Curr Osteoporos Rep (2015) 13:52–59
DOI 10.1007/s11914-014-0248-6

Lifestyle and Osteoporosis

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Published online: 23 November 2014

Abstract Osteoporosis is associated with a number of lifestyle factors, including nutritional factors such as intake of calcium, protein, dairy food, fruits and vegetables and vitamin D status, and behavioural factors such as physical activity, smoking and alcohol consumption. Ensuring adequate calcium intake and vitamin D status and having regular weight-bearing physical activity throughout life are important for bone health and the prevention of osteoporosis and related fractures. Studies have shown that smoking and excessive alcohol intake have adverse effects on bone health and increase the risk of fracture. There is evidence suggesting that adequate protein intake and higher intake of fruits and vegetables are beneficial to bone health.

Keywords Osteoporosis · Bone mineral density · Fracture · Nutrition · Calcium · Vitamin D · Protein · Fruits and vegetables · Physical activity · Smoking · Alcohol consumption

Introduction

Osteoporosis and related fractures are a major cause of morbidity and mortality in older people. From the age of 50, the residual lifetime risk of fracture is estimated to be around 50 % in women and 30 % in men [1]. Although bone density is largely determined by heredity and genetic factors, a number of lifestyle factors play a role in the development or prevention of osteoporosis, through their effects on bone development during growing years and the rate of bone loss in later life (Fig. 1). This chapter focuses on the influence of nutritional factors, including intake of calcium, protein, dairy food, fruits and vegetables and vitamin D status, and behavioural factors such as physical activity, smoking and alcohol consumption on bone health.

This article is part of the Topical Collection on *Nutrition, Exercise, and Lifestyle in Osteoporosis*

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Nutritional Factors

Calcium

Adequate calcium intake is important for the achievement of optimal peak bone mass and the maintenance of bone mass in older age. During childhood and adolescence, increased calcium intake is associated with increased bone mineral accumulation up to a threshold level [2, 3]. The minimal intake to achieve maximal retention is 1300 mg/day for white girls and 1140 mg/day for white boys [4, 5]. The requirement has been reported to be slightly lower for Chinese-American girls and boys of 970 and 1100 mg/day, respectively [6•], possibly related to their high calcium retention efficiency [3]. Epidemiological studies have shown that dairy food and calcium intake during childhood and adolescence is related to bone mineral accretion during growth [7, 8], childhood fracture [9] and bone mineral density (BMD) at adulthood [10]. A meta-analysis including 19 intervention trials in children showed that calcium supplementation had a modest effect on forearm BMD and total body bone mineral content (BMC) [11]. Another meta-analysis that included 12 randomized controlled trials (RCTs) of dairy or calcium intervention (n=2460)

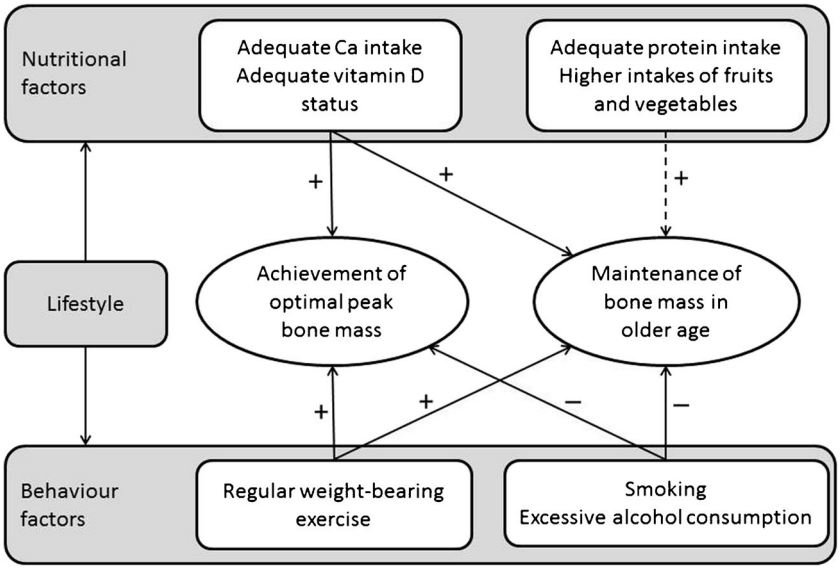

Fig. 1 Current evidence on the influence of lifestyle factors on peak bone mass development during growth and bone mass maintenance in older age

showed that increased calcium or dairy intake led to 1–3 % higher total body bone mineral accretion only in the three studies in subjects with low calcium intake (450–750 mg/day) [12]. Therefore, it seems that calcium and dairy intervention is particularly effective in children with low habitual calcium consumption. However, it remains uncertain whether these effects could translate into reduced childhood fracture and/or result into high bone density at adulthood.

