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Exposure to lead and cadmium of children living in different areas of North-West Germany: results of biological monitoring studies 1982–1986*

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Summary. Between 1982 and 1986 several surveys were carried out to determine the levels of lead and cadmium in blood, urine, and shed deciduous teeth (incisors only) of children living in rural, suburban, urban, and industrial areas of North-West Germany. Blood lead (PbB) and blood cadmium (CdB) were measured in about 4000 children. In rural, suburban and urban areas the median PbB levels vary between 5.5 and 7 μg/dl, with 98th percentiles varying between 10 and 13 μg/dl. The median CdB levels are between 0.1 and 0.2 μg/dl, with 95th percentiles between 0.3 and 0.4 μg/l. Children from urban areas have significantly higher PbB levels than children from rural and suburban areas. Regarding CdB no differences could be detected. Children living in areas around lead and zinc smelters, particularly those living very close to the smelters, have substantially increased PbB and CdB levels. Children from lead worker families also have substantially increased PbB and CdB levels. The lead levels in shed milk teeth (PbT) were determined in about 3000 children. In rural, suburban and urban areas the median PbT levels are between 2 and 3 μg/g, with 95th percentiles between 4 and 7 μg/g. Children from urban areas have significantly higher PbT levels than children from rural and suburban areas. The highest PbT levels (on a group basis) are in children from nonferrous smelter areas. The median levels of lead in urine (PbU) are between 6 and 10 μg/g creatinine, with 95th percentiles between 20 and 30 μg/g creatinine. Children from polluted areas have higher PbU levels than children from less polluted areas. The median levels of cadmium in urine (CdU) are in the order of 0.1 μg/g creatinine, with 95th percentiles being in the range of 0.5 and 1.0 μg/g creatinine. Girls have higher CdU levels than boys. There are no differences between groups of children from different areas. Children from lead worker families have higher PbU and CdU levels than otherwise comparable children. The results of the present studies indicate a further decrease of PbB in children from North-West Germany since the CEC blood lead campaigns carried out in 1979 and 1981. The decrease of lead exposure also seems to be reflected by a decrease of tooth lead levels.

Key words: Lead exposure – Cadmium exposure – Children – North-West Germany

Introduction

There is general agreement that children are a population at increased risk with respect to lead exposure and adverse health effects resulting from increased lead exposure. The reasons for this may be summarized as follows:

- children have behavioural characteristics (outdoor activity, less concern for hygienic conditions, oral activities), which increase the risk of undue lead exposure;

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- children eat and drink more per unit of body weight than adults, and so the relative lead intake is greater than in adults;
- lead absorption in the gastrointestinal tract is higher in children than in adults;
- among children there is a greater prevalence of nutritional deficiencies (e.g. iron, vitamin D), which may enhance the absorption of lead from the gastrointestinal tract;
- haematological and neurological effects of lead occur at lower thresholds in children than in adults.

Since 1982 we have performed several blood lead surveys among children living in different rural, urban and industrial areas of North-West Germany. In total, blood lead levels of more than 4000 children were determined. We also analysed the lead levels in shed milk teeth and urine samples. Whereas lead in blood and urine are indicators of relatively recent exposure, the analysis of mineralizing tissues, specifically deciduous teeth, provides an assessment of internal exposure integrated over a longer period of time. Additionally, we determined the cadmium levels in blood and urine. The objective of these surveys was to obtain data on the current background levels of the above mentioned biological exposure indices in child populations of North-West Germany and to determine the influence of some constitutional and environmental factors on these indicators of exposure. Moreover, the surveys were aimed to assess to what extent critical blood lead levels occur in child populations of these areas.

Subjects and methods

Study areas and their environmental pollution by lead and cadmium

The surveys were carried out in eleven cities of North-Rhine Westfalia and in Nordenham, a seaport city located in northern Germany.

Borken, Dülmen, and Goch are small cities without industrial sources of lead and other metals located in rural areas north and north-west of the Ruhr area. The children living in these areas may be considered as reference populations with presumably low lead exposure.

Bottrop (about 114000 inhabitants), Essen (about 640000 inhabitants), Gelsenkirchen (about 300000 inhabitants), Herne (about 180000 inhabitants), and Lünen (about 85000 inhabitants) are industrial cities located in the Ruhr area, in which motor traffic exhaust represents the major source of lead. There are a number of metallurgical plants in these areas, but the lead and cadmium emissions from these plants are insignificant.

