# Dietary and Environmental Determinants of Blood and Bone Lead Levels in Lactating Postpartum Women Living in Mexico City

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Despite the recent declines in environmental lead exposure in the United States and Mexico, the potential for delayed toxicity from bone lead stores remains a significant public health concern. Some evidence indicates that mobilization of lead from bone may be markedly enhanced during the increased bone turnover of pregnancy and lactation, resulting in lead exposure to the fetus and the breast-fed infant. We conducted a cross-sectional investigation of the interrelationships between environmental, dietary, and lifestyle histories, blood lead levels, and bone lead levels among 98 recently postpartum women living in Mexico City. Lead levels in the patella (representing trabecular bone) and tibia (representing cortical bone) were measured by K X-ray fluorescence (KXRF). Multivariate linear regression models showed that significant predictors of higher blood lead included a history of preparing or storing food in lead-glazed ceramic ware, lower milk consumption, and higher levels of lead in patella bone. A 34 μg/g increase in patella lead (from the medians of the lowest to the highest quartiles) was associated with an increase in blood lead of 2.4 μg/dl. Given the measurement error associated with KXRF and the extrapolation of lead burden from a single bone site, this contribution probably represents an underestimate of the influence of trabecular bone on blood lead. Significant predictors of bone lead in multivariate models included years living in Mexico City, lower consumption of high calcium content foods, and nonuse of calcium supplements for the patella and years living in Mexico City, older age, and lower calcium intake for tibia bone. Low consumption of milk and cheese, as compared to the highest consumption category (every day), was associated with an increase in tibia bone lead of 9.7 μg Pb/g bone mineral. The findings of this cross-sectional study suggest that patella bone is a significant contributor to blood lead during lactation and that consumption of high calcium content foods may protect against the accumulation of lead in bone. *Key words*: bone lead, calcium intake, environmental factors, Mexico, pregnancy. *Environ Health Perspect* 104:1076–1082 (1996)

Environmental pollution has become one of the leading public health problems affecting the 25 million inhabitants of Mexico City. The federal government has launched several control measures to decrease the effects associated with air pollution, particularly exposure to lead (*1*). Control measures have been effective in reducing exposure in most urban areas in Mexico; however, relatively high levels of lead exposure remain endemic.

Bone serves as a long-term repository of 75% and 90–95% of lead in children and adults, respectively (*2*). Many studies have demonstrated that bone lead levels remain elevated despite declines in blood lead, raising the issue of whether bone lead may be a better biological marker for predicting chronic toxicity (*3,4*). Recent studies suggest that significant amounts of lead are released from bone. A recent clinical study that focused on changes in the composition of lead isotopes in blood clearly documented that bone lead can be a substantial source of circulating lead in women (*5*). This release can be expected to increase during physiologic states associated with increased bone turnover, such as pregnancy and lactation (*6*). As a result, a significant amount of lead may be transferred to the fetus or to the breast-fed infant. This possibility is alarming in view of recent studies linking ever lower levels of lead exposure with deficits in neurobehavioral function in infants (*7–9*).

Until recently, human studies on the toxicological significance of bone lead stores have not been possible. However, with the development of *in vivo* X-ray fluorescence (XRF), it is now possible to conduct epidemiological studies using bone lead level as a measure of cumulative lead exposure (*10*). In this report, we present the results of a pilot study of the determinants of blood and bone lead levels among postpartum women living in Mexico City. This cross-sectional study is the forerunner of a larger prospective study on the toxicokinetics of lead during pregnancy and lactation among women in Mexico City.

## Methods

### Subjects

Women were recruited from two maternity hospitals, 68% ($n$ = 58) from the Instituto Nacional de Perinatología and 39% ($n$ = 37) from the Hospital Manuel Gea Gonzalez. Participants were approached during the prepartum period by an interviewer who explained the study and obtained informed consent. At delivery, blood samples were taken from consenting subjects for lead and hemoglobin analysis. One month after delivery, lactating participants were invited to attend our research center for bone lead measurement; at this time, a questionnaire was administered and blood, urine, and breast milk samples were collected. Only the blood samples collected at 1-month postpartum were used in the statistical analyses. This research protocol was evaluated and approved by the human subjects committee of the National Institute of Public Health (Mexico). All participants received a detailed explanation of the study aims and procedures and counseling on lead exposure reduction.

### Blood Lead Measurements

Blood samples were analyzed using atomic absorption spectrophotometry (Perkin Elmer 3000; Perkin Elmer, Norwalk, CT) by a standardized laboratory (ABC Hospital Laboratory, Mexico). External quality control samples were provided by the laboratory standardization program of the Centers for Disease Control and Prevention (CDC), Atlanta, GA. With respect to the lead levels of the blind duplicate samples provided by the CDC, the results of our laboratory had a correlation of 0.98 and a mean difference of 0.71 μg/dl (SD = 0.68).