From middle age, the age-related bone loss in both male and female is approximately 0.5–1.0 % per year [13]. Observational studies demonstrated that when calcium intake is below 700–800 mg/day, the risk for bone loss and fracture increases [14]. A recent large cohort study in 61,433 women with a median follow-up of 19.2 years showed that women in the lowest quintile of calcium intake (<751 mg/day) had an increased risk for osteoporosis, any fracture and hip fracture, but above this base level, further increase in calcium intake did not lead to further fracture risk reduction, reflecting a non-linear association of dietary calcium intake and fracture risk [15]. A meta-analysis including 23 trials showed that calcium or calcium and vitamin D supplementation was associated with a 1.2 % reduction in spine bone loss and a 0.5 % reduction in hip bone loss [16]. RCTs have also shown that milk supplementation (providing calcium 800–1000 mg/day, with or without vitamin D) could reduce bone loss in older men [17] and women [18]. For fracture outcome, a meta-analysis summarizing data of 17 trials showed that calcium treatment was associated with a 10 % reduction, and calcium in combination with vitamin D was associated with a 13 % reduction in risk for any types of fractures [16]. A more recent meta-analysis of 16 RCTs of calcium and vitamin D supplementation found that the supplementation was associated with a 12 % reduction in risk for any fracture, but the benefits were significant only among institutionalized patients [19••].

Hip Fracture Meta-analyses of pooled cohort studies reported a neutral effect of total calcium intake on hip fracture risk in both older men and women [20] and of milk intake in women [21], but a possible benefit of milk intake in men [21]. A recent report from the Framingham Original Cohort with 830 men and women aged 68–96 years showed that there was a non-significant trend of reduced hip fracture risk in older adults with high milk intake (≥7 servings/week, hazard ratio (HR) 0.58, 95 % confidence interval (CI) 0.31–1.06) or medium milk intake (>1 and <7 servings/week, HR 0.61 95 % CI 0.36–1.08) compared to those with low milk intake (≤1 serving/day) [22]. In contrast, two meta-analyses of calcium monotherapy have suggested that calcium supplementation could be associated with a higher risk of hip fracture [20, 23], which might be resulted from suppressed periosteal expansion at the femoral neck [23]. Nevertheless, intervention studies using calcium in combination with vitamin D have demonstrated a significant reduction in hip fracture risk in older women [24, 25]. In the Women's Health Initiative (WHI), among those who were not taking personal calcium or vitamin D supplements at baseline and adhering to the calcium (1000 mg/day) and vitamin D (400 IU/day) supplementation for 5 years or more, a 38 % reduction in hip fracture was observed (HR 0.62, 95 % CI 0.38–1.00) [26]. As older people at high risk of hip fracture tend to have both low calcium intake and vitamin D deficiency, it is recommended that calcium should be used in combination with vitamin D to prevent bone loss and fracture.

Recommendation of the Institute of Medicine for daily calcium intake is 1000 mg/day for men and women aged up to 50, and women aged over 50 and men aged over 70 are recommended to increase their intake to 1200 mg/day [27]. Good sources of calcium include dairy products, dark-green leafy vegetables and calcium-fortified foods and beverages. In

our recent study with 564 elderly women with a mean age of 84.7 years (SD 2.5), we found that higher dairy intake was associated with higher appendicular bone mass and volumetric density as assessed by peripheral quantitative computed tomography (QCT), and these associations were dependent on dairy calcium and protein intake [28]. There is also evidence suggesting that the impact of dairy consumption on bone health is similar or better than the calcium supplement alone [29]. In the Postmenopausal Health Study with women aged 55–65 years, those who consumed dairy products for 12 months (containing 1200 mg calcium and 300 IU vitamin D) had significantly greater improvement in hip, spine and total body BMD compared to women who received calcium supplement only or placebo [30]. However, many older people are at the risk of not having an optimal level of calcium intake from diet [31]. When an adequate amount of calcium cannot be obtained via dietary intake, calcium supplements would be needed. Given that most people have dietary intake of around 500–1000 mg/day, most adults will require a dose of supplement around 500–600 mg/day to ensure their calcium intake is close to the recommended daily allowances.

