Blood Lead Levels in Pregnant Women of High and Low Socioeconomic Status in Mexico City

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This study examined the determinants of blood lead (BPb) in 513 pregnant women in Mexico City: 311 from public hospital prenatal clinics, representing primarily women of low socioeconomic status (SES), and 202 from private hospitals, primarily women of high SES. Overall, BPb levels ranged from 1.38 to 29 µg/dl, with geometric means of 6.7 and 11.12 µg/dl for women from private and public hospitals, respectively. The crude geometric means difference obtained by *t*-test was 4.42 (p<0.001). BPb was measured from January 1994 to August 1995 and showed higher levels during fall and winter and lower levels during spring and summer. The main BPb determinants were the use of lead-glazed ceramics in women from public hospitals and season of the year in women from private hospitals. Consumption of tortillas (corn bread rich in calcium) decreased BPb levels in the lower SES group, but the relationship was not statistically significant (p>0.05). Consumption of milk products significantly (p<0.05) reduced BPb levels in the higher SES group. In 112 women whose diets were deficient in calcium, taking calcium supplements lowered their blood lead levels about 7 µg/dl. A predictive model fitted to these data, using the strongest predictors plus gestational age, showed a difference of 14 µg/dl between the best and worst scenarios in women from public hospitals. Avoiding use of lead-glazed ceramics, consuming diets rich in calcium, and, if needed, taking calcium supplements, would be expected to result in substantial lowering of BPb, especially in pregnant women of low socioeconomic status.
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Adverse systemic health effects from lead (Pb) exposure have been well known since before the twentieth century and have been thoroughly documented in animal and human populations, especially in children (*1*). Pregnancy is also a period of high susceptibility to the effects of Pb for both the mother and the embryo or fetus. The reasons are that 1) Pb may be mobilized from its storage site in the bone to the blood (*2*); 2) pregnancy induces a physiologic anemia and hemodilution, which in turn decrease iron levels, resulting in increased toxicity and absorption of Pb (*3*); and 3) there is no placental barrier for this metal (*4*).

Exposure to Pb may be through inhalation or ingestion. Atmospheric Pb comes from industrial emissions or vehicular exhaust. The latter has been the most important atmospheric source in Mexico City (*5*). Rothenberg et al. (*6*) identified atmospheric Pb as a predictor of maternal BPb during pregnancy in Mexico City. Other possible lead sources are canned food, water from distribution systems with lead pipes, and the use of lead-glazed ceramics fired at low temperatures to prepare, store, or serve food. Studies in Mexico have shown that the use of lead-glazed ceramics has been the most important in determining BPb levels in rural communities (*7*). In Mexico City, water has an alkaline pH that prevents Pb removal from the pipes (*6,8*), and although Romieu et al. (*9*) found that canned food is still a Pb source, its role has been declining (*8,10*).

Some nutritional factors associated with susceptibility to lead are total food intake; sources of calories; and calcium, phosphorus, iron, zinc, and various vitamins (thiamine, ascorbic acid, vitamin E). In experimental studies, lead absorption has been shown to be greatly increased during fasting and with diets rich in fat or poor in calcium (*3*). Low calcium dietary intake also produces an increase in lead toxicity and deposition in bone. Iron deficiency is a widespread problem and results in an increased susceptibility to lead toxicity (*3,11,12*). Generally, calcium and iron are the most important of these factors, and during pregnancy their importance is enhanced due to changes in calcium and iron metabolism and increased demand (*10*). In addition, Pb can be removed from storage sites in bone in response to pregnancy (*2,13*).

Considering the widespread exposure to Pb, its adverse effects during pregnancy, and the socioeconomic inequity in Mexico City, this investigation aimed to study the specific determinants of BPb in pregnant women from high and low socioeconomic groups in this city so that future intervention efforts could be targeted appropriately.

Methods

A cohort of 513 pregnant women seeking pregnancy diagnosis or prenatal care was recruited in 13 private and public hospitals in Mexico City. The type of hospital served as a proxy for socioeconomic status (SES): private clinics served primarily high SES patients and public clinics served primarily women of low SES. Women in both settings were given information about the study and their informed consent was obtained. All study participants answered a questionnaire and had a blood sample taken when they were recruited. The percentages of women recruited at each gestational age group were as follows: 79, 18, 2, and 1% for weeks 1–12, 13–18, 19–24, and 25–36, respectively. The women were provided with information about the potential effects of lead during pregnancy.