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### Questionnaires

We used a questionnaire to collect information on reproductive health characteristics and known risk factors for elevated lead exposure, which we had identified in previous studies (*1*). Risk factors studied included use of lead-glazed ceramics, exposure to lead paint, or history of employment in occupations with lead exposure. Questions about the use of lead-glazed ceramics were illustrated by photographs to help participants recall the type of pottery used at home.

To assess dietary calcium intake, we used a food frequency questionnaire based on the frequency of consumption of 128 food items in the past 12 months. This questionnaire has been validated in the Mexican population and used previously in women of reproductive age in Mexico City (*11,12*). The food frequency questionnaire was developed following the approach suggested by Willett et al. (*13*). In the construction of the instrument, an effort was made to include all common foods that in aggregate accounted for approximately 85% of kilocalorie intake and intake of individual nutrients of interest. From this questionnaire we extracted information in relation to milk, cheese, and corn tortilla consumption. These three foods are the most important sources of calcium in the Mexican population.

### KXRF Bone Lead Measurements

Bone lead measurements were taken of each subject's mid-tibia shaft (cortical bone) and patella (trabecular bone) using a spot-source $^{109}$Cd K X-ray fluorescence (KXRF) instrument constructed at Harvard University and installed in a research facility at the American British Cowdray Hospital in Mexico City (Hospital ABC). The physical principles, technical specifications, and validation of this particular instrument have been described in detail elsewhere (*14*). The instrument uses a $^{109}$Cd gamma-ray source to provoke the emission of fluorescent photons from target tissue that are then detected, counted, and arrayed on a spectrum. The net lead signal is determined after subtraction of Comptom background counts using a linear least-squares algorithm. The lead fluorescence signal is then normalized to the elastic or coherently scattered gamma-ray signal, which arises predominantly from the calcium and phosphorus present in bone mineral. The unit of measurement so derived is micrograms of lead per gram of bone mineral (μg Pb/g). Since the instrument provides a continuous unbiased point estimate that oscillates around the true bone lead value, negative point estimates are sometimes produced when the true bone lead value is close to zero. The instrument also provides an estimate of the uncertainty associated with each measurement that is derived from a goodness-of-fit calculation of the spectrum curves, which is equivalent to a single standard deviation. Although a minimum detectable limit calculation of twice this value has been proposed for interpreting an individual's bone lead estimate, experiments have shown that retention of all point estimates, including negative estimates, makes better use of the data in epidemiological studies (*15*).

By normalizing the measurement to calcium counts, the measurement is rendered insensitive to variations in bone shape, size, and density, overlying tissue thickness, and movement (*11*). Validation studies of the instrument indicate a fairly high degree of precision and accuracy of the point estimates in comparison to chemical analyses in studies of lead-doped phantoms (*11*). For the present study, 30-min measurements were taken at the midshaft of the left tibia and at the left patella after each region had been washed with a 50% solution of isopropyl alcohol. The KXRF beam collimator was placed perpendicular to the bone surface for the tibia and at 30° in the lateral direction for the patella.

The energy line coefficients used to convert channel numbers into energy (eV) were obtained daily by measuring the K X-ray peak positions from a lead target. Once per week, the room housing the KXRF instrument was cleaned with a high-energy particulate air filter vacuum cleaner (Nilfisk, Malvern, PA) and the subject test chair was wiped down with isopropyl alcohol. A blank phantom was then positioned and measured 20 consecutive times overnight as an additional calibration check. Analysis of means and standard deviations did not show a significant shift in accuracy or precision.

### Data Analysis

The SAS (SAS Institute, Cary, NC) and Stata (Stata Corporation, College Station, TX) systems (*16,17*) were used for database management and statistical analysis. Univariate statistics were calculated for all variables. Variables measured on a continuous scale were used in their original distribution and in categorical classifications. Dietary calcium intake was evaluated by estimating the individual effect of milk, cheese, and corn tortillas. We also evaluated the combined effect of milk and cheese consumption. The use of calcium supplements was evaluated as a yes/no variable, mainly because we did not record information about the brand of calcium supplements. Time living in Mexico City and age were also analyzed as categorical variables.

To verify the quality of the KXRF bone lead data, we examined the individual measurement uncertainty estimates for both tibia and patella. The value of uncertainty generated with each bone measurement represents an estimate of the standard deviation of multiple measurements. High measurement uncertainty in KXRF measurements of adults is usually due to movement of the limb out of the measurement field or extreme thickness of overlying tissue. In accordance with previously published procedures (*18*), measurements were tagged if the estimate of measurement uncertainty was greater than 10 μg Pb/g (for the tibia) or 15 μg Pb/g (for the patella), and final analyses were run both with and without these values. However, given that the results were essentially the same, we present the results derived from the full set of observations.

