Environmental Urban Lead Exposure and Blood Lead Levels in Children of Mexico City

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Lead contamination is now a leading public health problem in Mexico. However, there are few data on the lead content of various environmental sources, and little is known about the contribution of these sources to the total lead exposure in the population of children residing in Mexico City. We conducted a cross-sectional study in a random sample of 200 children younger than 5 years of age who lived in one of two areas of Mexico City. Environmental samples of floor, window, and street dust, paint, soil, water, and glazed ceramics were obtained from the participants' households, as well as blood samples and dirt from the hands of the children. Blood lead levels ranged from 1 to 31 µg/dl with a mean of 9.9 µg/dl (SD 5.8 µg/dl). Forty-four percent of the children 18 months of age or older had blood lead levels exceeding 10 µg/dl. The lead content of environmental samples was low, except in glazed ceramic. The major predictors of blood lead levels were the lead content of the glazed ceramics used to prepare children's food, exposure to airborne lead due to vehicular emission, and the lead content of the dirt from the children's hands. We conclude that the major sources of lead exposure in Mexico City could be controlled by adequate public health programs to reinforce the use of unleaded gasoline and to encourage production and use of unleaded cookware instead of lead-glazed ceramics. *Key words:* glazed ceramics, lead, Mexico City, vehicular emissions. *Environ Health Perspect* 103:1036–1040 (1995)

Already the second most populated city in the world, Mexico City will enter the twenty-first century with nearly 5 million more inhabitants than it had in 1991. This kind of growth comes at a high price. Environmental pollution is one of the city's leading public health problems, and this is greatly exacerbated by rapid urban growth and continued use of inappropriate production and control technology.

Exposure to lead is a major concern. Even at low blood levels, potential adverse health effects have been observed. Several epidemiologic studies have reported blood lead levels and risk factors for the population of Mexico City (*1–7*). However, information is scarce about the concentration of lead in the environment and the contribution of various sources to total lead exposure in the population of Mexico City. This knowledge gap must be closed so that adequate control measures to decrease lead exposure in the general population can be applied. Because sources of lead exposure may vary widely according to the area of residence and also by age (given that children have different habits from adults), we conducted a cross-sectional study to determine the contribution of various environmental media to the blood lead levels in women of reproductive age (15–48 years) and their children younger than 5 years of age. In this report, we address the impact of environmental lead exposure on children's blood lead levels.

Methods

Study population. The population studied was composed of women of reproductive age (15–48 years) and their children younger than 5 years of age. The subjects livied in the southern part of Mexico City (Tlalpan) or in a more northern area (Xalostoc). These two areas were selected because we expected the major sources of lead exposure to differ: Tlalpan is mostly a residential area, and Xalostoc is located within the industrial part of Mexico City.

In each area, a random sample of 250 households was selected. All houses were visited to obtain a sample size of 100 pairs (mother–child). Selected women were invited to participate in the study, which included the completion of a questionnaire, environmental sampling of their household, and collection of blood samples from each woman and her child. Participants were informed of the study objectives and asked to sign an informed consent form. Sampling procedures were conducted from October 1992 to June 1993. Additional environmental monitoring of street dust was conducted from May to June 1994. After all data were collected, dietary counseling and advice to minimize lead exposure was provided to all participants.

Environmental samples. Environmental sampling procedures for soil, dust, paint, and water were carried out in accordance with the technique proposed by the Environmental Sciences and Technology Laboratory, Georgia Technical Research Institute (Atlanta, Georgia) and recommended by the U.S. Department of Housing and Urban Development (*8*). Training of the field personnel and standardization of procedures were provided by a senior scientist from the Georgia Technical Institute. All procedures were carried out using vinyl gloves.

Composite soil samples were obtained from various places close to each participant's house (yard, front door, children's play area, place where rain water drains from the roof). These samples were obtained from superficial soil, using a spoon that was cleaned between collection of each sample. Five subsamples were taken in each area. All were collected in plastic containers with hermetic lids.

