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Original Article

Bone Density and Lifestyle Characteristics in Premenopausal and Postmenopausal Chinese Women

J.-F. Hu[1], X.-H. Zhao[2], J.-S. Chen[2], J. Fitzpatrick[3], B. Parpia[1] and T. C. Campbell[1]

[1]Division of Nutritional Sciences, Cornell University, New York, USA; [2]Institute of Nutrition and Food Hygiene, Chinese Academy of Preventive Medicine, Beijing, P. R. China; and [3]Serex, Inc., Maywood, New Jersey, USA

Abstract. The relationships between bone health and various lifestyle factors were examined in a cross-sectional study in 775 Chinese women aged 35–75 years. Bone mass was significantly positively associated with body weight, height, body mass index (BMI) and duration of breastfeeding, but was not significantly associated with other lifestyle variables, including alcohol consumption, parity, age at menarche and age at menopause after adjusting for age and body weight. A positive association was observed in premenopausal women (but not in postmenopausal women) for bone density with current cigarette smoking and plasma and urinary cotinine (the major metabolite of smoking). However, the confounding effects of other unknown factors present in this cross-sectional study may not be excluded. Daily physical activity, as indicated by time spent working in the fields, was found consistently to be positively associated with bone mass ($p<0.0001$). When these women were grouped into three physical activity levels on the basis of occupation and daily work intensity, those undertaking heavy labor also had significantly higher radial bone mass than women undertaking light or medium labor. These results suggest a protective effect of daily physical activity on bone health in both pre- and postmenopausal women.

Keywords: Bone mass; Cotinine; Lactation; Lifestyle; Osteoporosis; Parity; Physical activity; Smoking

Correspondence and offprint requests to: T. Colin Campbell, PhD, N204 MVR Hall, Division of Nutritional Sciences, Cornell University, Ithaca, NY 14853–4401, USA. Fax: 607–255–5489.

Introduction

Low bone mass, which predisposes women to osteoporotic fractures, has been shown to be associated with multiple factors. In addition to calcium nutritional status and genetic differences, there has been considerable interest in the effects on bone mass of other lifestyle characteristics, such as reproductive history, physical activity, alcohol consumption and cigarette smoking.

Menopausal status of women, which is accompanied by changes in circulating estrogen levels, undoubtedly is an important dimension in the age-related decline in bone mass. Women with earlier menopause or with removal of bilateral ovaries before natural menopause often experience a low bone mass and have an increased risk of hip fractures [1,2]. Among other reproductive characteristics, lactation and parity have been studied but with inconsistent results [3,4]. A significantly lower bone mass at the ultra-distal and mid radius was reported in mothers with long-term lactation (10.7 months) than in mothers with short-term lactation (2.8 months) even though their habitual calcium intakes were over 90% of RDA [5].

Alcoholic women have been shown to have a lower bone mass and to lose bone more rapidly than their non-alcoholic counterparts [6]. Consumption of alcohol, even in moderate amounts, was found to increase the risk of osteoporotic fractures at the hip or wrist [7]. Multiple factors are believed to contribute to the development of alcohol-associated osteoporosis although altered metabolism of sex hormones and dysfunction of osteoblastic cells are primarily implicated.

Cigarette smoking has also been considered as another risk factor for low bone density and bone fractures. Female smokers were found to have reduced levels of estrogen in plasma [8] and in the urine [9], probably due to the increased metabolic degradation of the sex hormone [8]. However, it is not clear whether low levels of cigarette consumption in women or lifetime exposure to smoking via a passive pathway, as is the case for women in most rural areas in China, have any effects on bone health.

This report is based on the results of a cross-sectional survey in which some of these lifestyle characteristics were documented for 775 pre- and postmenopausal women selected from five geographically scattered rural counties in China. The study has been described in detail in a previous paper, in which the positive association between dietary calcium intake and bone mass among these same Chinese women was reported [10]. In this comprehensive study, a broad spectrum of parity histories was recorded, ranging from a woman with a maximum of 16 livebirths to younger women whose reproductive history was influenced by the official Chinese 'one child' birth control policy. In addition, due to the local tradition and the unavailability of baby foods and formulae in these survey areas, virtually all women had a long period of breastfeeding. The usual pattern observed was a breastfeeding period that lasted until the next birth. The duration of breastfeeding was even longer for the last baby, often lasting for several years. It is worthwhile investigating the effects of such long-term lactation with multiple parity on bone health in these females. Additionally, calcium intakes of these women were generally very low (394 ± 252 mg/day), virtually all of which were derived from plant sources in some rural areas [10]. Furthermore, although the women were non-smokers or light smokers, virtually all the men in most rural areas in China are heavy smokers. Thus, most of the women were usually exposed to cigarette smoking through a passive pathway rather than an active pathway. The issue of whether light or passive cigarette smoking has an effect on bone health in these female subjects has not been established. These unique lifestyle characteristics, including the wide range of parity, lengthy breastfeeding periods, minimal exposure to cigarette smoking, and low calcium intakes during pregnancy and lactation, make this study ideal for examining the relationship between these lifestyle features and bone mass, which has rarely been studied previously in Chinese women. The primary objective of the present paper was to examine these specific lifestyle variables in relation to bone density in women selected on the basis of their unique dietary and lifestyle patterns, thus providing more corroborative evidence of the importance of these lifestyle features in prevention and management of osteoporosis. Additionally, plasma and urinary cotinine, a major metabolite of nicotine and the reliable indicator of smoking exposure [11], was measured to assess the possible effects of cigarette smoking, via both the active and passive pathway, on bone density at the radius.

