Requirements of calcium: are there ethnic differences?*

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Calcium is an essential dietary element to maintain the integrity of the skeleton. A higher peak adult bone mass has been shown to reduce the risk of osteoporotic fractures later in life. It is postulated that a lifelong higher calcium intake would reduce bone loss in advancing age. Available scientific evidence seems to indicate that within any ethnic group, calcium intake is positively associated with bone mass. Controlled calcium supplementation trials in both low and high dietary calcium intake children and adolescents showed that there is an association between calcium intake and gains in bone mass. Furthermore, studies in adolescents showed that genetic inheritance and skeletal responses to hormonal changes at puberty have great influences on bone mass increments in addition to calcium intake. Interestingly, across-cultural comparisons are not convincing enough to demonstrate that lower calcium intake would predispose to higher risk of osteoporosis. It implies that the genetic inheritance and complex environmental factors may be important modulators on bone mass achievement in addition to calcium intake within any ethnic group. There are pitfalls in the current Recommended Dietary Allowances (RDAs) for calcium which are usually based on clinical studies conducted in Caucasians with higher calcium intakes and the extent of nutritional adaptation to low calcium intake is ignored. Given the fact that there are ethnic differences in calcium absorption, dietary habits, bone metabolism, physical activity and skeletal size as well as body build, the requirements of calcium in Asians may be different from Caucasians. Ideally, each nation should establish its own RDA based on the ethnic make-up of its population. In Asian countries, the major sources of calcium are derived from vegetable types of foods, fish and shell fish with edible bones, fins and shells, etc. Recent absorption studies in humans with low-oxalate and low-phytate vegetables and pulses also showed that contrary to common presuppositions, these vegetables with low calcium chelators do have a comparable calcium absorbability to milk. Studies on bioavailability of calcium from Asian foods and diets are warranted in order to identify rich sources of calcium.

Introduction

The rising incidence of osteoporotic fractures is becoming a global public health problem. Currently, medical therapies for osteoporosis only help to retard the rate of bone loss but cannot help to regain the bone that is lost. The achievement of a higher bone mass by increasing calcium intake throughout life is considered to be a better preventive measure to prevent the risk of developing osteoporosis later in life[1,2]. However, there is no unequivocal evidence across cultures to support the contention that a lifelong higher calcium intake is associated with a lower risk of developing osteoporotic fractures.

Calcium and bone mass

Over 99% of body calcium is stored in the skeleton in the form of calcium phosphate. Body calcium salts form an architectural framework to maintain skeletal integrity, less than 1% of calcium is in an ionized form or bound to proteins in the extracelluar fluid, in which calcium is actively involved in vital biochemical processes namely, cell membrane permeability, nerve conduction, cardiac and muscle contraction and blood coagulation[3]. If there is a chronic insufficiency of calcium intake, calcium will be resorbed from the skeleton, a calcium reservoir, into the extracelluar fluid to maintain its concentration such that the vital processes can be maintained[4,5].

Bone is a dynamic tissue inside which there is a continuous process of bone turnover characterized by ongoing bone formation coupled with resorption. During the years of growth bone formation exceeds resorption, body calcium accretion increases from 30g at birth to 850–1400g in adulthood as a result of net bone formation[6]. The rates of skeletal calcium accretion vary at different stages of life. During the first six months of life, the daily calcium accretion in the skeleton is rapid at

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150–200mg/d, with less influx in mid-childhood years (75–100mg/d), and up to 400mg/d during puberty growth spurt in adolescence[7].

The process of bone formation does not terminate after cessation of linear growth, consolidation of bone mass continues until 'peak bone mass' is achieved in the second decade to the third decade of life[2]; however, the timing is varied in different ethnic groups [8,9,10]. Genetic inheritance accounts for 70–80% of the attainment in peak bone mass[11,12,13], whereas body build[14-17] including lean body mass[18-19]; physical activity [18,20-22]; dietary intake including calcium[22-25], protein[26-28], phosphorus[26,29] and sodium[30,31]; smoking[32,33] and alcohol consumption[22,34], etc are modifiable environmental factors that may determine the remaining 20–30% variation in peak bone mass. The amount of peak bone mass varies in different ethnic groups at skeletal maturity too. Black Africans have a relatively higher amount of bone mass compared with Caucasians[35-37], whereas there is some evidence that Orientals[38,25] have a relatively lower bone mass when compared with Caucasians[39], despite the fact that Oriental people were often reported to have lifetime lower bone mass and body frame than Caucasians[40-42].