Reports from secondary analyses of RCTs raised the concern that calcium supplementation might lead to increased cardiovascular events [32, 33]. However, expert reviews of current evidence concluded that there was insufficient evidence suggesting that calcium supplements could increase the risk of cardiovascular events [34, 35]. Indeed, a recent study in older women showed that calcium supplementation did not increase carotid artery intimal medial thickness, whereas high calcium intake was actually related to reduced carotid atherosclerosis [36]. A further analysis of the WHI data showed that calcium and vitamin D supplementation had little influence on coronary heart disease risk or cardiovascular disease risk [26]. Furthermore, a recent meta-analysis summarizing data of 18 RCTs in postmenopausal women (n=63,563) concluded that calcium supplementation with or without vitamin D does not increase the risk of coronary heart disease or all-cause mortality [37••].

Vitamin D

Vitamin D plays an important role in calcium absorption and bone health. Persistent severe vitamin D deficiency causes rickets in children and osteomalacia in adults, whereas mild vitamin D deficiency has been reported to be associated with hyperparathyroidism and increased bone turnover [38]. One study in Europe showed that osteomalacia (subclinical lack of bone mineral content) was a common problem and presented in up to 43 % of the study population aged 15 to 95 years [39]. However, epidemiology studies evaluating the association between circulating 25-hydroxyvitamin D (25-OHD) levels and bone density in older people yielded conflicting results; while some showed positive associations [40–42], others showed no association [43]. In the NHANES III study, in both older adults aged above 50 years and younger adults aged 20 to 49 years, higher serum 25-OHD levels were associated with higher BMD up to 90–100 nmol/L in all ethnic groups [40]. Results of vitamin D supplementation trials with bone density as the outcome measures have also been conflicting, and the effects have been reported as beneficial, detrimental or null [44]. A recent meta-analysis of 23 trials (n=4082) concluded that there is little evidence to support a beneficial effect of vitamin D supplementation alone on bone density; however, a significant positive effect was observed for femoral neck BMD of 0.8 % (95 % CI 0.2–1.4) [45]. The lack of benefit on the other sites evaluated could be because most of the studies included in the meta-analysis were conducted in postmenopausal women (mean age of 59 years), who were less likely to be vitamin D deficient, and the duration of most trials was 2 years or less. In a 5-year study with older Australian women aged 70–85 years, we found that bone loss was prevented at total hip in both the group which received calcium alone and the group which received both calcium and vitamin D at year 1 compared to the placebo group, but the effect was only maintained in the group which received both calcium and vitamin D at 3 and 5 years [46].

Increased risk for falling is another risk factor for fracture, and vitamin D also plays a role in muscle health maintenance and fall prevention [47]. However, findings of prospective cohort studies on the associations of vitamin D status and fracture risk in older people are contradictory; while some showed that higher vitamin D status associated with a reduced risk of osteoporotic fractures [48–50], others failed to demonstrate such association [43, 51]. A recent pooled analysis of 11 oral vitamin D supplementation RCTs evaluated vitamin D dose requirements for fracture prevention in people aged 65 and older and found that vitamin D supplementation was related to a significant reduction of non-vertebral fracture (HR 0.93, 95 % CI 0.87–0.99) and a non-significant reduction of hip fracture (HR 0.90, 95 % CI 0.80–1.01) [52••]. By quartiles of actual intake, those in the highest quartile of vitamin D intake of 800 IU/day (range of 792 to 2000) had a 30 % lower risk for hip fracture and a 14 % lower risk for non-vertebral fracture, suggesting that vitamin D intake of 800 IU/day and above could play a role in hip and non-vertebral fracture prevention [52••].

Vitamin D can be obtained through exposure to sunlight. However, many older people do not attain sufficient vitamin D through sunlight exposure [53]. A cluster randomized controlled trial also showed that sunlight exposure was not an effective way to reduce vitamin D deficiency or risk of falls in frail older people because of poor compliance [54]. Another source of vitamin D is via nutritional intake. Foods with high vitamin D content include egg yolks, saltwater fish and liver. The adequate vitamin D intake as suggested by the Institute of

Medicine is 600 IU/day for healthy adults aged under 71 and 800 IU/day for healthy adults aged 71 and above, with a safe upper limit of 4000 IU/day [27]. Many people, especially those who are older, may need vitamin D supplements to achieve the recommended intake. A recent trial showed that there is little ethnic difference in vitamin D requirement, as 800 IU/day vitamin D supplementation could increase serum 25-OHD level to ≥50 nmol/L in 97.5 % of older African-American women in the study, similar to the findings in Caucasian women [55].

