Osteoporos Int (2002) 13:663–668

Osteoporosis International

Original Article

Household Tobacco Smoke Exposure is Negatively Associated with Premenopausal Bone Mass

M. Blum[1], S. S. Harris[1], A. Must[2], S. M. Phillips[2], W. M. Rand[2] and B. Dawson-Hughes[1]

[1]Calcium and Metabolic Bone Laboratory, Jean Mayer United States Department of Agriculture Human Nutrition Research Center on Aging at Tufts University; and [2]Department of Family Medicine and Community Health, Tufts University, Boston, Massachusetts, USA

Abstract. Subjects exposed to environmental tobacco smoke have been found to be at increased risk for several health problems. Whether exposure to passive tobacco smoke is associated with reduced bone mineral density (BMD) is unknown. In order to examine this, we measured BMD in 154 healthy premenopausal women (age range 40–45 years). BMD of the total hip, femoral neck, lumbar spine and total body was measured by dual-energy X-ray absorptiometry (DXA). Data were collected on exposure to household tobacco smoke from age 10 years to the present as well as on other lifestyle factors related to bone mass. We found that 67.5% of the subjects had a history of household tobacco smoke exposure. Subjects exposed to household tobacco smoke had a mean adjusted BMD that was significantly lower at the total hip (p = 0.021) and femoral neck (p = 0.018) compared with subjects who were not exposed. In addition, duration of household tobacco smoke exposure was negatively associated with BMD at the total hip (p = 0.010), femoral neck (p = 0.004), lumbar spine (p = 0.037) and total body (p = 0.031). Subjects exposed to household tobacco smoke for 15 years or more had mean adjusted BMD that was 4% lower at the total body, and more than 8% lower at the total hip, femoral neck and lumbar spine, compared with subjects who were not exposed. In conclusion, household tobacco smoke exposure during adolescence and young adulthood was found to be negatively associated with BMD at the total hip and femoral neck, and duration of exposure was negatively associated with BMD at the total hip, femoral neck, lumbar spine and total body in premenopausal women.

Keywords: Bone mass; Bone mineral density; Household tobacco smoke

Correspondence and offprint requests to: Miriam Blum, MD, Calcium and Bone Metabolism Laboratory, Jean Mayer USDA HNRC at Tufts University, 711 Washington Street, Boston, MA 02111, USA. Tel: +1 (617) 556 3074. Fax: +1 (617) 556 3305. e-mail: mblum@hnrc.tufts.edu

Introduction

Exposure to environmental tobacco smoke has been reported to be a risk factor for several health problems. Subjects exposed to passive tobacco smoke have been found to have an increased risk of lung cancer, asthma, acute respiratory infection and cardiovascular disease [1,2]. There is growing evidence that the effect of passive smoke exposure has a biological basis. Subjects exposed to passive tobacco smoke have measurable increases in biomarkers of tobacco smoke, with increased levels of nicotine and cotinine in serum, urine, hair and saliva [3–10]. In addition, because of differences in combustion temperatures, levels of ammonia, carbon monoxide, nicotine, aromatic amines, nitrosamines and polycyclic aromatic hydrocarbons may actually be higher in sidestream smoke (emitted from the burning tobacco into the air) than in mainstream (inhaled) smoke [11].

Active tobacco smoking has been shown to be associated with reduced bone density and increased risk of fractures in postmenopausal women [12–15], but the literature is less consistent in premenopausal women [12,16–26]. Mechanisms by which tobacco smoke may influence bone mass include local or systemic toxic

effects of nicotine on bone collagen synthesis [27], alterations in the level of circulating estrogens [28] and decreased calcium absorption [29].

Little information is available about the impact of exposure to passive tobacco smoke on bone mass. In the present analysis, we sought to evaluate the association of exposure to household tobacco smoke with bone mineral density of the total hip, femoral neck, lumbar spine and total body in a group of healthy premenopausal women.