The questionnaire was specially designed for this study, taking into account previous findings. It collected information on the following: nutritional sources of BPb (use of lead-glazed ceramics and consumption of canned food) or protective factors (consumption of foods rich in calcium and supplements of vitamins, calcium, and iron); socioeconomic characteristics; sources of lead exposure; and the woman's medical and reproductive history. Participants from private hospitals answered the questionnaire by themselves, whereas those from public hospitals were interviewed in person, because not all of them could read or write. Missing or questionable responses were verified through telephone calls or house visits to the patient or through the gynecologist.

To confirm the usefulness of the type of hospital as a proxy for SES, another variable was created. This variable categorized women into three levels of SES using a ratio of the monthly per capita income and the number of years of education. The cut-off points of the two variables were the 33.33

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and 66.66 percentiles. This way, 83% of the women from private hospitals were classified in the high SES, and 12% in the middle class, and 5% in low SES; 79% of the women from public hospitals were classified in the low SES, 14% in the middle, and 7% in the high SES. Since the type of hospital reflected SES fairly well and also correlates with other social and prenatal care aspects not observed by the above index , this variable was used for further analyses.

When patients had blood samples taken for pregancy diagnosis or clinical purposes, blood samples to measure BPb were also taken. Specimens were obtained through a lead-free vacutainer and stored at 4°C until analysis. BPb determinations were carried out in duplicate using atomic absorption spectrometry with a graphite furnace (*14*). These analyses were conducted at the National Institute of Neurology and Neurosurgery in Mexico City. This laboratory has a quality control program to guarantee precision using quality control samples of bovine blood and is certified by the U.S. Centers for Disease Control Blood Lead Proficiency Testing Program; external quality control was achieved through participation in this program. Women were given results of their BPb with guidelines to avoid sources of exposures.

The information from the questionnaires and samples was checked, corrected, and captured electronically. Descriptive analyses were conducted on all variables. Patients from the two hospital types were compared in terms of sources of lead and nutritional and other factors. Since BPb had a moderate positive asymmetry, it was transformed to its natural logarithm (lnPb) to achieve normality. In the bivariate analysis, simple linear regression was used to evaluate the relationship between BPb and each potential Pb source. Multiple linear regression models to predict lnPb were constructed for each hospital type with all independent variables that had a statistical association of $p \leq 0.1$; once all of these variables were included, a backward elimination was applied. Interactions, confounding, and collinearity were also evaluated in these models. Since a loss of interpretability was produced when BPb was transformed, expected BPb values were calculated for two scenarios (the best and the worst) to indicate the potential for modifying BPb levels. This was done with the final multivariate models for each hospital.

Results

The cohort included 513 women, 202 from private hospitals and 311 from public hospitals. Their ages ranged from 14 to 43 years, with a mean of 27. On average, these women were recruited in gestational week 10 (dated from the first day of their last menstrual period). Most of the women were housewives (60%), with the second most common occupational group being professionals (21%). Only 1% of all the women reported an occupational exposure to Pb, but 9.5% reported that their husband had such exposure.

Fourteen percent of the women reported that they were current smokers and, of these, the mean number of cigarettes per day was four. Exposure to second-hand smoke was reported by 57% of all the women; these women reported being exposed to daily means of two persons who smoked near them, or seven cigarettes smoked near them.

Cooking or storing food in lead-glazed ceramics fired at low temperatures was more frequent in the public than private hospital patients (47% vs. 18%). Consumption of tortillas was more frequent in the public clinic patients, and private hospitals patients consumed more milk products. The percentage of women taking vitamins and calcium supplements was higher in patients from private hospitals than in those from public hospitals (38% vs. 29% for vitamins and 24% vs. 16% for calcium, respectively), whereas iron supplements were taken by the same percentage (18%).

In both types of hospitals, half of the women reported spending 2 hr/day outdoors, but total median transportation time differed: 1.5 hr/day for private and 0.5 for public patients.

Another important difference between the two hospital types was that approximately 80% of the women from public hospitals were recruited during the autumn and winter, whereas women from private hospitals were recruited in similar percentages (27–29%) throughout the year except during winter (17%).

Overall, BPb values ranged from 1.29 to 29 µg/dl, with a mean of 11.08 and a standard deviation of 6.4 µg/dl. Women from the public hospitals had higher levels than women from private hospitals: geometric mean BPb levels were 11.12 µg/dl in public hospital patients and 6.7 µg/dl in private hospital patients. Using <10 mg/dl as an acceptable value of BPb (*15,16*), 63% of women from private hospitals and 39% of women from public hospitals had acceptable BPb levels. As expected, BPb levels declined with increasing education or income. Regression coefficients for lnPb associated with years of schooling and per capita income in Mexican pesos were β = -0.04 (p = 0.000) and β = -0.0001 (p = 0.000), respectively. A slight decline with age (β = -0.02; p = 0.001) was observed, but it was strongly confounded by hospital type (adjusted β = -0.0002; $p>0.1$).

