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Blood lead concentrations of Swedish preschool children in a community with high lead levels from mine waste in soil and dust

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BJERRE B, BERGLUND M, HARSBO K, HELLMAN B. Blood lead concentrations of Swedish preschool children in a community with high lead levels from mine waste in soil and dust. *Scand J Work Environ Health* 1993;19:154–61. The lead concentration in capillary blood was investigated in 49 preschool children (0.7–7.4 years of age) visiting a day-care center in a Swedish community with high lead contamination from mining and milling in soil and dust in populated areas [up to 1400 and 14 000 $\mu\text{g} \cdot \text{g}^{-1}$ (6.76 and 67.63 $\mu\text{mol} \cdot \text{g}^{-1}$) of dry weight, respectively]. The blood lead levels were examined twice (in April and in September) in 33 of the children. The lead levels were low on both sampling occasions [arithmetic mean 31 (SD 13, median 30, range 13–79) $\mu\text{g} \cdot \text{l}^{-1}$, ie, arithmetic mean 0.15, (SD 0.06, median 0.14, range 0.06–0.38) $\mu\text{mol} \cdot \text{l}^{-1}$]. Whereas children up to four years of age showed significantly increased levels from April to September, a significant decrease was seen in older children. The level of lead in soil at home, gender, smoking habits at home, and estimated level of hand-to-mouth activity did not appear as strong determinants of lead in blood. The results indicate that lead from mine waste in soil and dust fallout does not constitute a significant health hazard for preschool children in Falun.

Key terms: capillary blood, environmental lead, soil exposure.

Falun is a city in the middle of Sweden with about 50 000 inhabitants. For centuries the town has grown up around a thousand-year-old copper mine. The town is partly built on, and even by, mine deposits. There is some 10 000 t of lead in the waste dumps and residential fill materials scattered throughout the town area. Airborne dust from the mining and milling activities, various ore processing activities (eg, production of sulfuric acid), and extensive mine waste deposits have contributed to a significant metal contamination of the soil in the community. During some hundreds of years, until the 20th century, there were also extensive smelting activities in Falun.

Repeated measurements of lead in soil and dust fallout over the last few years have shown that the lead concentrations can be as high as 1400 $\mu\text{g} \cdot \text{g}^{-1}$ (6.76 $\mu\text{mol} \cdot \text{g}^{-1}$) of dry weight soil [geometric mean 362 (SD 2.3) $\mu\text{g} \cdot \text{g}^{-1}$, ie, geometric mean 1.75 (SD 0.01) $\mu\text{mol} \cdot \text{g}^{-1}$] and 14 000 $\mu\text{g} \cdot \text{g}^{-1}$ (67.63 $\mu\text{mol} \cdot \text{g}^{-1}$) of dust, in populated areas of the community. The

lead content in samples of soil taken at three different locations outside the city of Falun [geometric mean 119 (SD 1.6) $\mu\text{g} \cdot \text{g}^{-1}$, ie, geometric mean 0.57 (SD 0.01) $\mu\text{mol} \cdot \text{g}^{-1}$] was significantly lower ($P < 0.001$) than the mean lead content in the samples taken in the central areas of the community. Background values for lead in Swedish soils have been estimated to be 16 $\mu\text{g} \cdot \text{g}^{-1}$ (0.08 $\mu\text{mol} \cdot \text{g}^{-1}$) dry weight (1).

Young children have been identified as the particular group at risk in a general population continuously exposed to lead-contaminated soil and dust due to their normal hand-to-mouth activity and their greater susceptibility to and higher gastrointestinal absorption rate of lead (2–8). The principal sources of lead exposure differ between young children, older children, and adults. The younger children ingest more soil and dust than older children because of their more prominent hand-to-mouth activity. Blood lead levels have been shown to increase from about six months of age, peak at about one to four years of age, and thereafter decline with age (9–13).

