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ORIGINAL ARTICLE

Veganism, bone mineral density, and body composition: a study in Buddhist nuns

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Abstract
Summary This cross-sectional study showed that, although vegans had lower dietary calcium and protein intakes than omnivores, veganism did not have adverse effect on bone mineral density and did not alter body composition.
Introduction Whether a lifelong vegetarian diet has any negative effect on bone health is a contentious issue. We undertook this study to examine the association between lifelong vegetarian diet and bone mineral density and body composition in a group of postmenopausal women.
Methods One hundred and five Mahayana Buddhist nuns and 105 omnivorous women (average age=62, range=50–85) were randomly sampled from monasteries in Ho Chi Minh City and invited to participate in the study. By religious rule, the nuns do not eat meat or seafood (i.e., vegans). Bone mineral density (BMD) at the lumbar spine (LS), femoral neck (FN), and whole body (WB) was measured by DXA (Hologic QDR 4500). Lean mass, fat mass, and percent fat mass were also obtained from the DXA whole body scan. Dietary calcium and protein intakes were estimated from a validated food frequency questionnaire.
Results There was no significant difference between vegans and omnivores in LSBMD (0.74±0.14 vs. 0.77±0.14 g/cm^2; mean ± SD; P=0.18), FNBMD (0.62±0.11 vs. 0.63±0.11 g/cm^2; P=0.35), WBBMD (0.88±0.11 vs. 0.90±0.12 g/cm^2; P=0.31), lean mass (32±5 vs. 33±4 kg; P=0.47), and fat mass (19±5 vs. 19±5 kg; P=0.77) either before or after adjusting for age. The prevalence of osteoporosis (T scores≤−2.5) at the femoral neck in vegans and omnivores was 17.1% and 14.3% (P=0.57), respectively. The median intake of dietary calcium was lower in vegans compared to omnivores (330±205 vs. 682±417 mg/day, P<0.001); however, there was no significant correlation between dietary calcium and BMD. Further analysis suggested that whole body BMD, but not lumbar spine or femoral neck BMD, was positively correlated with the ratio of animal protein to vegetable protein.
Conclusion These results suggest that, although vegans have much lower intakes of dietary calcium and protein than omnivores, veganism does not have adverse effect on bone mineral density and does not alter body composition.

Keywords Body composition · Bone mineral density · Osteoporosis · Veganism

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Introduction

Osteoporosis is a global public health problem because of its large magnitude and adverse effects on the general population. Recent studies in Caucasian populations showed that, among women aged 60 or above, approximately 20%

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had osteoporosis [1], and this prevalence was also observed in Asian populations [2, 3]. The consequence of osteoporosis is fragility fracture, particularly hip fracture, which is associated with increased risk of mortality [4], reduced quality of life [5], and significant healthcare cost [6, 7]. Prevention is recognized as a preferred approach to reduce the burden of osteoporosis and fractures in the community. Several studies have shown that, among others, nutrition is an important component in the prevention of osteoporosis [8, 9] because it is potentially modifiable by the population.

An ecologic analysis of data from 33 countries in the world found that countries with high intakes of animal protein had higher risk of hip fracture [10]. On the other hand, the analysis also found that countries with higher intakes of vegetable protein (or higher ratio of vegetable to animal protein) were associated with lower risk of hip fracture [10]. Higher ratio of animal to vegetable protein was also shown to be associated with increased bone loss and increased risk of hip fracture [11]. However, evidence of the association between vegetarian diet and bone health has been inconsistent. While there are data suggesting that raw vegetarian diet was associated with lower bone mass [12], other studies found no such association [13]. The inconsistent findings could be attributed to differences in study design and characteristics of participants. Most of the studies were based on small sample sizes with different types of vegetarian diet, which could compromise the delineation of an association between veganism and bone health.

The term "vegetarian diet" is rather generic, because it actually refers to four types of diet: *semi-vegetarian* which excludes meat intake; *lacto-ovo-vegetarian* excludes meat and seafood; *lacto-vegetarian* excludes meat, seafood, and eggs, except milk and dairy products; and *vegan* excludes all foods of animal origin. Thus, vegan diet is probably the "true" vegetarian diet. Mahayana Buddhism is practiced by most populations in Vietnam, China, and Japan. In Mahayana Buddhism, nuns must follow a vegan or lacto-vegetarian diet, and they thus represent an ideal group for studying the effect of vegetarian diet on bone health. Therefore, the present study was designed to examine the association between lifelong vegetarian diet and osteoporosis in the Buddhist nuns.