Mean BPb was substantially and significantly higher among users of lead-glazed ceramics (13 µg/dl) regardless of hospital type, and there was an upward trend in BPb as the frequency of use increased. Compared with non-users, the coefficients for frequencies of 1–4/month, 2–3/week, and >3/week were 0.24, 0.33, and 0.37, respectively ($p<0.01$).

Women who took vitamin, calcium, or iron supplements had lower BPb levels compared with women who did not take them, but these associations did not achieve statistical significance ($p>0.1$). If the analysis is restricted to 112 women with low dietary calcium intake (definied by any quantity of tortillas and milk consumption less than three times a week), women who took calcium supplements (n = 17) had a BPb level that was substantially lower than those who did not (n = 95): the difference observed with a t-test was 7 µg/dl (p = 0.05).

Factors not associated with BPb in these subjects were consumption of canned foods, coffee, alcohol, soft drinks, smoking, time spent outdoors or in traffic, and location of the house in relation to traffic and nearby industries with possible Pb emissions.

Important differences were seen in BPb levels depending on the time of the year the blood sample was taken (Fig. 1). Grouping the months into seasons (winter: January–March; spring: April–June; summer: July–September; and fall: October–December), the lowest mean levels were seen during summer (4.7 µg/dl), followed in order by spring (6.4 µg/dl), autumn (11 µg/dl), and winter (12.7 µg/dl). These differences were highly significant between summer (as reference) and the other seasons ($p<0.01$).

BPb was related to the gestational week at which it was measured. Dividing gestational age in four categories (weeks 1–12, 13–18, 19–24, and 25–36), BPb showed a declining trend after week 12, but the numbers were small beyond 18 weeks. ($p<0.05$ from week 13–24 and $p>0.05$ afterwards) (Fig. 2).

Final multivariate models for each public hospital were obtained by initially including all Pb determinants and confounders with a statistical significance of $p<0.1$ in at least one category in the bivariate analysis and then eliminating all of the variables with a statistical significance of $p>0.05$ and with no important effect in the rest of the coefficients in the multivariate analysis. The final models for private and public hospitals are shown on Tables 1 and 2, respectively.

For women receiving prenatal care in

private hospital clinics, the main determinants of BPb were the season of blood sampling and the consumption of milk products. BPb is progressively higher in spring, autumn, and winter, compared with summer, and there are highly significant differences. Consumption of milk products reduces BPb levels, but this difference is only statistically significant for the comparison of the lowest with the middle category and there was no trend.

Using the final multivariate model to predict BPb for women from private hospitals, the following adjusted levels were calculated for two scenarios: the most favorable and the least favorable. The lowest expected value of BPb of 4.3 μg/dl was for a blood sample taken during summer in a woman who consumes milk products 3–4 times/week. The highest expected BPb level of 15.3 μg/dl was for a blood sample taken during winter in a woman who consumes milk products 0–2 times/week.

In women from public hospitals, the main BPb determinants were the use of lead-glazed ceramics, seasonal variations, week of gestation, and tortilla consumption. When comparing non-users of lead-glazed ceramics, an increasing trend can be seen for the first two categories; however, the final category shows a decrease, and only the middle category achieves statistical significance ($p<0.05$). Tortilla consumption did not achieve statistical significance and its protective effect is stronger in the middle category than in the highest, but it was kept in the model because of its influence on other coefficients (gestational week and season of the year).

Using this final multivariate model to predict BPb for women from public hospitals, the adjusted levels were calculated as the most favorable and the least favorable. The lowest expected BPb level of 2.12 μg/dl was for a woman who never uses lead-glazed ceramics, eats tortillas 3–4 times/week and has her BPb measured during spring and gestational weeks 25–36. The highest expected BPb level of 16.2 μg/dl was for a woman who uses lead-glazed ceramics 2–3 times/week, eats tortillas 0–2 times/week, and has her BPb measured during winter in the first 12 gestational weeks.