Duisburg (about 550000 inhabitants) and Dortmund (about 600000 inhabitants) represent two of the most important centers of iron and steel production in Europe. In Duisburg, there also exist a large lead zinc smelter as well as a number of other metallurgical plants processing lead and other non-ferrous metals. Additionally, a large copper smelter was in operation in this area until 1983. The lead emission from industrial sources was estimated to be about 800 tons/year in the 1970s (MAGS 1977). At present, they are estimated to be about 220 tons/year (MAGS 1985). The emission of cadmium and its compounds was in the order of 6 tons/year and is currently estimated to be about 2.7 tons/year (MAGS 1977), 1985). In the Dortmund area, the lead emission from industrial sources (mainly from iron and steel production) was estimated to be 130 tons/year in the 1970s (MAGS 1978). Due to pollution control and a substantial reduction of iron and steel production, the emission of lead decreased to, at present, about 65 tons/year (MURL 1986). The emission of cadmium from industrial sources is insignificant (< 1 ton/year). In both areas the lead emission from motor traffic exhaust is estimated to be 50 to 60 tons/year.

The Stolberg area (about 57000 inhabitants) is known to be highly polluted by lead, cadmium and other non-ferrous metals due to the presence of several primary lead and zinc smelters in operation since the 19th centruy. A number of these plants have been closed down in recent years. At present, a large primary lead smelter represents the major source of lead and cadmium emissions. The lead emission from this smelter was about 35 tons/year in the 1970s and has been reduced to, at present, about 18 tons/year. The cadmium emission is in the order of 0.5 tons/year (MAGS 1975, 1983). Since 1972 several studies have been carried out to screen the population, mainly children, for undue lead and cadmium exposure (Einbrodt et al. 1974; Rosmanith et al. 1975a, b; Ewers et al. 1982, 1984, 1985).

Nordenham is a medium-sized seaport in Northern Germany with about 33000 inhabitants. Pollution problems arise from a lead zinc smelter located near the city. The surrounding areas are largely rural. Lead intoxication of cattle has a long history in this area. The most recent incident occurred in 1972. Since then the Federal Health Agency has been active in screening the population of any signs of undue lead exposure and possible health consequences (Thron et al. 1984; Winneke et al. 1985).

The degree of environmental pollution by lead and cadmium has been recorded in some of the above mentioned areas for several years by means of a monitoring network maintained by the State Agency for Immission Control (Landesanstalt für Immissionsschutz NW, LIS). The monitoring activities include the measurement of lead, cadmium, and other environmental contaminants in air, dust fall-out, top soil and plants. Whereas the contaminant levels in dust fall-out and soil are measured by means of a 1×1 km monitoring network, air and plant contaminants are measured by means of a 4×4 km monitoring network. The results have been published by the State Agency for Immission Control (see "Schriftenreihe der Landesanstalt für Imissionsschutz NW"). The means and ranges of lead and cadmium fall-out (PbD and CdD, respectively) are summarized in Table 1. It should be noted that, in the polluted areas (Duisburg, Nordenham, Stolberg), there are large variations of the contaminant levels, particularly with regard to lead and cadmium in dust fallout and soil. Especially around the smelters high levels of lead and cadmium in dust fallout ranging up to 6000 μg Pb/m^2/d and 30 μg Cd/m^2/d have been recorded. The annual means of lead and cadmium in air vary between 0.2 and 0.5 μg Pb/m^3 and 1 and 5 ng Cd/m^3 respectively, and do not differ very much between the study areas. Close to the smelters, however, significantly increased levels have been measured.

Table 1. Levels of lead and cadmium in dust fall-out (PbD and CdD, respectively) in the study areas[a]

Area (year)	PbD(μg/m²/d)			CdD (μg/m²/d)		
	Whole city area	Children's residence areas		Whole city area	Children's residence areas	
	Mean	Mean	Range	Mean	Mean	Range
Duisburg (1983)	361	397[b]	100–6992	4.0	7.0	1.6–29.7
Dülmen/Borken (1984)	76[c]	–		1.2[c]		
Dortmund (1985)	112	112	60– 280	1.8	1.8	1.1– 3.4
Bottrop (1985)	121	155	110– 220	1.9	2.2	1.6– 2.7
Essen (1985)	149	181	120– 410	2.2	2.6	1.8– 3.6
Gelsenkirchen (1985)	140	169	80– 350	2.2	2.8	1.7– 5.6
Herne (1985)	102	106	70– 160	1.9	2.0	1.2– 3.1
Stolberg (1982)	430		max. 2134[d]	8.2		max. 29.0[d]
(1985)	440			5.3		

[a] Source: MAGS (1983), Radermacher et al. (1986), MURL (1986)
[b] Mean calculated after excluding two 1 km² areas with PbD > 6000 μg/m²/d. Including these two unit areas the mean PbD is 1198 μg/m²/d
[c] Mean of 4 dust collectors only
[d] Mean of three 1 km² areas exhibiting the highest PbD and CdD levels

Study populations and collection of biological specimens

Blood samples were obtained from children aged 4 to 11 years. In Stolberg some boys and girls aged up to 17 years were also examined. In all cases blood sampling was performed on a voluntary basis.