We used two techniques to collect interior dust samples. 1) Dust was collected from carpeting and furniture with a personal monitoring pump (2.5 l/min) connected to a two-piece air monitoring cassette with a 0.8-µg cellulose ester filter (37 min). Several samples (30 cm^2 each) were obtained. All personal monitoring pumps were calibrated on a daily basis before field work. 2) Samples were obtained from floors and window sills using moist wipes (K-Mart "Little Ones"). The sample area was wiped three times in an "S" pattern, while trying to achieve 100% coverage over a sur-

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face of at least 30 cm^2. Each wipe was placed in a 100-ml plastic tube with a hermetic lid. Sampling was conducted in the living room, the kitchen, the children's room, and the parents' room. A similar technique was used to sample the dirt on the children's hands. Street dust was collected using a small broom over an area of 1 m^2 and sealed in a plastic container with hermetic lid.

We tested for lead in paint using a XK-3 (Princeton Gamma Tech, Princeton, New Jersey) instrument. The instrument was calibrated at the beginning of each work period and during usage. Quick calibration checks were made according to the protocol for quality control of field measurements made with X-ray fluorescence (XRF) instruments. Three readings were obtained over a selected area and the arithmetic mean was calculated. For results between 0.5 and 1.5 mg/cm^2, paint chips were obtained over an area of at least 4 cm^2 and kept in a plastic bag.

Water samples were obtained in 250-ml plastic containers prewashed with 5% nitric acid. To obtain samples of pH equal to 2.0, 2 ml of nitric acid was added to the container. At the time of the household visit, samples were obtained from the kitchen faucet as well as from water stored for drinking or cooking purposes. Participants using low-temperature lead-glazed ceramic ware to cook or store foods were asked to provide the cookware for analysis. A steel pan was offered in exchange. Atmospheric lead levels were provided by the monitoring network of Mexico City (monitoring stations in Tlalpan and Xalostoc).

All laboratory analyses were conducted using atomic absorption spectrophotometry. Laboratory analysis for lead in soil, dust, and paint was conducted by the HES Laboratory (Charleston, South Carolina). Laboratory analyses for lead in water were conducted using a Perkin Elmer 3000 instrument by the ABC Hospital Laboratory, Mexico City, Mexico. Ceramic ware lead analyses were conducted at the laboratory of the National Institute of Neurology and Neurosurgery, Mexico City, Mexico. All laboratories had internal and external quality controls. Efforts were made to obtain environmental samples from each participating household. In some cases (for example, if the house was not painted), specific environmental samples could not be obtained.

Blood samples. Venipuncture blood samples were obtained from each pair (mother–child) in their household, collected in lead-free tubes by a trained pediatric nurse. Blood samples were analyzed by atomic absorption spectrophotometry (Perkin Elmer 3000) by a standardized laboratory (ABC Hospital Laboratory). External quality control was provided by the Centers for Disease Control and Prevention Laboratory (Atlanta, Georgia). Blood lead measurements were reported in micrograms per deciliter (1 µg/dl = 0.0484 µmol/l).

Statistical analysis. The statistical analyses included environmental data collected in 200 households (100 in the southwest part of the city and 100 in the northeast part of the city) and the blood lead levels of children living in these households. In many households, we obtained several samples of soil, dust, and paint from various areas of the house. The lead contents of specific samples were averaged, and the median was used in the analyses. We analyzed the data first using environmental samples with detectable levels of lead and second including samples below the detection limit, assuming a value of 0.5 of the detection limit for these samples. Results were similar using both methods. In the results we present only those including samples with complete information. To combine the two types of lead paint measurements (XRF and wet chemistry), we used the ordinal scale proposed by Rabinowitz et al (*9*). A score of 0 corresponded to <0.5% lead by wet chemistry or <0.4 mg/cm^2 by XRF. Similarly, a score of 1 corresponded to 0.5–1.5% lead by wet chemistry or 0.5–1.5 mg/cm^2, and so on to a score of 10, which was assigned to any value equal to or greater than 10% or 10 mg/cm^2.

