Survey of Lead Exposure Around a Closed Lead Smelter

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ABSTRACT. *Objective.* **To test the hypothesis that elevated lead in soil is positively correlated with blood lead (BPb) levels in children in an urban population surrounding a closed lead smelter, a US Environmental Protection Agency Superfund clean-up site was surveyed.**

Method. **A total of 827 volunteers including 490 children under 6 years of age participated. A questionnaire was administered. Blood lead was determined as was lead content of samples of house dust, soil, paint, and water of the participants' homes.**

Results. **The arithmetic mean venous BPb in 490 children between 6 and 72 months of age was 6.9 μg/dL (0.33 μmol/L) range 0.7 to 40.2 μg/dL (0.03 to 1.94 μmol/L). The BPb of 78 (16%) children in this group was ≥ 10 μg/dL (0.48 μmol/L). Based on multiple regression modeling, lead in house dust accounted for 18% of the variance in BPb. Lead in paint together with the condition of the house were the main contributors to the dust lead variance (26%) with soil lead accounting for an additional 6%. Lead in paint alone accounted for 3% of the BPb variance. Lead in paint together with the condition of the house accounted for 12% of BPb variance, and lead in soil accounted for an additional 3%. Factors other than environmental lead such as education of parents, household income, and behavior were associated with BPb levels.**

Conclusions. **The mean BPb in children was below the present level of concern of the Centers for Disease Control and Prevention. Children with BPb of ≥ 10 μg/L (0.48 μmol/L) tended to live in poorly maintained older houses. Based on these findings lead in soil and paint in well-maintained homes contributed little to the lead exposure of children.** ***Pediatrics*** **1995;95:550–554;** ***lead exposure; lead smelter; survey; Superfund; lead paint.***

ABBREVIATIONS. EPA, Environmental Protection Agency; BPb, blood lead; CDC, Centers for Disease Control and Prevention; XRF, radiographic fluorescence analyzer; SAS, Statistical Analysis System.

Under the present "Superfund" law, the US Environmental Protection Agency (EPA) is not required to conduct health studies to determine whether a contaminated Superfund site should be remediated. The decision by EPA to take action is based on environmental data such as lead levels in soil and on theoretical calculations of risk and exposure. In the community where the study reported here was performed, many residents were not persuaded by the EPA calculations of risk, and others were concerned about their health. Both groups wanted to know whether the EPA risk assessment was realistic and demanded a "health study."

The industrial site, a closed lead smelter, is located in a mixed industrial and residential area in Granite City, IL. It is one of 41 National Priority List or Superfund hazardous waste sites in Illinois. Industrial lead operations began in 1895. Battery recycling began in the 1950s. The smelter was closed in 1983 and, in a preliminary site assessment in May 1983, it was estimated that 200 000 tons of lead waste were present at the site. Before the present study, the site had been evaluated by federal and state environmental and health agencies. Soil samples collected on the industrial site in 1988 contained lead in concentrations ranging from 1500 to 48 000 ppm (mg/kg). Lead concentrations in samples from residential yards at varying distances from the site ranged from 106 to 9493 ppm (mg/kg). Ambient air lead levels taken from monitors closest to the site (when the smelter was active) regularly exceeded the 1.5 $\mu g/m^3$ National Ambient Air Quality Standard for lead. Air levels have not exceeded National Ambient Air Quality Standard since the smelter was closed.

In 1991, based on high soil lead levels, the US EPA proposed a clean-up area extending 0.8 to 1.0 km from the smelter. The present study was conducted to determine the blood lead (BPb) levels in the population residing within and outside this area for another 3.2 km around the designated clean-up area. This report describes the blood lead levels in children between 6 months and 6 years of age.

METHODS

Study Population

A population census of the proposed National Priority List clean-up site and the surrounding area was conducted in July 1991 to identify all households with children under 6 years of age. The census included all residential units within the proposed Superfund clean-up site and an additional area extending 3.0 km in all directions from the border of the proposed Superfund clean-up site. A suitable comparison group that was not a continuum of the EPA proposed clean-up area could not be identified in the immediate urban area.

Trained census takers recorded age, gender, and length of residence of all household members for every residential unit in the defined area. Families with children under 6 years of age who had lived at their present address for at least 90 days were invited to participate in the study.