Protein

Excessive protein intake has been thought to lead to chronic metabolic acidosis which causes hypercalciuria and increased mineral dissolution [56]. However, there are data suggesting that the effect of protein on calcium balance could be natural as it increases gut calcium absorption [57]. Furthermore, protein represents 25 % of bone by mass and 50 % of bone by volume. During bone turnover, a significant proportion of amino acids in bone collagen cannot be reutilized; therefore, adequate protein intake may benefit the skeleton of older people, who have high bone turnover rate, through providing amino acids as substrates for building matrix. The positive impact of protein on bone might also be mediated through increased circulating insulin-like growth factor I (IGF-I), a recognized bone growth-promoting factor, and the protein-IGF-I-related increase in muscle mass/strength [58]. Therefore, in older people, inadequate protein intake could be a problem for bone health.

A number of cross-sectional and longitudinal studies in older subjects have shown that relatively high protein intake was associated with reduced bone loss [59–62]. A systematic review and meta-analysis published in 2009 showed that protein supplementation had a positive effect on lumbar spine BMD; however, no significant influence on hip fracture risk was identified in cohort studies [63]. Since the publication of this meta-analysis, a 1-year RCT in 47 postmenopausal women on caloric restriction showed that high dietary protein intake (24 vs 18 % of total calories) could attenuate bone loss associated with weight reduction at the radius, spine and hip [64]. The only long-term dietary protein intervention study in the general population was a 2-year randomized controlled trial of 30 g/day whey protein intervention with 219 healthy ambulant women aged 70–80 years. At 2 years, the protein group had a marginally higher urinary calcium excretion and significantly higher IGF-I levels compared to placebo, but there were no significant differences between the two groups in changes in bone mass or strength [65•]. One possible explanation for the lack of effect in this study could be the relatively high usual dietary protein intake of the study subjects of 1.1 g/kg body weight/day, which is well above the estimated average intake (EAI) of 0.75 g/kg body weight/day [66]. In a study in frail hip fracture patients which showed that 20 g/day protein supplementation for 6 months could reduce bone loss at the proximal femur by 2.4 % at 12 months, the average dietary protein intake was much lower (45–51 g/day) [67]. Therefore, protein supplementation could be more effective in populations with low protein intake, and further intervention studies in such populations are needed.

Fruit and Vegetable Intake

A diet rich in fruits and vegetables is thought to enhance bone health as it contains greater alkaline ions (potassium, magnesium and calcium), which can lower dietary acid load and thus promote positive calcium balance [68, 69]. Fruits and vegetables are a good source of vitamin K, which is important for bone matrix synthesis [70]; also a good source of dietary antioxidants and biologically active phytochemicals (polyphenols, carotenoids, tocopherols, etc.), which can reduce bone resorption resulted from oxidative stress; and may promote osteoblast function or inhibit osteoclastogenesis [71, 72].

Findings from studies examining the association between fruit and vegetable intake and bone health have been inconsistent. A systematic review on the association of fruits and vegetables and bone health in women aged ≥45 years found a positive association between fruit and vegetable intake and BMD in three out of the four cross-sectional studies and reduced forearm fracture risk in one case-control study, but in two cohort studies and two RCTs with change in BMD or bone biomarkers as outcome measures, no association was observed [73]. Since the publication of the systematic review, a retrospective cohort study based on the Canadian Multicentre Osteoporosis Study showed a beneficial effect of fruits and vegetables on low-trauma fractures [74], and a case-control study in older Chinese people showed that higher intake of fruits and vegetables was related to a lower risk of osteoporotic hip fracture [75]. Fruits and vegetables may help to maintain bone health or reduce the risk of fracture, but well-designed RCTs are needed to confirm the benefits.

Behavioural Factors

Physical Activity

It is well recognized that the mechanical loading above that experienced in daily activities is needed to improve bone density [76]. Therefore, physical activity or exercise is an important lifestyle factor for improving bone mass throughout life. In children and adolescents, physical activity or school-based exercise programs have been shown to have

positive effects on bone mineral accretion [77]. Pre- or peripubertal years are both important time for incorporating physical activity to promote bone health, and there are suggestions that prepubertal years could be more important for girls as it is a period for increasing periosteal apposition [77].