Many organs may be adversely affected by lead. A major concern is its neurophysiological effects, typically manifested as deteriorated performances on various psychometric tests for cognitive functions or hyperactive behavior (14–19). Such effects have been observed at blood lead levels of 100–150 $\mu\text{g} \cdot \text{l}^{-1}$ (0.48–0.72 $\mu\text{mol} \cdot \text{l}^{-1}$) (7, 11, 20), and it has even been suggested that there is no distinct threshold for the adverse effect of lead on early cognitive development (20).

A theoretical risk assessment made specifically for the Falun area (Hellman; unpublished) was not able

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to exclude the possibility that blood lead levels were increased in certain infants living in heavily contaminated areas. Since this conclusion was in agreement with more general risk assessments made by others (21, 22), the present study was undertaken to determine the blood lead levels of a group of preschool children visiting a day-care center in Falun, where the lead content of soil and dust fallout is high.

Subjects and methods

Subjects

All children visiting a day-care center in Falun were offered the possibility to participate in a blood lead examination study through an invitation to their parents, who were also informed of the purposes of the study. The day-care center was the only one located in an area with notably high concentrations of lead in soil [about 1000 $\mu\text{g} \cdot \text{g}^{-1}$ (4.83 $\mu\text{mol} \cdot \text{g}^{-1}$ dry weight)]. Blood samples were taken from 49 children (0.7–7.4 years of age) whose parents had accepted their participation. Only one child of the 50 children at the day-care center did not participate in the study.

Questionnaire

Information on present and previous home addresses and the birth date of the children was obtained from questionnaires given to the parents. Furthermore, information was collected about passive smoking (ie, number of smokers and number of cigarettes smoked per day in the home) and other possible sources of lead exposure at home [ie, the children's estimated intake of food from tin cans (0, 1–2, or >2 times per week) or the presence of a hobby involving a potential use of lead, such as soldering, welding, or pottering. The hand-to-mouth activity of each child was estimated by the parents on the basis of questions on how often their child put things into their mouth (never, sometimes, or often), used a pacifier or sucked fingers (never, sometimes, or often), and ate snow or soil (never, sometimes, or often). Information about how much time (estimated) the children spent outdoors per day was also obtained from the parents.

Blood sampling

The first blood sample was taken in April 1991 when the ground was still covered with snow (for about

four months). The second sample was taken in September of the same year (ie, at the end of the summer season when the children could be expected to have been exposed to outdoor soil and dust fallout for at least five months). The number and gender of the preschool children participating in the blood sampling in April and September 1991 is given in table 1.

The average age of the youngest children (up to four years of age) donating blood was 2.5 (range 1.2–3.0) years in April and 2.4 (range 0.7–3.5) years in September. The corresponding figures for the older children was 5.3 (range 3.8–7.2) years in April and 5.6 (range 4.2–7.4) years in September. The decrease in average age in the youngest group was explained by the increased number of young children attending the day-care center after the summer season. Thirty-three of the children donated blood on two occasions. Blood samples from the remaining 16 children were, for reasons already indicated, taken only on one of the two sampling occasions (3 children in April and 13 children in September).

Capillary blood samples (500 μl) were taken from the left hand of each child by a trained nurse. The hand and fingers were carefully cleaned with the use of a brush, soap, and water, followed by 1% nitric acid, to avoid contamination of blood from the skin. Sterile mini lancets (Clean Chemical, Sweden AB, Stockholm, Sweden) were used for the finger puncture. Blood was collected in acid-washed Microvette CB 1000 (Sarstedt, Stockholm, Sweden) with 5 μl of ethylenediaminetetraacetic acid (0.15 g EDTA $\cdot$ ml $^{-1}$ water) added (1.5 mg EDTA $\cdot$ ml $^{-1}$ blood). All of the material used for sampling was tested for metal content. The samples were kept deep-frozen until the analysis.