All adult members of the participating households signed

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Southern Illinois School of Medicine approved consent forms giving permission for themselves and/or their minor children to provide venous blood specimens, to measure lead in soil, house dust, water, and paint from the residence and for a detailed interview of the head of the household. Blood was collected at the local hospital by trained pediatric phlebotomists. The interviews were administered by a trained interviewer at a centrally located office using a precoded questionnaire. Questions were asked about the demographics of each household member; occupation, income and education of the parents; history of smoking for all household members; the behavior of the children, time at home and outdoors, play areas, number of weekly baths, and alternative lead exposures. Information about age of the house, presence of air conditioning, and recent repairs or renovations were also obtained. Interview information, blood specimens, and environmental samples were collected from August 22 to September 18, 1991. The teams collecting the environmental samples did not know the results of the BPb analyses.

Blood Sampling

The BPb analyses were performed by the Centers for Disease Control and Prevention (CDC) using a published method[1] with a limit of detection of 0.6 μg/dL (0.03 μmol/L). Duplicate samples and quality control samples were also collected and analyzed. Within 1 week following the blood specimen collections, soil, house dust, and drinking water samples were collected from each residence, and in situ paint analyses were performed. All environmental sampling and analyses were performed by EPA-paid trained contractors.

Soil Sampling and Analysis

The yards around the houses were very small. Play areas were identified on each property. At least 10 locations were sampled with a corer of no less than 2 aliquots per location at a depth of 1 inch (2.54 cm) and composited. Debris and leafy vegetation was removed. Unless children played close to the house, soil samples were taken at least 1 foot (30 cm) from the house per story to avoid the drip line. Soil samples were analyzed by EPA method 6010 using inductively coupled argon plasma emission spectroscopy.[2] The limit of detection for lead in soil was ≥ 20 ppm (mg/kg). For the calculations one-half the limit of detection was used for nondetectable values. Only the dry weight soil lead levels are reported in this paper. Obvious chips of paint were removed from soil. Thirty-nine duplicate soil samples were analyzed.

Dust Sampling and Analysis

Interior surface dust was collected by using a Hoover brush vacuum cleaner, ⅓-horsepower, 2-amp motor. Dust samples consisted of a composite of at least three subsamples from an area adjacent to the main entrance, a floor area from the room most utilized by the study child, and a floor area of the child's bedroom. At least 1 m^2 per surface area was vacuumed three times. Dust samples were analyzed by EPA method 6010 using inductively coupled argon plasma emission spectroscopy.[2] The limit of detection for lead in house dust was ≤20 ppm (mg/kg). For the calculations, one-half the limit of detection was used for nondetectable values. To more accurately relate lead in dust to exposure a variable named "dust lead load" was calculated by dividing the dust sample weight by the surface area vacuumed and multiplying this ratio by the dust lead concentration.

Water Sampling and Analysis

The concentration of lead in tap water was determined in a first draw sample by graphite furnace atomic absorption.[3] The limit of detection for lead in drinking water was ≤2 ppb (μg/L); for the calculations one-half the limit of detection was used for nondetectable values.

Analysis of Paint

Lead in paint was determined in situ by a licensed contractor using a radiographic fluorescence analyzer. An XK-3 instrument manufactured by Princeton Gamma-Tech, Inc, was used. This instrument has a range of 0 to 10 mg of lead per cm^2. At each site three readings were made, and an average was calculated. In each room a reading was made on the woodwork and the painted wall. Up to 18 readings of walls and woodwork were taken from the main living area, the child's bedroom, and another frequently occupied area. Three readings/surface area for a total of 9 to 12 exterior readings were made on the front, back, and one side of the house. The XK-3 instruments measure lead paint concentrations up to 10 mg/cm^2. The amount of lead in paint above 10 mg/cm^2 was estimated by using the average weekly calibration time and dividing the test reading of 10 by the ratio of the time to obtain the reading over the average calibration time.

The condition of paint at the reading site was rated by the certified contractor for the inside of the house as intact = 1, slight peeling = 2, moderate peeling = 3, and extreme deterioration = 4. For the outside of the house three conditions were used: good = 1, fair = 2, and poor = 3.

For the XRF readings, the value 0.001 mg/cm^2 (one-half the limit of detection) was used for zero readings. Since intact paint is less likely to result in exposure, the XRF readings were transformed by multiplying each paint XRF reading by its surface condition C (C × XRF). An average was calculated over all condition × XRF readings per house separately for indoor and outdoor paint.