Subjects and Methods

Subject Sampling

Sampling procedures used in the selection of survey counties and subjects have been described in detail elsewhere [10] and are noted briefly below. On the basis of the broad range of dietary intakes and lifestyle patterns [12], five of the original 65 rural counties surveyed in 1983 were initially selected for this study. These five counties, characterized by distinct lifestyles and diets, were geographically scattered across China. Xianghuangqi (county YA) and Tuoli (county WA) were located in two pastoral areas of China (Neimongol Autonomous Region and Xinjiang Autonomous Region, respectively). The rest of the counties were selected from three rural farming areas (Jiexiu County in Shanxi Province, Cangxi County in Sichuan Province and Changle County in Fujian Province, abbreviated as counties CD, SB and LC, respectively). Women in counties YA and WA were Mongolian and Kazak minorities, respectively, and women in the three non-pastoral counties were all of Han origin.

As in the 1983 survey [12], two townships from each county and then two villages from each township were selected randomly as the survey sites. Using the available population records of the township administration offices, women aged 35–75 years were selected in each county, with equal distribution of subjects among four age groups (35–44, 45–54, 55–64 and 65–75 years) and four villages in each county. Within each village, subjects were selected by a block sampling procedure. All women in the block, aged 35–75, were invited to participate in the survey until enough subjects were obtained in each age group. A general physical examination was conducted initially by local medical personnel in the public health clinic to recruit subjects. Women with diseases known to be related to calcium metabolism were excluded from the survey.

Table 1 presents the relevant characteristics of these subjects, among whom 472 were postmenopausal and had received no hormone therapy. The use of contraceptive pills was reported by 17 survey subjects. A total of 27 women in the entire study (3.2%) reported histories of bone fractures caused by minor trauma, including 20 wrist, 2 hip, 1 rib, 3 pelvis and 1 olecranon. None of the subjects reported diseases or long histories of taking medication related to bone status. The selection procedures for human subjects was approved by the Human Subject Committee of Cornell University and the Chinese Academy of Preventive Medicine.

Anthropometric Measurements

Anthropometric measurements, including body weight, height and blood pressure, were carried out according to standard clinical procedures. Weight was measured with a spring scale for each woman in typical indoor clothing without shoes, and height was measured with a

Table 1. Selected lifestyle characteristics of 857 rural Chinese women aged 35–75 years

Variables	Premenopausal		Postmenopausal	
	n	Mean±SD	n	Mean±SD
Age (yr)	380	42.3 ±6.7	477	59.7 ±7.8
Weight (kg)	364	52.7 ±8.7	477	48.6 ±8.7
Height (cm)	364	154.5 ±5.9	477	150.4 ±6.1
BMI (kg/m^2)[a]	364	22.0 ±3.2	477	21.4 ±3.4
Age at menarche (yr)[b]	306	16.5 ±1.8 (17)	477	16.7 ±1.9 (17)
Age at menopause (yr)[b]	–	–	477	46.5 ±4.3 (47)
Years past menopause (yr)[b]	–	–	477	13.2 ±8.6 (13)
Parity (total births)[b]	306	5 ±2 (5)	477	7 ±3 (7)
Lactation				
Total (months)	305	86.9 ±48.0	477	129.2 ±72.1
Average (months/child)	305	18.6 ±9.3	477	19.8 ±11.4
Smoking (cigarette/day)[c]	41	10.8 ±7.2	118	10.7 ±7.3
Cotinine				
Plasma (mmol/l)	285	0.11±0.31	432	0.21±0.46
Urinary (mmol/12 h)	289	0.73±1.93	444	1.35±3.03
Alcohol consumption (g/day)	17	11.7 ±13.4	31	20.9 ±26.8
Dietary calcium (mg/day)	302	445 ±296	470	365 ±214

[a] Body mass index (weight/height^2).
[b] Numbers in parentheses are the median values.
[c] Cigarette equivalents in which tobacco consumption was converted to cigarette by attributing 1 g of tobacco to one commercial cigarette.

standard measuring device. All devices were calibrated prior to the survey.

