CHILDREN'S HEALTH
Articles

Methods of Exposure Assessment: Lead-Contaminated Dust in Philadelphia Schools

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This study was conducted to develop a method that would accurately assess children's exposure to lead in schools in Philadelphia, Pennsylvania. We examined three wipe sample protocols: one included accessible surfaces such as desktops and windowsills, the second included inaccessible surfaces such as the top of filing cabinets and light fixtures, and the third included hand wipes of the study participants. Surface wipes were collected at 10 locations from accessible and inaccessible classroom surfaces (n = 11 at each location) and from the palms of student subjects in the same locations (n = 168). We found a significant difference in lead dust concentrations determined by the three protocols (F = 4.619; 2,27 degrees of freedom; p = 0.019). Lead dust concentrations were significantly elevated at the inaccessible surfaces yet they were uniformly low on the accessible surfaces and the children's palms. These findings were consistent with observed changes in blood lead levels of study participants: after 6 months of exposure to the study locations, 156 of 168 children experienced no change in blood lead level, whereas 12 experienced only a minimal change of 1–2 µg/dL. The mere presence of lead in inaccessible dust in the school environment does not automatically constitute a health hazard because there may not be a completed exposure pathway. ***Key words*: children, dust, lead poisoning, sampling, school, screening. *Environ Health Perspect* 108:663–666 (2000). [Online 6 June 2000]**
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Considerable efforts have been made to reduce the exposure of children to lead in the environment, yet such exposure still occurs, primarily in urban settings. In many cities, including Baltimore, Maryland (*1*,*2*), Boston, Massachusetts (*3*), Duluth, Minnesota (*4*), and Philadelphia, Pennsylvania, (*5*) a high percentage of child blood lead (PbB) levels exceed the recommended Centers for Disease Control and Prevention intervention level of 10 µg/dL. The source of lead in these contamination scenarios is often correlated with the presence of lead-based paint, although soil and atmospheric deposition are important sources as well (*6*,*7*).

Lead uptake in children is strongly correlated with the age and condition of their housing and socioeconomic factors (*1*,*3*). Lead-based paint in poor condition will peel and flake, producing chips and dust, which become the primary sources of exposure for young children (*8*,*9*). Although this source is easily recognized and can be quickly controlled, fine dust fractions (particle sizes < 10 µm) can contain significantly greater lead concentrations than the more coarse fractions (*10*). The smaller fractions are more difficult to control and represent an important component of exposure.

The preschool child is at significant risk of exposure to lead because he or she engages in mouthing activities that can result in the ingestion of lead-contaminated dust (*11*). The Philadelphia school district has only five buildings constructed after 1970 and surveys have shown that most of the district's buildings have lead-based paint. Head Start programs are located in buildings containing lead-based paint and children may spend as many as 8 hr/day in these buildings. U.S. Department of Housing and Urban Development guidelines (*12*) are followed and abatement is conducted in all schools that house elementary grades and Head Start programs. However, this may not be enough; evidence suggests that in many cases abatement does not significantly reduce PbB levels (*2*). Often, lead in soil dust and road dust is a more significant contributor to total dust lead levels than are the paint dust sources (*10*).

Before this study, grab sample collection protocols in Philadelphia schools focused on surfaces where dust collects, regardless of whether these sites represent potential exposure points. Often, the leap from "presence of lead-contaminated dust" to "assumed exposure of children" was made by school officials, with little examination of probability of actual intake or routes of entry. Lead absorption can only occur when there is a completed exposure pathway such as inhalation or ingestion of contaminated dust or ingestion of paint chips. Any grab sample program is limited in interpretation to a single point in time, yet results from sample collection protocols designed merely to assess the worst-case presence of lead contaminated dust cannot be used to realistically predict exposure. Our study examined the fate of lead in the school environment and assessed the actual exposure of children to lead-contaminated dust. We developed three grab sample protocols to assess lead exposure.

Methods

Experimental design. The Philadelphia school district consists of numerous buildings; of these, more than 40 school buildings in the district house Head Start programs. We chose 10 classrooms in five buildings located throughout the city. To qualify, each building showed the confirmed presence of lead-based paint (using X-ray fluorescent analysis) and must have housed the Head Start program for at least 2 years. Classrooms chosen for the study were not carpeted, but each room had a small area rug used for storytelling activities. Floor-wipe samples were collected on hard surfaces only.