Ratings for the exterior condition of the house were missing for 59 houses (15%). The mean building condition score was assigned to these houses. Missing values for the building condition were not associated with any other variable.

Data Analysis Methods

Data from the census forms and the questionnaires were entered into electronic data files. Quality control was maintained by double entry of important data points.

Statistical analyses were done using the statistical analysis system (SAS) for the microcomputer.[4] Univariate statistics were performed using chi-square analyses for all categorical variables and two-tailed t tests for all continuous variables, both requiring a significance level of $P < .05$. A correlation matrix was calculated to determine what factors were associated with BPb as well as the degree of intercorrelation of independent variables. Blood lead values ≥ 10 μg/dL (0.48 μmol/L) were used to define the high BPb group for group comparisons. Positively skewed data were transformed to logarithms. Multiple regression and correlation modeling[5] was performed to identify variable(s) that predicted BPb, and to determine the independent influence of environmental lead measures on BPb.

RESULTS

Study Population

Based on the census questionnaires, 906 (17.6%) households had one or more children under 6 years of age who had lived at the residence for at least 3 months (Table 1). Of these households, 116 were disqualified because the family had moved or could not be contacted by phone, there were repeated visits to the home, inquiries to neighbors were made during the 3.5 weeks of the field study, or all children were >6 months or <6 years old at the time of the study. Thus, the final target population consisted of 790 households of which 355 households participated in the study (Table 1). A total of 266 (34%) households refused to participate, because they did not want to subject their child to a venipuncture or their children recently had had a BPb determination.

TABLE 1. Number of Households

	Number
Eligible households	906
Unable to contact	116
Final target population	790
Refused to participate	266
Missed appointments	169
Final household participation	355

Another 169 (21%) missed repeated appointments or could not be contacted to reschedule appointments. This resulted in an overall participation rate of 45% of those eligible.

The houses occupied by the participants and by families who refused to participate were scattered throughout the same neighborhood. To better relate distance from the closed smelter to the location of the participants' houses and the proposed EPA clean-up area, we created four regions roughly representing concentric circles around the closed smelter. Region I, a commercial area, was located closest to the smelter and contained few residences with 20 of 39 eligible families participating (51%). In the second concentric circle, Region II, 60% of the eligible households participated. In Region III, 53% of the households participated and 39% participated in the outer circle, Region IV. Region I extended roughly 0.8 to 1 km from the boundaries of the closed smelter in all directions. Regions II and III were also about 0.8 to 1 km in width. Region IV was 1.2 km wide.

Occasionally more than one family shared a household. A total of 230 families with one child, 106 families with two children, and 14 families with three or more children between 6 months and 72 months of age participated. Of the 101 non-white children under 6 years of age, 87% were African-American.

Blood Lead Levels

Results of BPb analyses are given in Table 2. The arithmetic mean BPb was 6.9 μg/dL (0.33 μmol/L), below the present CDC level of concern.[6] In the entire group of 490 children, 78 children (16%) had BPb levels of ≥ 10 μg/dL (0.48 μmol/L). Only 5 (1%) had BPb above the pre-1991 CDC level of concern of 25 μg/dL (1.21 μmol/L). The arithmetic mean age of all children under 6 years was 3.3 years, and the mean ages of the two groups of children with low and high blood lead levels were 3.2 and 3.3 years, respectively.

Among the 101 non-white children under 6 years of age, 19% had BPb ≥ 10 μg/dL. The arithmetic mean BPb of all white children <6 years was 6.8 μg/dL (0.32 μmol/L) and for the non-white children 7.4 μg/dL (0.35 μmol/L). There was no statistically significant difference in the mean BPb of these white and non-white children ($t = -1.1$, $P > .05$). The two groups were therefore combined in the analyses.