We first examined the bivariate relationships between factors that we hypothesized were determinants of lead dose (use of lead-glazed ceramics to prepare, store, or serve food; years living in Mexico City, occupation, years of education, running water in house, foods with high calcium content, smoking, parity, and age) and each biological marker of lead dose (blood lead, patella bone lead, and tibia bone lead). Relationships were examined graphically using box plots and smoothed plots for categorical and continuous variables, respectively. We then constructed multivariate regression models of each biological lead dose marker. Variables were selected for inclusion if they were associated with the biological lead dose marker in bivariate analyses ($p < 0.10$). Bone lead variables were included as predictors of blood lead to test the hypothesis that, in addition to environmental exposure, bone lead levels are independent predictors of blood lead. To minimize the influence of extreme outliers, final models were fit using a robust regression technique. For this procedure we used the algorithm provided by the statistical program Stata.

## Results

We obtained baseline information from 156 women at the time of birth of their infants; 61% ($n = 95$) of these women came to the second data collection session at the research clinic. The most frequently reported reason for incomplete participation was loss of interest in the study. The mean blood lead level for nonparticipants was 9.4 μg/dl and did not differ significantly from the mean blood lead of those women who completed the study.

The mean age of women with complete information was 25.6 years (SD = 6.8), the

mean blood lead level was 9.6 µg/dl (SD = 4.5), and the mean bone lead levels were 12.5 µg Pb/g (SD = 11.6) for tibia and 16.7 µg Pb/g (SD = 13.3) for patella. Nine percent of patella measurements and 8% of tibia measurements had associated uncertainties greater than 15 and 10 µg/g, respectively. Bone lead levels in the tibia and the patella were highly correlated ($r$ = 0.45; $p < 0.000$, with a regression slope ($\beta$) = 0.52; intercept = 10.0). Of the bivariate relations between trabecular and cortical bone lead on one hand and blood lead on the other, only that of patella to blood lead was significant. The observed correlations and regression slopes with blood lead were $r$ = 0.15, $\beta$ = 0.038, $p$ = 0.13 for the tibia and $r$ = 0.31, $\beta$ = 0.088, $p<0.001$ for the patella. Table 1 presents characteristics of study participants and their relation to bone and blood lead concentrations. The single most important environmental predictor of blood lead was the use of lead-glazed ceramic ware. We observed a significant positive trend in blood lead levels associated with increasing frequency of use of lead-glazed ceramics. Women who reported use of calcium supplements during pregnancy had lower blood lead levels (1.84 µg difference); this difference was marginally significant ($p$ = 0.07). Milk consumption was inversely associated with blood lead levels. Women who reported milk consumption only once per month had significantly higher blood lead levels than women who reported milk consumption more frequently (Table 1). Other high calcium foods were not associated with blood lead levels.

The results of our final multivariate model for blood lead levels are shown in Table 2. The most significant predictors were history of preparing or storing food in lead-glazed ceramic ware, milk and cheese consumption, and patella bone lead levels. We observed a positive linear relation between blood lead and patella lead levels. From the regression model, we estimated an increase of 0.6 µg/dl in blood lead levels for each 10 µg Pb/g in the patella and an increase of 5.37 µg/dl associated with frequent use of lead-glazed ceramics. An increase in patella lead from the medians of the lowest to the highest quartiles (a difference of 34 µg/g) was associated with an increase in blood lead of 2.4 µg/dl. Women who consumed milk and cheese frequently (on a weekly and daily basis) had on average 2.5 µg Pb/g less than those who consumed milk and cheese infrequently. When we examined the bivariate relationships of potential predictors with bone lead, we observed a positive linear relation with age and time living in Mexico City (Fig. 1 and 2). The observed regression slopes and correlations with age were $\beta$ = 0.32, $r$ = 0.17; $p$ = 0.10, intercept = 8.28 for the patella and $\beta$ = 0.30, $r$ = 0.18, $p$ = 0.08, intercept = 4.78 for the tibia. Time living in Mexico City was a significant linear predictor of bone lead. The observed correlations and slopes were for patella $r$ = 0.29, with a slope of 0.48 ($p < 0.001$) per year living in Mexico City, and for tibia $r$ = 0.23, with a slope of 0.25 per year living in Mexico City ($p$ = 0.01). In comparison with those women who had lived 5 years or less in the Mexico City area, those who had lived 20 or more years in Mexico City had significantly higher levels of bone lead (9.6 µg Pb/g more in patella and 4.8 more in tibia; Fig. 2). Smoking was also positively correlated with bone lead levels. In comparison with women who never smoked, women who were cur-