Subjects and Methods

Subjects

One hundred and fifty-four healthy premenopausal women participated in this study. The women were all participants in a growth and sexual maturation study conducted 30 years ago [30–32]. The original study recruited 793 9- and 10-year-old girls from local public schools in a New England town (Newton, MA). In 1998–9, we attempted to contact the subjects from the original study to invite them to participate in a follow-up study. Overall, 62% of the participants in the original study responded to our inquiries. Forty-eight percent of the respondents completed screening to determine eligibility for participation in the visit to our center. The present study population consists of women who were eligible for participation and able to come for one visit to our center in Boston, MA. A total of 19 of the women who were screened were excluded from participation based on the following exclusion criteria: natural or surgical menopause (5 subjects), pregnancy or breastfeeding within the previous 4 months (6 subjects), use of oral glucocorticoids for more than 4 consecutive months (2 subjects) and history of a medical condition affecting bone metabolism (6 subjects). The protocol was approved by the Human Investigation Review Committee of Tufts University, and written informed consent was obtained from each participant.

Measurements

Information on exposure to household tobacco smoke, active smoking history, highest level of education completed, marital status, oral contraceptive use, alcohol use, reproductive history and daily walking (both current and during adolescence) were obtained with a questionnaire designed for this study. Subjects were asked how many smokers (excluding themselves) were living in their households for the specific age ranges of 10–17, 18–22, 23–29 years and 30 years to the present. Subjects were considered exposed to household tobacco smoke if they had been exposed during any age range. Duration of exposure to household tobacco smoke (household exposure-years) was computed by adding up the years of household tobacco smoke exposure from each age range. Subjects were asked if they ever smoked cigarettes, and if the answer was yes, to give the average number of cigarettes smoked per day for the specific age ranges of 10–17, 18–22, 23–29 years and 30 years to the present. Total pack-years of active smoking was determined by multiplying the average number of packs smoked per day (20 cigarettes per pack) by the duration (number of years in each age range). Additional information about participants' medical history, family history, medication use, milk consumption (both current and during adolescence) and current use of calcium supplements was obtained in a medical interview. Assessment of current dietary calcium intake was made with the Fred Hutchinson Food Frequency Questionnaire [33] and total calcium intake was calculated by adding together daily dietary calcium intake (mg) and calcium from supplements (mg). Body weight was measured with a conventional digital scale, and height was measured with a stadiometer.

Bone Densitometry

Bone mineral density (BMD) of the hip, lumbar spine (L2–L4) and total body was measured by dual-energy X-ray absorptiometry (DXA; model DPX-L scanner, Lunar Radiation, Madison, WI). The coefficient of variation (CV) of these scans in our laboratory is 2.1 for the femoral neck, 1.0 for the spine and 0.62 for the total body [34]. One spine scan was excluded from analysis due to marked vertebral scoliosis.

Statistical Analysis

Characteristics of the participants are reported as means or proportions. Associations between variables were examined using Pearson correlation coefficients and analysis of covariance (ANCOVA). Preliminary analyses included investigation of potential interactions between active smoking and exposure to household tobacco smoke. Covariates that are known to affect BMD were examined and those that affected the parameter estimates were retained in the final ANCOVA models. Differences between subjects exposed to household tobacco smoke and subjects not exposed to household tobacco smoke were compared by analysis of variance and by chi-square tests. p values of < 0.05 were used to establish significance. All analyses were done in SPSS (version 9.0; Chicago, IL).

Results

The mean age of the 154 subjects was 41.6 ± 0.1(SE) years (range 40–45 years) and 98% of the subjects were white. The subjects had a mean weight of 66.0 ± 1.1 kg and mean body mass index (BMI) of 24.9 ± 0.4 kg/m^2. Overall, 67.5% of the subjects had a history of household tobacco smoke exposure. For subjects exposed to household tobacco smoke, the mean duration of exposure was 15.2 ± 0.8 years (range 5–33 years).