Bone Mass Measurement

Bone mass was measured by a single-photon absorptiometer (SPA) with an ^{125}I source (Model 2780; Norland Fort Atkinson, WI) at both the distal and mid radius of the non-dominant arm. The mid radius, consisting of primary cortical bone, was set at one-third the distance from the distal radius styloid process to the olecranon. The distal radius containing >50% of trabecular bone was measured at the 5-mm gap site between the radius and ulna as identified by densitometer scanning [13]. The results were reported as bone mineral content (BMC, g/cm) and bone mineral density (BMD, g/cm^2, the ratio of BMC and bone width). At the beginning and end of each working day, SPA measurements of the radius were calibrated using a standard bone phantom provided by the manufacturer. Both precision and accuracy were assessed. For the precision test, a less than 2% coefficient of variation for nine repeated scans of the phantom was obtained; and for the accuracy test, the difference between the authentic value and the measured value of the phantom was less than 1%.

Lifestyle Information

A questionnaire was administered to each subject by a member of the health team to obtain lifestyle information, including reproductive characteristics, alcohol consumption, cigarette smoking, physical activity, use of medication, frequency of food consumption and history of bone fractures. Because a block sampling design was used to select subjects there were many more potential subjects in the younger age group than in the older age groups. Due to cost and time constraint, bone density was measured for all women in the sample but the questionnaire was administered only to those women who participated in the dietary survey, which excluded lifestyle variables for some women in the younger age groups.

Questions concerning reproductive history included age at menarche, age at menopause, birth control practices, parity, and length of breastfeeding for each child. Duration of breastfeeding was expressed in months, both as months per child and as total number of months for all children.

To control the variation in type of alcohol, amounts of all alcoholic beverages consumed by each subject were converted into alcohol intakes according to the alcohol content of each kind of beverage listed in the Chinese Food Composition Table [14].

Each woman was also asked whether she currently was or used to be a smoker. Further questions were asked for women who ever smoked, including the type and amount of tobacco used per week, and the ages at which she started and stopped smoking. In order to standardize the amount of exposure to tobacco smoking, tobacco consumption was converted and expressed as cigarette equivalents by attributing 1 g of tobacco equivalent to one commercial cigarette.

Information about daily physical activity was obtained by asking each woman the average time spent working outdoors in the fields, resting in bed, and walking both indoors and outdoors. In order to evaluate daily activity levels, the women were also interviewed by members of county survey teams to answer questions related to type of occupation and intensity of daily work. On the basis of this information, each woman was then assigned to an activity group by using the criteria of five levels of physical activity defined in the Chinese RDA [15]. The physical activity levels used in this study included very light (sedentary work: office work, radio assembly and repair), light (primarily standing with some walking: sales person at counter, teacher, laboratory work), medium (very active occupation: household work, milking, electrician, metal worker), heavy (heavy labor: non-mechanical farm work, steel worker, dancer, sportsperson) and very heavy (very heavy labor: non-mechanical loading, lumbering, mining). During the data analysis it was found that only one female subject undertook very heavy work, while a few elderly females belonged to the group of very light physical work. Thus, only three groups of physical activity (light, medium and heavy) were included in the following analyses.

Estimation of Dietary Calcium

Dietary intakes were estimated as previously described [10]. Foods consumed by each subject were weighed directly by trained members of the county survey team over a period of 3 days. Consumption of simple foods, such as cheese, cake, bread and pickled vegetables, was directly weighed and recorded at each meal. The differences in food weight before and after each meal were calculated as the amount of food consumed by the subject. To estimate the components of prepared mixed dishes, the raw ingredients were first weighed before cooking to obtain the 'recipe'. After cooking, the whole ready-to-eat dish was measured using a scoop or other small utensil as the measuring unit, which subsequently was used to measure the amount of the dish consumed by the subject. Intakes of the raw ingredients by the subject from the mixed dish were then calculated proportionallly. Calcium intakes of subjects were calculated using the recently revised Chinese Food Composition Table [14].

Plasma and Urinary Cotinine

Fasting blood samples were drawn from the antecubital vein in the early morning and were centrifuged to separate plasma, which was then frozen at −70 °C for analysis of cotinine and other variables.

As part of the survey, each subject was also asked to collect an overnight (12-h) urine sample in an acid-washed polyethylene container. After the total volume of the urine sample had been measured and recorded, an aliquot (50 ml) of the sample was frozen for cotinine analysis.

Plasma and urinary cotinine levels were measured using a Coti-Traq Test kit (Serex Inc., Maywood, NJ).

