Blood Lead Levels of Primary School Children in Dhaka, Bangladesh

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Dhaka, Bangladesh, has one of the highest air lead levels in the world. In February 2000, we evaluated children at five primary schools in Dhaka to determine blood lead (BPb) levels, sources of environmental exposure, and potential risk factors for lead poisoning. Selected schools represented a range of geographic and socioeconomic strata. A total of 779 students 4–12 years of age participated. The mean BPb level was 15.0 µg/dL (range 4.2–63.1 µg/dL). Most students (87.4%) had BPb levels above the Centers for Disease Control and Prevention's level of concern (10 µg/dL). Elevated BPb levels correlated with soil eating [odds ratio (OR) = 3.31; 95% confidence interval (CI), 1.30–8.39], low parental education (OR = 2.72; 95% CI, 1.97–3.75), living close to major roads (OR = 2.30; 95% CI, 1.23–4.29), and increasing age (OR = 1.11; 95% CI, 1.06–1.16). BPb levels measured were similar to those in other countries that use leaded gasoline. No other potential sources of lead exposure were consistently identified. Combustion of leaded gasoline is the main source of lead exposure in Dhaka, resulting in ubiquitous contamination of the environment. The increase in BPb levels with age, a finding contrary to observations in the United States and Australia, may be related to increased outdoor activities. The Bangladeshi government recently announced a plan to eliminate leaded gasoline. Baseline BPb surveys are critical to develop and evaluate intervention policies. Strategies to reduce BPb levels need to address variations in socioeconomic status, construction type and location of housing, and levels of hygiene.
Key words: Bangladesh, blood lead levels, children, lead poisoning, risk factors. *Environ Health Perspect* 109:563–566 (2001). [Online 21 May 2001]
http://ehpnet1.niehs.nih.gov/docs/2001/109p563-566kaiser/abstract.html

Automobiles that burn leaded gasoline are a major source of lead in air, dust, and soil (*1*). High levels of lead in the air are associated with elevated blood lead (BPb) levels in humans (*2*). An elevated BPb level is defined as ≥ 10 µg/dL according to the guidelines of the Centers for Disease Control and Prevention (CDC) (*3*). The World Health Organization has adopted a critical level of 10–15 µg/dL (*4*). In children, BPb levels as low as 10 µg/dL have been associated with developmental delays, deficits in intellectual performance and neurobehavioral functioning (*5,6*), decreased stature (*7,8*), and diminished hearing acuity (*9*). Long-term follow-up studies have demonstrated an inverse relation between early exposure to low levels of lead and cognitive ability in later years (*10–12*). Removing lead from gasoline in 17 countries showed that population BPb levels below 10 µg/dL can be achieved (*2*).

In Dhaka, Bangladesh, one of the highest air lead levels in the world was recorded in 1997 (*13*). In 1999, the mean BPb levels among 49 children from Tejgaon, Mohammadpur, and Keraniganj areas in Dhaka was 17.6 µg/dL (*14*). Five children seen at the Dhaka children's hospital in 1998 had BPb levels of 80–180 µg/dL (*15*). In neighboring India, a survey of 1,852 children tested in 1997 in five major cities reported that 51.4% children had BPb levels over 10 µg/dL, and 12.6% children had BPb levels > 20 µg/dL (*16*). In July 1999 the government of Bangladesh announced a plan to eliminate leaded gasoline. In February 2000, the CDC provided technical assistance to the Bangladeshi Ministry of Health to conduct the first BPb level survey among children in that country. The study objective was to measure baseline lead levels before lead is removed from gasoline and to determine potential risk factors for lead poisoning among these children.

Methods

School selection. The survey was conducted during school hours at five primary schools in Dhaka (ages 4–12 years; Figure 1). We selected schools to represent various geographic and socioeconomic strata from Dhaka. Mohammadpur, a predominantly girls' school of approximately 500 students, and Rajdhani, a small school of approximately 200 students, for the most part serve children from higher economic and parental education levels. Nawabpur school is located in the old section of Dhaka, a commercial area of narrow streets lined by small businesses. It serves 500 students, primarily male, from an intermediate socioeconomic level. These three schools consist of multistory concrete buildings with multiple, well-equipped classrooms. Khilgaon school serves an estimated 200–300 students from a poor neighborhood and consists of two single-story brick buildings. Ambar school comprises small, one-room sheet-metal buildings scattered throughout an extremely poor area and serves an undetermined number of children. Students in Khilgaon and Ambar schools sit on dirt floors. Mohammadpur, Rajdhani, Khilgaon, and Ambar schools are located approximately 2–4 miles (3.2–6.4 km) from the old city center (Figure 1). In the study, we included all children in grades 1–5 that had parental consent to participate in the study on the day of testing.