In Borken, Bottrop, Dülmen, Dortmund, Essen, Gelsenkirchen, Herne, and Lünen, blood sampling was performed in selected school districts on the occasion of the children's preschool medical examination. The collection of the blood samples was carried out by physicians of the municipal public health departments between March and June of 1985 and 1986.

In Duisburg and Goch, 7- to-11-year-old German children were randomly selected from the municipal registers of residents. The parents of the children selected were contacted by letter in order to request the participation of their child. The participation rates were about 30% in both areas. In Duisburg we selected only children living in the southern parts of the city, where the highest levels of lead and cadmium in dust fall-out were recorded. Blood sampling was performed in June and July 1983.

In the Stolberg area three campaigns were carried out, the first in June and July 1982, the second in June 1983, and the third in April and May 1986. The first campaign involved 4- and 5-year-old children randomly selected from the municipal register of inhabitants (participation rate: 50%) as well as a group of 43 boys and girls living close to the lead smelter (less than 2 km). The latter group mainly consisted of children from Turkish families. In part, their fathers were employed in the lead smelter. The second survey was also aimed at children living close to the lead smelter. In the third round, 109 children who had participated in the 1982 campaign were re-examined. Moreover, we could collect venous blood samples from 41 boys and girls who had delivered milk teeth to us during a previous study (Ewers et al. 1982).

Shed milk teeth were collected from children living in the areas of Borken, Bottrop, Dortmund, Dülmen, Essen, Gelsenkirchen, and Herne in 1985 and 1986. The children were largely identical to those who provided us with blood samples (see above). Additionally, we collected shed milk teeth from children living in Nordenham (1982) and Stolberg (1986). Only incisors were accepted for analysis.

Urine samples were collected from children living in the areas of Stolberg, Duisburg, Goch, and Dortmund. Urine sampling took place in June 1982 (Stolberg), May/June 1983 (Duisburg, Goch), and May/June 1985 (Dortmund).

Metal analyses

Venous blood samples were collected with syringes and needles, which previously had been examined to be free of contamination by lead and cadmium. The syringes contained EDTA-K as an anticoagulant. The blood was deep-frozen within the syringes and stored at −20°C until analysis. The urine samples were collected in lead- and cadmium-free plastic vials, acidified with HNO_3, and kept at 4°C until analysis.

The PbB and CdB levels were measured by graphite furnace atomic absorption spectrometry (GF-AAS) as described previously (Brockhaus et al. 1983) using a Perkin Elmer Model 5000 instrument equipped with a deuterium background compensator, a Perkin Elmer HGA 500 atomizer and a Perkin Elmer AS-40 automatic sample dispenser for injection of 20-μl aliquots. The method applied was the deproteinization method developed by Stoeppler et al. (1978). Each blood sample was analysed in duplicate. The levels of cadmium and lead in urine were also determined by GF-AAS as described previously (Ewers et al. 1984, 1985).

The lead concentration in teeth was measured by L'vov platform GF-AAS after dissolving the pre-washed and preweighed teeth in 3 ml of concentrated HNO_3. Calibration solutions were prepared by the addition of known amounts of lead to dissolved teeth with low lead content. Each dissolved tooth was measured in duplicate.

All analyses were carried out under conditions involving internal and external quality control. For internal quality control commercially available control materials (control blood and urine for metals from Behring, Marburg, FRG) were used. The accuracy of the methods was confirmed on several occasions by participation in interlaboratory comparison programmes performed on the national and international level,

Table 2. Blood lead levels (μg/dl) of children living in different areas of North-West Germany[a]

Area (year of survey)	Age (years)	*n*	GM	GSD	P50	P90	P95	P98	Range
Sururban/rural areas									
Goch (1983)	7–11	504	6.8	1.3	6.8	9.7	10.8	11.7	3.2–17.2
Borken (1985)	6– 7	227	6.1	1.3	6.0	8.8	9.7	12.3	2.7–13.8
(1986)	6– 7	225	5.5	1.3	5.5	8.1	8.9	9.4	2.5–17.1
Dülmen (1985)	6– 7	186	6.1	1.3	6.0	8.7	10.6	13.2	3.0–19.5
(1986)	6– 7	138	6.0	1.3	6.1	9.1	9.7	10.9	2.3–12.9
Urban/industrial areas									
Dortmund (1985)	6– 7	523	7.0	1.3	6.9	9.9	11.0	12.9	3.1–17.8
Lünen (1985)	6– 7	180	6.6	1.3	6.5	9.7	10.4	11.6	3.1–14.9
Bottrop (1986)	6– 7	361	6.6	1.3	6.6	9.4	10.4	11.1	3.0–13.5
Essen (1986)	6– 7	326	6.3	1.3	6.3	8.7	10.4	12.1	2.5–21.2
Gelsenkirchen (1986)	6– 7	201	6.6	1.3	6.7	9.3	10.6	12.6	3.0–14.2
Herne (1986)	6– 7	300	6.2	1.3	6.2	8.9	9.8	11.8	2.9–15.3
Risk areas									
Duisburg (1983)	7–11	437	8.4	1.4	8.3	13.2	15.7	17.9	3.4–20.8
Stolberg (1982)	4– 5	213	10.7	1.4	10.4	16.6	19.7	23.2	4.7–30.8
(1982)	3–17	43[b]	21.2	1.4	20.5	34.1	36.2	–	10.3–44.9
(1983)	4–13	33[b]	13.8	1.4	14.0	21.5	22.4	–	6.6–23.3
(1986)	7– 9	109	7.4	1.3	7.1	10.8	13.0	15.7	4.2–18.0
(1986)	13–15	41	5.6	1.5	5.4	9.7	10.4	–	2.4–11.3