**Table 1.** Relation between different sociodemographic characteristics and lead measurements among 95 postpartum women residing in Mexico City in 1993

| Sociodemographic characteristics | No. | Blood Pb (µg Pb/dl) | Patella Pb (µg Pb/g bone mineral) | Tibia Pb (µg Pb/g bone mineral) |
|---|---|---|---|---|
| Age (years) | | | | |
| 14–20 | 24 | 10.4 ± 4.1 | 14.1 ± 13.3 | 11.8 ± 14.9 |
| 21–29 | 44 | 10.3 ± 4.8 | 17.1 ± 13.4 | 10.7 ± 10.9 |
| 30–43 | 27 | 7.8* ± 3.7 | 18.1 ± 12.7 | 16.3** ± 8.4 |
| Years living in Mexico | | | | |
| 1–5 | 8 | 8.5 ± 4.2 | 9.2 ± 13.9 | 9.8 ± 9.7 |
| 6–19 | 25 | 10.5 ± 4.4 | 13.6 ± 19.8 | 7.4 ± 10.1 |
| 20–40 | 58 | 9.5 ± 4.6 | 18.8* ± 13.5 | 14.6 ± 11.8 |
| Years of education | | | | |
| Elementary school | 10 | 10.3 ± 3.5 | 19.7 ± 11.9 | 13.7 ± 10.0 |
| High school | 49 | 9.3 ± 3.9 | 17.9 ± 14.0 | 12.8 ± 13.4 |
| College or higher | 36 | 9.9 ± 5.4 | 14.1 ± 12.0 | 11.9 ± 9.5 |
| Number of pregnancies | | | | |
| 1 | 36 | 9.3 ± 4.0 | 16.4 ± 12.0 | 10.9 ± 12.9 |
| 2 | 22 | 9.0 ± 3.6 | 14.1 ± 14.0 | 13.4 ± 11.2 |
| 3 or more | 37 | 10.4 ± 5.7 | 18.4 ± 13.7 | 13.7 ± 10.6 |
| History of abortion | | | | |
| No | 69 | 9.3 ± 4.9 | 16.8 ± 13.3 | 12.3 ± 2.5 |
| Yes | 26 | 10.4 ± 4.6 | 16.4 ± 12.9 | 13.1 ± 8.9 |
| Occupation | | | | |
| Housewife | 81 | 9.2 ± 4.5 | 15.6 ± 12.9 | 12.5 ± 12.1 |
| Other | 14 | 9.7 ± 4.5 | 22.9 ± 12.9 | 12.6 ± 8.3 |
| Running water in the house | | | | |
| Yes | 92 | 9.5 ± 4.5 | 16.6 ± 13.3 | 12.7 ± 11.74 |
| No | 3 | 13.63 ± 0.7 | 20.0 ± 7.7 | 9.4 ± 7.03 |
| Use of calcium supplements | | | | |
| Yes | 25 | 8.3 ± 2.4 | 10.9 ± 11.7 | 10.3 ± 12.8 |
| No | 70 | 10.2 ± 4.9 | 18.7* ± 13.1 | 13.3 ± 11.1 |
| Milk consumption | | | | |
| Monthly | 9 | 13.4 ± 4.2 | 18.2 ± 16.0 | 17.2 ± 15.1 |
| Weekly | 14 | 9.0* ± 4.5 | 16.3 ± 17.1 | 9.1 ± 14.9 |
| Daily | 25 | 8.7** ± 4.3 | 17.4 ± 12.3 | 14.6 ± 10.6 |
| Twice or more per day | 44 | 9.5* ± 4.5 | 15.6 ± 12.3 | 11.3 ± 10.3 |
| Cheese consumption | | | | |
| None | 13 | 9.6 ± 5.5 | 20.3 ± 14.5 | 16.9 ± 11.4 |
| Monthly | 29 | 9.6 ± 5.0 | 19.2 ± 14.6 | 13.7 ± 12.5 |
| Weekly | 37 | 10.0 ± 4.4 | 15.3 ± 12.3 | 10.9 ± 12.3 |
| Daily | 13 | 8.3 ± 2.5 | 9.7* ± 9.2 | 9.5 ± 7.5 |
| Corn tortilla consumption | | | | |
| Monthly or weekly | 9 | 8.4 ± 3.8 | 14.5 ± 13.0 | 15.5 ± 9.1 |
| Daily | 16 | 11.5 ± 4.6 | 19.65 ± 11.1 | 11.1 ± 8.5 |
| Twice or more per day | 67 | 9.3 ± 4.5 | 16.01 ± 13.8 | 12.4 ± 12.7 |
| Smoking | | | | |
| Never | 70 | 9.7 ± 4.6 | 15.6 ± 12.9 | 10.8 ± 9.9 |
| Past smoker | 15 | 9.0 ± 3.4 | 19.3 ± 11.5 | 14.0 ± 11.9 |
| Current smoker | 10 | 10.1 ± 5.1 | 20.1 ± 17.1 | 22.1** ± 17.3 |
| Exposure to lead-glazed ceramics | | | | |
| None | 48 | 8.2 ± 3.4 | 15.4 ± 13.8 | 12.5 ± 9.5 |
| Low | 24 | 9.6 ± 5.0 | 18.3 ± 12.9 | 14.2 ± 13.9 |
| Medium | 13 | 11.7* ± 4.4 | 16.6 ± 11.4 | 9.9 ± 14.8 |
| High | 10 | 13.8** ± 4.7 | 18.7 ± 17.9 | 12.1 ± 11.1 |