Table 1. Characteristics of subjects exposed to household tobacco smoke compared with subjects who were not exposed

Characteristic	Exposed (n = 104)	Not exposed (n = 50)	p
Age (years)	41.7 ± 0.1	41.5 ± 0.1	0.18
Weight (kg)	66.0 ± 1.4	66.1 ± 2.1	0.99
Height (cm)	162.3 ± 0.6	164.2 ± 0.8	0.06
Daily calcium intake (mg/day)[a]	1042.2 ± 56.0	1250.3 ± 88.9	0.04
Age at menarche (years)[b]	12.9 ± 0.1	13.1 ± 0.2	0.22
Adolescent milk servings[c]			
< 1 cup/day	14.4%	8.0%	0.38
1–2 cups/day	47.1%	44.0%	
2 or more cups/day	38.5%	48.0%	
Adolescent walking[c]			
< 1 mile/day	40.2%	41.7%	0.91
1–2 miles/day	45.1%	45.8%	
3 or more miles/day	14.7%	12.5%	
Ever used oral contraceptives	80.6%	70.0%	0.14
Highest level of education[d]			
Some college	21.2%	10.0%	0.07
College	39.4%	32.0%	
Graduate/professional school	39.4%	58.0%	
Use of steroid inhaler			
Current use	10.6%	2.0%	0.15
Former use	7.7%	6.0%	
Active smoking			
Never	30.4%	74.0%	0.01
⩽10 pack-year history	43.1%	18.0%	
> 10 pack-year history	26.5%	8.0%	

Values given are mean ± SE or percentage.
[a] Daily calcium intake is the sum of current dietary calcium intake and calcium supplements.
[b] Assessed prospectively.
[c] Assessed retrospectively, representing periods of 10–17 years (milk servings) and 14–17 years (walking).
[d] Represents highest level of education completed.

Characteristics of subjects exposed to household tobacco smoke and subjects not exposed are summarized in Table 1. Subjects who were exposed to household tobacco smoke were similar in age, weight, contraceptive use, use of steroid inhaler, adolescent milk intake and adolescent walking to subjects who were not exposed. The two groups also did not differ significantly in current alcohol consumption ($p = 0.92$), current daily walking ($p = 0.99$), regularity of menses ($p = 0.65$) or marital status ($p = 0.66$) (data not shown). Subjects who were exposed to household tobacco smoke tended to be less educated and shorter in height than subjects who were not exposed. In addition, exposed subjects had significantly lower daily calcium intakes. As expected, subjects exposed to household tobacco smoke were more likely to have actively smoked themselves; however, the median total pack-years of active smoking was low in both groups (3.6 in exposed vs 0.0 in not exposed).

BMD of subjects exposed to household tobacco smoke was compared with that of subjects who were not exposed in both unadjusted and adjusted models. Mean unadjusted and adjusted BMD values for these two groups are shown in Table 2. For subjects exposed to household tobacco smoke, mean BMD was significantly lower at the total hip ($p = 0.031$) and femoral neck ($p = 0.032$) compared with subjects who were not exposed. Mean BMD at the lumbar spine and total body did not differ significantly in the two groups. After adjusting for weight, height, active smoking history (never, ⩽10 pack-years, >10 pack-years), highest level of education completed and daily calcium intake, subjects who were exposed to household tobacco smoke were still found to have lower mean adjusted BMD at the total hip ($p = 0.021$) and femoral neck ($p = 0.018$) compared with subjects who were not exposed to household tobacco smoke (Fig. 1). Similar findings, although not significant, were seen at the lumbar spine and total body. Adjusting for other factors that may influence BMD such as walking (both current and during adolescence), adolescent milk intake, oral contraceptive use and regularity of menses did not significantly affect the results. Active smoking as well as height, highest level of education completed and daily

Table 2. Unadjusted and adjusted[a] mean BMD (gm/cm^2) and differences in mean BMD of subjects exposed to household tobacco smoke compared with subjects who were not exposed