To analyze the impact of lead-glazed ceramics on the children's blood lead levels, we created a new variable that combined the questionnaire response on the use of lead-glazed ceramics to prepare or store children's food and the measurements of lead leached from the ceramic ware obtained from the participating households. When the mother reported not using lead-glazed ceramics to prepare her child's food, the value assigned to the variable was 0. Otherwise we assigned the value of lead leached by the ceramic ware from the corresponding household.

To determine the correlation between atmospheric lead and other environmental variables, we used the lead content of particulates on the sampling date of each specific household. Since measurements of atmospheric lead were performed only every 6 days, the value was assigned for the date of the air sampling, 2 days before, and 3 days after the monitoring day. To determine the correlation between children's blood lead and atmospheric lead, we averaged monitoring data over the 3 months before blood sampling, thus establishing a better estimate of children's exposure.

To determine the socioeconomic level of the participants, we used an adaptation of the socioeconomic index developed by Bronfman et al. (*10*). This index has been widely used in Mexico and has been proven to discriminate social strata very well. Because the distribution of blood lead levels was skewed, we used the log-transformed value of blood lead levels in all analyses. To determine the relation of blood lead levels and environmental measurements, we used correlation coefficients and linear regression analysis accounting for potential confounding variables (*11*). Chi-square value due to linear regression was used for the significance of the linear trend. All analyses were performed using SAS software (Cary, North Carolina) (*12*).

Results

The average blood level among the 200 children participating in the study was 9.9 µg/dl (SD 5.8 µg/dl; range 1–31 µg/dl). Table 1 presents the mean blood levels according to age groups and areas of residence. Blood lead levels were slightly higher in children in the industrial area of Xalostoc than children in the residential area of Tlalpan (mean 10.5, SD 5.5 µg/dl versus mean 9.4, SD 6.0 µg/dl, respectively). This was observed in all age groups. As shown in Table 1, in both areas there was an increase in the blood lead level of children between the ages <18 months and 18–35 months (p = 0.02 in Tlalpan and p = 0.15 in Xalostoc), and a significant increasing trend in blood lead levels was observed with increasing age in both areas (p = 0.0035); older children tended to have higher blood lead levels than younger ones. Among the children ≥18 months of age, 52% had blood lead levels exceeding 10 µg/dl in Xalostoc versus 36% in Tlalpan (p = 0.05).

Lead concentrations in the environmental samples are presented in Table 2. Most of the lead levels in indoor dust were low, and only a few samples exceeded the guidelines of the U.S. Department of Housing and Urban Development (*13*). The highest indoor lead levels were observed in dust samples from window sills: 7.1% of these samples exceeded 0.215 µg/cm^2 of lead content (corresponding to 200 µg/ft^2). Residential soil samples had a low lead content. Only 6% of these samples exceeded a lead content of 200 ppm; one soil sample exceeded a lead content of 500 ppm. In comparison, lead concentrations in street dust were high, with 44.5% of the street dust samples exceeding a lead content of 200 ppm and 7.5% exceeding

Table 1. Blood lead levels (µg/dl) in relation to age and study area, Mexico City, 1993[a]

	Xalostoc				Tlalpan				Total			
Age	*n*	$\bar{x}$	SD	% >10 µg/dl	*n*	$\bar{x}$	SD	% >10 µg/dl	*n*	$\bar{x}$	SD	% >10 µg/dl
<18 months	27	7.89	4.53	25.9	25	6.82	5.13	20	52	7.38	4.81	23.1
≥18–35 months	30	10.93	6.77	46.7	25	9.17	4.67	28	55	10.13	5.92	38.2
≥35–49 months	22	11.86	4.19	54.5	22	10.27	7.13	31.8	44	11.07	5.83	38.2
≥50 months	21	11.59	5.04	57.1	28	11.26	6.33	46.4	49	11.40	5.76	51.0
Total	100	10.45	5.50	45.0	100	9.40	6.02	32.0	200	9.91	5.78	38.5