Statistical Analyses

Bone density at the distal and mid radius of the forearm was measured for all 843 women, among whom 775 completed the dietary survey and were asked to complete the questionnaire addressing lifestyle characteristics. Only those subjects with both bone measurements and complete questionnaire information were included in the following regression analyses. The female subjects were grouped into pre- and postmenopausal women according to their menopausal status, and were analyzed separately in the following correlation analyses.

The data were analyzed using the Statistical Analysis System (SAS Institute, Cary, NC) software package. Descriptive statistics including means and standard deviations were calculated for each variable of interest. The least square means option was used to analyze differences in bone density and related variables between smokers and non-smokers after adjusting for age and body weight. A similar procedure also was used to compare the bone density of female subjects by their levels of physical activity.

In this female sample, bone mass was strongly correlated with age ($r=-0.66$ to -0.74, $p<0.0001$) and body weight ($r=0.30$–0.40, $p<0.0001$). Thus, multivariate regression analyses adjusting for age and body weight were performed to assess the independent effect of lifestyle variables on bone density. Several models, which included age, body weight, dietary calcium and location (county), were initially specified to evaluate the effects of various lifestyle characteristics on bone health. Although dietary calcium intake was an important dietary factor related to bone mass [10], it did not significantly affect the results of the regression analyses of the lifestyle variables included in this report. Adjusting for differences in residence location also did not contribute much towards explaining the total variance of bone mass and did not affect the overall effects observed for the selected lifestyle characteristics of interest. Therefore, only those models including age and body weight as control variables are reported in the results presented here.

Results

Age-Related Changes in Bone Density

Means and percentage differences in bone density by age groups are presented in Table 2. Bone mass is seen to decrease, though at different rates, at both the distal and mid radius after the 35–39 year age group of premenopausal women. Bone mass declined very significantly with age with an overall slope of −5.8 mg/cm^2 per year for distal BMD and −8.4 mg/cm^2 per year for mid-radial BMD for this female sample. Bone decline then accelerated after menopause (i.e. 46 years), reaching the peak of bone changes in the 50–54 and 55–59 year age groups (Table 2). When the women

Table 2. Means and percentage differences of radial BMC and BMD for 828 Chinese women by age groups

Age (yr)	No. of subjects	Distal radius				Mid radius			
		BMC (g/cm)		BMD (g/cm²)		BMC (g/cm)		BMD (g/cm²)	
		Mean±SD	%[a]	Mean±SD	%[a]	Mean±SD	%[a]	Mean±SD	%[a]
35–39	142	1.049±0.154	–	0.419±0.060	–	0.918±0.109	–	0.780±0.072	–
40–44	113	1.020±0.202	2.8	0.402±0.069	4.1	0.888±0.119	3.3	0.747±0.076	4.2
45–49	102	0.961±0.202	5.8	0.382±0.069	5.0	0.871±0.134	1.9	0.728±0.080	2.5
50–54	123	0.813±0.208	15.4	0.321±0.074	16.0	0.809±0.142	7.1	0.676±0.111	7.1
55–59	105	0.717±0.191	11.8	0.286±0.065	10.9	0.733±0.122	9.4	0.614±0.089	9.2
60–64	100	0.668±0.194	6.8	0.264±0.065	7.7	0.683±0.138	6.8	0.565±0.092	8.0
65–69	78	0.631±0.193	5.5	0.254±0.069	3.8	0.635±0.111	7.0	0.531±0.091	6.0
70–75	65	0.587±0.162	7.0	0.233±0.047	8.3	0.597±0.099	6.0	0.498±0.071	6.2

[a] Percentage differences in bone density compared with the previous age group.

Table 3. Partial regression coefficients for bone mineral content (BMC) and bone mineral density (BMD) in pre- and postmenopausal women adjusting for age and body weight: reproductive variables

	Distal radius		Mid radius	
	BMC (mg/cm)	BMD (mg/cm²)	BMC (mg/cm)	BMD (mg/cm²)
Premenopausal women (n=305)				
Menarche age (yr)	−8.539	−4.400	−2.039	0.135
Pregnancy (times)	1.300	−1.588	4.649	0.137
Lactation				
Total (months)	0.798***	0.141	0.559***	0.131
Ave. (months/child)	4.177***	1.450***	3.067***	0.489
Postmenopausal women (n=477)				
Menarche age (yr)	6.730	2.456	3.844	4.542*
Age at menopause (yr)	−1.144	−0.170	1.747	2.115
Years past menopause (yr)	1.141	0.170	−1.747	−2.115
Pregnancy (times)	−4.720	−1.597	−1.861	−1.200
Lactation				
Total (months)	0.173	0.022	0.029	−0.110
Ave. (months/child)	2.313**	0.503*	0.866	−0.181

*p<0.05; **p<0.01; ***p<0.0001.

were divided into premenopausal, early postmenopausal (<10 years postmenopause) and late postmenopausal (>10 years postmenopause) groups, an increased bone decline at the distal and mid radius was also found in early menopausal women (1.06% and 0.80% per year, respectively) as compared with late postmenopausal women (0.73% and 0.66% per year, respectively) and postmenopausal women (0.71% and 0.57% per year, respectively). These results imply the possible involvement of postmenopausal estrogen depletion on bone loss in addition to a simple effect of age in early postmenopausal women.