We focused our study on children in Head Start programs because they represent the age group (younger than 6 years old) that is most susceptible to the deleterious effects of lead poisoning (*11*). Children were included in the study (n = 168) if they had been enrolled in a Head Start program for at least 1 full year at the same school, had determinations of PbB before entry into the program, and had follow-up determinations no less than 6 months after Head Start enrollment. The income level of families was uniformly low for all participants. The school district of Philadelphia report for 1996 (*13*) indicated that a range of 82.1–96.2% (South Philadelphia High School and Belmont Elementary, respectively) of pupils came from low-income families.

The potential offsite exposure to lead of each child could be an important confounding

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factor in assessing the relationship between test subjects and their exposure to lead in a preschool facility. For this reason, parents of the subject children completed a simple three-question yes-or-no survey to identify possible home sources of lead. The survey asked three questions. First, "Within the past 6 months, have you done any work in your home that involved scraping or sanding paint?" Second, "Does anyone in your family work in an occupation involving exposure to lead (for example, a battery factory)?" Third, "Is anyone in your family involved in a hobby that uses lead (for example, making your own fishing weights)?" Of the 97 replies received (rate of return = 58%), none indicated significant lead sources from renovation work, home hobbies, or parental occupation. Based on these replies, no potential participants were disqualified from the study.

We developed three surface-sampling protocols. The first included only inaccessible surfaces and represented a worst-case situation, although the probability of actual exposure was low. The second protocol included accessible surfaces and was designed to represent a high probability of exposure. The third protocol consisted of actual hand wipes of children and represented the final environmental stage before an ingestion exposure could occur. We collected hand wipes between 1030 and 1145 hr to ensure adequate contact time with accessible surfaces at the study sites while precluding any hand washing before the children's lunch. Inaccessible surfaces included the tops of lights (n = 2), tops of storage cabinets (n = 3), tops of bulletin boards (n = 2), tops of chalkboards (n = 1), and tops of file cabinets (n = 3). Accessible surfaces included desktops (n = 2), floors (n = 2), books (n = 2), toys (n = 2), windowsills (n = 2), and doorknobs (n = 1).

Analytical methods. All samples were collected 12–13 February 1997. We used National Institute for Occupational Safety and Health (NIOSH) method 9100 (*14*) to collect all surface-wipe samples. In brief, the method is as follows: Disposable wipes were folded into 5 cm × 5 cm squares and sealed into zippered plastics bags before sample collection. The wipes were consistently handled with new latex gloves that were changed between samples. After collection, the wipes were replaced in the bags and shipped for analysis by acid digestion and atomic absorption spectrometry according to NIOSH methods 7082 (*15*) or 7105 (*16*).

Solid surfaces. We placed a disposable 30 cm × 30 cm square template over the surface and collected wipes using four firm "S" strokes in each horizontal and vertical direction.

Children's palms. Children were asked to hold their hands palms-up in front of them. Using a clean wipe for each hand, we wiped the total area of each palm and placed the two wipes in a single bag for analysis. Hand areas were estimated by sketching the outlines of the children's hands. Sample times were restricted to between 1030 and 1145 hr to ensure adequate contact time with contaminated surfaces and precede any hand-washing for lunch.

PbB. We collected venous samples from children before admission to the Head Start program and after at least 6 months of attendance in one of the test buildings. All samples were analyzed using established Philadelphia Department of Public Health protocols (*17*). Reported results are changes in PbB: levels after minus levels before.

Soil and drinking water lead. We collected soil samples at all five of the schools in an effort to characterize the soil as a source of lead in school dust. Children had direct access to the soil at only two of the five sites. We used U.S. Environmental Protection Agency (EPA) method 3050B (*18*) for sample collection and analysis. Additionally, water from drinking water fountains at all 10 sites was collected and analyzed by standard method 3500-PbB (*19*) to assess this potential source.

Results and Discussion

Sources. Lead is ubiquitous in the urban environment despite years of public effort to control its use and release. Our conceptual model (Figure 1) attempts to describe the sources and fate of lead as it moves through the urban school environment. We propose that the major solid phase sources in older buildings are lead-based paint and soil. Paint exposures occur through the ingestion of either intact chips or paint-contaminated dust on hands or mouthed objects. None of the test sites contained paint chips, but dust was present at all sites.