Lead levels are shown as mean ± SD.
*$p>0.05$.
**$p<0.01$.

rent smokers had, on average, an excess of 4.2 μg Pb/g in the patella ($p$ = 0.48) and 11.3 μg Pb/g in the tibia ($p$ = 0.01).

Calcium supplement intake was inversely correlated with bone lead levels. Women who used supplements during pregnancy had, on average, 7.8 μg Pb/g less in the patella ($p$ = 0.02) and 3.0 μg Pb/g less in the tibia ($p$ = 0.45) than women who did not use supplements. Milk and cheese consumption was also inversely related to bone lead concentrations; however, these associations were only marginally significant (Table 1).

Final multivariate models for patella and tibia lead levels are presented in Tables 3 and 4. For patella lead, the most important predictors were time living in Mexico City, milk and cheese consumption, and calcium supplement use. We observed an increasing trend in patella lead levels with increasing time living in Mexico City (Table 3). We estimated a mean difference of 20.0 μg Pb/g in the patella when comparing women who had lived in Mexico City for 5 years or less with those with 20 years or more of residency. Intake of calcium-rich foods was inversely associated with patella lead, although we did not observe a significant trend. Calcium supplement use was associated with significantly lower levels of patella lead. Supplement users had 8.5 μg Pb/g less mineral than nonusers. For tibia bone lead, the important predictors were age and consumption of milk and cheese (Table 4). We observed an increasing trend in tibia lead levels with increasing age; those women who were 30 years of age or older had 7.5 μg Pb/g more mineral than women 14 to 20 years of age. High intake of milk and cheese was inversely and significantly related to tibia lead. However, this observed association was not linear; we did not observe a decreasing trend in lead concentrations with increasing milk and cheese intake (Table 4).

## Discussion

Our results show that bone lead concentrations varied according to different environmental and dietary variables. Since the number of subjects in this study was relatively small, these results should be interpreted with caution; nevertheless, it is noteworthy that the associations were much clearer for bone lead than those for blood lead. This reflects the power of using markers of cumulative dose (bone lead) rather than recent exposure (blood lead). Median bone lead levels among these women (tibia median, 12.0 μg/g; patella median, 16.0 μg/g) were three times higher than the postpartum median bone levels of women who gave birth in a Boston Hospital in

**Table 2.** Multivariate robust regression model of blood lead among 95 postpartum women residing in Mexico City in 1993

| Pb | Coefficient | SE[a] | $p$ value | 95% | C.I.[b] |
|---|---|---|---|---|---|
| Use of lead-glazed ceramics | | | | | |
| Never | Reference | | | | |
| Rarely | 1.00 | 0.92 | 0.288 | -0.84 | 2.85 |
| Often | 2.49 | 1.22 | 0.045 | 0.06 | 4.93 |
| Frequently | 5.37 | 1.28 | 0.001 | 2.81 | 7.93 |
| Milk and cheese consumption | | | | | |
| Low | Reference | | | | |
| Medium-low | -4.28 | 1.68 | 0.013 | -7.62 | -0.94 |
| Medium | -3.87 | 1.55 | 0.014 | -6.96 | -0.79 |
| Medium-high | -2.98 | 1.51 | 0.053 | -5.99 | 0.03 |
| High | -2.55 | 1.44 | 0.080 | -5.42 | 0.31 |
| Patella lead | 0.06 | 0.02 | 0.045 | 0.001 | 0.12 |
| Intercept | 9.95 | 1.57 | 0.000 | 6.82 | 13.08 |
| Adj $R^2$ = 0.18 | | | | | |

[a]Standard error.
[b]Confidence interval.