[a]Significant increasing trend of blood lead levels with age was observed in both areas ($p<0.04$)

Table 2. Environmental lead measurements, Mexico City, 1993–1994

Type of sample[a]	*n*	$\bar{x}$	SD	Q_{25}–Q_{75}[b]
Bare-floor dust (µg/cm²)	169	0.03	0.08	0.005–0.024
Carpet dust (µg/cm²)	53	0.006	0.007	0.002–0.008
Furniture dust (µg/cm²)	70	0.009	0.003	0.001–0.007
Window sill dust (µg/cm²)	104	0.11	0.19	0.02–0.10
Street dust (ppm)	200	205.6	182.1	89.5–270
Soil (ppm)	66	117.2	305.2	30–104
Hand dirt (µg/subject)	139	3.45	2.26	2.0–4.6
Water (ppm)[c]	195	0.004	0.003	0.0016–0.0042
Lead in ceramic ware (ppm)[d]	54	2163	1686	230–3559
Paint score[e]	128	1.02	0.60	0.8–1.0
Air lead (µg/m³)[f]	200	0.54	0.59	0.20–0.52

[a]Only samples with detectable levels of lead are included.
[b]Interquartile range 25%–75%.
[c]Standard guideline = 0.01 ppm.
[d]The Mexican norm has been established at <75 ppm for 1994 and ≤25 ppm for 1996.
[e]Paint score is the combination of X-ray fluorescence and wet chemistry.
[f]24-hr average.

Table 3. Spearman correlation between different environmental lead measurements, Mexico City, 1993–1994

Sample	Floor dust	Carpet dust	Furniture dust	Window sill dust	Soil	Street dust	Hand dirt
Air lead	0.08	0.15	0.18	0.32**	0.16	0.21**	0.28**
Bare-floor dust		0.41**	0.39**	0.11	0.30**	0.05	0.15
Carpet dust			0.45*	0.55**	0.34	0.30*	0.10
Furniture dust				0.06	0.15	-0.008	0.0005
Window sill dust					0.21	0.01	0.21*
Soil						0.41**	0.26*
Street dust							0.15
Hand dirt							1.00

*$p \leq 0.05$.
**$p \leq 0.01$.

500 ppm. Comparing the areas of Tlalpan and Xalostoc, we observed that the lead content of soil and window sills was on average significantly higher in Xalostoc (p = 0.013 and p = 0.010, respectively).

Lead in residential paint was also low, and most of the XRF measurements fell within the "inconclusive" range (0.5–1.4 mg/cm²). Among 419 measurements, 61.1% (n = 256) were inconclusive and only 10% (n = 42) were classified as positive for lead content (>1.6 mg/cm²). From those samples with inconclusive lead content by XRF measurement (>0.5 mg/cm² and <1.6 mg/cm²), we obtained 66 (21%) paint-chip samples for laboratory analysis. Thirty-three samples (50%) exceeded 5000 ppm. However, we noticed that samples of oil-based paint were significantly more likely to contain lead than water-based paint (69% versus 16.7%). We also obtained additional paint-chip samples (n = 46) from some homes without prior XRF screening. Among these, 28% (n = 13) exceeded 5000 ppm.

We obtained 54 samples of lead-glazed ceramic ware from the households enrolled in the study. Among these, 81% leached a quantity of lead that exceeded the Mexican norm of 7 ppm (*14*). The quantity of lead leached ranged from 0.05 to 4968 ppm (mean 2163.3 ppm). The lead content of all water samples were well below World Health Organization standard guidelines (*15*).

Over the study period, the mean atmospheric lead level did not exceed 1.5 µg/m³. However, some extreme values were observed, with a maximum of 2.41 µg/m³ (24-hr average). Over the study period, atmospheric lead levels were significantly higher in Xalostoc then in Tlalpan (p = 0.001).