Reproductive Histories

Table 3 shows the partial regression coefficients for bone mass with the reproductive variables measured in pre- and postmenopausal women. After adjusting for age and body weight in the model, age at menarche, age at menopause and times of pregnancy were not significantly correlated with bone mass though age at menarche was marginally significant for BMD at the mid radius in postmenopausal women. Although age at menopause was not significantly related to bone mass after adjusting for age, analyses based on these cross-sectional study data showed that women at early postmenopausal ages (<10 years postmenopause) exhibited a steeper slope than late postmenopausal women (>10 years postmenopause) (data not show). These results thus suggest that postmenopausal bone loss was primarily manifested in the early postmenopausal years (i.e. 50–54 and 55–59 year age groups; Table 2).

Breastfeeding time, expressed as months per child, was correlated significantly and positively with bone density in both pre- and postmenopausal women,

Table 4. Partial regression coefficients for bone mineral content (BMC) and bone mineral density (BMD) in pre- and postmenopausal women adjusting for age and body weight: cigarette smoking (n=159) and alcohol consumption (n=48)

	Distal radius		Mid radius	
	BMC (mg/cm)	BMD (mg/cm^2)	BMC (mg/cm)	BMD (mg/cm^2)
Premenopausal women				
Smoking (packs/wk)	43.880**	12.774**	17.190*	12.593*
Duration of smoking (yr)	8.507	2.992*	2.377	0.074
Plasma cotinine (mmol/l)	0.823***	0.256**	0.375**	0.213*
Urinary cotinine (mmol/12 h)	0.154***	0.052***	0.071***	0.046***
Amount of alcohol (g/wk)	0.178	0.079	0.155	−0.025
Duration of alcohol (yr)	7.821	3.254	2.321	0.823
Postmenopausal women				
Smoking (packs/wk)	11.882	2.976	6.665	1.134
Duration of smoking (yr)	1.998	0.635	0.833	0.602
Plasma cotinine (mmol/l)	0.077	0.033	0.053	−0.048
Urinary cotinine (mmol/12 h)	0.013	0.004	0.012	−0.005
Amount of alcohol (g/wk)	0.031	−0.037	−0.065	−0.087
Duration of alcohol (yr)	−2.159	−0.399	0.263	0.504

*$p<0.05$; **$p<0.01$; ***$p<0.0001$.

predominantly at the distal radius (Table 3). Total lactation time (duration of breastfeeding for all children), however, was related significantly only to BMC in premenopausal women.

A small interaction between breastfeeding and calcium intake in relation to bone mass was found in this female sample as seen by a higher correlation between bone density and breastfeeding in women with high calcium intake (>600 mg/day, b=0.17, p=0.03) than in women with low calcium intake (<600 mg/day, b=0.04, p=0.23) (data not shown). However, this interaction was so small that it was not significant when female subjects were divided into pre- and postmenopausal groups. Adjusting for dietary calcium in the regression analysis for pre- and postmenopausal women also did not alter significantly the observed trend in the relationship.

Cigarette and Alcohol Consumption

Of 775 women examined, a total of 159 reported a history of cigarette smoking, and 48 women drank alcoholic beverages on a regular basis. They were usually light smokers or drinkers although virtually all males in the households were heavy smokers. Most of these women only smoked cigarettes socially while drinking tea and talking with others. Table 4 presents the partial correlation coefficients between cigarette smoking, alcohol consumption and bone mass.

In postmenopausal women, both current patterns of cigarette and alcohol use were not significantly related to bone mass at either the distal or mid radius; neither were the cotinine levels measured in the urine and plasma. In premenopausal women, in contrast, cigarette consumption was associated significantly and positively with bone mass. Plasma and urinary cotinine levels were also correlated positively with bone mass in these premenopausal women ($p<0.0001$), even though most of the women were non-smokers or light smokers. These associations remained significant when other factors, known to be related to bone mass, were controlled both separately or simultaneously, including age, body weight, dietary calcium, lactation, physical activity and residential location (data not shown).