TABLE 2. Blood Lead Levels (BPb) in 6- to 72-Month-Old Children*

Total *N*	490
Males (%)	261 (53%)
Mean BPb	6.9 μg/dL (0.33 μmol/L) S.D (5.02)
Range	0.7–40.2 μg/dL (0.33–1.94 μmol/L)
Number	≥10.0 μg/dL (0.48 μmol/L) = 78 (16%)
	≥15 μg/dL (0.72 μmol/L) = 32 (7%)
	≥25 μg/dL (1.21 μmol/L) = 5 (1%)

* Eight children from five households with a mean BPb of7.1 μg/dL (0.34 μmol/L) had moved within their immediate neighborhood and had lived at their present residence slightly less than 3 months at the time of the study. The limit of detection for the blood lead analyses is <0.6 μg/DL (<0.03 μmol/L). The range of the means at 6-month age intervals for children with blood lead levels of ≥10 μg/dL (0.48 μmol/L) was 13.6 μg/dL (0.66 μmol/L) at 6 to 12 months to 18.2 μg/dL (0.88 μmol/L) at 36 to 42 months. The range of the means at 6-month age intervals for children with blood lead levels <10 μg/dL (0.48 μmol/L) was 4.3 μg/dL (0.21 μmol/L) at 6 to 12 months to 5.9 μg/dL (0.29 μmol/L) at 30 to 36 months.

Environmental Lead Measures

Mean lead levels measured in soil, house dust, drinking water, and paint of the houses are given in Table 3. The majority of houses in this study were built between 1900 and 1960. The lead levels in the paint of many houses reflect the use of leaded paint during that period.

Soil

The mean soil lead level for the 338 analyzed composite soil samples from participant yards was 449 ppm (mg/kg) with a range of 37 to 3010 ppm (mg/kg) (Table 3). The concentration of lead in 39 split soil samples ranged from 106 to 1610 ppm (mg/kg). The average difference between the primary and the duplicate sample was 89 ppm (mg/kg), not a statistically significant difference.

Dust

Lead levels for 334 house dust samples are given in Table 3. Blood lead levels of children under 6 years of age were highly correlated with the lead dust load (the concentration of lead in dust/m^2 of area vacuumed) ($r = 0.42$, $P < .0001$).

Drinking Water

Lead in drinking water from 336 households was below the limit of detection of 2 ppb (μg/L) in 62% of the samples and 97% of the samples had levels below 15 ppb (μg/L), the present EPA action level. In 13 instances, levels of lead in drinking water were higher with a range of 15.4 to 95.5 ppb (μg/L). None of the study participants using this water had elevated BPb. The correlation between the log water measure and log BPb was very low ($r = 0.07$, NS).

Home Repairs

Among families with children under 6 years of age whose blood lead levels were <10 μg/dL (0.48 μmol/L), 192 (48%) had done some repair work on their house in the last year. In contrast, 44 (63%) of the families whose children had blood lead levels ≥10 μg/dL (0.48 μmol/L) had done some repair work on their house in the year before the study, a statistically significant difference ($P < .02$). The information was missing for 17 households.

Factors Associated With Blood Lead Levels

At the univariate level the following factors were positively correlated ($P < .01$) with an increase in the BPb of children <6 years old: dust lead load and concentration; composite soil lead; cigarettes smoked in the house per day; hours of outdoor play; baths per week; indoor paint lead; and number of smokers in household. The BPb were negatively correlated ($P < .01$) with parents' education, distance from the closed smelter, and parents' income. The BPb in children <6 years old were likely to be higher when their residence was in poor condition, lacked air condi-

TABLE 3. Lead in Environmental Samples: Dry Soil Composite, Dust, Water, and Paint

Environmental Sample	*N*	Mean Lead	Minimum	Maximum	Standard Deviation
Soil (mg/kg; ppm)	338	449	37	3 010	420
Dust by weight (mg/kg; ppm)	334	1 299	5.2	71 000	5 239
Dust by surface (μg/m^2)*	331	956	1.6	58 800	4 722
Tap water (μg/L; ppb)	336	3.4	<2	96	8
Indoor paint (mg/cm^2)‡	337	1.2	0	10.4	1.6
Outdoor paint (mg/cm^2)‡	345	5.3	0	31.2	6.4

* The "dust lead load" was calculated by dividing the dust sample weight by the surface area vacuumed and multiplying this ratio by the dust lead concentration. Surface area was not recorded for three samples.

‡ The paint values represent means for 18 indoor and 9 to 12 outside readings. Readings of zero were included in the calculations.

tioning, was rented, was under repair during the last year, and was older ($P < .01$).

In addition to univariate associations to BPb, many of these factors were significantly ($P < .01$) correlated and associated with each other. For example, soil lead levels were positively correlated with dust lead load; indoor lead paint; cigarettes smoked in the house; and the age of the home. As parents' education and income improved children were more likely to have significantly ($P < .01$) lower BPb. Lead in soil was significantly and positively associated with renting versus owning; absence of air conditioning and a poor rating of the "condition of the house."