[a] Abbreviations: GM = geometric mean; GSD = geometric standard deviation; P50 = 50th percentile; P90 = 90th percentile; P95 = 95th percentile; P98 = 98th percentile
[b] Children living less than 2 km from the lead smelter

e.g. comparison programmes organized within the framework of the WHO-Euro research projects on 'Biological Indicators of Lead Neurotoxicity in Children' and 'Health Effects of Exposure to Cadmium in the General Population' as well as comparison programmes organized by the IUPAC Subcommittee on Cadmium and the Deutsche Gesellschaft für Arbeitsmedizin.

Statistical analyses

The frequency distribution of the biological exposure indices are presented in the form of percentiles (P50, P90, P95, P98). In general the frequency distributions of the biological parameters are approximately log-normal; therefore, the geometric means and geometric standard deviations were calculated. The association between blood lead (PbB) and certain demographic, social, and environmental variables was examined by multiple regression analysis using log PbB as the dependent variable. The same procedure was applied to tooth lead (log PbT) and blood cadmium (log CdB).

Results

Means and distribution of PbB levels

The results presented in Table 2 show that, on average, blood lead concentrations of children living in rural and urban areas without industrial sources of lead are in the range of 5.5 to 7.0 μg/dl. The 98th percentiles range from about 9 to 12 μg/dl. Individual PbB values range up to about 21 μg/dl. Children from urban areas have higher PbB levels than children from suburban and rural areas. After adjusting for some social variables and population characteristics (age, sex, socio-economic status, nationality, consumption of home-grown vegetables) the differences are significant at the $P < 0.001$ level. The highest mean PbB levels were found in children living in areas polluted by industrial lead emissions, particularly in those living in the vicinity of the Stolberg lead smelter. Although it is critical to compare the PbB levels of children of different age groups, the data suggest that there has been a substantial reduction of children's PbB levels in this area from 1982 to 1986.

Means and distribution of CdB levels

Since the CdB levels were below the detection limit in a number of samples the geometric means could not be calculated. The 50th, 90th, and 95th percentiles are shown in Table 3. The median values are between 0.1 and 0.2 μg/l and the 95th percentiles are usually below 0.4 μg/l. There are no systematic differences between rural, urban, and non-ferrous smelter

Table 3. Blood cadmium levels (µg/l) of children living in different areas of North-West Germany[a]

Area (year of survey)	Age (years)	*n*	P50	P90	P95	Range
Suburban/rural areas						
Goch (1983)	7–11	504	0.20	0.33	0.41	<0.1–1.2
Borken (1985)	6– 7	227	0.17	0.25	0.27	<0.1–0.8
(1986)	6– 7	225	0.14	0.23	0.25	<0.1–0.6
Dülmen (1985)	6– 7	186	0.19	0.29	0.39	<0.1–7.0
(1986)	6– 7	138	0.14	0.22	0.26	<0.1–0.3
Urban/industrial areas						
Dortmund (1985)	6– 7	523	0.15	0.25	0.29	<0.1–0.7
Lünen (1985)	6– 7	180	0.16	0.28	0.32	<0.1–0.8
Bottrop (1986)	6– 7	361	0.13	0.21	0.26	<0.1–1.6
Essen (1986)	6– 7	326	0.13	0.22	0.28	<0.1–4.8
Gelsenkirchen (1986)	6– 7	201	0.15	0.26	0.29	<0.1–1.6
Herne (1986)	6– 7	300	0.13	0.22	0.29	<0.1–1.2
Risk areas						
Duisburg (1983)	7–11	437	0.20	0.34	0.39	<0.1–0.8
Stolberg (1982)	4– 5	213	0.19	0.35	0.44	<0.1–0.6
(1982)	3–17	43[b]	0.43	0.66	0.90	<0.2–1.7

[a] For abbreviations see Table 2
[b] Children living less than 2 km from the lead smelter