A number of exercise trials have been conducted in older adults, mostly postmenopausal women, and positive effects have been observed in most studies [78]. A systematic review showed that in postmenopausal women, strength exercise is an effective way of improving or maintaining bone mass, and multi-component exercise programmes of strength, aerobic, high impact and/or weight-bearing training may help to prevent age-related bone loss [78]. It has been suggested that to achieve the best results of strength training, high-loading intensity training of three sessions per week and two to three sets per session is needed [79]. Similarly, in middle-aged and older men, a recent systematic review showed that resistance training alone or in combination with impact-loading activities is most effective in preventing bone loss [80•]. Both reviews concluded that walking is not effective in osteoporosis prevention, as it only provides a modest increase in the loads on the skeleton above gravity [78, 80•].

Smoking

Cigarette smoking has been identified as a risk factor for osteoporosis for more than 20 years [81]. Early initiation of smoking has been shown to be related to lower BMD in late adolescence in both boys and girls [82, 83]. In young women, a non-significant reduction in BMD in current smokers compared to non-smokers and a dose-response decrease in BMD with increased cigarette consumption among current smokers had been observed [84]. In older adults, meta-analyses have shown that cigarette smoking is related to reduced bone mass, increased bone loss [85] and increased risk of fracture [86]. Although smokers tend to be thinner than non-smokers, adjusting for body weight or BMI in these studies could not account for the negative association between smoking and low bone mass or increased fracture risk [85, 86]. The adverse influence of smoking on BMD seems to be most pronounced at the hip site [85], and the highest risk for fracture was observed for hip fracture as well, with a risk increase of 84 % (relative risk (RR) 1.84, 95 % CI 1.52–2.22), which could not be fully accounted for by the low BMD in smokers (BMD adjusted RR 1.60, 95 % CI 1.27–2.02) [86].

Cigarettes contain at least 150 known toxins, and cigarette smoke generates a large amount of free radicals. Smoke toxins increase the liver production of oestrogen-destroying enzymes [87]; thus, women who smoke often have low oestrogen levels and tend to have early menopause, both have negative impact on bone mass. Nicotine and free radicals can affect the activity of osteoblasts and thus impair bone formation [88]. Smoking could also lead to increased bone resorption. A recent study showed that smoke carcinogens could bind to the body's cellular aryl hydrocarbon receptors (AHRs) and stimulate excessive formation of osteoclasts and increase bone resorption through the activation of a group of cytochrome P450 enzymes known as Cyp1 [89]. Another study showed that cigarette smoke led to excessive production of two proteins, which triggered increased bone resorption [90]. Furthermore, older people who smoke tend to have a higher risk of fall, which increases the risk for fracture [91]. Smoking cessation has been shown to improve BMD and reduce fracture risk [84, 85, 92].

Alcohol Intake

Moderate alcohol consumption has been shown to have a protective effect against osteoporosis in female twins and elderly women [93•, 94], whereas excessive alcohol consumption has been reported to be a risk factor for low bone mass-related fracture in men [95]. A recent review concluded that one drink per day in women and two drinks per day for men do not have negative influence on bone, whereas bone tissues damage starts to emerge when the consumption is more than two glasses per day, and four or more glasses per day have deleterious effects on bone [96].

Alcohol suppresses osteoblastogenesis [97] while, at the same time, stimulates osteoclast activity and osteoclastogenesis [98], thus leading to reduced bone formation and increased bone resorption. In addition, excessive alcohol intake can interfere with the calcium balance through reduced gut calcium absorption, increased PTH levels, reduced production of the active form of vitamin D (1,25-dihydroxyvitamin D) and affected sex hormone production [96]. Furthermore, excessive alcohol consumption also can lead to more falls in older people and thus increase the risk for fracture.

Conclusions

There are a number of lifestyle-related risk factors for the development of osteoporosis. Ensuring adequate calcium intake and vitamin D status and having regular weight-bearing physical activity throughout life are important for the prevention of osteoporosis and related fractures. In addition, there is evidence suggesting that adequate protein intake and higher intake of fruits and vegetables are beneficial to bone health. Smoking and excessive alcohol consumption have negative impact on bone health and increase the risk of fracture and therefore should be avoided for health benefits.

Compliance with Ethics Guidelines

Conflict of Interest K Zhu and RL Prince both declare no conflicts of interest.

Human and Animal Rights and Informed Consent All studies by the authors involving animal and/or human subjects were performed after the approval by the appropriate institutional review boards. When required, written informed consent was obtained from all participants.

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- • Of importance
- •• Of major importance

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