Sampling of soil and dust

The latest soil lead analyses, commissioned by the Local Health Committee, were performed in 1991 in Falun. Lead concentrations were measured in the top soil from 48 locations in populated areas of the community. These areas were located at different directions and distances from the mine waste deposits. A sample comprised the humus layer of the top soil (0–5 cm). In 1991, dust samples were taken once a month at seven different locations in the populated

Table 1. Characterization of the study group in relation to age, gender, and blood sampling occasion.

Blood sampling occasion	Children ≤ 4 years of age			Children > 4 years of age			All children		
	Boys (N)	Girls (N)	Total (N)	Boys (N)	Girls (N)	Total (N)	Boys (N)	Girls (N)	Total (N)
April	7	4	11	17	8	25	24	12	36
September	12	7	19	19	8	27	31	15	46
Both April and September	6	4	10	16	7	23	22	11	33
Either April or September	13	7	20	20	9	29	33	16	49

areas of the city. Each sample represented the total amount of dust collected during a month in a sampling container (inside diameter 0.2 m) placed 1.4 m above the ground.

Analysis of lead in blood

The blood samples were analyzed on two occasions at the Institute of Environmental Medicine. Each of the two analytical series included the analysis of quality control samples of bovine blood spiked with lead. Two subsamples of 0.1 ml of blood were deproteinized by the addition of 0.4 ml of 0.8 M nitric acid. The supernatant was analyzed using graphite furnace atomic absorption spectrophotometry (GFAAS) with background correction and peak area evaluation (Perkin-Elmer model 5000 Zeeman, HGA-500, autosampler AS-40, PE computer model 7500). The detection limit for the lead concentration of blood was $5 \mu\text{g} \cdot \text{l}^{-1}$ ($0.024 \mu\text{mol} \cdot \text{l}^{-1}$). The analytical performance was evaluated by a linear regression analysis of sets of quality control samples (23). The evaluation guaranteed, with the power of 90%, that the true regression line would not fall outside the maximum allowable deviation interval $y = x \pm (0.05x + 10)$ (figure 1). The error of the method was $3.82 \mu\text{g} \cdot \text{l}^{-1}$ ($0.018 \mu\text{mol} \cdot \text{l}^{-1}$) in the first analytical series and $3.35 \mu\text{g} \cdot \text{l}^{-1}$ ($0.016 \mu\text{mol} \cdot \text{l}^{-1}$) in the second series. Thus it can be assumed that the accuracy of the blood lead levels was satisfactory.

Analysis of lead in soil

The soil samples were analyzed at SGAB Analys, Luleå, Sweden, together with quality control samples prepared from a certified lake sediment reference

sample (BCR 280, Delta Instituut voor Hydrobiologisch onderzoek, The Netherlands). The soil was dried at 105°C and weighed before being dissolved in 50% nitric acid in a sealed Teflon® container, using a microwave oven. The solution was filtered and then diluted with distilled water before being analyzed using inductively coupled plasma source mass spectrometry (ICP-MS) (24).

Analysis of lead in dust

The dust samples were analyzed at the laboratory of the mining company Stora Teknik, Falun, together with quality control samples prepared from a standard solution of lead in water (Titrisol, Merck, Darmstadt, Germany). The dust collector was washed out, and the entire content was dried before being dissolved in 20 ml of 7 M nitric acid. The lead content in aliquots of the dissolved samples was determined by atomic absorption spectrometry (AAS), using a Perkin-Elmer model 4000.

Statistical evaluation of the data

Statistical significance was judged according to the unpaired Mann-Whitney two-sample test, Mann-Whitney U statistics being employed for individual data. When blood lead levels before and after the summer season were compared for the 33 individuals donating blood in both April and September, the data were analyzed with the Wilcoxon signed rank test. Least squares linear regression analysis was used as an additional test when the impact of age and the soil lead level at home on the blood lead concentration was analyzed. Student's t-test of differences between the mean values was used when soil lead lev-

Figure 1. Analytical quality control for lead (Pb) in blood. Quality control samples analyzed together with the collected blood samples in May (left) and in October (right). The analytical performance was evaluated by linear regression of the reference values versus the laboratory results. The maximum allowable deviation interval (broken lines) is given by $y = x \pm (0.05x + 10)$. ($1 \mu\text{g Pb} \cdot \text{l}^{-1} = 0.0048 \mu\text{mol} \cdot \text{l}^{-1}$)

els (geometric means) at different locations were compared. Two-tailed statistics were used in all of the calculations. The level of significance was set at 5%.