Table 5 compares the adjusted means of bone variables as well as other indicators between smokers and non-smokers in pre- and postmenopausal women. There were no significant differences in body weight, height, BMI, age at menarche and age at menopause between smokers and non-smokers in both pre- and postmenopausal women. As expected, women who smoked had much higher levels of plasma and urinary cotinine than those who did not smoke in both pre- and postmenopausal groups. Consistent with the results of the regression analyses, female smokers had higher bone mass than non-smokers in the premenopausal group even though smokers were about 2 years older than non-smokers. However, these differences were not significant in postmenopausal women.

Daily Physical Activity

Daily activity levels in women were evaluated on the basis of the hours spent walking (indoors and outdoors), resting in bed, and working in the fields per day. Bone mass was correlated positively with amount of time spent working in the fields in both groups (Table 6). Relationships between bone density and hours spent walking (both indoors and outdoors) and resting in bed

Table 5. Comparison of selected lifestyle characteristics and adjusted mean bone density between non-smokers and smokers among 819 rural Chinese women (mean±SD)

Variables	Premenopausal women		Postmenopausal women	
	Non-smokers (n=326)	Smokers (n=41)	Non-smokers (n=355)	Smokers (n=117)
Age (yr)	41.1 ±6.8	44.0 ±5.8*	59.1 ±7.8	61.7 ±7.3*
Weight (kg)	52.7 ±8.8	53.0 ±8.6	49.0 ±8.7	47.4 ±8.7
Height (cm)	154.6 ±5.9	153.9 ±5.2	150.5 ±6.1	150.0 ±6.0
BMI (kg/m^2)	22.0 ±3.2	22.4 ±3.4	21.6 ±3.4	21.0 ±3.4
Age at menarche (yr)[a]	16.6 ±1.8 (17)	16.4 ±1.6 (16)	16.7 ±1.9 (17)	16.6 ±1.8 (17)
Age at menopause (yr)[a]	–	–	46.6 ±4.4 (47)	46.5 ±3.8 (47)
Cotinine				
Plasma (mmol/l)	0.05 ±0.19	0.50 ±0.52**	0.07 ±0.30	0.61 ±0.60**
Urinary (mmol/12 h)	0.32 ±1.19	3.37 ±3.26**	0.54 ±2.23	3.83 ±3.77**
Distal radius[b]				
BMC (g/cm)	0.863±0.014	1.012±0.030**	0.794±0.012	0.822±0.019
BMD (g/cm^2)	0.348±0.005	0.400±0.010**	0.314±0.004	0.316±0.007
Mid radius[b]				
BMC (g/cm)	0.787±0.009	0.875±0.020**	0.779±0.008	0.787±0.013
BMD (g/cm^2)	0.666±0.006	0.720±0.014**	0.658±0.005	0.638±0.009

[a] Numbers in parentheses are the median values.
[b] Least square means adjusting for age.
*p<0.05, **p<0.001 compared with non-smokers.

Table 6. Partial regression coefficients for bone mineral content (BMC) and bone mineral density (BMD) and daily activity in pre- and postmenopausal women adjusting for age and weight: daily physical activity

	Distal radius		Mid radius	
	BMC (mg/cm)	BMD (mg/cm^2)	BMC (mg/cm)	BMD (mg/cm^2)
Premenopausal women (n=364)				
Walking time (h/day)	3.607	1.871	2.943	0.850
Resting time (h/day)	−10.073	−3.853	−6.705	−2.700
Time working outside (h/day)	17.164***	5.576***	12.784***	4.383**
Postmenopausal women (n=477)				
Walking time (h/day)	1.960	0.888	3.003*	1.198
Resting time (h/day)	−4.927	−0.484	−1.100	2.799
Time working outside (h/day)	14.670***	4.448***	8.442***	3.354

*p<0.05; **p<0.01; ***p<0.0001.

per day were very weak and were no longer significant after age and body weight were adjusted for.

Table 7 presents the adjusted mean radial bone density of females by different levels of physical activity. Women undertaking medium physical activity tended to have higher BMC at the distal and mid radius than women undertaking light physical activity, but these differences were not statistically different after age and body weight were adjusted for. However, a significantly higher bone mass was found in women undertaking heavy labor work than women undertaking light and medium labor, suggesting that heavy labor may promote accretion of bone mass in these women.

No significant interaction between calcium consumption and daily physical activity was observed in these cross-sectional data. Stratifying the sample by calcium intakes or including dietary calcium in the regression model did not alter the results obtained in the analysis of physical activity levels (data not shown).