BMD site	Exposed (n = 104)	Not exposed (n = 50)	Difference [95% CI]
Total hip			
Unadjusted	1.01 ± 0.01	1.06 ± 0.02	−0.05 [0.005, 0.089]
Adjusted	1.02 ± 0.01	1.07 ± 0.02	−0.05 [0.007, 0.086]
Femoral neck			
Unadjusted	0.97 ± 0.01	1.02 ± 0.02	−0.05 [0.004, 0.093]
Adjusted	0.98 ± 0.01	1.03 ± 0.02	−0.05 [0.009, 0.096]
Lumbar spine			
Unadjusted	1.24 ± 0.01	1.27 ± 0.02	−0.03 [−0.021, 0.072]
Adjusted	1.25 ± 0.01	1.28 ± 0.2	−0.03 [−0.017, 0.082]
Total body			
Unadjusted	1.17 ± 0.01	1.19 ± 0.01	−0.02 [−0.006, 0.041]
Adjusted	1.17 ± 0.01	1.19 ± 0.01	−0.02 [−0.003, 0.043]

Values given are mean ± SE.
[a] Adjusted for active smoking (never, ⩽10 pack-years, >10 pack-years), highest level of education completed, weight, height and daily calcium intake.

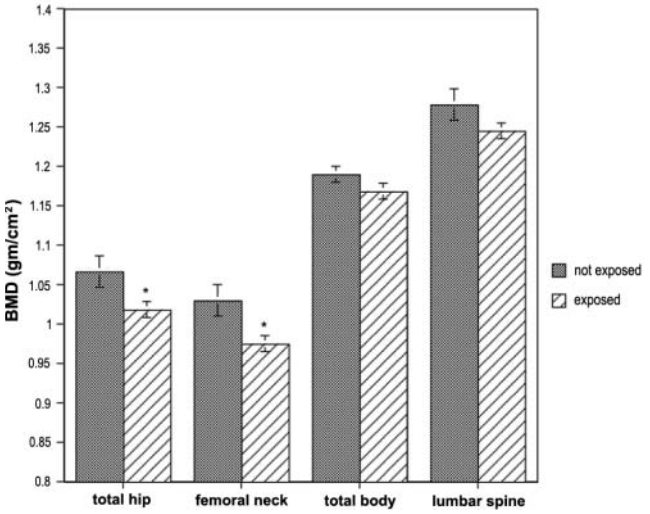

Fig. 1. Mean adjusted BMD for subjects exposed to household tobacco smoke (n = 104) compared with subjects who were not exposed (n = 50) at the total hip (p=0.021), femoral neck (p=0.018), lumbar spine (NS) and total body (NS). BMD is adjusted for weight, height, active smoking (never, $\leqslant$10 pack-years, >10 pack-years), highest level of education completed and daily calcium intake. *Significantly differs from not exposed (p<0.05).

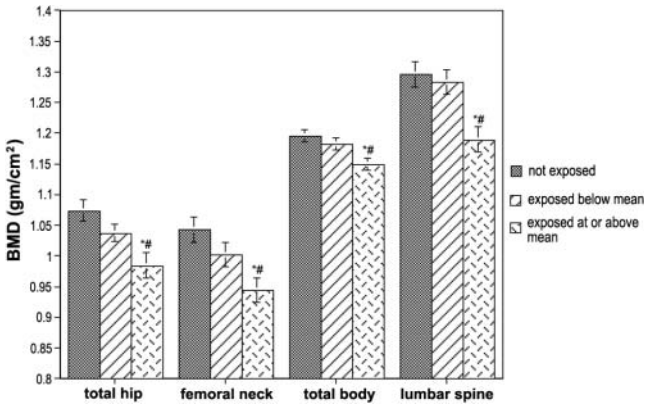

Fig. 2. Mean adjusted BMD for subjects who were not exposed to household tobacco smoke (n = 50), subjects who were exposed to household tobacco smoke with household exposure-years below the mean (15.2 years) of exposure (n = 71), and subjects with household exposure-years at or above the mean (n = 33). Mean BMD at the total hip (p=0.008), femoral neck (p=0.008), lumbar spine (p=0.007) and total body (p=0.015) is adjusted for weight, height, active smoking (never, $\leqslant$10 pack-years, >10 pack-years), highest level of education completed and daily calcium intake. *Significantly differs from not exposed (p<0.05). #Significantly differs from exposed below mean (p<0.05).