Results

Soil analyses (7 in 1981, 22 in 1986, and 48 in 1991) made it possible to divide the city into four zones with regard to the soil lead concentration: ≤ 200 , 201–400, 401–600, and 601–1400 $\mu\text{g} \cdot \text{g}^{-1}$ (≤ 0.97 , 0.97–1.93, 1.94–2.90, and 2.90–6.76 $\mu\text{mol} \cdot \text{g}^{-1}$). Most of the children (71%) lived in areas with soil lead concentrations of 601–1400 $\mu\text{g} \cdot \text{g}^{-1}$ (2.90–6.76 $\mu\text{mol} \cdot \text{g}^{-1}$). Only one child lived in an area with a soil lead concentration below 200 $\mu\text{g} \cdot \text{g}^{-1}$ (0.97 $\mu\text{mol} \cdot \text{g}^{-1}$). The children had not changed home addresses during the year preceding the study. The day-care center was located in the zone with a soil lead concentration of 601–1400 $\mu\text{g} \cdot \text{g}^{-1}$ (2.90–6.76 $\mu\text{mol} \cdot \text{g}^{-1}$). The lead content in the dust fallout measured close to the day-care center varied between 350 and 3500 $\mu\text{g} \cdot \text{g}^{-1}$ over the year.

The average (arithmetic mean) blood lead level for all of the children included in the study was 31 (SD 13, range 13–79, median 30) $\mu\text{g} \cdot \text{l}^{-1}$ [0.15 (SD 0.06, range 0.06–0.38, median 0.14) $\mu\text{mol} \cdot \text{l}^{-1}$] in April (36 children), and 32 (SD 13, range 13–69, median 30) $\mu\text{g} \cdot \text{l}^{-1}$ [0.15 (SD 0.06, range 0.06–0.33, median 0.14) $\mu\text{mol} \cdot \text{l}^{-1}$] in September (46 children). The correlation between the blood lead levels and age,

gender, soil lead level, and smoking habits in the home for the children donating blood in September 1991 is shown in table 2. To study the effect of seasonal variation, we made a pairwise comparison of the blood lead levels of the 33 individuals donating blood in both April and September (table 2). Whereas a paired nonparametric test was used to analyze whether the median blood lead levels differed significantly from April to September, an unpaired nonparametric test was used to examine whether the median blood lead levels differed between the groups for the other parameters. It was not possible to carry out any meaningful multiple variate analysis because of the small number of children included in the study.

When the children participating in the blood sampling in September were divided into two age groups (four years of age or younger in September and older than four years of age in September), the younger children were found to have significantly ($P=0.04$) higher blood lead levels than the older children (table 2). This difference was confirmed when the data were analyzed with the use of least squares linear regression (figure 2). In April the situation was just the opposite, namely, the youngest children were found to have significantly lower ($P=0.03$) blood lead levels than the older children.

Whereas the blood lead concentrations increased significantly (32%) ($P=0.008$) over the summer season among the children four years of age or younger from 25 (SD 8) $\mu\text{g} \cdot \text{l}^{-1}$ [0.12 (SD 0.04) $\mu\text{mol} \cdot \text{l}^{-1}$]

Table 2. Effects of various study parameters on the blood lead levels of preschool children living in a community with high concentrations of lead from mine waste in soil and dust.