Discussion

Results from this study suggest that BPb determinants are different among women of different SES. For pregnant women at public hospital clinics, primarily a population of low SES, use of lead-glazed ceramic cookware is the main risk factor for higher BPb levels, and consumption of tortillas may be the main protective factor. For women at private prenatal care clinics, seasonal variation is the main determinant of BPb levels, increasing them during autumn to winter and decreasing them during spring to summer. This finding suggests that the main source for this group of women is atmospheric Pb, even though no association was observed between BPb and variables such as total time spent outdoors, total transportation time, location of the house in relation to traffic, and nearby industries with possible Pb emissions. These variables may not have been well measured, i.e., there could have been substantial nondifferential misclassification errors resulting in underestimated associations. Moreover, the differences by season may have outweighed variability due to these factors. Notably, the climate and housing construction are such that windows are open year-round and indoor levels probably do not differ markedly from outdoor levels. Summer is the rainy season in Mexico City, which reduces atmospheric pollution, and schools are on vacation (diminishing traffic), with many people travelling out of the city. In contrast, winter is a dry, cold season with frequent thermal inversions. Thus, the seasonal variations do make sense and provide evidence of a major role of atmospheric pollution in determining BPb levels in pregnant women and others.

As for protective factors in private hospital participants, consumption of milk products was the most important. Tortilla consumption did not appear to be protective in this group perhaps because of low tortilla consumption, because calcium requirements are already satisfied by other dietary sources, or because we didn't specify we meant corn flour tortillas (rich in calcium) and not wheat flour tortillas (not rich in calcium and more likely to consumed by these women).

An interesting finding was the strong protective effect of calcium supplements in women with low dietary calcium intake. Experimental studies have shown that absorption of lead by the gastrointestinal tract is inversely related to calcium content of the diet (*12*).

The fact that a dose response was not found for use of lead-glazed ceramics and tortilla consumption in public hospitals and milk products in private hospitals and that statistical significance was not achieved in all of the categories could be due to the decrease in the number of women after division into SES groups.

The lack of association with canned food was expected because of voluntary cessation of lead soldering and the recently enacted regulations against Pb solders in Mexico. Smoking did not contribute to BPb levels, even though it has been associ-

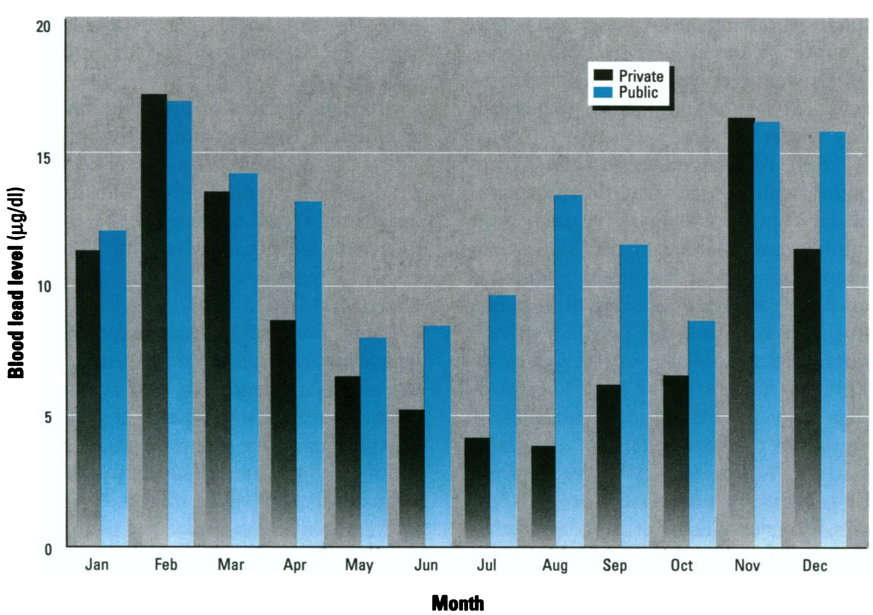

Figure 1. Mean blood lead levels by month blood sample was taken and hospital.

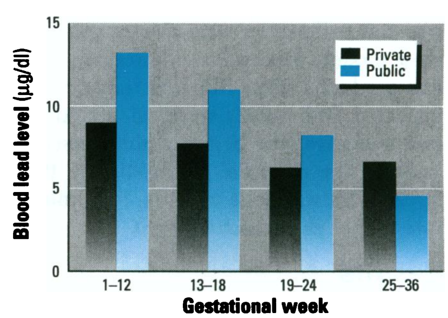

Figure 2. Mean blood lead levels by gestational week and hospital.

ated with BPb in other studies (*13,17*). This is probably due to the small percentage of smokers and the low amounts they smoked during prenancy. Many who had smoked stopped smoking during pregnancy, which is important because the half life of BPb is aproximately 4–6 weeks (*18*).