Study design and methods

Study design and subjects

The study setting was Ho Chi Minh city (formerly Saigon), a major city and an economic hub in Vietnam. The city has a population of 6.4 million, with a density of 7,943 people per square mile (www.hochiminhcity.gov.vn, date of access 10 July 2008). The current annual average GDP of the city was $2,180 (GDP adjusted for purchasing power parity was $10,870).

The study was designed as a cross-sectional investigation which involved 20 monasteries and temples within the city. The temples were randomly selected from 286 temples and monasteries that are listed by a local Buddhist association. We sent letters of invitation to each monastery or temple to invite nuns over 50 years of age to participate in the study. In Vietnam, voting is compulsory; therefore, each ward or district must keep an electoral roll. In the next step, we obtained the electoral roll, and then randomly selected households where there are female residents aged 50 or above. We sent a letter of invitation to female members of the selected households. No women refused our invitation. The women received free health check-up and DXA measurement, but they did not receive any financial incentive. The study was approved by the ethics committee of the Pham Ngoc Thach University of Medicine.

Under the assumption that the difference in bone mineral density between vegetarians and omnivores was 0.05 g/cm^2 (a difference of clinical relevance), and given that the between-subjects standard deviation of bone mineral density is around 0.12 g/cm^2, we estimated that a sample size of ~91 individuals in each group was required to have a power of 80% to detect the difference at the confidence interval of 95%. Ultimately, 105 nuns and 105 women aged 50 years or above were eligible to participate in the study. On average, between five and six nuns of each temple/monastery participated in the study. None of the participants had any diseases deemed to affect osteoporosis (such as hyperthyroidism, hyperparathyroidism, renal failure, malabsorption syndrome, alcoholism, chronic colitis, multi-myeloma, leukemia, chronic arthritis) or previous use of therapies that interfere with bone metabolism (e.g., glucocorticoid, heparin, warfarin, thyroxin, estrogen).

Data collection

Clinical data including blood pressure, pulse, and reproductive history (i.e., parity, age of menarche, age of menopause), medical history (i.e., previous fracture, previous and current use of pharmacological therapies) were obtained by a standardized questionnaire. The questionnaire also solicited data on physical activity and lifestyle factors. The women were asked to report their past and current cigarette smoking, alcohol use, and coffee drinking.

Anthropometric parameters including age, weight, and standing height were obtained. Body weight was measured by using an electronic balance with indoor clothing without shoes. Height was determined without shoes on a portable stadiometer with mandible plane parallel to the floor.

Bone mineral density measurement

BMD was measured at the lumbar spine (LS), femoral neck (FN), and whole body (WB) in all participants. The measurement was done with a dual energy X-ray absorptiometry (DXA) densitometer (Hologic QDR 4500). The precision error (%CV) in our laboratory was 2% for lumbar spine, 1.8% for femoral neck BMD, and 1.5% for whole body BMD. The densitometer was standardized by standard phantom every time before measurement.

Bone mineral density was expressed in grams per square centimeter or in *T* score, which represents the number of standard deviations from the peak bone mass (taken as aged between 20 and 30). Since there was a lack of population reference in bone mineral density in Vietnam, we chose the Thai reference database for determining the *T* score. Using the World Health Organization criteria, we classified women into two groups based on the *T* score: those with osteoporosis if their *T* scores were equal to or lower than −2.5 and those without osteoporosis if their *T* scores were higher than −2.5.

Nutrient analysis

The participants were also asked to fill out a structured questionnaire for collecting data concerning 2-day dietary habits. We used models, spoons, and glasses of various sizes to help participants estimate their food intakes. The data were then entered into "Eiyokun", a computer software specifically designed for analyzing nutritional components in Vietnamese food. The software was developed and validated by the Vietnam National Institute of Nutrition. The nutrient estimates from this program include the amount of calories, animal and vegetable protein intakes, animal and vegetable lipids, carbohydrate, dietary calcium intake, phosphate, sodium, potassium, and magnesium.

