticipated that this disease will affect an even larger proportion of the population in future (Melton *et al.* 1992). However, while low bone mass may be taken as an estimate of low Ca status, it should be noted that there are a number of contributory factors to this besides dietary Ca deficiency (e.g. altered hormonal status associated with amenorrhoea or menopause, physical inactivity).

In the absence of reliable indicators of nutritional adequacy for Ca, estimates of Ca deficiency are based largely on adequacy of dietary intake relative to recommendations. However, this approach is complicated by the lack of agreement between expert groups on recommended Ca intakes (Table 1). In practice, estimates of the proportion of the population in different countries with inadequate Ca intake are based on recommended intakes for the individual countries. Using this approach, it has been reported that a significant proportion of some population groups fails to achieve the recommended Ca intakes in a number of western countries.

For example, about half of adult women and one third of adult men in Germany are consuming Ca intakes lower than recommended (Heseker *et al.* 1992; van Dokkum, 1995). Similarly, in Switzerland, a large proportion of adult women fail to achieve the recommended Ca intake (van Dokkum, 1995). In Ireland, over 50 % of females aged 12 to 18 years fail to achieve the recommended Ca intake (Irish Nutrition and Dietetic Institute, 1990). In Italy, 50 % of elderly subjects (> 60 years) do not meet the recommended allowance for Ca (van Dokkum, 1995). In the Netherlands, a significant proportion (8–25 %) of adult males and females fail to achieve even 80 % of the recommended allowance for Ca (van Dokkum, 1995). In the US, most females aged 9 to 18 years and 31 years onwards fail to achieve the recommended Ca intake (Cleveland *et al.* 1996). Even in countries where recommended intakes are relatively low inadequate intakes have been reported in some population subgroups. For example, for females in the UK 13–18 % of 14–34-year-olds and 8–15 % of those over 65 years have habitual Ca intakes less than the lower reference nutrient intake, a level below which intake is almost certainly deficient (Department of Health, 1998).

It should be noted that estimates of Ca intakes from foods might provide an underestimate of Ca intake due to under-reporting of food intakes in self-reported food consumption surveys. Furthermore, many surveys do not include the contribution of supplements, medicines or drinking water to total Ca intakes. Such contributions may be significant for some people.

Table 1. Recommended Ca intakes in the EU, UK and US

EU PRI (1993)*		UK RNI (1998)†		US AI (1997)‡	
Age group (years)	mg/d	Age group (years)	mg/d	Age group (years)	mg/d
0·5–1	400	0–1	525	0–0·5	210
1–3	400	1–3	350	0·5–1	270
4–6	450	4–6	450	1–3	500
7–10	550	7–10	550	4–8	800
11–14 M	1000	11–14 M	1000	9–13	1300
15–17 M	1000	15–18 M	1000	14–18	1300
>18 M	700	11–14 F	800	19–30	1000
11–14 F	800	15–18 F	800	31–50	1000
15–17 F	800	19–50	700	51–70	1200
>18 F	700	>50	700	>70	1200
				Pregnancy	
Pregnancy	700	Pregnancy	NI	≤ 18	1300
				19–50	1000
Lactation	1200	Lactation	+ 550	Lactation	
				≤ 18	1300
				19–50	1000

* Population Reference Intakes (PRI) (European Commission, 1993).
† Reference nutrient intake (RNI) (Department of Health, 1998).
‡ Adequate intake (AI) (Institute of Medicine, 1997).
Estimates of Ca requirements refer to males and females unless stated otherwise.
M = requirements for males; F = requirements for females. NI = No increment.

Improving calcium intakes and calcium bioavailability in the population

The dietary deficiency of Ca identified in some population groups may be addressed in a number of ways. This includes changing eating behaviour at the population level by increasing the consumption of foods which are naturally rich in Ca (e.g. milk and milk products), Ca fortification of foods consumed by target groups, or increasing Ca intakes from Ca supplements. These may be seen as complementary rather than alternative strategies and each has advantages and disadvantages (Flynn & Cashman, 1999). For example, it is notoriously difficult to achieve changes in the diet of entire populations, and thus persuading individuals to consume more dairy produce represents a considerable challenge. The use of Ca supplements can be effective in increasing Ca intake in individuals who consume them regularly, but it has limited effectiveness at the population level due to the poor compliance with supplement use (Flynn & Cashman, 1999). Calcium-fortified food products could provide additional choices for meeting Ca requirements; however, attention should be paid to the selection of products so that they reach the target groups (i.e. those population groups who have the greatest difficulty in meeting Ca requirements).

Besides the amount of Ca in the diet, the absorption of dietary Ca in foods is also a critical factor in determining the availability of Ca for bone development and maintenance. Thus, there is a need to identify food components and/or functional food ingredients that may positively influence Ca absorption in order to ensure that Ca bioavailability from foods can be optimised (Kennefick & Cashman, 2000).