Condition of the house was significantly and positively associated with the number of cigarettes smoked in the house, indoor and outdoor paint lead, soil lead, water lead, and dust lead ($P < .01$).

Distance to the closed smelter was correlated with several factors in addition to BPb. The older houses were located closer to the smelter. As distance from the smelter increased, home ownership increased and lead in house dust decreased. The number of houses with air conditioning increased and the condition of the houses improved. Number of cigarettes smoked and the number of smokers per house, correlated negatively with distance from the smelter. Income and education of the parents improved with distance from the smelter. Thus, distance from the smelter was strongly associated with socioeconomic factors which may have contributed to the variation seen in BPb levels.

Multivariate Analysis

Multivariate analyses were conducted to determine the independent influence of environmental measures, and demographic and socioeconomic factors on BPb in children <6 years of age. However, BPb, while not well accounted for by any set of variables in this study, was significantly associated with more than a dozen study factors. The interpretation of these associations is complicated, because most of the variables associated with BPb are also associated with one another.

Lead in tap water, house paint lead, recent repair work, and building condition accounted for 12% of the BPb variance (adjusted $R^2 = 0.12$). When composite soil lead measures were added, the adjusted R^2 increased slightly to an adjusted $R^2 = 0.15$. Thus, only 3% of the variance in BPb observed in this population was accounted for by soil lead. The contribution of dust lead was assessed by multiple regression of BPb with log dust lead load, and demographic and behavioral variables. The R^2 for all factors was equal to 0.37. The log dust lead load if taken alone accounted for about half of that variance ($R^2 = 0.18$).

Indoor and outdoor paint lead, and the condition of the building, accounted for 26% of the variance in dust lead. When the composite soil data were added, R^2 increased to 0.32, an increase of 6% in dust lead variance. Thus, paint lead and building condition accounted for about four times as much variance in dust lead as soil lead.

DISCUSSION

Children under 6 years of age ingest lead primarily through dust, but they may also ingest lead-containing paint chips and soil. In addition, children will be exposed to lead through food, water, and air. How much lead a child will receive from these various sources depends on behavioral variables and the child's nutrition.[7]

A general decrease in BPb observed in the United States pediatric population in recent years[7,8] has resulted from the decreased use of leaded gasoline and concomitant lower air lead levels.[8] Lead in food has also been reduced.[9] In spite of high lead levels in soil and in indoor and outdoor paint, many children in our study also had very low BPb. Even the group with elevated BPb had mean BPb levels that 20 years ago were representative of small children of the general population and were mostly below the CDC level of concern of 25 μg/dL (1.21 μmol/L) in effect until October 1991.

Condition of the house, lead in paint, lead in dust, lead in soil, smoking of the parents, proximity to the closed smelter, education and income of the parents, and behavioral factors of the children predicted BPb in young children. Only about 37% of the variance could be accounted by the variables investigated in this study. Of the 37%, lead from soil made a very minor contribution, (an upper boundary of 3% of the variance) while the "condition of the house" and the amount of lead in paint were responsible for 11% of the variance. Weitzman et al.[10] recently demonstrated that removal of lead-contaminated soil around homes and interior loose paint removal resulted in a modest mean blood lead level decline of 2.44 μg/dL (0.12 μmol/L) within an 11-month period in children <6 years of age. Since the decline was so small, the authors stated that removing lead-contaminated soil is not a useful clinical intervention for the majority of urban children. Our results support these findings. Our data show that elevated BPb is encountered in poorly maintained houses with high lead paint, lead dust, and lead soil values. Simply correlating BPb to individual environmental sources (e.g., soil) is a misrepresentation of the data. Overall, the environmental lead measures per se did not account for most of the variation in BPb of the children. Other variables such as the "condition of the house" and housekeeping practices played a major role.

Improving the condition of homes and educating the parents and caretakers about personal hygiene such as washing hands and cutting fingernails short, house cleaning, and pathways of lead exposure appear to be effective in reducing slightly elevated BPb and should be studied further.[11]

Most of the important variables such as education and income of the parents, behavior, smoking, air conditioning, lead in paint, soil, and house dust were all highly correlated. Thus, correlations, *t* tests, and chi-square tests, if taken out of context, would be misleading. Very small, but statistically significant, differences of a few percent of the variance contributing to BPb are not of any apparent clinical importance. We attempted to determine by step-wise regression of 22 variables the overall contribution of these variables to lead exposure. However, as some variables were added to the analyses, other variables dropped out, and variables that had previously dropped out were in the regression again. This suggested that some variables were proxies for other variables and did not represent a meaningful contribution to the overall exposure of small children.