Data analysis

The primary purpose of analysis was to assess the association between vegetarian diet and bone mineral density and body composition. The main statistical model was the analysis of covariance, in which BMD or body composition was considered the primary outcome. Diet (whether vegan or omnivore) was treated as a predictor. Clinical factors and lifestyle factors were considered as covariates. In a further analysis, we examined the correlation of various nutrients and BMD in a multiple linear regression model. Specifically, we were interested in the correlation between ratio of animal to vegetable protein intakes, ratio of animal to vegetable lipid intakes, and BMD. The R program was used for the statistical analysis [14].

Results

Characteristics of participants

Demographic and anthropometric characteristics of participants are shown in Table 1. The average age of the entire sample (n=210) was 62 years (range=50–85). There were no significant differences in height, weight, and body mass index between vegans and omnivores. Although the two groups were similar in terms of menarcheal age, the average age of menopause among vegans (47.8 years) was significantly lower than that among omnivores (49.6 years). Among 105 women in the vegan group, 20 had previously been married and had children. The 105 nuns had been on vegan diet for 33 years (range=10–72); among those who were previously married, the average duration of vegan diet was 25 years (range=10–65).

None of the women were smokers. The prevalence of self-reported alcohol use was 10% among the omnivorous

Table 1 Characteristics of participants stratified by group

Variable	Vegans	Omnivores	*P* value
Number of women	105	105	
Age (years)	62 (10)	62 (10)	0.95
Duration of vegan diet (years)[a]	33 (10, 72)	0	
Age of menopause (years)	47.7 (4.8)	49.2 (4.9)	0.03
Age of menarche (years)	15.3 (2.0)	15.0 (2.1)	0.21
Parity[b]	0.8 (2.1)	3.0 (2.0)	<0.001
Weight (kg)	53 (9)	54 (7)	0.59
Height (cm)	148 (6)	149 (6)	0.15
BMI (kg/m^2)	24 (2)	24 (3)	0.78
Morning exercise (n, %)	82 (78.1)	81 (77.1)	0.86
Coffee drinking (n, %)	28 (26.7)	48 (45.2)	0.004
Alcohol use	0	10 (10%)	0.011

Values are means and standard deviations (in brackets). For variables "Morning exercise", "Coffee drinking", and "Alcohol use", values are number of women and percent of total sample size for each group

[a] Duration of vegan diet is shown in median and range in brackets

[b] Twenty nuns were previously married and had children prior to becoming a nun

Table 2 Daily nutrient intakes in vegans and omnivores

Variable	Vegans[a]	Omnivores[a]	*P* value
Number of women	105	105	
Total protein intake (g)	35.4 (11.6)	62.6 (18.3)	<0.0001
Animal protein intake (g)	2.1 (3.2)	34.6 (15.8)	<0.0001
Vegetable protein intake (g)	33.2 (11.6)	28.0 (8.4)	<0.0001
Ratio of animal to vegetable protein intake	0.08 (0.16)	1.33 (0.72)	<0.0001
Total lipid intake (g)	23.1 (10.7)	38.6 (17.7)	<0.0001
Animal lipid (g)	1.8 (3.0)	17.7 (11.8)	<0.0001
Vegetable lipid (g)	21.0 (10.7)	20.6 (11.3)	0.798
Ratio of animal to vegetable lipid	0.16 (0.44)	1.19 (1.62)	<0.0001
Phosphate (mg)	465 (155)	865 (278)	<0.0001
Energy intake (kJ)	1130 (298)	1486 (381)	<0.0001
Dietary calcium (g)	375 (193)	683 (417)	<0.0001
Ratio of vegetable protein to dietary calcium intake	0.089 (0.031)	0.052 (0.025)	<0.0001
Sodium (g)	2,819 (967)	2,147 (1075)	<0.0001
Potassium (g)	1,328 (476)	1,916 (627)	<0.0001
Magnesium (g)	120 (53)	168 (75)	<0.0001

[a] Nutrient intakes are shown in means and standard deviations (in brackets)

group, but was none in the vegetarian group. Approximately 45% of women in the omnivorous group reported drinking coffee daily, and this proportion was significantly higher than that reported in the vegan group (27%). Approximately 80% of women reported to have performed daily exercise in the form of morning jogging, and there was no significant difference between the two groups in terms of exercise.