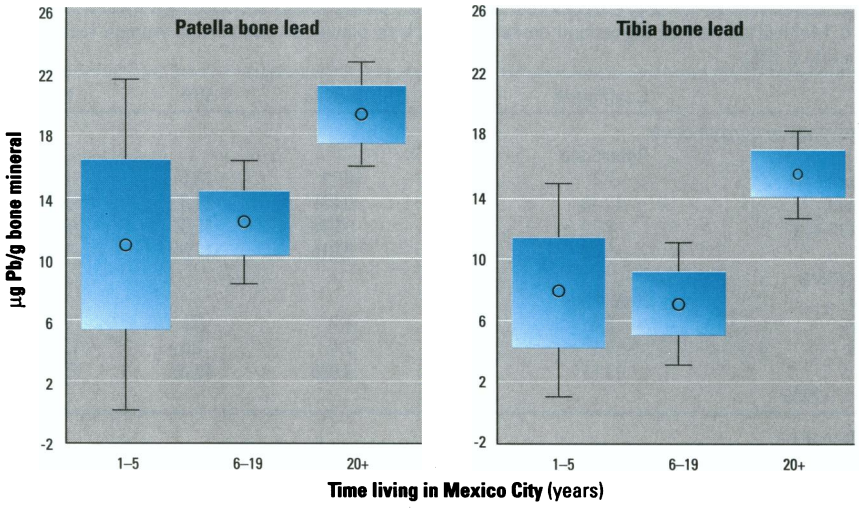


**Figure 1.** Distribution of patella and tibia bone lead levels (μg PB/g bone mineral) of 95 postpartum women according to age in Mexico City in 1994. The circle in each bar designates the mean.

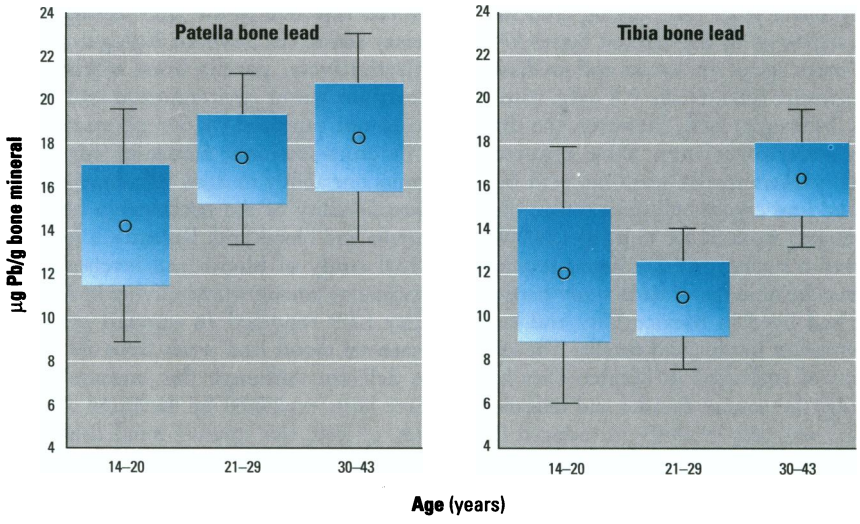


**Figure 2.** Distribution of patella and tibia bone lead levels (μg PB/g bone mineral) of 95 postpartum women according to time living in Mexico City in 1994. The circle in each bar designates the mean.

**Table 3.** Multivariate robust regression model for patella lead among 95 postpartum women residing in Mexico City in 1993

| Predictors | Coefficient | SE[a] | *p* value | 95% | C.I.[b] |
|---|---|---|---|---|---|
| Supplement use | | | | | |
| No | Reference | | | | |
| Yes | -8.5 | 2.9 | 0.004 | -14.39 | -2.75 |
| Milk and cheese consumption | | | | | |
| Low | Reference | | | | |
| Medium-low | -4.98 | 5.4 | 0.36 | -15.8 | 5.83 |
| Medium | -12.98 | 4.9 | 0.01 | -22.7 | -3.2 |
| Medium-high | -6.17 | 4.8 | 0.20 | -15.7 | 3.3 |
| High | -10.04 | 4.6 | 0.03 | -19.2 | -0.80 |
| Time living in Mexico City | | | | | |
| 5 years or less | Reference | | | | |
| 6–15 years | 11.9 | 5.0 | 0.001 | 1.9 | 21.9 |
| 20 years or more | 20.0 | 4.5 | 0.001 | 10.9 | 29.1 |
| Alpha | 10.36 | 5.6 | 0.07 | -0.86 | 21.59 |
| Adj $R^2 = 0.17$ | | | | | |

[a]Standard error.
[b]Confidence interval.