A number of food constituents have been suggested as potential enhancers of Ca absorption. Individual milk components, such as lactose, lactulose and casein phosphopeptides have attracted considerable attention. Phosphopeptides derived from the intestinal digestion of casein (casein phosphopeptides, CPP) have been proposed as potential enhancers of Ca absorption (Mellander, 1950; Kitts & Yuan, 1973). Berrocal *et al.* (1989) demonstrated that such phosphopeptides have the capacity to chelate Ca and to prevent the precipitation of Ca phosphate salts and suggested that they may help to maintain a high concentration of soluble Ca in the intestinal lumen. There is some evidence that CPP increase Ca absorption in rats, minipigs, and chicks (West, 1991). However, there have been only a few studies in humans examining the effect of CPP on Ca absorption. Hansen *et al.* (1997*a*) found that Ca absorption from a high-phytate-containing bread meal was not significantly influenced by the addition 250 mg of CPP in healthy adults but was significantly reduced by the addition of 1000 mg. The same group also reported that fractional Ca absorption was not affected by CPP addition (1000 or 2000 mg) to a rice-based cereal or from whole-grain cereal, in healthy adults (Hansen *et al.* 1997*b*). Furthermore, Heaney *et al.* (1994) reported that CPP administration was associated with better absorption of co-ingested Ca by postmenopausal women with low basal absorptive performance. Therefore, the significance of these phosphopeptides for Ca absorption in humans remains unclear.

Ziegler & Fomon (1983) showed that Ca absorption in human infants was significantly higher from a soy-based infant formula containing lactose than from a similar formula in which the carbohydrate source was a mixture of starch hydrolysate and sucrose. Enhancement of Ca absorption by lactose has also been shown in rats (Lengemann, 1959; Armbrecht & Wasserman, 1976; Brommage *et al.*, 1993; Suzuki *et al.* 1985). However, studies on the effect of lactose on Ca absorption in human adults generally have failed to demonstrate this effect. Miller, in a review of this area, concluded that it is likely that lactose enhances Ca absorption in human infants and in rats, while, at levels normally present in milk, lactose does not have a significant effect on Ca absorption by healthy adults consuming normal diets (Miller, 1989). Recently, Van den Heuvel *et al.* (1999) reported that a 9-day consumption of lactulose (5 or 10 g/day) increased Ca absorption in postmenopausal women in a dose-responsive manner.

Emerging evidence has shown that certain non-digestible oligosaccharides (NDOs) can improve Ca absorption in adolescents and adults. For example, Coudray *et al.* (1997) fed nine healthy young men a control diet or the same diet supplemented with 40 g/day of either inulin or sugar beet fibre for a period of 26 days (2 days of control diet followed by 14 days of progressive increase in inulin amount and then 12 days at the maximum inulin consumption) and determined apparent Ca absorption. They found that upon inulin ingestion, apparent Ca absorption increased significantly ($P<0{\cdot}01$) from 21·3 % to 33·7 % (an increase of 58 %); ingestion of sugar beet fibre had no effect. In a randomised, double blind, cross-over design study, Van den Heuvel *et al.* (1999) fed twelve healthy male adolescents (aged 14–16 years) either orange juice supplemented with 5 g oligofructose or sucrose (control treatment) three times daily for 9 days, after which time, they measured true fractional Ca absorption by a dual stable isotope technique. An increase of 26 % in true fractional Ca absorption (47·8 % with placebo to 60·1 % with oligofructose) was observed upon ingestion of the daily 15 g supplement of oligofructose. In an earlier study by the same group, a daily supplement of 15 g of oligofructose had no effect on Ca absorption in healthy adult men (Van den Heuvel *et al.* 1998). However, in that study, unlike the latter one, the colonic component of Ca absorption (a putative target for enhancement by NDO) was not included because the urine collection was limited to 24 h after isotope administration. In a recent, randomised, double-blind, crossover design study, twenty-nine young adolescent girls (11–14 years, consuming a relatively high Ca intake, 1500 mg/day) received either 8 g servings of a mixture of inulin + oligofructose or placebo (sucrose) in a Ca-fortified orange juice daily for 3 weeks. True Ca absorption was measured using a dual stable isotope method at the end of each 3-week period (Abrams & Griffin, 2001). A 48 h urine collection was carried out after isotope administration so as to detect any modulatory effect of the mixture of inulin + oligofructose on the colonic component of Ca absorption. Consumption of the mixture of inulin + oligofructose resulted in an 18 %

increase in true fractional Ca absorption and in an absolute increase in Ca absorption of 90 mg/day (Abrams & Griffin, 2001).

The findings of these studies strongly suggest that addition of some NDO to food represent an opportunity for increasing the uptake of Ca present in the diet. However, studies are necessary to prove that the benefits of these ingredients to Ca absorption persist in the longer term and, importantly, that they can be translated into benefits to bone health.

Conclusion

Adequate and appropriate nutrition is important for all individuals, but not all follow a diet that is optimal for bone health. Calcium is the specific nutrient most important for attaining PBM and for preventing and treating osteoporosis. However, significant proportions of some population groups fail to achieve the recommended Ca intakes in a number of western countries. The challenge remaining for interested groups (including nutritionists, health professionals, and the food industry) is to encourage such individuals to meet their Ca requirements. This task is not an easy one when so few high-Ca foods, except for dairy products, are readily available. Calcium supplements or Ca-fortified foods may be needed by individuals who do not or will not consume Ca-rich foods as recommended in the dietary guidelines of many western countries. In addition, consumption of a functional food, which contains an ingredient (such as lactulose, inulin, oligofructose or both) that may positively influence Ca absorption, will ensure that the Ca bioavailability from foods can be optimised.

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