In contrast, the incidence of fractures in Oriental women were reported much lower than Caucasian women[40] who have relatively higher bone mass. A recent cross-sectional study[25] in over 840 women at aged 35–75 years from 5 rural counties of Mainland China where mean calcium intakes varied from 230–720mg/d showed that nearly all the study women over the age of 50 had bone mass less than the fracture threshold point which is specifically for the U.S. Caucasian women[43]. However, a majority of these Chinese subjects had not experienced any signs of osteoporosis or episodes of osteoporotic fractures in their life. Less than 4% of the study women reported incidents of fractures in their life. This fracture rate is much lower than those reported in Caucasian populations[44,45]. The low fracture incidence in this investigation was consistent with those reports in Chinese populations of Hong Kong and Singapore[40]. It is postulated that other risk factors besides bone mass and body frame, such as hereditary factors, dietary constituents, physical activity and the risk of fall may be important to explain the difference in prevalence of fracture. Oriental people usually have smaller body frame and skeletal mass than Caucasians, it is logical to consider that less mechanical stress, hence lower bone mass, may be required by Oriental women to support their smaller body weight when compared with Caucasians. In fact, studies have shown that racial difference in bone density disappeared after confounding factors of body weight and height were controlled in comparing ethnic differences in bone density[9,46].

It is a universal phenomenon that bone mass after reaching the peak gradually declines when the process of bone degradation predominates in older age. Although the loss of bone mass occurs both in men and women with advancing age, the rate of decline in women is greater due to accelerated bone loss after menopause as a result of deficient in production of estrogen which is a major protective factor to maintain positive bone turnover in women[47]. The phenomenon of age-related bone loss is believed to be associated with several factors: an increased bone resorption mediated by estrogen deficiency[47], age-related decline in intestinal calcium absorption[48,49], and a fall in the hydroxylation of 1,25-dihydroxyvitamin D_3 in the elderly due to age-related fall in renal function[50]. However, other workers reported normal 1,25-dihydroxyvitamin D_3 level in the elderly[51,52] including elderly Chinese women[53]. Osteoporotic fractures may occur in individuals when bone mass falls below a certain threshold level[43,48,54]. Adults with average bone mass less than the population mean in which he/she belongs to during skeletal maturity may be at a higher risk of osteoporosis later in life[54,55]. Hu and co-workers, however, showed that the fracture threshold level for Chinese women[25] may be lower than women in western countries[43,54]. Osteoporosis in men in general occurs more frequently over 70[48].

Calcium intakes and requirements

Many nations recommend specific amounts of calcium as reference intakes for the normal healthy populations. Recommended Dietary Allowance (RDA) of calcium is the quantity of calcium to be consumed on a regular basis for the maintenance of health and the prevention of calcium deficiency diseases, the RDA should also take into account the known environmental dietary and morbidity characteristics of the nation concerned. Thus, caution should be taken to apply RDA from one particular ethnic group to another. Furthermore, the scientific basis which national RDA figures are based, should be carefully scrutinized. For example, the U.S. RDA for calcium has been traditionally set at two standard deviations above the mean requirements which aims at providing a wide margin of safety above the needs for the majority of the population in the U.S.[56]. It is believed that an ample food supply in the U.S. should be able to meet the escalated requirements without difficulty[57]. Consequently, the levels of RDA for calcium in the U.S. may be inflated and may not necessarily indicate the actual mean requirements of the population. In the U.S., there is also a suggestion to further increase the current calcium RDA (800mg/d) by about 50% during adulthood as a prophylactic means to reduce the risk of developing osteoporosis[1].

Calcium intakes of the world populations vary a great deal. In countries with dairy farming, average calcium intake may be as high as 1000mg/d or even higher, whereas in communities where animal milks are not available or not traditionally consumed, habitual calcium intakes are often below the recommended amounts of 500mg/d[58,59]. Ironically, epidemiological data have shown that the incidence of osteoporosis is lower in some regions of the world where milk is not customarily consumed and therefore calcium intake is low[9,60,61]. No convincing data have shown that populations subsisting on habitual lower calcium diets would hamper the general health and bone growth[62-65], except individual cases of rickets occurring in African children associated with lifelong extremely low calcium intakes[66,67].