Parameter	Blood lead level ($\mu\text{g} \cdot \text{l}^{-1}$) ^a				
	Mean	SD	Range	Median	P-value ^b
Age ^c					
A. ≤ 4 years (N = 20)	37	15	14–69	35	0.04 ^d
B. > 4 years (N = 26)	28	10	13–60	26	
Gender ^c					
A. Boys (N = 31)	31	14	13–69	26	0.19 ^d
B. Girls (N = 15)	34	12	16–61	36	
Soil lead concentration at home ^c					
A. 0–600 $\mu\text{g} \cdot \text{g}^{-1}$ (N = 14)	27	8	13–40	28	0.17 ^d
B. 601–1400 $\mu\text{g} \cdot \text{g}^{-1}$ (N = 32)	34	14	16–69	32	
Smoking habits in the home ^c					
A. No smokers (N = 35)	31	14	13–69	27	0.09 ^d
B. Smokers (N = 11)	34	7	21–46	35	
Seasonal variation					
A. April, all children (N = 33)	32	13	13–79	29	0.51 ^e
B. September, all children (N = 33)	30	12	13–68	27	
A. April, ≤ 4 years of age (N = 10)	25	8	13–40	26	0.008 ^e
B. September, ≤ 4 years of age (N = 10)	33	14	14–68	34	
A. April, > 4 years (N = 23)	34	14	16–79	32	0.005 ^e
B. September, > 4 years (N = 23)	28	11	13–60	26	

^a 1 $\mu\text{g} \cdot \text{l}^{-1} = 0.0048 \mu\text{mol} \cdot \text{l}^{-1}$.

^b A–B.

^c September study.

^d Mann-Whitney two-sample test (Mann-Whitney U-statistics).

^e Wilcoxon signed rank test of data obtained from individuals donating capillary blood in both April and September.

Figure 2. Relationship between blood lead levels and age (September 1991). The linear regression values are as follows: correlation coefficient $r = -0.353$ ($r^2: 0.124$), slope = -0.23 (95% confidence interval: -0.41 to -0.04), and two-tailed P-value = 0.016 (ie, the slope is significantly different from zero). ($1 \mu\text{g} \cdot \text{l}^{-1} = 0.0048 \mu\text{mol} \cdot \text{l}^{-1}$)

Figure 3. Relationship between blood lead and soil lead (September 1991). The inhabited areas of Falun were divided into four zones (zone 1: $\leq 200 \mu\text{g} \cdot \text{g}^{-1}$ soil, zone 2: $201-400 \mu\text{g} \cdot \text{g}^{-1}$, zone 3: $401-600 \mu\text{g} \cdot \text{g}^{-1}$, and zone 4: $601-1400 \mu\text{g} \cdot \text{g}^{-1}$). The linear regression values are as follows: correlation coefficient $r = 0.2640$ ($r^2: 0.0697$), slope = 3.92 (95% confidence interval: -0.31 to 8.16), and two-tailed P-value = 0.0762 (ie, the slope was not significantly different from zero). ($1 \mu\text{g} \cdot \text{l}^{-1} = 0.0048 \mu\text{mol} \cdot \text{l}^{-1}$)

to 33 (SD 14) $\mu\text{g} \cdot \text{l}^{-1}$ [0.16 (SD 0.07) $\mu\text{mol} \cdot \text{l}^{-1}$], there was a significant decrease (18%) ($P=0.005$) among the older ones, from 34 (SD 14) $\mu\text{g} \cdot \text{l}^{-1}$ [0.16 (SD 0.07) $\mu\text{mol} \cdot \text{l}^{-1}$] to 28 (SD 11) $\mu\text{g} \cdot \text{l}^{-1}$ [0.14 (SD 0.05) $\mu\text{mol} \cdot \text{l}^{-1}$]. Among the 33 children donating blood in both April and September, 18 (average age 5.2 years) had blood lead levels that had decreased from April to September, and 13 children (average age 3.5 years) had increased levels. The highest blood lead level ($79 \mu\text{g} \cdot \text{l}^{-1}$, ie, $0.38 \mu\text{mol} \cdot \text{l}^{-1}$) was observed in April in a boy (4.2 years of age) living in an area with a soil lead level of $>600 \mu\text{g} \cdot \text{g}^{-1}$ ($>2.90 \mu\text{mol} \cdot \text{g}^{-1}$). In September, his blood lead level was $60 \mu\text{g} \cdot \text{l}^{-1}$ ($0.29 \mu\text{mol} \cdot \text{l}^{-1}$). The next two highest blood lead levels (69 and $68 \mu\text{g} \cdot \text{l}^{-1}$, ie, $0.33 \mu\text{mol} \cdot$