Nutrient intakes

Results of analysis of daily nutrient intakes stratified by group are presented in Table 2. As expected, animal protein in vegans (2.1 g/day) was lower than in omnivores (34.6 g/day). The presence of animal protein in the vegan group was mainly due to the fact that some nuns reported to have used commercial milk in their daily meal. In contrast, vegetable protein intake was significantly higher in the vegan group (33.2 g/day) compared to the omnivorous group (28.0 g/day). Total energy intake among vegans was also significantly lower than that among omnivores (1,130 vs. 1,486 kJ/day, $P<0.0001$).

The average dietary calcium intake among vegans was 375 g/day, which was significantly lower than the intake reported by omnivores (683 g/day, $P<0.0001$). The ratio of vegetable protein to dietary calcium intake was 0.09 (SD 0.03) in omnivores, which was significantly higher than in vegans (0.05±0.02; $P<0.0001$). Moreover, compared to omnivores, vegans generally had lower intakes of total lipid, phosphates, sodium, potassium, and magnesium.

Bone mineral density and body composition

BMD at the lumbar spine, femoral neck, and whole body among vegans was lower than omnivores by about 0.01 to 0.03 g/cm^2, but none of the differences was statistically significant. There was no significant differences in lean mass ($P=0.47$), fat mass ($P=0.77$), and percent fat mass ($P=0.75$) between vegans and omnivores (Table 3). There was also no significant correlation between the duration of vegan diet and BMD or body composition measures.

The prevalence of osteoporosis (i.e., femoral neck BMD *T* scores≤−2.5) in the entire sample was 35/210 or 17% (95% confidence interval=12% to 22%). There was no

Table 3 Bone mineral density in vegans and omnivores

BMD and body composition	Vegans[a]	Omnivores[a]	Difference and 95% CI	*P* value
Femoral neck (g/cm^2)	0.62 (0.11)	0.63 (0.11)	−0.01 (−0.051, +0.009)	0.17
Lumbar spine (g/cm^2)	0.74 (0.14)	0.77 (0.14)	−0.03 (−0.067, +0.10)	0.15
Whole body (g/cm^2)	0.88 (0.11)	0.90 (0.12)	−0.02 (−0.058, +0.001)	0.07
Lean mass (kg)	32 (5)	33 (4)	−0.4 (−1.5, 0.7)	0.47
Fat mass (kg)	19 (5)	19 (5)	−0.2 (−1.5, 1.1)	0.77
Percent fat mass (%)	34.9 (5.9)	35.1 (6.2)	−0.3 (−1.9, 1.4)	0.75

[a] Values are means and standard deviations (in brackets)

significant difference in the prevalence of osteoporosis between vegans (18.1%) and omnivores (15.2%). However, in both groups, the prevalence increased with advancing age such that it reaches 40% by the age of 70 and above (data not shown).

In univariate analysis, there was no significant correlation between dietary calcium intake and BMD (P=0.12 for femoral neck BMD, P=0.99 for lumbar spine BMD, and P=0.09 for whole body BMD). There was also no significant correlation between dietary calcium intake and lean mass (P=0.43) and fat mass (P=0.98). In a multivariable analysis that included age, dietary calcium intake, animal protein, and vegetable protein (Table 4), higher intakes of vegetable protein were associated with lower whole body BMD, but the association was only statistically significant for whole body BMD (P=0.033). There was no statistically significant correlation between either animal protein or vegetable protein and lean mass and fat mass.

In a further analysis, the dietary calcium and protein data were reduced to three ratios: ratio of animal to vegetable protein intakes (rAVP), ratio of vegetable protein intake to dietary calcium intake (rVCa), and ratio of animal protein intake to dietary calcium intake (rACa). After adjusting for age, only rAVP (but not rVCa or rACa) was positively correlated with whole body BMD (P=0.045). There was no significant correlation between the rVCa and lean mass or fat mass (data not shown).