Calcium requirements in adulthood

The RDA for calcium varies from 400mg/d[58] to 800mg/d[68]. Calcium requirements in adults are determined by the amount of calcium needed to promote consolidation of the skeleton after cessation of linear growth, and to compensate for obligatory losses in the intestine, kidney and skin.

Early studies in adults accustomed to low calcium diets shows that humans are capable of adapting to a low calcium intake by enhancing intestinal calcium absorption and reducing urinary calcium excretion[69-71]. The success of adaptation is mediated by increased serum level of parathyroid hormone and vitamin D to facilitate the uptake of calcium in the intestine[69,72,73] and to reduce obligatory urinary calcium excretion[23,69,74]. When subjects accustomed to daily calcium diet of about 1000mg, a sudden reduction of calcium intake by half would lead to negative balance, although full adaptation occurred with positive calcium retention several months later[70]. In fact, very few current calcium RDAs are based on balanced studies in populations with lifelong low calcium intakes[58].

In western societies, the estimates of calcium requirements are based on balance studies of higher calcium intake individuals[59]. These estimations do not address the ability of the body to adapt various levels of calcium intakes. In fact, the amount of calcium required to maintain positive balance depends on previous calcium intakes, and a high habitual calcium intake requires higher requirement of calcium to maintain positive balance[75,76]. Due to this adaptive response, calcium requirements cannot be simply determined by estimating positive calcium balance at various levels of intakes over a relatively short period of time unless the period of the balance study is sufficiently prolonged such that full adaptation can be assured. Therefore, estimation of calcium requirements based on a sudden decrease in calcium intake as found in most traditional balance studies is liable to errors[63]. Today, with an advancement in the technique of non-radioactive stable isotopes[77], calcium requirements can be determined in individuals from infancy to elderly with self-selected diets without the shortcomings incurred in traditional balance studies[77,78].

Furthermore, calcium requirements can be modified by dietary factors: a habitually higher calcium diet renders a lower calcium absorption and *vice versa*[71]. Certain amino acids and complex sugars are known to facilitate calcium absorption, whereas chelators such as oxalic acid and phytic acid, dietary fibres, and unabsorbed organic phosphates may inhibit calcium bioavailability in the gut[79]. In addition, high intakes of protein and sodium are proven to induce a higher urinary calcium loss[80,81]. In affluent societies a greater allowance for calcium intakes is recommended because of the high consumption of animal protein and sodium. In summary, determinants of calcium retention are multifactorial, with a complex interaction between genetic, dietary and other lifestyle factors. As a result, caution should be exercised when adopting recommendations which are based on specific ethnic populations with specific food cultures and lifestyles.

Calcium requirements in childhood

The calcium RDAs for children around the world vary from 400mg/d to 1000mg/d[59] reflecting that there is no agreed consensus among the expert groups on the optimum calcium requirements for children. In children and adolescents, calcium requirements are mainly determined by two major factors, namely the rate of calcium absorption and the daily skeletal calcium accretion[68,82]. The U.S. RDA assumes that calcium absorption in Caucasian children is less than 40%[68]. Furthermore, two recent absorption studies in Caucasian adolescents demonstrated that calcium absorption of adolescents is no different from their adults (less than 40%)[83,84]. In contrast, our recent study in Chinese children, those with a usual calcium intake of 300mg/d showed a rate of true absorption to be 63%, whereas that of children with habitual calcium intake at 860mg/d was less at 55%[85]. The results agree with earlier balance studies in low calcium intake Indian and Sri Lankin children that children could adapt to calcium intake at around 300mg/d and were able to maintain positive calcium retention[74,86]. The net calcium absorption of rural Indian children subsisting on a diet as low as 200mg/d could reach about 50%, and the urinary calcium loss was at minimal[74,86]. These absorption studies suggest that there may be an ethnic difference in calcium absorption. The capability of enhancing calcium absorptive efficiency in some ethnic populations may be inherited from their ancestors who might have adapted successfully to low calcium diets for many generations.