l^{-1}) were observed in two boys (3.5 and 2.9 years of age, respectively) in September. They were both living in areas with a soil lead level of $>600 \mu\text{g} \cdot \text{g}^{-1}$ ($>2.90 \mu\text{mol} \cdot \text{g}^{-1}$). None of these three boys had smoking parents.

Eleven of the children donating blood in September lived in homes with smoking family members. (Only two of them lived in homes with family members smoking more than 20 cigarettes per day.) Children older than four years of age and exposed to passive smoking at home ($N=6$) had significantly higher blood lead levels ($P=0.03$) than those living in homes without smoking family members ($N=22$). However, since there was no effect of passive smoking at home on the blood lead levels, neither among

the older children donating blood in April nor among the younger children, this parameter was judged to be of minor importance in the present study.

As shown in table 2 and figure 3, there was a tendency towards increased blood lead levels in the children living in areas with a soil lead level of $>600 \mu\text{g} \cdot \text{g}^{-1}$ ($>2.90 \mu\text{mol} \cdot \text{g}^{-1}$). However, neither this parameter nor the gender of the children (table 2), the parents' estimations of the hand-to-mouth activity, the consumption of canned food of the children (not shown), nor the presence of hobbies at home possibly involving the use of lead (not shown) were found to have a statistically significant correlation with the blood lead levels. However, it should be pointed out that the groups were relatively small, and it was not possible to standardize for age and soil lead concentration at home.

Discussion

In the present study, blood lead levels were measured in preschool children living in a Swedish community with high levels of lead from mine waste in soil and dust fallout. Despite the fact that the children were selected to represent a group with a potential exposure to soil and dust with high concentrations of lead, the blood lead levels were found to be relatively low. The average blood lead level was $31 \mu\text{g} \cdot \text{l}^{-1}$ ($0.15 \mu\text{mol} \cdot \text{l}^{-1}$) in April and $32 \mu\text{g} \cdot \text{l}^{-1}$ ($0.15 \mu\text{mol} \cdot \text{l}^{-1}$) in September.

Previous Swedish studies of blood lead levels among older schoolchildren (14 to 15 years of age, some of whom were from Falun) showed a mean blood lead level of $26 \mu\text{g} \cdot \text{l}^{-1}$ ($0.12 \mu\text{mol} \cdot \text{l}^{-1}$), with a median value of $21 \mu\text{g} \cdot \text{l}^{-1}$ ($0.10 \mu\text{mol} \cdot \text{l}^{-1}$) and a range between <10 and $273 \mu\text{g} \cdot \text{l}^{-1}$ (<0.05 and $1.32 \mu\text{mol} \cdot \text{l}^{-1}$) (25). Schoolchildren (8 to 13 years of age) in a glassworks area with lead-emitting industries and a reference area, in the south of Sweden, had a mean blood lead level of $35 \mu\text{g} \cdot \text{l}^{-1}$ ($0.17 \mu\text{mol} \cdot \text{l}^{-1}$), with a range between 10 and $89 \mu\text{g} \cdot \text{l}^{-1}$ (0.05 and $0.43 \mu\text{mol} \cdot \text{l}^{-1}$) (26). There was no difference in the blood lead levels between the areas. Blood lead levels have been monitored among schoolchildren (mean age 11 years) in the south of Sweden, in both urban and rural areas, since 1978. In 1988, the mean blood lead level was $33 \mu\text{g} \cdot \text{l}^{-1}$ ($0.16 \mu\text{mol} \cdot \text{l}^{-1}$), with a range between 15 and $71 \mu\text{g} \cdot \text{l}^{-1}$ (0.07 and $0.34 \mu\text{mol} \cdot \text{l}^{-1}$) (27). The indicated blood lead levels among Swedish schoolchildren are similar to those found in the general Swedish adult population (28, 29).