Discussion

Vegetarianism is increasingly popular in Western countries, with the proportion of self-reported vegetarians being 5% in the United Kingdom [15]. However, an opposite trend is observed in economically less developed countries, where animal protein is increasingly becoming more accessible, and a high consumption of animal protein is sometimes considered a sign of affluence. Despite the trends, the effect of vegetarianism on bone health has not been clear, with conflicting findings from previous studies [16], probably due to study design and characteristics of participants. Vegetarian diet has always been central to Buddhism, and because Buddhist nuns follow a strict vegan diet, they are an ideal group to study the effect of veganism on bone health. In this study, by using a "Buddhist model", we found that although postmenopausal lifetime vegans had lower BMD than omnivorous women by ~0.16 standard deviation, the difference was neither statistically nor clinically significant.

Our finding is consistent with some recent studies in Taiwan [13] and Hong Kong [17] in which there was no significant difference in BMD between vegetarians and non-vegetarians in either men or women. Moreover, in a

Table 4 Association between ratio of animal to vegetable protein intake and BMD: results of multivariable linear regression analysis

BMD and body composition	Regression coefficient (standard error) and *P* value associated with each predictor[a]				
	Group (vegans)	Age (+5years)	Dietary calcium (+300g)	Animal protein (+10g)	Vegetable protein (+10g)
Femoral neck BMD	0.014 (0.023) P=0.531	−0.031 (0.003) P<0.0001	0.005 (0.007) P=0.461	0.008 (0.006) P=0.175	−0.008 (0.007) P=0.261
Lumbar spine BMD	0.012 (0.030) P=0.703	−0.039 (0.004) P<0.0001	0.010 (0.010) P=0.287	0.013 (0.008) P=0.108	0.014 (0.009) P=0.128
Whole body BMD	0.004 (0.022) P=0.847	−0.034 (0.003) P<0.0001	0.007 (0.007) P=0.300	0.006 (0.006) P=0.313	−0.014 (0.006) P=0.033
Lean mass	−0.494 (0.9850) P=0.617	−0.351 (0.147) P=0.018	0.020 (0.300) P=0.946	0.024 (0.256) P=0.925	0.364 (0.289) P=0.209
Fat mass	−0.169 (1.208) P=0.889	0.257 (0.181) P=0.158	0.240 (0.369) P=0.515	0.178 (0.314) P=0.572	0.641 (0.354) P=0.072

[a] Unit of comparison was arbitrarily set to be close to the standard deviation of each variable. For example, the regression coefficient for "Age" actually represents the change in BMD for each 5 years increase in age. The regression coefficient for the "Group" variable represents the difference in BMD between vegans and omnivores after adjusting for covariates in the model

study of more than 19,000 individuals in the EPIC–Oxford study (UK), there was no significant difference in BMD between vegetarians and omnivores [18]. In a study of 51 Chinese adolescents aged between 4 and 14 years, Leung et al. found that those on lacto-ovo-vegetarian diets had similar physical growth and increase in BMD with omnivores [19]. However, three previous studies found that BMD in vegans was slightly lower than in omnivores [20–22]. Taken together, these data seem to suggest that lifetime vegetarianism or veganism has no clinical adverse effect on BMD.

Furthermore, although vegans in this study had a very low intake of dietary calcium (375 g/day) compared to omnivores (683 g/day), there was no correlation between calcium intakes and BMD. We also found no difference in either lean mass or fat mass between vegetarians and omnivores, and this finding is consistent with a recent study on 20 vegans and ten omnivorous individuals of Caucasian background [23]. Thus, our and others' data suggest that veganism does not induce any adverse change in body composition.

Fracture is the clinical outcome of osteoporosis, and it is therefore important to know whether veganism has any effect on fracture. Ecologic studies showed that the rate of fracture in countries with high intakes of animal protein was greater than in countries with lower intakes of animal protein. In this cross-sectional study, we did not ascertain the incidence of fracture. However, the self-reported prevalence of fracture in vegetarians (21%) was virtually identical to that in omnivores (23%), suggesting that veganism probably has no adverse effect on fracture risk. In the EPIC–Oxford study, there is no significant association between veganism and fracture risk [24]. Taken together, these data imply that veganism has no clinically detrimental effect on bone health.