calcium intake were not found to be significantly associated with BMD at any site, but weight was significantly associated with BMD at all measured sites.

To evaluate whether the duration of exposure was associated with BMD, we determined the total number of years of household tobacco smoke exposure (household exposure-years) from age 10 years to the present. After adjusting for weight, height, active smoking status (never, $\leqslant$10 pack-years, >10 pack-years), highest level of education completed and daily calcium intake, household exposure-years was negatively associated with BMD at the total hip ($p = 0.010$), femoral neck ($p = 0.004$), lumbar spine ($p = 0.037$) and total body ($p = 0.031$). This association is illustrated in Fig. 2. As shown, BMD at the total hip ($p = 0.008$), femoral neck ($p = 0.008$), lumbar spine ($p = 0.007$) and total body ($p = 0.015$) decreased as household exposure-years increased.

To further examine the possible confounding effect of active smoking, we evaluated the association of household tobacco smoke exposure and BMD in a subset analysis of subjects who never actively smoked. Of the 68 never smokers, 31 were exposed to household tobacco smoke. Mean adjusted BMD was 1–2% lower at each measured site in subjects exposed to household tobacco smoke compared with those who were not exposed (not significant). For the 31 never smokers who were exposed to household tobacco smoke, mean household exposure-years was 12.3 $\pm$ 6.3 (SD).

In our study population as a whole, exposure to household tobacco smoke was more common at younger ages. Eighty-nine of the subjects were exposed to household tobacco smoke from age 10 to 17 years. Of those exposed to household tobacco smoke before age 18 years, 66.3% had additional exposure to household tobacco smoke at some time after age 18 years. Only 9.7% of the subjects were exposed to household tobacco smoke exclusively after age 18 years. In analyzing the age ranges of exposure to household tobacco smoke together and individually, we were not able to determine at which age range household tobacco smoke exposure had the greatest impact on BMD. We additionally examined active smoking at different age ranges. Fifty-five of the subjects reported active smoking from age 10 to 17 years and the median pack-year history from age 10 to 17 years for those who smoked during this age range was 1.1 pack-years. Of those who actively smoked prior to age 18 years, 96.3% additionally reported active smoking at some time after age 18 years, while 18.8% of the subjects actively smoked exclusively after age 18 years. The median pack-year history from age 18 years onwards for those who smoked after age 18 years was 5.0 pack-years. We did not find active smoking at any age range to be associated with current BMD. Furthermore, controlling for active smoking at different age ranges in the models did not appreciably change the association of exposure to household tobacco smoke with BMD.

Discussion

This study indicates that exposure to household tobacco smoke during adolescence and young adulthood may be a risk factor for reduced BMD in premenopausal women, and that the duration of exposure is important. Indeed, we found that duration of household tobacco smoke exposure was negatively associated with BMD at all measured sites. For subjects exposed to household tobacco smoke for 15 years or more, BMD was 4%

lower at the total body and more than 8% lower at the total hip, femoral neck and lumbar spine compared with subjects who were not exposed.