The lead levels in indoor dust on bare (not carpeted) floor, carpeted floor, furniture, and window sills were positively correlated (Table 3). Soil and street dust were also positively correlated. Atmospheric air lead levels were correlated with furniture and window sill dust lead and street dust lead. There was a positive correlation between the amount of lead collected on children's hands and atmospheric lead, as well as indoor dust lead collected on floors and window sills. The highest correlation was observed with the lead content of window sill dust samples (r = 0.21, p = 0.07) (Table 3). Residential soil and street dust lead contents were also positively correlated with the lead content of dirt on children's hands.

We observed a positive correlation between children's blood lead levels and the lead content of glazed ceramic ware used to prepare food (Table 4; r = 0.24, p = 0.002). None of the other environmental lead measurements were significantly correlated to the children's blood lead levels. Atmospheric lead was only marginally related to blood lead levels (r = 0.11, p = 0.14). However, we observed a significant correlation between the lead content of the dirt on children's hands and their blood lead levels (r = 0.19, p = 0.025).

We then determined the major predictors of children's blood lead levels. Age was significantly related to children's blood lead levels, but socioeconomic level and housing location were not. Blood lead levels tended to increase with the intensity of the traffic close to the children's homes and the amount of atmospheric lead measured over the 3 months before blood sampling. Children who ate food prepared in lead-glazed ceramic had significantly higher blood lead than their counterparts. Finally, blood lead levels increased with the lead content of dirt from children's hands.

When we included these variables in a multivariate model, the only variables that

remained significant were the lead content of the ceramic ware used to prepare food, the intensity of traffic (traffic score) close to children's home, the amount of atmospheric lead measured over the 3 months before blood sampling, and the lead content of dirt from children's hands (Table 5). Our model explained 18.8% of the variability of the children's blood lead (Table 5). When we stratified the data by age groups, we noted that among younger children (25 months or younger), the major predictors of blood lead levels were the intensity of the traffic close to the house (F = 3.85, p = 0.06), and the lead content of dirt from children's hands (F = 2.58, p = 0.11). Among children older than 25 months, the major predictors were the use of lead-glazed ceramic cookware to prepare the child's food (F = 5.76, p = 0.02), the vehicular traffic close to the household (F = 5.49, p = 0.02), and the lead content of dirt from hands dirt (F = 4.76, p = 0.03).

Discussion

This is the first large cross-sectional study to evaluate the lead content of various environmental samples in Mexico City. Environmental lead levels were low, except for the lead content leached from glazed ceramic ware. We found that lead levels in such cookware greatly exceeded the Mexican norm for the lead content of ceramic ware (*14*).

Children's blood lead levels were similar in the two areas of the study but were slightly higher among children living in Xalostoc, an industrialized area, in each age group. We also observed that the lead content of environmental samples was higher in Xalostoc, especially for soil, window sill, and air. The major predictors of blood lead levels were the use of lead-glazed ceramic to prepare or store the child's food, lead from motor vehicular emissions, and the lead content of dirt from children's hands.

These results confirm that the use of lead-glazed ceramic is a major source of lead exposure (even among young children), and that airborne lead, mainly from motor vehicular traffic, also plays an important role as a determinant of children's blood lead levels.

Compared with results from studies conducted in the United States (*9,16–18*), we did not observe high lead levels in residential paint, and there was no association between blood lead levels and paint lead scores. The main source of indoor lead seemed to be related to atmospheric lead levels. Leaded fuel is still used in Mexico, and lead accumulates indoors, especially on window sills, which are not cleaned as frequently as floors. The lead content of the street dust samples was higher than in the other environmental dust samples. These levels were not correlated with the children's blood lead, probably because children of the age groups included in the study were more likely to stay at home.