It has long been hypothesized, but remained to be demonstrated, that a high animal protein diet exerts a negative effect on bone health, because it generated a high endogenous acid load that would require buffering from bone, and thus increasing bone resorption [25]. In this study, higher vegetable protein intakes were associated with lower BMD, but the association was only marginally significant (P=0.03) at the whole body BMD, not at the clinically important sites of femoral neck and lumbar spine. In view of the multiple tests of hypothesis, this "significance" must be viewed with caution. In fact, after adjusting for multiple tests, the association is no longer significant. The non-significant correlation between dietary protein intakes and BMD is also consistent with the non-significant effect of veganism on BMD.

The relation between protein intake, particularly animal protein, and bone health has been controversial. On the one hand, there are data suggesting that higher dietary protein intakes were associated with lower risks of fragility fracture [26] and hip fracture [27]. On the other hand, other studies showed that higher dietary protein intakes were associated with increased bone loss [11] and greater risk of fragility fracture [11, 28]. Although the present study did not ascertain the incidence of fracture, an analysis of association between dietary protein intake and prevalence of fracture did not reveal a significant association. By and large, it is still not clear whether high protein intakes have positive or negative effects on bone health.

The present results should be interpreted in relation to some strengths and weaknesses. The participants were randomly drawn from the general population which should ensure its external validity. The vegetarians were Mahayana Buddhist nuns who are an ideal group for the study of veganism and bone health. The average protein intake in the omnivorous group in this study (63 g/day) was comparable to the intake observed in Caucasian populations [11, 29]. However, the average protein intake in the vegan group, as expected, was low. Thus, the present study's results reflect the effects of normal versus low protein intakes, not between high versus low protein intakes. The sample size was statistically adequate to estimate the effect between lifelong vegetarian diet on bone mineral density. The study design was cross sectional, and it is not possible to make any cause-and-effect inference on the relationship between veganism and bone health. Moreover, since there was no incident fracture data, no inference on the association between veganism and fracture is possible.

In summary, the present study suggests that veganism does not have any adverse effect on bone mineral density and body composition, even though veganism was associated with lower dietary intakes of protein and calcium.

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Conflicts of interest None.

References

1. Nguyen TV, Center JR, Eisman JA (2000) Osteoporosis in elderly men and women: effects of dietary calcium, physical activity, and body mass index. J Bone Miner Res 15:322–331
2. Limpaphayom KK, Taechakraichana N, Jaisamrarn U, Bunyavejchevin S, Chaikittisilpa S, Poshyachinda M, Taechamahachai C, Havanond P, Onthuam Y, Lumbiganon P, Kamolratanakul P (2001) Prevalence of osteopenia and osteoporosis in Thai women. Menopause 8:65–69
3. Ho SC, Lau EM, Woo J, Sham A, Chan KM, Lee S, Leung PC (1999) The prevalence of osteoporosis in the Hong Kong Chinese female population. Maturitas 32:171–178