Table 4. Lead concentration in whole milk teeth (incisors only) of children living in different areas of North-West Germany[a]. Unit: µg Pb/g

Area (year of survey)	*n*	GM	GSD	P50	P90	P95	Range
Suburban/rural areas							
Borken (1985)	104	2.0	1.5	1.9	3.7	4.0	0.8– 5.3
(1986)	140	1.8	1.6	1.8	3.0	3.9	0.5– 8.0
Dülmen (1985)	93	2.3	1.7	2.1	4.3	6.8	0.3– 9.3
(1986)	148	2.0	1.5	2.0	3.5	4.2	0.7– 9.7
Urban/industrial areas							
Dortmund (1985)	1265	2.8	1.6	2.7	5.3	6.7	0.6–12.2
Lünen (1985)	227	2.7	1.6	2.6	4.8	6.3	0.8–10.1
Bottrop (1986)	149	2.4	1.5	2.4	4.4	5.1	0.9– 8.8
Essen (1986)	157	2.7	1.6	2.5	5.3	5.8	0.6–16.7
Gelsenkirchen (1986)	112	2.3	1.6	2.2	3.9	5.3	0.8–35.8
Herne (1986)	491	2.3	1.5	2.3	4.0	4.8	0.8– 8.7
Risk areas							
Nordenham (1982)	77	4.5	1.7	4.3	8.4	11.2	1.5–28.1
Stolberg (1986)	41	3.5	1.5	3.1	6.3	6.5	1.2– 7.3

[a] For abbreviations see Table 2

areas. Due to the increase of CdB with age the children from Duisburg and Goch (aged 7–11 years) have slightly higher CdB-levels than the children from the other areas (aged 4–7 years). Children living in the close vicinity of the Stolberg lead smelter were found to have substantially increased CdB concentrations.

Means and distribution of tooth lead levels (PbT)

The results presented in Table 4 show that children from rural and suburban areas have mean PbT levels of about 2 µg/g, whereas children from urban/industrial areas have higher PbT levels with group means

Table 5. Levels of lead and cadmium in urine of children living in different areas of North-West Germany. Units: μg/g creatinine

Area (year of survey)	n	Parameter	GM	GSD	P50	P90	P95	Range
Stolberg (1982)	106[a]	PbU[b]	9.6	2.3	10.5	26.2	30.1	0.2–43.0
		CdU[b]	0.14	2.3	0.1	0.4	0.5	<0.1– 1.2
Duisburg (1983)	529	CdU[c]	0.15	2.1	0.1	0.4	0.6	<0.1–16.9
Goch (1983)	496	CdU[c]	0.15	2.1	0.1	0.3	0.7	<0.1– 4.6
Dortmund (1985)	78	PbU[b]	6.7	2.0	6.6	17.3	22.0	1.6–41.0
	79	CdU[b]	–[d]	–	<0.1	0.4	1.2	<0.1– 3.7

[a] Boys only
[b] Determination in spot urine samples
[c] Determination in 24-h urine samples
[d] Since in a number of samples CdU was below the detection limit, the geometric mean could not be calculated

Table 6. PbB and PbT levels in relation to sex of children from different areas of North-West Germany

Area (year of survey)	PbB (μg/dl)						PbT (μg/g)					
	Boys			Girls			Boys			Girls		
	n	GM	GSD	n	GM	GSD	n	GM	GSD	n	GM	GSD
Nordenham (1982)	–	–	–	–	–	–	40	4.2	1.6	37	4.9	1.8
Goch (1983)	228	6.9	1.3	276	6.6	1.3	–	–	–	–	–	–
Duisburg (1983)	230	8.7	1.4	207	8.0	1.4	–	–	–	–	–	–
Dortmund (1985)	286	7.1	1.3	237	6.9	1.3	616	2.8	1.6	649	2.8	1.6
Lünen (1985)	84	6.7	1.4	96	6.4	1.3	99	2.6	1.6	128	2.7	1.6
Borken (1985)	114	6.5	1.4	113	5.8	1.3	52	2.0	1.5	52	2.1	1.6
(1986)	117	5.8	1.3	108	5.2	1.4	66	1.7	1.5	74	1.9	1.6
Dülmen (1985)	83	6.5	1.4	103	5.8	1.3	37	2.4	1.7	56	2.3	1.6
(1986)	71	6.3	1.4	63	5.8	1.3	71	1.9	1.5	77	2.1	1.5
Bottrop (1986)	202	6.7	1.3	159	6.4	1.3	76	2.4	1.5	73	2.5	1.6
Essen (1986)	170	6.4	1.3	156	6.1	1.4	73	2.5	1.6	84	2.9	1.6
Gelsenkirchen (1986)	103	6.8	1.3	98	6.4	1.3	59	2.3	1.5	53	2.3	1.7
Herne (1986)	158	6.3	1.3	141	6.1	1.3	226	2.2	1.5	265	2.4	1.5
Stolberg (1986)	62	7.5	1.3	47	7.2	1.4	26	3.6	1.5	15	3.4	1.6

varying between 2.3 and 2.8 μg/g. The differences of the group means are significant at the $P < 0.001$ level after adjusting PbT for the above named social variables and population characteristics. The highest mean PbT values were found in children living in polluted areas such as Nordenham and Stolberg. Considering the frequency distribution of the PbT levels, it can be concluded that in urban areas about 95% of all values are below 6 to7 μg/g. In rural areas the 95th percentiles are in the range of 4 μg/g. Individual PbT levels may range up, however, to substantially higher values.