An estimation of daily calcium increments in the skeleton is another key factor in evaluating calcium requirements in growing children. There is evidence to support that there are ethnic differences in bone mineral accretion in children and adolescents[36]. Several expert groups[68,82,87] devised calcium RDA for children based on the predictive values of daily skeletal calcium increments using the anthropometric data of British children and adolescents in the early 1990s[7]. One of the major pitfalls in this study[7] is an assumption that calcium increments in the skeleton at different ages are proportional to the increase in body weight during growth, these data may no longer be valid. In addition, these calculated values also relied on an estimation of skeletal calcium content derived from a limited number of young individuals at post-mortem. Given the fact that the skeletal size of Chinese is in general smaller than Caucasians[38], it follows that the annual deposition of calcium in the skeleton during growth in the Chinese children and adolescents would also be lower in comparison. As a result, the daily bone mineral accretion rate in Chinese children may be less than the Caucasian children and adolescents. Therefore, the values derived from Caucasians may not be applicable to Chinese populations. As a result, enhanced rates of calcium absorption together with seemingly less daily bone mineral accretion in the Chinese children, the requirements of calcium for Chinese children may be lower than those recommended for American children[68].

Other factors affecting bone mass differences between ethnic groups

Several population studies have shown that there is a correlation between habitual calcium intake and bone mass within the same ethnic group[88-94]. Two recent randomized double blind controlled calcium supplementation trials in pre-pubertal children conducted in

China[65] and the USA[95] together showed that prepubertal children with either high or low baseline calcium intakes had additional gains in bone mass after receiving supplemental calcium. However, Johnston and coworkers[95] could not find any significant effect of calcium supplementation on the difference in gain of bone density among 23 pairs of pubertal or post-pubertal twin children. The authors commented that a larger sample size was required to test the effect of supplementation, or the results might imply that hormonal changes during sexual maturity in adolescents override the benefits of calcium supplementation on bone mass increase. Nevertheless, a more recent 18-month calcium supplementation study in 94 Caucasian adolescent girls confirms the effect of calcium supplementation on total bone acquisition in healthy adolescent girls[24].

It is interesting to note that cross culturally, bone mass differs between different ethnic groups even if calcium intake and lifestyles are similar[96,97]. The acquisition of bone mineral accelerates dramatically due to increased production of sex hormones during the progression of puberty until sexual maturity is reached[10,14,98-100]. Gilsanz[36] studied the influence of hormonal and hereditary factors on bone mineral accretions in black and white adolescent girls. The spinal bone mass of prepubertal black girls and white girls were not different significantly; however, at the onset of puberty, black girls increased bone mass by 34%, whereas white girls only increased by 11%. This observation provides strong evidence of inheritability in modulating bone mass acquisition. The authors speculated that differences in the production of estrogen and other hormones as well as the differences in sensitivity of the bone to these hormones between black and white adolescents may explain for this discrepancy. Ethnic differences in bone mass are not confined to black and white populations. Garn[38] found that Chinese and Japanese had significantly less cortical bone mass than Caucasians. Polynesians with similar or even lower calcium diets have higher bone mass than New Zealand Caucasians[97].

The results of controlled intervention studies in children and adolescents so far seem to indicate that within a particular ethnic group, increasing calcium intake tends to increase bone mass in children[65,95] and adolescents[24]. Significant correlations between habitual calcium intakes and bone density are also found in adults of the same ethnicity[25,89,90,94]. However, a positive association between calcium intake and bone mass is not usually seen in cross-cultural comparisons[60,96]. As it has been discussed previously, there are ethnic differences in body size, peak bone mass achievement, sensitivity of bone to hormonal changes at sexual maturity, efficiency of calcium absorption, dietary intake and physical activity; therefore, the derivation of calcium RDA based on one ethnic group, predominantly Caucasians, may not apply to other ethnic populations.

Available evidence gathered so far appears to indicate that the optimum requirements of calcium in order to achieve optimum bone mass may vary from ethnic group to ethnic group depending on the systemic controls on calcium metabolism and the environmental conditions to which the individuals adapt. As a result, the calcium RDAs for Asian populations, who have lower calcium intake due to lower animal milk consumption, may not be as high as those recommended in the western societies. Promotion of milk consumption in a nation in which people do not traditionally or customarily consume milk may have a significant impact on food culture, agricultural practice and health status. More importantly, taking higher doses of calcium supplements above the RDAs to prevent osteoporosis may interfere iron and zinc absorptions[101,102], and may predispose to the risk of developing urolithiasis[103]. More research is needed in the eastern world to determine the optimum calcium requirements.