4. Center JR, Nguyen TV, Schneider D, Sambrook PN, Eisman JA (1999) Mortality after all major types of osteoporotic fracture in men and women: an observational study. Lancet 353:878–882
5. Randell AG, Nguyen TV, Bhalerao N, Silverman SL, Sambrook PN, Eisman JA (2000) Deterioration in quality of life following hip fracture: a prospective study. Osteoporos Int 11:460–466
6. Randell A, Sambrook PN, Nguyen TV, Lapsley H, Jones G, Kelly PJ, Eisman JA (1995) Direct clinical and welfare costs of osteoporotic fractures in elderly men and women. Osteoporos Int 5:427–432
7. Ray NF, Chan JK, Thamer M, Melton LJ 3rd (1997) Medical expenditures for the treatment of osteoporotic fractures in the United States in 1995: report from the National Osteoporosis Foundation. J Bone Miner Res 12:24–35
8. Nieves JW (2005) Osteoporosis: the role of micronutrients. Am J Clin Nutr 81:1232S–1239S
9. Reid IR (1989) The role of dietary calcium in the pathogenesis and treatment of osteoporosis. N Z Med J 102:532–533
10. Frassetto LA, Todd KM, Morris RC Jr, Sebastian A (2000) Worldwide incidence of hip fracture in elderly women: relation to consumption of animal and vegetable foods. J Gerontol A Biol Sci Med Sci 55:M585–592
11. Sellmeyer DE, Stone KL, Sebastian A, Cummings SR (2001) A high ratio of dietary animal to vegetable protein increases the rate of bone loss and the risk of fracture in postmenopausal women. Study of Osteoporotic Fractures Research Group. Am J Clin Nutr 73:118–122
12. Fontana L, Shew JL, Holloszy JO, Villareal DT (2005) Low bone mass in subjects on a long-term raw vegetarian diet. Arch Intern Med 165:684–689
13. Wang YF, Chiu JS, Chuang MH, Chiu JE, Lin CL (2008) Bone mineral density of vegetarian and non-vegetarian adults in Taiwan. Asia Pac J Clin Nutr 17:101–106
14. R Development Core Team (2008) R: A Language and Environment for Statistical Computing. URL:http://wwwR-projectorg Vienna, Austria
15. New SA (2004) Do vegetarians have a normal bone mass? Osteoporos Int 15:679–688
16. Smith AM (2006) Veganism and osteoporosis: a review of the current literature. Int J Nurs Pract 12:302–306
17. Lau EM, Kwok T, Woo J, Ho SC (1998) Bone mineral density in Chinese elderly female vegetarians, vegans, lacto-vegetarians and omnivores. Eur J Clin Nutr 52:60–64
18. Appleby P, Roddam A, Allen N, Key T (2007) Comparative fracture risk in vegetarians and nonvegetarians in EPIC-Oxford. Eur J Clin Nutr 61:1400–1406
19. Leung SS, Lee RH, Sung RY, Luo HY, Kam CW, Yuen MP, Hjelm M, Lee SH (2001) Growth and nutrition of Chinese vegetarian children in Hong Kong. J Paediatr Child Health 37:247–253
20. Chiu JF, Lan SJ, Yang CY, Wang PW, Yao WJ, Su LH, Hsieh CC (1997) Long-term vegetarian diet and bone mineral density in postmenopausal Taiwanese women. Calcif Tissue Int 60:245–249
21. Outila TA, Karkkainen MU, Seppanen RH, Lamberg-Allardt CJ (2000) Dietary intake of vitamin D in premenopausal, healthy vegans was insufficient to maintain concentrations of serum 25-hydroxyvitamin D and intact parathyroid hormone within normal ranges during the winter in Finland. J Am Diet Assoc 100:434–441
22. Parsons TJ, van Dusseldorp M, van der Vliet M, van de Werken K, Schaafsma G, van Staveren WA (1997) Reduced bone mass in Dutch adolescents fed a macrobiotic diet in early life. J Bone Miner Res 12:1486–1494
23. Siani V, Mohamed EI, Maiolo C, Di Daniele N, Ratiu A, Leonardi A, De Lorenzo A (2003) Body composition analysis for healthy Italian vegetarians. Acta Diabetol 40(Suppl 1):S297–298
24. Key TJ, Appleby PN, Rosell MS (2006) Health effects of vegetarian and vegan diets. Proc Nutr Soc 65:35–41
25. Barzel US, Massey LK (1998) Excess dietary protein can adversely affect bone. J Nutr 128:1051–1053
26. Hannan MT, Tucker KL, Dawson-Hughes B, Cupples LA, Felson DT, Kiel DP (2000) Effect of dietary protein on bone loss in elderly men and women: the Framingham Osteoporosis Study. J Bone Miner Res 15:2504–2512
27. Munger RG, Cerhan JR, Chiu BC (1999) Prospective study of dietary protein intake and risk of hip fracture in postmenopausal women. Am J Clin Nutr 69:147–152
28. Feskanich D, Willett WC, Stampfer MJ, Colditz GA (1996) Protein consumption and bone fractures in women. Am J Epidemiol 143:472–479
29. Fulgoni VL 3rd (2008) Current protein intake in America: analysis of the National Health and Nutrition Examination Survey, 2003–2004. Am J Clin Nutr 87:1554S–1557S