**Table 4.** Multivariate robust regression model for tibia lead among 95 postpartum women residing in Mexico City in 1993

| | Coefficient | SE[a] | *p* value | 95% | C.I.[b] |
|---|---|---|---|---|---|
| Milk and cheese consumption | | | | | |
| Low | Reference | | | | |
| Medium-low | -7.5 | 4.7 | 0.11 | -17.0 | 1.84 |
| Medium | -12.13 | 4.3 | 0.007 | -20.8 | -3.4 |
| Medium-high | -8.32 | 4.3 | 0.048 | -16.5 | -0.84 |
| High | -9.73 | 3.9 | 0.016 | -17.6 | -1.82 |
| Age in years | | | | | |
| 14–20 | Reference | | | | |
| 21–29 | 2.0 | 2.8 | 0.7 | -3.6 | 7.6 |
| 30–43 | 7.5 | 3.0 | 2.4 | 1.4 | 13.4 |
| Alpha | 17.51 | 3.7 | 0.000 | 10.02 | 25.0 |
| Adj $R^2 = 0.2209$ | | | | | |

[a]Standard error.
[b]Confidence interval.

1990–1992 (tibia median, 4.0 µg/g; patella median, 5.0 µg/g) (*19*). The mean levels (tibia, 12.5 µg/g; patella, 16.7 µg/g) were also somewhat higher than those reported by Watanabe et al. (*20*) among construction carpenters in the United States who had a mean age of 48.5 years and moderate lead exposure (tibia mean, 9.8 µg/g; patella mean, 14.0 µg/g) (*20*). However, the tibia levels were lower than those reported among workers in the smelting, acid battery, and lead crystal industries (mean tibia lead ranging from 31 to 55 µg/g) (*21*). We observed a strong positive linear relation between the amount of time study participants had lived in Mexico City and lead concentration in tibia and patella. The lead content of fuel used in Mexico City has been high for several decades and unleaded gasoline was only recently introduced (in 1991) (*1*). It is likely that the strong relation observed between the number of years of residence in the city and bone lead levels reflected the effect of cumulative exposure to airborne lead, principally from gasoline.

The influence of patella bone lead on blood lead that we observed in the model supported the hypothesis that bone lead mobilization may be an important source of lead exposure to the fetus during pregnancy and to the newborn during lactation. Alternatively, patella bone might be a proxy for recent environmental lead exposures not captured by our questionnaire. The cross-sectional nature of our study limits our ability to draw inferences on the directionality of the relationship between patella and blood lead. Recently, a longitudinal study of blood lead levels during pregnancy among women living in Mexico City (*22*) reported an upward trend in maternal blood lead levels from 20 weeks to delivery. Although this increase could have been explained by increased absorption of lead, this upward trend could also indicate increased mobilization of lead from bone during the last half of pregnancy. In a recent longitudinal study of the change in lead isotope profiles, it was documented that the predominant source of lead in blood was bone lead reserves rather than the contemporaneous environment (*5*). This suggests that current blood lead levels reflect both current and past lead exposure.

We observed a positive, but not significant, association between tibia lead and blood lead levels. The difference in results observed between the two bone lead markers could be attributed either to the small sample size in our study or to the differences in kinetics of lead in cortical and trabecular bone (*23*). Patella lead levels have been reported to increase and decrease more quickly than tibia lead levels, probably because of the trabecular nature of the composition of the patella (*24*). Tibia bone lead is cortical and therefore tends to have a longer half-life (*24,25*). We cannot exclude that processes such as lactation may have preferentially affected trabecular bone, although our study design does not allow us to distinguish such an effect. A greater statistical association between patella and blood lead levels may normally exist and this should be evaluated in future studies.

Experimental studies conducted in animals have provided evidence that maternal lead stores are a strong determinant of lead exposure to the fetus during pregnancy (*26,27*). Studies of bone metabolism during pregnancy have shown that during this time there is an increased demand for calcium that is satisfied either by dietary calcium or by physiological reserves in the body (*28*). Maternal bone may serve as a major source of calcium for the fetus, as reflected by changes in bone formation rate, loss of bone mineral as a function of the number of pregnancies, and osteoporosis in some cases (*29–31*), particularly in women whose diets are deficient in calcium. Since lead has been found to be incorporated into bone in a way similar to calcium (*32*), it appears likely that pregnancy and lactation release accumulated lead as well as calcium from bone. The use of glazed ceramics has been reported as a source of acute intoxication in children (*33*) and as a risk factor for high blood lead levels among women of reproductive age in Mexico City (*34*). In our study, the use of lead-glazed ceramics was a strong predictor of blood lead levels and was positively, but not significantly, related to bone lead concentrations. This lack of association with bone lead concentration may be attributed to our inability to capture long-term exposure to lead-glazed ceramics using our questionnaire. Exposure was evaluated as current use and not as life-time history of exposure, whereas long term use of lead-glazed ceramics would be more likely to have an effect on bone lead. In addition, during the

last few years, the inhabitants of Mexico City have been exposed to information about the dangers associated with the use of this type of ceramics. This may have conditioned changes in the patterns of use, making exposure evaluated at the present time less reflective of long-term exposure.