Questionnaires. Before sample collection, parents completed a questionnaire about sociodemographic parameters, child's behavior, and potential sources of lead exposure in the home environment. Questionnaires were translated from English into Bangla and then re-translated into English. Some questionnaires had to be administered by trained interviewers because some parents were not able to complete them without assistance. To determine exposure to automobile exhaust at home, parents where asked whether their house was close to a highway or intersection of major roads, a street with moderate to heavy traffic, or a street with little traffic.

Blood samples. BPb levels were measured using portable LeadCare instruments (ESA Inc., Chelmsford, MA, USA) that have an analytic range of 1.4–65 µg/dL (*17*). Before testing, children washed their hands under supervision of an adult to avoid lead contamination from the skin. Each child's finger was pricked with a single-use lancet, and a 50 µL capillary tube was filled after discarding the first blood droplet. Test results were available within 10 min. Daily quality-assurance measures were performed according to

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We thank R. Jones and K. Caldwell, National Center for Environmental Health, Centers for Disease Control and Prevention (NCEH/CDC), for laboratory support, including training and advice in using the LeadCare instrument, support with laboratory equipment, and the analysis of environmental samples. We also thank R. Kaufmann, NCEH/CDC, for advice in preparing the questionnaire.

Received 12 October 2000; accepted 11 December 2000.

the user's manual. Children with BPb levels > 30 µg/dL rewashed their hands, and a second blood sample was taken and analyzed.

Environmental samples. Environmental samples of dust, soil, paint, and water were collected from schools and from homes of children with the highest BPb levels in each school. Soil samples were collected from the school yard and from outside the front door of children's homes. Dust and paint samples were collected from the classroom and from the children's bedrooms, or from the living room if the child did not have a separate room. A water sample was collected from the tap used for drinking water or the family's water storage container if no tap water was available in the home. Samples of soil, paint, and water were collected in lead-free containers. Dust samples were collected with a lead-free disposable moist towelette that was furnished in sampling kits obtained from the instrument manufacturer (*18*). A 1-foot-square template (929 cm^2) was placed on the floor area to be sampled and the area was wiped three times in opposing directions. All floors that were tested were concrete. At Khilgaon and Ambar schools, no dust samples were collected because classroom floors consisted of compressed soil. Qualitative tests (Leadcheck Swabs; HybriVet Systems, Inc., Framingham, MA, USA) were performed on potential sources of lead exposure such as household utensils, cookware, food containers, and toys.

Lead in soil, dust, and paint samples were analyzed at the CDC laboratory in Atlanta, Georgia, using a Palintest instrument (Palintest USA, Erlanger, KY, USA) with ultrasonic acidic extraction and anodic stripping voltometry. Analysis methods have been described in detail elsewhere (*19*). Water samples were analyzed in Bangladesh, also by the Palintest instrument. Detection limits were 25 ppm for soil samples, 25 µg/ft^2 for dust samples, 20 ppm for paint samples, and 2 ppb for water samples (*20*).

Statistical analysis. Statistical analyses were conducted using SAS software (*21*). We calculated geometric mean BPb levels by taking the antilog of the mean of $\log_e$ of the measured lead values. We constructed a scale for parental school education with 0 points for no school education to 3 points for college or higher school education. Both parents' points were combined to a score of 0–6. Low parental education was defined as a score less than or equal to the median of 2. We used generalized estimating equations (GEE) to determine the relation between elevated BPb levels and potential risk factors for lead poisoning while controlling for sex and age. GEE models allowed us to account for the correlation of observations among children in the same school. Independent variables in the final models were parental education, close proximity of home to highway or intersection of major roads, and soil-eating behavior of the child. Sucking on fingers, toys, pencils, or other objects and exposure to metal containers, cosmetics, folk medicine, and occupational risks were also examined but not included in the final models because they did not significantly add to the fit of the models.