Outside soil may be the major contributor to the total concentration of lead in dusts (*6,7*); soil lead values for the five school sites are given in Table 1. It is impossible in any simple dust-sampling protocol to differentiate between sources; this model refers to the combined source as room dust. Adgate et al. (*10*) attributed two-thirds of the lead in New Jersey house dust to crustal (soil and street) sources and atmospheric deposition, with the remaining third coming from interior lead-based paint sources. In our study there was no overall correlation between soil lead concentration and interior dust lead concentration ($p = 0.328$). However, Jackson Elementary School had both the highest soil lead concentration (7,800 mg/kg) and the highest dust lead concentration (1,134 μg/ft^2 on an inaccessible surface). Fortunately, children have no direct access to this highly contaminated soil and accessible surface lead levels were uniformly low.

The efficacy of routine room cleaning is a critical element in the prevention of exposure to lead. At each test site, accessible surfaces were cleaned on a regular basis, whereas inaccessible surfaces were not. Cleaning activities for accessible surfaces were also very similar among the 10 study locations. All

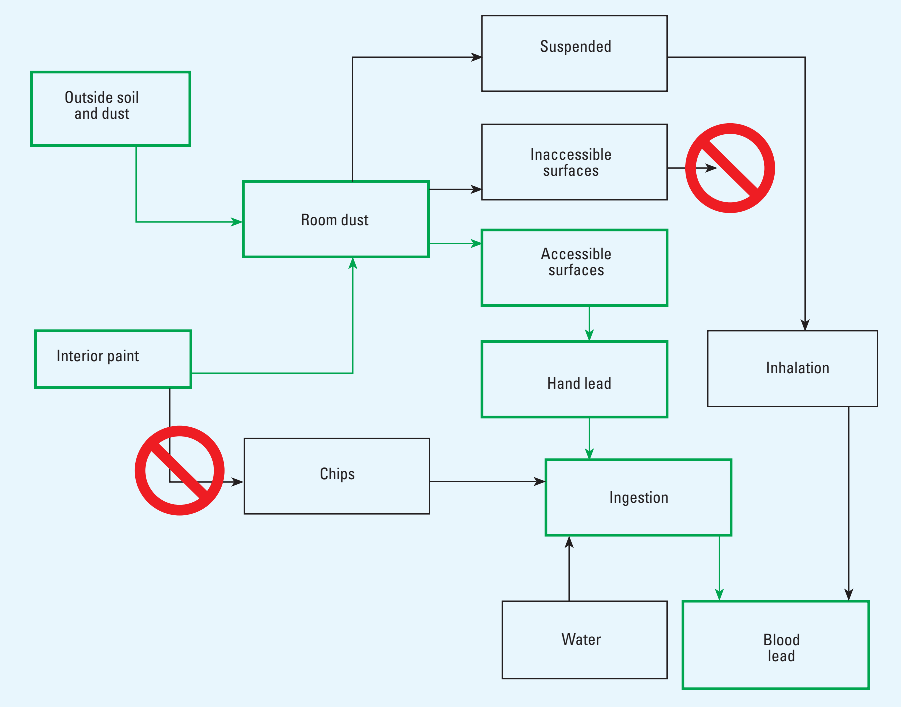

Figure 1. A model of lead exposure in the school environment. The major presumed pathway is shown in green. The slash/circle symbol represents improbable or controlled access pathways.

accessible surfaces, except for toys and books, were cleaned with a soap and water mixture after the children had left for the day. Desk surfaces, windowsills, and doorknobs were cleaned first as one component; the floor surface was cleaned last as a separate component. We did not observe cleaning activities for inaccessible surfaces during any site visit for any of the study locations.

Other potential sources include drinking water, particularly where coolers using lead-soldered joints are found. None of the drinking water fountains contained lead levels above the EPA maximum contaminant level of 15 µg/L (*20*), as shown in Table 1. We did not consider this a significant source.

Surveys sent home and returned (n = 97 of 168) indicated no known home exposures to lead from renovation activities, home hobbies, or parental occupation, eliminating as much as possible the outside source factor.