In the aforementioned studies, blood was collected from the cubital vein. The risk for contamination of the blood is higher with the finger puncture technique than with venipuncture. However, good agreement between the two methods has been achieved when measures have been taken to eliminate the risk for contamination (30). We tested our sampling tech-

nique by collecting blood from the cubital vein and from finger puncture from adults. It was shown that blood could be collected with the finger puncture technique without contaminating the blood with lead (Berglund et al, unpublished results).

A reasonable explanation for the observed increase in blood lead levels from April to September among the youngest children (up to four years of age) could be that the daily intake of soil and dust during the summer season is higher among younger children because of more prominent hand-to-mouth activity. To confirm and further elucidate our findings, additional investigations are needed. However, seasonal patterns in blood lead levels, with a minimum in the winter and a maximum in the summer, have been observed in various blood screening programs (31, 32), and it has also been shown that children under three years of age are at the greatest risk of showing an increase in blood lead level during the summer season (31).

One explanation for the observed low blood lead levels in Falun is that the lead compounds present in soil and dust fallout have a low bioavailability. It is known that young children can absorb up to 40–50% of ingested lead (33, 34). Such a high absorption rate may not be true for older children or for lead in the form of lead sulfide, mainly present in the soil and dust contaminated by mine waste from Falun (Qvarfort, personal communication).

Another possible explanation for the relatively low blood lead levels in the preschool children from Falun could be that these children were not exposed to soil and dust to the extent expected or that the lead levels measured in the soil and dust were not representative of what was generally available to the children. Blood lead level is a measure of recent total lead exposure. However, due to the design of the study, and the restricted number of children, it has not been possible to assess the relative importance of lead from lead-contaminated soil and dust. It is, for example, not known how much lead each child in the study ingested via food and water.

Several attempts have been made to estimate the amount of soil and dust ingested by young children (6, 35–38) and to predict the blood lead levels of children from the concentration of lead in the soil and dust in their surroundings (3, 39–41). When Steele et al (42) investigated the relationships between soil and blood lead concentrations in residents living in communities with lead-contaminated soil, they found that the impact of lead derived from mine waste on the blood lead levels was less than that for lead in soil derived from smelter, vehicle, or paint sources. It was suggested that the low bioavailability of lead derived from mine waste (ie, lead sulfide) could be explained by the relatively large particle sizes typically observed in mine wastes, and also by the low solubility of lead sulfide.

The idea that lead derived from mines appears to have a low bioavailability is supported also by health

survey data from other "mining" communities with elevated levels of lead in the soil (43). Studying the bioavailability of inorganic lead in rats after oral administration, Freeman et al (44) observed that only a small fraction of lead was absorbed from soil contaminated by mine waste in comparison with lead acetate. In contrast to the observations made from rats, LaVelle et al (45) reported a relatively high bioavailability of lead derived from mine waste in soil given orally to young pigs.

In children up to four years of age, blood lead levels increased during the summer season. This finding indicated that mine-waste lead in soil contributed to the total lead exposure. However, the blood lead levels measured in the preschool children from Falun did not indicate a significant risk of adverse health effects. Our study suggests a low bioavailability of lead deposited in soil and dust during mining, milling, and ancient smelting activities, as well as during modern processing activities such as sulfuric acid production. At least in Falun, it appears as if these sources of lead do not constitute the same environmental health hazard for children as other lead sources do, for example, emissions from modern smelters, vehicle exhaust, and lead-based paints. Thus it seems clear that the bioavailability of various types of lead contamination should be considered when the risk of health effects due to contaminated soil are assessed, and before extensive clean-up actions are initiated.

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