Results

A total of 779 students participated in the survey, corresponding to approximately 60% of the total number of students eligible to participate in the five schools. Sex and age distributions varied considerably across schools because Mohammadpur is a girls' school and Nawabpur is a boys' school (Table 1). Almost 90% of the children had BPb levels ≥ 10 µg/dL; 50% had BPb levels ≥ 15 µg/dL; and about 20% had had BPb levels ≥ 20 µg/dL (Table 2). The overall geometric mean BPb level was 15.0 µg/dL (range 4.2–63.1 µg/dL). Geometric mean BPb levels differed significantly across schools ($p < 0.0001$). We retested 10 children with BPb levels measurements > 30 µg/dL. In 4 of the 10 children (40%), the second measurement was 17.0 to ≥ 43.1 µg/dL lower than the first, but all remained > 20 µg/dL; among those with lower second measurements were two children with first measurements of ≥ 65 µg/dL. Venous blood samples instead of a second microcapillary sample were taken from one primary school student and two members of his family that lived above a print supply shop where the father was employed. All tested ≥ 65 µg/dL by the LeadCare instrument. Venous blood samples were analyzed at the CDC laboratory. BPb levels were 63.1 µg/dL (student), 69.2 µg/dL (brother), and 91.9 µg/dL (father).

Table 3 presents odds ratios (OR) and 95% confidence intervals (CI) for risk factors associated with BPb levels ≥ 10 µg/dL. Of the 10 associations examined, age, low parental education, close proximity of home to highway or intersection of major roads, and soil-eating behavior of the child showed positive associations for both crude and adjusted data. Male sex was not a predictor for elevated BPb levels.

We collected soil and water samples from all schools except Ambar, and from 11 of 27 (41%) homes of children with BPb levels > 30 µg/dL. We collected dust samples from Rajdhani and Nawabpur Schools and from six homes. Paint samples were collected only in Khilgaon School and in three homes

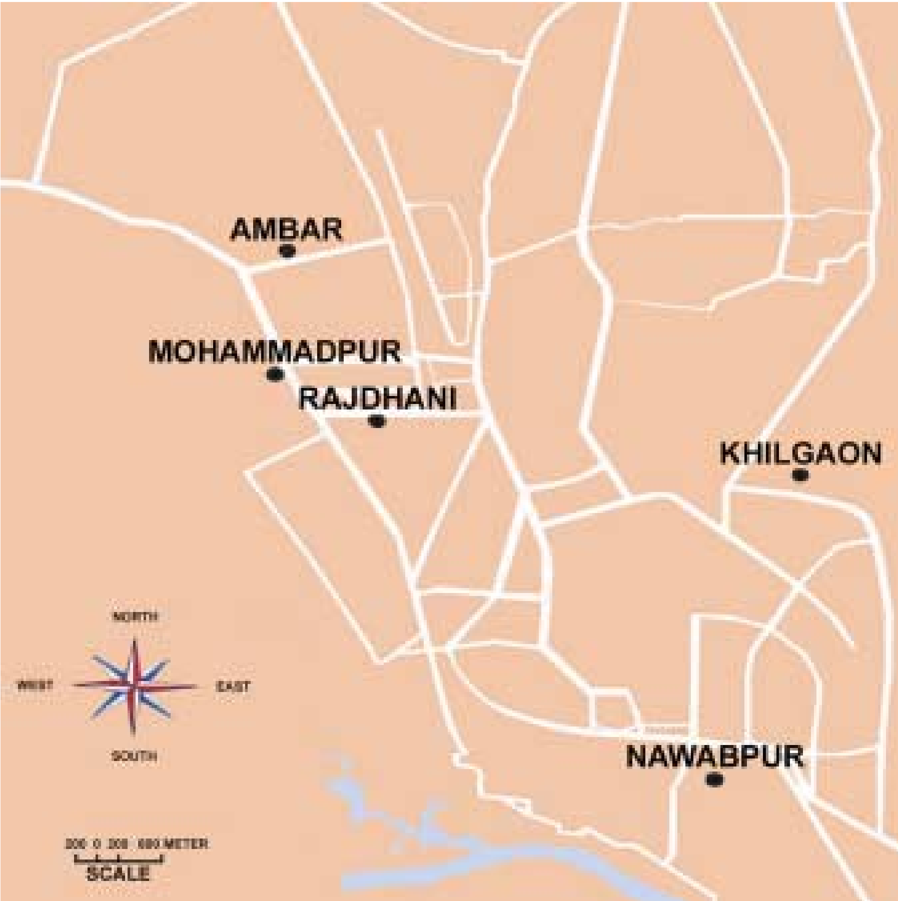

Figure 1. Primary schools in Dhaka, Bangladesh, that participated in blood lead survey.