Fate. Once the lead-based paint or lead-contaminated soil leaves the point of origin it is most easily transported by the heating, ventilation, and air conditioning system as a fine dust, depositing wherever air circulation patterns are most stagnant. Dust settles on surfaces that are accessible to children, but these surfaces are routinely washed and may not accumulate appreciable amounts of lead. Inaccessible surfaces are not routinely cleaned, however, and although these may provide a good indicator of the loading of lead contamination to the building (thus their selection in most sampling protocols), they do not accurately indicate exposure potential. We evaluated three protocols designed to assess the fate of lead contaminated dust in Philadelphia schools. Results of sampling using the various protocols are given in Table 1.

In the first protocol only inaccessible surfaces were sampled, and, as expected, they showed the most contamination (range 60–1,134 µg/ft^2, mean = 232 µg/ft^2). This level of contamination falls between the EPA recommendations of 50 µg/ft^2 for uncarpeted floors and 250 µg/ft^2 for interior windowsills (*21*). We observed behavioral controls such as restrictions on climbing and throwing of objects, as well as other unacceptable classroom activities that limit a child's potential exposure to dust found at inaccessible sites; therefore it is reasonable to conclude that the children have no exposure to the settled dust. Hand-to-mouth transport of lead-contaminated dust, the primary route of entry (*6,12*), cannot occur at inaccessible surfaces. An important point to consider, however, is that nonroutine events such as moving of filing cabinets or replacing light fixtures may mobilize lead-contaminated dust. For this reason, cleaning activities should closely follow these events to minimize potential exposure. Despite this possibility, there was no significant correlation between lead dust concentrations on accessible surfaces and those on inaccessible surfaces (p = 0.65).

In the second protocol, we sampled only accessible surfaces. Based on the results of our sampling (range 6–66 µg/ft^2, mean = 13 µg/ft^2), the cleaning of these surfaces appears to be effective at reducing dust lead levels to below acceptable values for carpeted and bare floors. These results also indicate that Philadelphia school site dust lead levels are well below the acceptable levels for windowsills and wells. Current cleaning practices provide an acceptable degree of exposure prevention.

Receptors. In the third protocol, we attempted to move past the source term toward the receptor. Following the assumption that most exposure results from mouthing behavior (including the hands) and subsequent ingestion of lead-contaminated dust, we examined the palms of children. Means by classroom ranged from 5 to 11 µg/ft^2, as shown in Table 1. The highest palm lead value was observed for only one classroom at the Jackson Elementary School, where inaccessible dust lead and outside soil lead were the most contaminated. For all other students, however, the risk of ingesting lead from contaminated hands is uniformly low. Palm lead levels were not correlated to accessible dust lead levels (p = 0.71).

A single-factor analysis of variance and a post hoc analysis using Tukey's multiple comparison test showed that the accessible surface and palm wipe protocols were uniformly low and not significantly different from each other. The inaccessible surface protocol yielded significantly higher numbers and was different from the other two protocols (p = 0.02). Obviously, the choice of protocol can have a significant effect on the results. We believe that any sample collection method used should best match the desired outcome and that if actual exposure potential for children is to be determined, then the worst-case inaccessible surface protocol is misleading.

Blood is most frequently used as the receptor tissue to demonstrate lead poisoning. In 1991, the Centers for Disease Control and Prevention estimated that over 2.3 million American children had PbB levels in excess of the established safe levels of 10 µg/dL (*6*). Our study showed that 28% of the children entered the preschool programs with PbB levels at or above the 10 µg/dL level—an alarming rate. The preexposure PbB levels of the test population are shown in Table 2, and changes in test subjects' PbB over at least 6 months of exposure are shown in Figure 2. Most of the children (110 of 168, or 65%) showed either no change or a slight decrease

Table 1. Potential sources of lead contamination for children attending Head Start programs in Philadelphia schools.

	Surface (dust) lead (µg/ft^2)				
School, room	Inaccessible surfaces[a]	Accessible surfaces[a]	Children's palms[b]	Soil lead (mg/kg)[c]	Drinking water lead (µg/L)[d]
McMichael				985	
Room 108	107	66	5		10
Room 110	67	7	5		11
South Philadelphia High				135	
Room 201	84	10	5		9
Room 202	114	10	5		6
Jackson				7,800	
Room 103	216	7	5		3
Room 104	1,134	6	11		12
Belmont				270	
Room 115	134	5	5		2
Room 116	325	7	5		4
West Philadelphia				240	
Field house 1	60	6	5		7
Field house 2	79	6	5		7

FH, field house.