To the best of our knowledge, there are no other reports of an association of exposure to household tobacco smoke during adolescence and young adulthood with adult BMD. Two studies have found passive smoke exposure in utero to be negatively associated with BMD in children at age 8 years [35] and in women at age 45–49 years [36]. Jones et al. [35] also examined the association between passive tobacco smoke exposure in childhood and bone mass at age 8 years. These investigators did not find current smoking status in the mothers of 8-year-old children to be significantly associated with their children's BMD, perhaps because the duration of passive tobacco smoke exposure in these children was limited to a maximum of 8 years. In contrast, the duration of household tobacco smoke exposure in our study was potentially more substantial and may thus reflect a larger cumulative effect on BMD. In addition, since most of the subjects in our study were exposed to household tobacco smoke 20–30 years ago, perhaps the conditions of household tobacco smoke exposure have changed over the past three decades due to increased public awareness of the negative impact of smoking on health. Furthermore, the skeleton may not be as sensitive to tobacco exposure before puberty as it is later on during pubertal growth, consolidation and achievement of peak bone mass. In our study, 57.8% of the subjects were exposed to household tobacco smoke during the critical period of adolescence.

Since subjects with passive smoke exposure in the household may differ in other lifestyle factors from subjects in households without smokers, it is possible that exposure to household tobacco smoke could be a marker for factors which themselves are detrimental to bone mass. For example, in our study, subjects exposed to household tobacco smoke were more likely to have a history of active smoking than subjects who were not exposed. In young adult women, the association of active smoking and BMD has been examined with mixed results [12,16–26]. The inconsistent findings may be related to differences in the amount and/or duration or timing of smoking among the subjects. Studies that report a negative association of active smoking and BMD in premenopausal women have predominantly demonstrated this in subjects who had more than a 10 pack-year history of smoking [19,21,23,24]; in more moderate smokers, the association was generally not observed [19,20,23,24,26]. In our study population, while there was a significant association between exposure to household tobacco smoke and BMD, we did not find a significant association between active smoking and BMD. This may be due to the fact that subjects who smoked had relatively low pack-year histories, or due to the timing of active smoking. Although 35.8% of the subjects actively smoked from age 10–17 years, the reported amount of active smoking before age 18 years was relatively low. Adjusting for active smoking in the model did not appreciably alter estimates of the association between household tobacco smoke exposure and BMD.

We attempted to isolate the potential effect of household tobacco smoke exposure on BMD by examining a subset of women who never actively smoked. Compared with the group as a whole, this subset analysis suggested a similar pattern but a reduction in the magnitude of the effect. It is difficult to draw conclusions from this analysis, however, because the sample size was quite limited and the duration of household tobacco smoke exposure was somewhat shorter than that of the group as a whole.

With regard to other lifestyle factors, subjects exposed to household tobacco smoke tended to be less educated than subjects who were not exposed. Since education may be an indicator of socioeconomic status, and factors that influence bone mineral accretion may be affected by socioeconomic status, we controlled for education in our analyses. Subjects exposed to household tobacco smoke also had lower calcium intakes and tended to be shorter than subjects who were not exposed, and we controlled for current calcium intake and height in all analyses. We also accounted for other lifestyle factors including weight, alcohol consumption, physical activity (both current and during adolescence), contraceptive use and adolescent milk intake, and found that these factors could not explain the association between household tobacco smoke exposure and reduced BMD. Nevertheless, many lifestyle factors are difficult to measure precisely and statistical analyses may not adequately control for their effect on BMD.

This study has several limitations. First, exposure to household tobacco smoke was based on recall, and although recalled data on exposure to passive tobacco smoke have been demonstrated to be reasonably valid [37], they may still be subject to bias. In addition, without biomarkers the intensity of household tobacco smoke exposure is difficult to quantify since many factors, such as the amount of time spent in contact with the smoke as well as the concentration of smoke present, are uncertain. Furthermore, we considered the home to be the predominant venue for passive smoke exposure, but did not account for exposure to passive smoke outside the home. We also were not able to determine at which ages household tobacco smoke exposure was most influential, due to the decreased number of subjects exposed to household tobacco smoke after age 18 years. Finally, since our study population was highly educated and relatively homogeneous with regard to ethnic background, our findings are not necessarily representative of the general population.