because most walls were white-washed or consisted of bamboo, paper, or other materials that were not painted. All environmental samples from schools contained lead levels within U.S. standards [400 ppm for soil; 100 µg/ft^2 for dust; 5,000 ppm for paint; 15 ppm for water (*22*)]. Lead levels in environmental samples were as follows: soil samples (n = 4) all below level of detection (LOD); dust samples (n = 7), median 49 µg/ft^2, range 53–83 µg/ft^2; water samples (n = 5) ≤ 2 ppb; and paint sample (n =1) below LOD. Quantitative samples from 2 of 11 (18%) homes exceeded the U.S. standards. Soil and dust samples from the home of a child attending Mohammadpur School showed levels of 429 ppm and 123 ppm, respectively. The child had an elevated BPb level of 31.1 µg/dL. We could not identify a point source of lead exposure in the home or in the neighborhood. In the second home where standards were exceeded (soil samples 9,070 ppm and 429 ppm), print letters produced in a print supply shop tested qualitatively positive for lead. In another home, we found that a can used to store rice contained lead. All other qualitative tests on kitchen utensils, cookware, food container, and toys were negative.

Discussion

Almost 90% of primary school children tested in Dhaka, Bangladesh, had BPb levels that can affect their development and learning abilities. Low levels of parental education, close proximity of home to highway or intersection of major roads, and soil eating by the child were identified as risk factors for BPb levels > 10 µg/dL. Increasing age was a significant risk factor for elevated BPb levels, and male sex was not associated with elevated BPb levels.

Low parental education levels and living in a home near a highway or intersection of major roads may represent differences in sociodemographic status of the child. The construction type and location of buildings and varying levels of hygiene in low sociodemographic status areas in Dhaka are likely to increase exposure to lead in soil and dust and to make it more difficult to keep these buildings clean. Disparities in environmental lead exposure as a result of income or geographic location are well documented internationally (*23*).

Increased age as a risk factor for elevated BPb levels among children 4–12 years of age has not been reported from many countries. We identified one study from Mexico that confirmed our finding of a significant trend with increasing age from 4 to 10 years (*24*). In another study from Russia, little variation in lead levels by age was found (*19*). However, these results are in contrast with reports from the United States and Australia, where BPb levels are highest in 1- to 2-year-old children and decline at later ages (*23*,*25*). One possible explanation for this discrepancy in age trends is that factors that make younger children more susceptible to lead exposure [i.e., hand-to-mouth behavior, lead absorption physiology (*1*)] may be superseded by other risk behaviors such as increased outdoor activities or malnutrition. The fallout of lead oxides in dust in Dhaka, especially in the dry season, is likely to be continuous and ubiquitous, affecting boys and girls to the same extent. The dust may be inhaled and deposited on all surfaces where children can be exposed, including toys, eating utensils, and food. Soil used to grow crops and feed livestock and soil in gardens and children's playgrounds can also be contaminated (*1*). In Dhaka, dust and soil samples from schools and from children's homes showed lead contamination. Although most lead levels did not exceed the U.S. standards, they may pose a substantial health threat because of the multiple potential sources of exposure in Dhaka. In addition, micronutrient malnutrition, which is extremely severe in Bangladesh (*26*), may predispose children to increased lead absorption and toxicity (*27*).

Representativeness was a major limitation of our study. Surveyed schools were not randomly selected. Within schools, recruitment of children depended on attendance and parental consent. Daily attendance rates varied among selected schools. In addition, schoolmasters estimated that only 60–80% of appropriately aged children ever attend school. Therefore, some primary school-aged children at high risk for lead poisoning may not have been included in our sample. We do not have information about sociodemographic characteristics of children who did not participate to enable us to compare participants with nonparticipants. However, the selected schools represented a spectrum of geographic and socioeconomic strata, and the true mean geographic BPb levels of 4- to 12-year-old children is likely to be within the range found of 12.3–17.5 µg/dL.

Our study had other limitations. Our sample size may not have allowed detection of small associations between exposure sources and elevated BPb levels. Finally, we may not have included all potential exposure sources in the questionnaire. For instance, we did not ask about parents' smoking habits (*25*).