Discussion

Bone loss with age occurs universally in both genders, at an accelerated rate in women after menopause. Overall, pre- and postmenopausal women from Western countries usually lose their bone mass at a rate of about 7%–10% per decade [16]. Results from this study, in spite of its cross-sectional nature, also indicated a lower bone mass with each decade in Chinese women, especially for postmenopausal ages (Table 2). The percentage differences in bone density were much

Table 7. Adjusted mean radial bone density of Chinese women undertaking light, medium and heavy levels of physical activity[a]

	Physical activity level		
	Light (n=35)	Medium (n=473)	Heavy (n=241)
Distal radius			
BMC (g/cm)	0.775±0.033***	0.791±0.009***	0.917±0.013
BMD (g/cm^2)	0.327±0.012*	0.317±0.003***	0.355±0.005
Mid radius			
BMC (g/cm)	0.747±0.021**	0.766±0.006***	0.828±0.008
BMD (g/cm^2)	0.658±0.016	0.651±0.004*	0.669±0.006

[a] Least square means (SEM) adjusting for age and body weight for all pre- and postmenopausal women combined.
Statistically significant compared with the heavy physical activity group: *$p<0.05$; **$p<0.01$; ***$p<0.0001$.

greater in the two age groups following menopause (50–54 and 55–59 years), implicating the importance of menopause in bone changes in these Chinese women. Interestingly, the percentage differences in BMC and BMD in these two age groups were much larger at the distal radius (10.9%–16.0%) than at the mid radius (7.1%–9.4%). These results suggest that bone mass at the distal radius, which consists of a greater proportion of trabecular bone, may be more responsive to estrogen loss after menopause.

There is some controversy regarding the effects of pregnancy and lactation on bone mass in women. On the one hand, increased parity and lactation histories have been reported to be associated with higher bone mass and reduced risk of osteoporotic fractures [3,17,18]. On the other hand, no significant association between bone density or osteoporotic fracture and these two reproductive characteristics has also been reported [19,20]. Lissner et al. [21], in contrast, found a deleterious effect of lactation and parity in 126 pre- and postmenopausal Swedish women. Results of the present study lend support for a protective role of lactation, but not parity, on bone health. Lactation, as expressed in months per child, was positively related to radial bone mass (Table 3), with more significant effects on bone density at the distal radius, especially in premenopausal women. All women in this sample were typical of the rural Chinese, and usually breastfed for long periods due to usual rural practice and the lack of supply of infant formula and baby foods. More importantly, calcium intakes in these subjects were relatively low, with average intakes being only about 50% of the Chinese RDA (800 mg/day) (Table 1). In county LC, one of the non-pastoral counties with no milk or dairy food consumption, average calcium intake was only 230 mg/day [10]. It is usually assumed that calcium status during lactation and pregnancy is an important determinant of bone mass. Low calcium intakes combined with high calcium requirements during pregnancy and lactation may exacerbate the bone loss. Results of this study, however, do not support this conclusion. A positive correlation between breastfeeding and bone mass was consistently present in those women who had very low dietary calcium intakes in their lifetime. No significant interaction was found between dietary calcium and breastfeeding in relation to bone mass in these female subjects.

In addition to these reproductive variables, possible influence of other lifestyle features were also examined in this cross-sectional study. Cigarette usage and alcohol intakes were not significantly associated with bone density in postmenopausal women after adjusting for age and weight (Tables 4, 5), consistent with some reported findings [22,23] but not with others [24–26] where female cigarette smokers or alcohol drinkers typically were found to have lower bone density. In this study, in contrast, a positive association was unexpectedly detected between bone density and cigarette consumption for premenopausal women, including amount and duration of cigarette smoking (Table 4). Similarly, levels of cotinine measured in the urine and plasma were also correlated positively with bone density in premenopausal women (Table 4). Further evidence was obtained when bone mass was compared between cigarette smokers and non-smokers in the premenopausal group (Table 5). Women who were current smokers tended to have a significantly higher radial bone mass than women who never smoked. These results are inconsistent with those reported by others [24–26] and are not easily interpreted, but it is possible to speculate that some important factors related to cigarette smoking may account for these associations. From the results presented here and in a previous paper [10], it is known that several factors were significantly associated with bone mass in this female sample, including age, body weight, body mass index (BMI), dietary calcium, physical activity and lactation. However, the associations between bone mass and smoking status (cigarette usage, urinary and plasma cotinine) in premenopausal women were still significant even after the possible confounding effects of age, body weight, dietary calcium, physical activity, lactation and location (county) were controlled. Differences in economic status and ethnicity among counties do not account for this positive association because adjusting for county of residence in the regression models failed to alter the results obtained. Because this association was noted only in premenopausal women not in postmenopausal women, alteration in sex hormone status may be one of the factors implicated in the explanation. In $3\frac{1}{2}$ years of clinical observation, higher serum estrogens and androgens have been detected in female light smokers (<20 pack-years) than in non-smokers and heavy smokers (>20 pack-years) [27]. A relatively high bone mass at the distal and mid radius also was found in light smokers (0.96 and 0.91 g/cm, respectively) as compared with non-smokers (0.91 and 0.84 g/cm, respectively) and heavy smokers (0.83 and 0.76 g/cm, respectively), though these differences were not statistically significant, probably due to the small sample size (n=8). Felson et al. [28] also reported a protective effect of cigarette smoking against the development of knee osteoarthritis in HANES I and the Framingham Osteoarthritis Study. It should also be emphasized that these results are based on a cross-sectional study and as such the effects of other unknown factors associated with cigarette smoking in these female subjects can not be excluded.