Diet is known to modify lead kinetics. In particular, deficiencies of calcium and iron have been found to enhance the absorption of lead (*35,36*). In our study, we observed an inverse association between the consumption of milk and cheese to blood and bone lead levels. Milk intake and calcium supplement use were significant negative predictors of blood lead levels. This observation is similar to that reported for dietary calcium and blood lead levels by Kostial et al. (*37*) and Mahaffey et al. (*38*). Recently, Muldoon et al. (*39*) studied a sample of elderly women and reported that women with higher levels of calcium intake had significantly lower blood lead levels. Similar data relating a protective effect of milk consumption was observed by Johnson and Tenuta (*40*). These authors evaluated the effect of calcium in children and observed an inverse correlation between blood lead levels and both calcium intake and milk consumption. In a study conducted among African American women during pregnancy, West et al. (*41*) reported a positive association between blood lead and serum calcium ($r$ = 0.44) and significantly higher blood lead levels among women who did not consume vitamin–mineral supplements.

Studies in other populations have been inconsistent with respect to a protective effect. Graziano et al. (*42*) reported a positive association between milk consumption and blood lead levels among women with high exposure to lead in Yugoslavia, although the authors concluded that this represented a noncausal association. Morris et al. (*43*) reported no effect of calcium supplements on blood lead levels in a sample of 142 subjects who received 1 g calcium supplements for 12 weeks.

Our study found that milk and cheese intake was also inversely related to bone lead levels. A diet rich in calcium may decrease the absorption of lead through the digestive mucus (*36*) and therefore decrease accumulation in the skeleton because lead has been found to be incorporated into bone in a way similar to calcium. It is estimated that at the age of twenty, 78% of total body lead in humans is stored in bone (*44,45*). We found no significant trend between calcium rich food levels and bone lead levels, however. Our data suggest that once a threshold consistent with the recommended daily allowance (1200 mg) for lactating women is reached, supraphysiologic doses of calcium may have no effect and bone lead levels will not continue to decrease. On the other hand, two sources of error may have attenuated the dose–response relationship. First, the use of calcium supplements was only measured as a yes/no variable. Second, since women in this study were pregnant, they may have increased their calcium intake in the last few months, thereby introducing error into our use of dietary intake to estimate long-term calcium intake. This could explain the lack of an observed trend over the frequency of consumption of milk and cheese.

Previous investigations of populations with moderate to low lead exposure have demonstrated a strong positive and relatively linear relationship of both tibia and patella bone lead with age (*20,46–48*). In this study, tibia and patella lead levels were positively related to age; however, the relationship between age and bone lead levels was significant only for tibia and not for patella bone lead concentrations. This lack of association may be due to susceptibility of trabecular bone lead to metabolic factors associated with physiological changes produced during pregnancy and lactation.

Our study was limited by a relatively small sample size that prevented the analysis of interactions and subgroups of interest. The cross-sectional nature of our study also limited our ability to evaluate the directionality of relationships observed. Bias from the use of historical data is unlikely since participants knew neither their lead concentrations nor the specific hypotheses being tested. Misclassification of environmental variables such as exposure to lead-glazed ceramic ware and dietary calcium were likely to have attenuated the observed associations.

In conclusion, the results of our study suggest that, in addition to environmental exposure, mobilization of lead from trabecular bone stores contributes significantly to circulating lead levels in lactating women. Although the contribution to total blood lead levels is relatively small (0.6 μg/dl per 10 μg/g patella lead increase), its contribution to plasma lead levels remains to be determined. Moreover, our estimate of the contribution of bone lead to blood lead is likely an underestimate because the substantial amount of error associated with our bone lead measurements can be expected to attenuate the beta estimates derived from using bone lead as an independent variable in least squares regression (*49*). Our data also support the hypothesis that low dietary calcium enhances lead absorption and bone lead deposition, a possibility suggested by previous reports of elevated blood lead levels among children with dietary calcium deficiency (*50*). Our findings emphasize the need for prospective epidemiological research on the effects of mobilization of bone lead on reproduction and on the relationship between calcium intake and lead dose. Our findings point to the potential utility of calcium supplementation and promotion of calcium rich foods as intervention strategies for reducing lead mobilization from bone during pregnancy and lactation, thereby decreasing the passage of lead to the fetus and the breast-fed infant.

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