In conclusion, this study found household tobacco smoke exposure during adolescence and young adulthood to be negatively associated with BMD at the total hip and femoral neck in premenopausal women. In addition, the duration of exposure to household tobacco smoke was negatively associated with BMD at the total hip, femoral neck, lumbar spine and total body. While additional studies are necessary to further assess the

potential risks associated with exposure to household tobacco smoke, our study results imply that modification of household exposure to tobacco smoke in adolescents and young adults may have a positive impact on bone mass.

Acknowledgements. This material is based on work supported by the US Department of Agriculture, under agreement No. 58-1950-9-001. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors, and do not necessarily reflect the view of the US Department of Agriculture. This work was presented in part as an abstract at the ASBMR meeting in Toronto, Canada, in September 2000.

References

1. US Department of Health and Human Services. The health benefits of smoking cessation. DHHS publication no. (CDC) 90–8416. Washington, DC: US Dept of Health and Human Services, 1990.
2. Glantz SA, Parmley WW. Passive smoking and heart disease: epidemiology, physiology and biochemistry. Circulation 1991;84:956–9.
3. Feyerabend C, Bryant A, Jarvis MJ, Russell MA. Determination of cotinine in biological fluids of non-smokers by packed column gas-liquid chromotography. J Pharmac Pharmacol 1986;38:917–9.
4. Eliopoulos C, Klein J, Phan MK, et al. Hair concentrations of nicotine and cotinine in women and their newborn infants. JAMA 1994;271:621–3.
5. Feyerabend C, Higenbottam T, Russel MAH. Nicotine concentrations in urine and saliva of smokers and non-smokers. BMJ Clin Res Ed 1982;284:1002–4.
6. Russell MAH, Feyerabend C. Blood and urinary nicotine in nonsmokers. Lancet 1975;I:179–81.
7. Greenberg RA, Haley NJ, Etzel RA, Loda FA. Measuring the exposure of infants to tobacco smoke. N Engl J Med 1984;310:1075–8.
8. Duff AL, Pomeranz ES, Gelber LE, et al. Risk factors for acute wheezing in infants and children: viruses, passive smoke, and IgE antibodies to inhalant allergens. Pediatrics 1993;92:535–40.
9. Bono R, Russo R, Arossa W, Scursatone E, Gilli G. Involuntary exposure to tobacco smoke in adolescents: urinary cotinine and environmental factors. Arch Environ Health 1996;51:127–31.
10. Pattishall EN, Strope GL, Etzel RA, Helma RW, Haley NJ, Denny FW. Serum cotinine as a measure of tobacco smoke exposure in children. Am J Dis Child 1985;139:1101–4.
11. US Department of Health and Human Services. The health consequences of involuntary smoking: a report of the surgeon general. DHHS publication no. (CDC) 87–8398. Washington, DC: US Dept of Health and Human Services, 1986.
12. Law MR, Hackshaw AK. A meta-analysis of cigarette smoking, bone mineral density and risk of hip fracture: recognition of a major effect. BMJ 1997;315:841–6.
13. Hollenbach KA, Barrett-Conner E, Edelstein SL, Holbrook T. Cigarette smoking and bone mineral density in older men and women. Am J Public Health 1993;183:1265–70.
14. Forsen L, Bjorndal A, Bjartveit K, et al. Interaction between current smoking, leanness, and physical inactivity in the prediction of hip fracture. J Bone Miner Res 1994; 9:1671–8.
15. Daniell HW. Osteoporosis of the slender smoker: vertebral compression fractures and loss of metacarpal cortex in relation to postmenopausal cigarette smoking and lack of obesity. Arch Intern Med 1976;136:298–304.
16. Fehily AM, Coles RJ, Evans WD, Elwood PC. Factors affecting bone density in young adults. Am J Clin Nutr 1992;56:579–86.