Means and distribution of PbU and CdU levels

As shown in Table 5 the means and 95th percentiles of PbU are in the range of 5 to 10 μg/g creatinine and 20 to 30 μg/g creatinine, respectively. Children living in the Stolberg area have higher PbU levels than children from Dortmund. The CdU levels are, on average, below 0.2 μg/g creatinine, with 95th percentiles of about 1.0 μg/g creatinine. There are no systematic differences between rural, urban, and polluted areas.

Levels of lead and cadmium in blood, urine, and teeth in relation to sex

On average boys have significantly higher PbB levels than girls as shown in Table 6. On the other hand there is a tendency towards increased PbT levels in girls. The CdB levels do not differ between boys and girls (not shown). Regarding cadmium in urine, girls have significantly higher levels than boys (see Table 7).

Factors affecting PbB levels of children living in risk areas

The factors influencing the PbB levels of children living in risk areas were studied in two groups of chil-

Table 7. CdU and PbU levels in relation to sex of children from different areas of North-West Germany

Area	Parameter	Unit	Boys			Girls		
			n	GM	GSD	*n*	GM	GSD
Duisburg	CdU	µg/l	276	0.15	1.8	253	0.22[a]	2.4
		µg/g creatinine	276	0.12	1.7	253	0.20[a]	2.4
		µg/24 h[b]	196	0.08	1.8	153	0.11[a]	2.1
Goch	CdU	µg/l	222	0.14	1.9	274	0.20[a]	2.4
		µg/g creatinine	222	0.12	1.8	274	0.18[a]	2.3
		µg/24 h[b]	165	0.08	1.8	191	0.12[a]	2.3
Dortmund	PbU	µg/l	34	5.2	1.6	44	5.4	1.8
		µg/g creatinine	34	6.5	1.8	44	6.8	2.1

[a] Significantly different from the GM found in boys (Student's *t*-test applying separate variance estimates; $P < 0.001$)
[b] Urine samples < 250 ml and/or containing less than 0.5 g creatinine were considered as incomplete 24-h urine and were therefore excluded

Table 8. Effect of various social, demographic and environmental variables on the variance of log PbB in 4- and 5-year-old children ($n = 192$) from Stolberg

Variable	Percentage of variance explained	*P*	Effect on PbB
Sex	0.3	n.s.[a]	PbB in boys > PbB in girls
Father employed in the lead smelter[b]	12.7	0.0001	PbB ↑ in children from lead worker families
Socio-economic status (SES)[c]	1.5	0.07	PbB ↑ in children with fathers in manual occupations
Foreigner family[d]	7.9	0.0001	PbB ↑ in children from foreign families
Lead-fall out[e]	4.4	0.001	PbB ↑ in children living in areas with high lead fall-out
Lead in top soil[f]	1.3	0.07	PbB ↑ in children living in areas with high soil lead
Interaction terms:			
Lead fall-out			
* Sex	0.6	n.s.	
* Playing outdoors	<0.1	n.s.	
* Hand-to-mouth activity	1.5	0.052	
* Socio-economic status	2.0	0.022	
* Consumption of homegrown vegetables	0.2	n.s.	
Soil lead			
* Consumption of homegrown vegetables	0.1	n.s.	
Total	32.5		

[a] Not significant
[b] 9 children from lead worker families
[c] Defined by father's employment. "Low" SES: fathers in manual occupations; "high" SES: fathers in non-manual occupations
[d] 30 children, mainly from Turkish families
[e] Relating to the unit area where the child's residence place is located
[f] Relating to the surrounding of the child's dwelling place. PbS was applied as ordinal variable with seven categories from < 200 ppm to > 10000 ppm

dren: 4- and 5-year-old children from the Stolberg area and 7- to 11-year-old children from the Duisburg area. The most detailed investigation, taking into account a number of independent variables as shown in Table 8, was carried out for the Stolberg group. The results indicate that the following variables are highly significant predictors of PbB: father employed in the lead smelter, foreign family, and lead fallout around the child's dwelling place. Taking into account the interaction variables additionally, lead fall-out accounts for about 8% of the variance of log PbB in this group of children. In total, 32.5% of the variance of log PbB can be explained by the variables indicated in Table 8. As shown in Table 9 children of lead worker families have significantly higher PbB levels than children of parents not employed in the lead industry. The same applies to CdB, PbU, and CdU.