Bioavailability of calcium from milk and plant foods

It is indisputable that milk and milk products are rich sources of calcium, the absence of calcium chelators such as oxalate and phytate in milk renders its calcium more available for absorption. Popular nutrition textbooks state that calcium from plant foods: dark green leafy vegetables, beans and pulses are poorly available for absorption. Oxalate in vegetables and phytate in beans and pulses may form insoluble compounds with calcium which are unavailable for absorption[104,105]. A recent clinical study in humans[106] shows that calcium absorption in low-oxalate and high-calcium dark green leafy vegetables belonging to the family of *Brassica* is comparable to milk. Kale, broccoli, mustard green, Chinese kale and dark green Chinese cabbage are examples in that family. In addition, another recent absorption study in humans also showed that calcium absorption from low-phytate content soy bean and products compares favourably with milk[107]. The results of these recent absorption studies in humans confirm that not all plant foods contain calcium chelators. Thus, calcium absorption is preserved in a wide variety of plant foods low in oxalate and phytate. The rates of calcium absorption in some of these foods may be comparable with milk. In fact, beans, pulses, dark green leafy vegetables, are the main source of calcium in the diets of Mainland Chinese. In addition, edible seeds, fish with edible bones and fins, soft-bones of poultry are potential sources of calcium in the Chinese diets, studying their bioavailability would be a worthwhile pursuit.

Conclusion

In conclusion, more local research should be carried out among indigenous Asian populations in the areas of calcium adaptation, peak bone mass attainment and related modulating factors such as calcium absorption and bioavailability of calcium from the traditional diets in order to establish a more reliable and practical RDA. In fact, a concern for ethnic difference in calcium requirement has been reflected in a recent Consensus Development Conference on Osteoporosis held in Hong Kong, April, 1993, which was organized by the American and European Foundations for Osteoporosis and Bone Diseases and the National Institute of Arthritis and Musculoskeletal and Skin Diseases of the USA. The consensus statements consider ethnic difference in calcium requirements is an important factor to formulate future RDAs for the world populations: '. . . . requirements (calcium) may differ in other ethnic groups and may be less in people with lower protein intakes and small skeletal size. . . .'

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Requirements of calcium: are there ethnic differences?

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鈣的需求：是否有種族的差異

摘要

鈣是一種維持骨骼完整性的必需膳食元素，骨質量較高的成人可減少晚年骨質疏鬆性骨折的危險。終身進食較高的鈣將可減少由於年齡增加而引起的骨質喪失。科學的証據指出，任何種族人群，鈣的進食量與骨質量成正相關。選用低鈣與高鈣進食的兒童和青少年進行鈣補充試驗顯示，鈣的進食與骨質量的增加有關。再者，除鈣進食外，在青少年的研究表明遺傳和骨骼對青春期激素改變的反應會大大地影響骨質的增加，有趣的是，比較不同種族得不到足夠令人信服的証據，指出低鈣進食將預示有骨質疏鬆的危險。這意味著任何種族人群，除鈣進食外，遺傳和複雜的環境因子也許是骨質增加的重要調節因素。目前推薦的鈣膳食供應量（RDAS）是根據高鈣進食白人的臨床研究訂出的，它忽略了低鈣進食營養適應的程度，是易犯錯誤的。事實上，鈣吸收、膳食習慣、骨質代謝、體育活動和骨骼體積和體液等方面是有種族差異的，亞洲人鈣的需求也許與白人不同。理想地，每個種族應根據他們自己的研究製定 RDA。在亞洲國家，鈣主要來源於植物性食物、魚類和甲殼魚類中可食的魚骨、魚鰭和殼等。最近用低草酸和低植酸的蔬菜和豆類進行人類吸收試驗，得出了比一般預料相反的結果，這些蔬菜含鈣螯合物較低，鈣吸收率與牛奶相似。研究亞洲食物和膳食中鈣的生物利用率可確定鈣的豐富來源。