[a] Mean value, n = 11 per site. [b] Mean values for all children in room; n varies from 15 to 20 per room. [c] Mean value associated with site, n = 2 per site. [d] Single value per site.

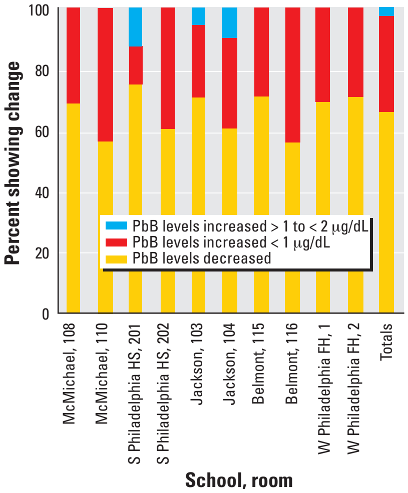

Figure 2. Changes in children's BPb level after 6 months of attendance in Philadelphia schools. Abbreviations: FH, field house; HS, high school.

Table 2. PbB statistics for study participants in Philadelphia preschool programs.

School, room	No.	PbB (μg/dL) Median, before entry into program	Median, after entry into program	Maximum during study	Minimum during study	Participants with PbB ≥ 10 μg/dL, *n* (%) Before classroom exposure	After classroom exposure
McMichael, 108	16	8	8	24	5	5 (31)	5 (31)
McMichael, 110	16	9	9	16	6	4 (25)	7 (44)[a]
South Philadelphia High, 201	16	5	5	9	1	0 (0)	0 (0)
South Philadelphia High, 202	15	4	4	7	1	0 (0)	0 (0)
Jackson, 103	17	6	6	15	2	1 (6)	1 (6)
Jackson, 104	20	6	6	10	2	1 (5)	0 (0)
Belmont, 115	17	8	8	27	6	4 (24)	4 (24)
Belmont, 116	18	8	8	22	4	4 (22)	4 (22)
West Philadelphia FH, 1	16	9	9	24	7	5 (31)	5 (31)
West Philadelphia FH, 2	17	8	9	14	4	4 (23)	4 (23)
Overall	168	8	8	27	1	28 (17)	30 (18)

FH, field house.

[a] All three of the increases noted here are attributable to changes in PbB from 9 to 10 μg/dL.

in PbB levels over 6 months of exposure to the test classrooms; 53 of 168, or 32%, showed a < 1-μg/dL increase and only 5 of 168 (3%) showed an increase of 1–2 μg/dL. Based on a paired-comparison *t*-test, none of the differences in pre- versus postprogram entry PbB levels were significant ($p = 0.84$).

Unfortunately, the relationship between exposure and PbB is not linear (*22*). In a test of four PbB collection methods, Sterling et al. (*23*) reported that correlation between dust lead and PbB levels using a wipe method was one of the strongest, but it was relatively poor ($R^2 = 0.25$, $p = 0.002$). We made no quantitative attempt to correlate the change in our test subjects' PbB levels to any of the wipe protocol measurements because the results from the accessible surface and hand palm protocols yielded uniformly low levels of lead contamination. Changes in PbB were also consistently low, so there was insufficient distribution to create a reliable regression. Only the inaccessible surfaces protocol yielded high levels of contamination. Our findings support the presumed pathway of hand-to-mouth activity as the major means of lead exposure in preschool age children.

Conclusions

Concentrations of lead in schoolyard soil and dust in inaccessible building locations are highly variable, yet they indicate a significant potential source of lead in Philadelphia schools. Sampling protocols designed to provide worst-case estimates of contamination are successful in finding those extreme values. The distribution of lead on accessible surfaces in Philadelphia school classrooms, where children spend a considerable portion of their waking hours, is uniformly low. Current cleaning procedures seem to be effective at keeping contaminated dust away from children.

The distribution of lead on children's palms, the contact point nearest to actual exposure, is uniformly low with the exception of one site, where outside soil lead concentrations were unusually high.

Most of the children in the study experienced no elevation of blood lead concentration after 6 months of exposure to dust and soil in the schools, despite high levels on some inaccessible surfaces and in outdoor soils. We conclude that there is no completed exposure pathway for lead from the most-contaminated surfaces to the children in these schools.

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