Given the high lead levels in air in Dhaka, the consistently elevated BPb levels

Table 1. Demographic characteristics of children who participated in the survey of blood lead levels by school, sex, and age, Dhaka, Bangladesh, February 2000.

	Number (%)					
	Mohammadpur	Rajdhani	Nawabpur	Khilgaon	Ambar	Total
Total	240 (100)*	57 (100)	117 (100)	216 (100)	149 (100)	779 (100)
Sex						
Male	14 (5.8)	25 (43.9)	116 (99.1)	88 (41.3)	78 (52.3)	321 (41.4)
Female	226 (94.2)	32 (56.1)	1 (0.9)	125 (58.7)	71 (47.7)	455 (58.6)
Age (years)						
4–6	19 (7.9)	13 (22.8)	8 (6.8)	12 (5.6)	42 (28.2)	94 (12.1)
7–9	136 (56.7)	29 (50.9)	55 (47.0)	125 (57.9)	49 (32.9)	394 (50.6)
10–12	85 (35.4)	15 (26.3)	54 (46.2)	79 (36.6)	58 (38.9)	291 (37.4)

*Rounding may yield > 100%.

Table 2. Percentage of children at or above selected BPb levels and geometric mean BPb level, by school, Dhaka, Bangladesh, February 2000.

	Number (%)					
BPb	Mohammadpur	Rajdhani	Nawabpur	Khilgaon	Ambar	Total
Total	240 (100)	57 (100)	117 (100)	216 (100)	149 (100)	779 (100)
≥ 10 µg/dL	181 (75.4)	50 (87.7)	106 (90.6)	202 (93.5)	143 (96.0)	682 (87.5)
≥ 15 µg/dL	76 (31.7)	25 (43.9)	68 (58.1)	143 (66.2)	104 (69.8)	416 (53.4)
≥ 20 µg/dL	19 (7.9)	7 (12.3)	29 (24.1)	66 (30.6)	49 (32.9)	170 (21.8)
Geometric mean*	12.3	14.3	15.4	16.7	17.5	15.0

*Geometric mean BPb level differed significantly by school (p < 0.001).

Table 3. Risk factors associated with elevated BPb level (≥ 10 µg/dL) in primary school children, Dhaka, Bangladesh, February 2000.

Variable	With elevated BPb	Without elevated BPb	Crude OR (95% CI)	Adjusted OR (95% CI)
Low education, *n* (%)	341 (61.2)	20 (25.0)	3.71 (1.94–7.09)	2.72 (1.97–3.75)
Eating soil, *n* (%)	110 (22.1)	2 (3.3)	3.73 (2.38–5.84)	3.31 (1.30–8.39)
House near highway or large intersection, *n* (%)	285 (66.7)	19 (35.9)	2.32 (1.62–3.33)	2.30 (1.23–4.29)
Male, *n* (%)	296 (43.7)	24 (24.7)	1.35 (0.79–2.31)	0.90 (0.64–1.27)
Age, median (range)	9 (4–12)	9 (5–11)	1.14 (1.06–1.22)	1.11 (1.06–1.16)

CI, confidence interval.

in sampled children, the absence of point sources, and the association with living close to major roads, we conclude that combustion of leaded gasoline is probably the main source of lead exposure in Dhaka, leading to universal contamination of the environment. Also, the mean BPb level in our study was consistent with previously reported levels from countries using leaded gasoline (*1*,*2*). The government of Bangladesh adopted a policy to ban the sale of leaded gasoline. At the time of the survey, however, leaded gasoline was still sold at gasoline stations in Dhaka. In countries that plan to phase out leaded gasoline, baseline BPb level surveys are critical to develop and evaluate intervention policies (*28*). International experience shows that substantially decreasing lead levels in the environment after lead is removed from gasoline will take years (*2*,*28*). Our survey indicates that strategies to reduce BPb levels in children need to address variations in socioeconomic status, construction type and location of housing, and levels of hygiene. We recommend an increase in public awareness about lead poisoning and education of families about improved hygiene at home. Possible interventions include providing soap and water for schools and homes, frequently washing hands and face, thoroughly cleaning fruit and vegetables, and keeping dust on floors and furniture as limited as possible (*29*). Children should be educated not to suck on their fingers, pencils, or toys or to eat soil. We also recommend that the clinical and laboratory capacity in Dhaka be improved to measure lead in blood and environmental matrices and that a follow-up BPb level survey be conducted after lead has been removed from gasoline.

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