Multiple regression modeling of the relationship between soil lead and blood lead permits statistical control of potential confounders. However, statistical adjustment for possible confounding may result in "over-control," incorrectly eliminating true effects of the adjusted variable. For instance, house dust lead is a composite of paint and soil lead. Statistical control of the relationship of soil and blood lead for the effect of confounding by house dust lead could result in overadjustment. Furthermore, the mechanism relating blood and soil lead to such potential confounders as education, income, cigarette smoking, air conditioning, and home ownership is not well understood. We have, therefore, taken a cautious approach to statistical adjustment for possible confounding.

Parental cigarette smoking was positively correlated with BPb in young children. Other authors have reported that environmental tobacco smoke may contribute to BPb.[12] However, cigarette smoking also correlated with other BPb predictors. Furthermore, the number of cigarettes smoked per day and the number of smokers per household did not correlate with lead in house dust. The lack of an association between cigarettes and lead in house dust has also been reported by Willers et al.[13,14] Cigarette smoking was most likely a proxy for other risk factors for lead exposure such as education and socioeconomic status.

In conclusion, indiscriminate removal of leaded paint and soil in residential areas may have little or no practical benefit. A more targeted approach in which the condition of the houses, socioeconomic, and behavioral variables are also considered should prove more useful and realistic. Education of parents about pathways of exposure, consistent and adequate removal of house dust (cleaning), personal hygiene and good nutrition are important additional measures to reduce lead exposure in children.[11]

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REFERENCES

1. Miller DT, Paschal DC, Gunter EW, Stroud PE, D'Angelo J. Determination of lead in blood using electrothermal atomization atomic absorption spectrometry with a L'vov platform and matrix modifier. *Analyst.* 1987;112:1701–1704
2. EPA Test methods for evaluating solid wastes. Physical chemical methods. Office of Research and Development. *US EPA Manual S. W. 846 Rev. 1*; Dec. 1987, Washington, DC
3. Craun GF, McCabe LJ. Problems associated with metals in drinking water. *J Am Water Works Assoc.* 1975;67:593–599
4. *SAS/STAT User's Guide, Release 6.03 Edition.* Cary, NC: SAS Institute; Feb 1991
5. Cohen J, Cohen P. *Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences.* New York: L. Erlbaum Associates; 1975
6. Centers for Disease Control (CDC). *Preventing Lead Poisoning in Young Children.* Atlanta, GA: US Department of Health and Human Services, Public Health Service; October 1991
7. Agency for Toxic Substances and Disease Registry (ATSDR). *The Nature and Extent of Lead Poisoning in Children in the United States: A Report to Congress.* Atlanta, GA: ATSDR; 1988
8. Annest JL, Pinkle JL, Makuc D, Meese JW, Bayse DD, Kovar MG. Chronological trend in blood lead levels between 1976 and 1980. *N Engl J Med.* 1983;308:1373–1377
9. Bolger PM, Carington CD, Capar SG, Adams MA. Reduction in dietary lead exposure in the United States. *Chemical Speciation and Bioavailability.* 1991;3:31–36
10. Weitzman M, Aschengrau A, Bellinger D, Jones R, Hamlin JS, Beiser A. Lead-contaminated soil abatement and urban children's blood lead levels. *JAMA.* 1993;269:1647–1654
11. Kimbrough RD, LeVois M, Webb, DR. Management of children with slightly elevated blood lead levels. *Pediatrics.* 1994;93:188–191
12. Willers S, Schuetz A, Attewell R, Skerfving S. Relation between lead and cadmium in blood and the involuntary smoking of children. *Scand J Work Environ Health.* 1988;14:385–389
13. Willers S, Attewell R, Bensryd I, Schutz A, Skarping G, Vahter M. Exposure to environmental tobacco smoke in the household and urinary cotinine excretion, heavy metal retention and lung function. *Arch Environ Health.* 1992;47:357–363
14. Willers S, Hein HO, Schuetz A, Suadicani P, Gyntelberg F. Cadmium and lead levels in house dust from smokers' and non-smokers' homes related to nicotine levels. *Indoor Environ.* 1993;2:14–18