It is also noteworthy that, in those reports in which a detrimental effect of cigarette smoking on bone mass was reported, smokers usually tended to be thinner than non-smokers [8,29], or had an earlier menopause [24,30], or were simultaneously heavy drinkers. For women selected in this study, however, neither body size as indicated by body weight, height and BMI, nor age at menopause and menarche, were significantly different between smokers and non-smokers (Table 5). This may partially explain why no adverse effects of cigarette smoking on bone mass were found in these light smokers.

Habitual physical activity has been implicated as an important determinant of bone mass and the development of osteoporosis. However, the impact of moderate physical activity on bone mass is still to be definitively established. Nelson et al. [31] reported a positive association between bone mass in the distal femur and time spent standing and working in a sample of 30 Caucasian women. Stillman et al. [32] observed a significantly higher bone mineral content in women who maintained an active lifestyle than women who were less active. Kriska et al. [33] found that estimates of historical physical activity were significantly correlated with bone area and bone density in postmenopausal women. In a case–control study in Hong Kong, Lau et al. [34] noted a higher risk of hip fracture in males and females undertaking less daily activity as estimated by time spent walking outdoors, upstairs, uphill, or with a load. As compared with weight-bearing activity, sedentary occupations in middle life were found to increase the risk of femur fracture in older ages [35]. Consistent with these reports, a positive association between regular daily activity and bone mass was observed in this analysis of Chinese pre- and postmenopausal women. This effect was primarily noticed for outdoor labor (time spent working in the fields). Weight-bearing exercise (hours per day spent walking), however, was not a significant factor when age and body weight were adjusted for. In order to examine the effect of labor intensity on bone mass, the women were categorized into different physical activity groups on the basis of the type of daily activity by using the criteria defined in the Chinese RDA [15]. Interestingly, those undertaking a heavy labor had increased bone mass at the distal and mid radius as compared with those doing light and medium work. However, no significant differences in bone mass were detected between the light and medium labor groups. Consistent results were also reported by Lacey et al. [36] in pre- and postmenopausal Japanese women. They observed only slightly higher bone density in women with a high activity level than in women with low and medium activity levels. Results of this study and others thus suggest that physical activity may be an effective means of maintaining a higher bone mass and thus preventing the development of osteoporosis in pre- and postmenopausal women. However, it is not possible to assess from these cross-sectional data whether the higher bone mass was achieved during early maturity, i.e. during the building of peak bone mass, or by the maintenance of bone mass thereafter, or by both mechanisms.

The stronger effect of heavy outdoor labor (i.e. time spent working in the field) than walking (both indoors and outdoors) on bone mass observed in this study could also implicate a possible role for sunlight. It has been well documented that vitamin D status declines with age, as indicated by the low circulating 25(OH)D levels in the elderly and possibly most osteoporotics, resulting in inefficient absorption of dietary calcium and failure to adapt to low calcium intakes. Hence, the longer exposure to sunlight may be one contributory factor in the higher bone mass of those women who regularly worked in the fields, rendering them able to respond adequately to low calcium intake. However, detailed consideration of this issue awaits the measurement of plasma levels of vitamin D and its metabolites.

In summary, data obtained in this cross-sectional study of pre- and postmenopausal Chinese women indicated that, in addition to dietary calcium, several lifestyle features were related closely to bone mass measured at the distal and mid radius, including lactation and daily physical activity. The results presented here thus suggest that regular daily physical activity may be necessary for maintaining maximal bone mass and preventing the development of osteoporosis in later life. Menopausal status was shown to play a prominent role in bone loss primarily in early postmenopausal women (<10 years menopause), and the effect was greater at the distal radius than at the mid radius. A surprising result obtained in this study was the positive effect of cigarette smoking status and bone mass in premenopausal women. This finding should by no means encourage women to smoke cigarettes, but it may suggest that their response to light cigarette smoking or passive smoking differs from that to heavy cigarette smoking in terms of bone mass. Because this was a cross-sectional survey, other unknown factors concomitantly present with cigarette smoking may also contribute to the association observed in premenopausal women.

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