17. Valimaki MJ, Karkkainen M, Lamberg-Allardt C, et al. Exercise, smoking, and calcium intake during adolescence and early adulthood as determinants of peak bone mass. BMJ 1994;309:230–5.
18. McCulloch RG, Bailey DA, Houston CS, Dodd BL. Effects of physical activity, dietary calcium intake and selected lifestyle factors on bone density in young women. Can Med Assoc J 1990;142:221–7.
19. Ortego-Centeno N, Munoz-Torres M, Hernandez-Quero J, Jurado-Duce A, de la Higuera Torres-Puchol J. Bone mineral density, sex steroids, and mineral metabolism in premenopausal smokers. Calcif Tissue Int 1994;55:403–7.
20. Daniel M, Martin AD, Drinkwater DT. Cigarette smoking, steroid hormones, and bone mineral density in young women. Calcif Tissue Int 1992;50:300–5.
21. Mazess RB, Barden HS. Bone density in premenopausal women: effects of age, dietary intake, physical activity, smoking and birth control pills. Am J Clin Nutr 1991;53:132–42.
22. Sowers MR, Clark MK, Hollis B, Wallace RB, Jannausch M. Radial bone mineral density in pre- and perimenopausal women: a prospective study of rates and risk factors for loss. J Bone Miner Res 1992;7:647–57.
23. Slemenda CW, Hui SL, Longcope C, Johnston CC. Cigarette smoking, obesity, and bone mass. J Bone Miner Res 1989;4:737–41.
24. Whiting SJ, McCulloch RG, Bailey DA, Houston CS. The effect of cigarette smoking on trabecular bone density in premenopausal women, aged 20–35 years. J Bone Miner Res 1990;5:S249.
25. Johnell O, Nilsson BE. Life-style and bone mineral mass in perimenopausal women. Calcif Tissue Int 1984;36:354–6.
26. Young D, Hopper JL, Nowson CA, et al. Determinants of bone mass in 10- to 26-year old females: a twin study. J Bone Miner Res 1995;10:558–67.
27. Ramp WK, Lenz LG, Galvin RJS. Nicotine inhibits collagen synthesis and alkaline phosphatase activity, but stimulates DNA synthesis in osteoblast-like cells. Proc Soc Exp Biol Med 1991;197:36–43.
28. Michnovicz JJ, Hershcopf RJ, Naganuma H, Bradlow HL, Fishman J. Increased 2-hydroxylation of estradiol as a possible mechanism for the anti-estrogenic effect of cigarette smoking. N Engl J Med 1986;315:1305–9.
29. Krall EA, Dawson-Hughes B. Smoking increases bone loss and decreases intestinal calcium absorption. J Bone Miner Res 1999;14:215–20.
30. Zacharias L, Rand WM, Wurtman RJ. A prospective study of sexual development and growth in American girls: the statistics of menarche. Obstet Gynecol Surv 1976;31:325–37.
31. Zacharias L, Rand WM. Adolescent growth in height and its relation to menarche in contemporary American girls. Ann Hum Biol 1983;10:209–22.
32. Zacharias L, Rand WM. Adolescent growth in weight and its relationship to menarche in contemporary American girls. Ann Hum Biol 1986;13:369–86.
33. Block G, Woods M, Potosky A, Clifford C. Validation of a self-administered diet history questionnaire using multiple diet records. J Clin Epidemiol 1990;43:1327–35.
34. Johnson J, Dawson-Hughes B. Precision and stability of dual-energy x-ray absorptiometry measurements. Calcif Tissue Int 1991;49:174–8.
35. Jones G, Riley M, Dwyer T. Maternal smoking during pregnancy, growth, and bone mass in prepubertal children. J Bone Miner Res 1999;14:146–51.
36. Torgerson DJ, Campbell MK, Reid DM. Life-style, environmental and medical factors influencing peak bone mass in women. Br J Rheumatol 1995;34:620–4.
37. Sandler DP, Shore DL. Quality of data on parents' smoking and drinking provided by adult offspring. Am J Epidemiol 1986;124:768–78.

Received for publication 17 December 2001
Accepted in revised form 16 February 2002