Table 9. Levels of lead and cadmium in blood and urine of children from lead worker families and other families living in the Stolberg area

Age (years)	Parameter	Lead worker families			Other families			P
		n	GM	GSD	n	GM	GSD	
4–5	PbB (μg/dl)	9	18.4	1.3	195	10.4	1.4	<0.001
	CdB (μg/l)	9	0.25	1.4	195	0.19	1.6	n.s.[a]
	PbU (μg/g creatinine)	5	30.0	1.1	97	8.9	2.3	<0.01
	CdU (μg/g creatinine)	5	0.34	2.6	97	0.13	2.2	0.01
8–9	PbB (μg/dl)	4	7.8	1.2	102	7.3	1.4	n.s.

[a] Not significant

Table 10. Effect of various social, demographic and environmental variables on the variance of log PbB in 7- to 11-year-old children (n = 401) from Duisburg

Variable	Percentage of variance explained	P	Effect on PbB
Sex	2.4	0.002	PbB in boys > PbB in girls
Socio-economic status (SES)[a]	1.3	0.022	PbB ↑ in children from "low" SES families
Lead fall-out[b]	16.1	<0.001	PbB ↑ in children living in areas with high lead fall-out
Lead in top soil[c]	0.1	n.s.[d]	
Interaction terms:			
Lead fall-out			
* Sex	< 0.1	n.s.	
* SES	1.3	0.012	
* Consumption of homegrown vegetables	1.6	0.005	
Soil lead			
* Consumption of homegrown vegetables	< 0.1	n.s.	
Total	22.9		

[a] Defined by parents' educational level. "Low" SES: primary school and professional training; "high" SES: high school, grammar school or university degree
[b] Relating to the unit area where the child's residence place is located
[c] Since lead in top soil mainly results from lead fall-out in this area there is a strong correlation between these two variables. Introducing lead in top soil into the regression model *before* lead fall-out shows that lead in top soil explains 11.3% of the variance of log PbB ($P < 0.001$). In this model lead fall-out additionally accounts for 5.1% of the variance of log PbB ($P < 0.001$)
[d] Not significant

A similar regression analysis was carried out for the Duisburg children. The results presented in Table 10 show that lead fallout explains 16.1% of the variance of log PbB. Sex, socio-economic status and some interaction variables related to lead fallout represent further significant predictors of log PbB. None of these factors was found to be a significant predictor of log CdB.

Discussion

The present study provides data on the lead and cadmium concentrations in venous blood, shed milk teeth and urine of more than 4000 children living in different areas of North-West Germany. Sampling of the biological specimens was performed between June 1982 and September 1986. A careful quality control was carried out throughout the studies and it should be possible, therefore, to compare the results with data from similar studies in which analytical quality control has been ensured.

In rural, suburban and urban areas without industrial lead emissions the mean PbB levels were found to be in the range of 5.5 and 7 μg/dl. The 98th percentiles are between 11 and 13 μg/dl. Children living in urban/industrial areas have, on average, significantly higher PbB levels than children living in rural areas. The difference is in the order of 0.5 to 1.0 μg/dl. Since the air lead levels do not differ very much among the rural, suburban and urban study areas, the differences in blood lead must be related to another factor. It seems likely that the higher PbB levels found in urban children results from a higher oral lead uptake due to ingestion of lead containing dust. As shown in Table 1, lead fall-out in the urban areas is substantially higher than in the rural and suburban areas (Borken, Dülmen). In all the surveys the distribution of PbB levels was significantly below the reference values of the CEC directive on the biological screening of the population for lead (CEC 1977) and also below the more stringent guideline values used by the Dutch Ministry of Public Health for the evaluation of blood lead surveys in child populations (Brunekreef et al. 1983).

The highest PbB levels were recorded in children living in risk areas (Duisburg, Stolberg), particularly in those living near the Stolberg lead smelter. It seems that, in the latter area, there has been a considerable decrease of children's PbB levels in the period from 1982 to 1986. Our findings indicate that, even in these highly polluted areas, only a small number of children have PbB levels over 20 µg/dl at present. Similar results were obtained in the Nordenham area, where during an examination of 122 children in 1982, a mean PbB of 8.2 µg/dl was found, with individual PbB levels ranging up to 23.8 µg/dl (Winneke et al. 1985). Children most at risk are children of lead worker families and children living very close to the leadworks.