We observed a positive correlation between lead in dirt from hands and blood lead levels. Lead levels in hand dirt were correlated with indoor dust lead content (floor and window sill); therefore, lead levels in hand dirt could be considered as a proxy for lead exposure from household dust. Among younger children (25 months or younger), hand dirt was an important predictor of blood lead levels. This is not surprising, since younger children are more likely to have pica habits and to crawl on the floor. Street traffic density near the house, as well as the three-month average atmospheric lead levels before blood sampling, were related to blood lead levels. These two factors emphasize the importance of the lead emitted in the atmosphere, by both mobile and fixed sources, to children's lead exposure.

In accordance with other studies conducted in Mexico, we observed that the use of lead-glazed ceramic to prepare and store food (*3–6*) was a major determinant of children's blood lead levels. In this study, however, we quantified the relation between the amount of lead leached from the ceramic ware and the blood lead levels of children and confirmed the importance of this source of lead exposure among children.

We were not able to measure the lead content of other potential sources of lead exposure, such as children's toys. As recently as 1994, it was reported that, in Mexico, the paint used to cover some toys and school equipment has a high lead content (*5*). Certainly, this could have contributed to the blood lead levels in the population studied. A recently established standard regulates the use of leaded paint for children's toys; however, until industry compliance is ensured and until items manufactured before the standard are phased out, studies to assess and monitor blood lead levels will be essential to the public's health.

All environmental samples in this study were obtained following a standardized protocol, and our technicians were trained by a senior scientist from Georgia Technical Institute. We believe that the lead levels observed in this study are accurate and that environmental indoor lead levels in households of Mexico City are, on average, low. Households were selected at random after census of the two study areas; therefore, our findings can be inferred to the general population of these areas, except for households located close to fixed sources of lead exposure (such as battery recycling shops).

We believe that our results are of great public health relevance. Using the quantitative assessment of the lead content of environmental media that we have provided, it is possible to reduce blood lead levels among children by focusing on the major sources of exposure. Environmental lead in Mexico City could be controlled by ade-

Table 4. Spearman correlation between children's blood lead levels and environmental variables

Variable	R	p
Floor dust	-0.03	0.73
Carpet dust	0.18	0.19
Window sill dust	0.07	0.47
Furniture dust	-0.15	0.23
Street dust	0.04	0.55
Soil	-0.04	0.73
Air lead	0.11	0.14
Air lead, 3-months[a]	0.30	0.000
Hand dirt	0.19	0.025
Lead in ceramic ware	0.24	0.002
Paint score	-0.08	0.36

[a]Average over 3 months before blood sampling, measured in μg/m^3.

Table 5. Regression analysis between children's blood lead levels and environmental variables and age, Mexico City, 1993[a]

	Univariate			Multivariate			
Variable	ß	SE	p	R^2(%)	ß	SE	p
Hand dirt	0.060	0.024	0.014	4.3	0.05	0.02	0.034
Lead glazed ceramic[b]	0.147	0.050	0.004	4.1	0.17	0.05	0.003
Traffic score[c]	0.308	0.128	0.017	2.8	0.33	0.13	0.021
Airbone lead[d]	0.213	0.049	0.000	8.5	0.150	0.06	0.015
Living area[e]	0.145	0.091	0.111	1.2	0.04	0.11	0.717
Age (months)	0.0146	0.007	0.039	2.1	0.003	0.008	0.652

[a]Blood lead is log transformed. The multivariate regression model explained 18.8% (R^2) of the variability of the children's blood lead levels.
[b]Log transformed; measured in ppm.
[c]Reference is low traffic score.
[d]Log transformed; average over 3 months before blood sampling, measured in μg/m^3.
[e]Reference is Tlalpan.

quate public health programs to reinforce the use of unleaded gasoline and to implement the production and use of unleaded cookware. An important element of these programs is an informed population. Parents who know the potential sources of lead exposure can and likely will act to decrease exposure by regularly washing younger children's hands, teaching older children to wash their hands often, and avoiding the use of lead-glazed ceramic ware to prepare or store food.

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