The mean BPb level (11.1 µg/dl) of the cohort is similar to the mean reported for women 21–57 years old of low SES from the southwest part of Mexico City in 1990 (10.6 µg/dl), although this was a general sample of women (*8*). Predictors of higher BPb found in this study agree with results of previous studies in Mexico City, use of lead-glazed ceramics (*6,8*) and low SES (*8*). Other researchers have also failed to find associations with smoking, canned foods, time spent outdoors, the couple's occupational exposure to Pb, and mother's age (*8*). The lack of association with mother's age, in spite of studies in other countries showing increases with age, may have been confounded by increased parity with consequent depletion of bone lead reserves. We also did not confirm positive associations with consumption of coffee, alcohol, and soft drinks, as shown by Rothenberg et al. (*10*). However, those relationships were mainly found in advanced pregnancies, which were very few in our study.

The strong seasonal association has not been reported in Mexico City, although only one study evaluated middle to high SES children (*19*). The main BPb determinant used by Romieu et al. (*19*) was place of residence, which could not be adequately assessed in our study. The finding in regard to seasonal differences has implications for studies of lead conducted elsewhere. Although some seasonality has been reported in the United States (*20*), meteorologic factors are likely to play a bigger role in areas with long dry seasons where either the population spends more time outdoors or where housing construction leads to more similarities between indoor and outdoor levels of lead.

The expected BPb levels calculated with multivariate regression models in best and worst case scenarios show that there is a difference of up to 14 µg/dl in the women of low SES. Since several of the strongest predictors are modifiable, it should be possible to reduce BPb levels in a substantial proportion of the population. Considering that women at public clinics have higher BPb levels and that these levels are strongly related to individual actions, it is urgent to encourage these women to avoid the use of lead-glazed ceramics, to consume diets rich in calcium and iron, and to promote calcium supplement use when the diet is deficient in calcium.

On the other hand, women attending private hospital clinics have lower BPb levels, and these seem to be determined by environmental exposures. Individual actions may therefore be less effective, and there is a clear need for societal and political measures. An increase in lead-free gasoline and possible modifications of transportation systems should be considered.

Table 1. Multivariate models of blood lead determinants in women from private hospitals (n = 204)

Independent variables	β	SE	*p* value	95% CI
Season[a]				
Spring	0.2992816	0.1093803	0.007	0.0835679 – 0.5149952
Autumn	0.7913921	0.1098958	0.000	0.5746619 – 1.008122
Winter	1.122878	0.1247826	0.000	0.8767886 – 1.368967
Milk products consumption[b]				
3–4/week	-0.20363	0.1094991	0.054	-0.4195777 – 0.0123178
5–7/week	-0.0926408	0.1131152	0.414	-0.3157201 – 0.1304385
Constant	1.535235	0.1091933	0.000	1.31989 – 1.75058

The dependent variable for all values is natural logarithm of blood lead.
[a]Summer is the reference category.
[b]The reference category is 0–2/week.

Table 2. Multivariate model of blood lead determinants in women from public hospitals (n = 311)

Independent variable	β	SE	*p* value	95% CI
Leaded ceramics use[a]				
1–4/month	0.1164076	0.768638	0.131	-0.0348551 – 0.2676703
2–3/week	0.1897804	0.0881313	0.032	0.0163441 – 0.3632168
>3/week	0.135357	0.0914228	0.140	-0.0445568 – 0.3152709
Tortilla consumption[b]				
2–4/week	-0.2212706	0.1301202	0.090	-0.4773382 – 0.034797
5–7/week	-0.0518216	0.0991529	0.602	-0.2469478 – 0.1433046
Gestational age[c]				
Week 13–18	-0.1837922	0.0934969	0.050	-0.3677876 – 0.0002032
Week 19–24	-0.5811774	0.2118286	0.006	-0.9980416 – -0.1643131
Week 24–36	-1.041991	0.5146594	0.044	-2.054806 – -0.0291769
Season[d]				
Summer	0.347384	0.1519641	0.023	0.0483291 – 0.6464388
Autumn	0.4661897	0.0875847	0.000	0.293829 – 0.6385504
Winter	0.4874398	0.0945585	0.000	0.3013551 – 0.6735244
Constant	2.043676	0.1147692	0.000	1.817818 – 2.269534

The dependent variable for all values is natural logarithm of blood lead.
[a]The reference category is never.
[b]The reference category is 0–2/week.
[c]The reference category is ≤12.
[d]Spring is the reference category.

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