In comparison with the results of the CEC blood lead campaigns, which were carried out in 1979 and 1981, the PbB levels found in this study are significantly lower. In the first campaign in (1979) which included PbB determinations in 2301 children from different areas of West-Germany, a median of 11 µg Pb/dl was obtained. The median value found in the second campaign in 1981, which involved 2097 children, was 10 µg Pb/dl (Wagner and Krause 1984). We found median PbB levels of about 6 µg/dl in children from rural and suburban areas and median PbB levels of 6 to 8 µg/dl in children from urban and industrial areas. Since in 1979 and 1981 the children were selected from similar areas, our results indicate that a further substantial decrease of PbB has occurred in German children since 1981. The reduction appears to be in the order of 30 to 40%.

Our conclusion is consistent with other findings, which indicate that during the last few years a further significant decrease in PbB levels has occurred in the general population of West Germany and some other countries (Claeys-Thoreau et al. 1983, 1987; Fischedick et al. 1983; Annest et al. 1985; Quinn 1985; Elinder et al. 1986; Elwood and Toothill 1986; Englert et al. 1986; Hinton et al. 1986; Huel et al. 1986; Myslak and Bolt 1987). It is assumed that the decrease of blood lead observed in these countries largely results from the reduction of lead added to petrol. According to the West German Petrol Lead Law (last amendment 1975), the maximum permissible lead content of motor vehicle fuels was set at 0.15 g/l in 1976. As a consequence there has been a significant decrease of air lead levels in urban areas to about 0.3 µg/m^3 (annual means) (Buck et al. 1982, MAGS 1985; MURL 1986). In addition, the decrease of PbB levels seems to reflect a significant reduction of dietary lead intake. In fact, market basket surveys over several years, as well as analyses of the lead content of specified dietary products such as bread, show a decrease of the average lead intake through food and beverages during the last few years (Ernährungsbericht 1984).

The mean PbB values obtained in our studies are similar to those now found in other areas of West Germany (Englert et al. 1986; Myslak and Bolt 1987). They appear to be somewhat lower than those found in children from some other areas of Europe at present. For example, the results of the UK blood lead surveys in 1984 show median PbB levels of urban children varying between 9 and 11 µg/dl (Quinn and Delves 1985).

The finding that boys have higher PbB levels than girls corresponds to the well known fact that adult males have higher PbB levels than females (Brockhaus et al. 1983; Elinder et al. 1983). Although some studies have failed to show such a sex-related difference in children, there are several reports indicating that this difference already exists in children (Roels et al. 1980). Surprisingly boys tended to have lower PbT levels than girls (Table 6). The reason for this difference is unknown.

Our results demonstrate that the PbB levels of children living in polluted areas are influenced by a number of demographic, social and environmental variables. Children from lead worker families, low SES families, and foreign families tend to have higher PbB levels than otherwise comparable children. Moreover, sex, lead fallout around the child's dwelling, and some combined variables including lead fallout, oral behaviour, and consumption of home-grown food represent significant predictors of PbB. In the Stolberg group, these variables explain about 32% of the variance of log PbB (Table 8). In the Duisburg group, which consisted of German children only, about 23% of the variance of log PbB could be explained by these factors with lead in dust fallout being the most prominent factor. Unfortunately, no data on lead in the home environment, e.g. lead in house dust, were available. It has been shown, however, that the lead levels in the home environment largely correlate with outdoor lead levels, i.e. lead in soil and street dust (Rabinowitz et al. 1985). The importance of lead in dust and soil as a source of lead exposure for young children has been demonstrated in a number of studies (Roels et al. 1980; Brunekreef et al. 1983; Duggan, 1983; Bornschein et al. 1985). The finding that children from lead worker families and low SES families have higher PbB levels than otherwise comparable children is also consistent with findings from previous studies (Zielhuis et al. 1979; Morton et al. 1982).

The mean lead concentrations in shed milk teeth found in the present study vary between 2 and 5 µg/g. On average, the lead concentration in teeth is about 30 times higher than in blood. This relationship clearly demonstrates the accumulation of lead in teeth. Children living in urban and lead polluted areas have significantly higher PbT levels than children from rural areas. The relative differences are more pronounced than the differences of PbB. Since PbT reflects the degree of lead exposure integrated over the greater part of a child's lifespan, the larger relative differences indicate the continuously higher degree of environmental lead exposure found in urban areas and in areas around lead and zinc smelters. In two previous studies we determined the PbT levels of children from Duisburg, Stolberg, and Gummersbach, a rural area about 50 km east of Köln. The geometric means of PbT were 4.6, 6.0 and 3.9 µg/g, respectively (Ewers et al. 1979, 1982). Compared to these data the PbT levels found in the present study are significantly lower suggesting that, similar to blood lead, there has been a decreasing trend of tooth lead concentrations over the last few years. The PbT levels found in our studies are also lower than those obtained in a recent study conducted in three areas of London (Pocock et al. 1987). In this study a geometric mean of 3.86 µg/g was found for lower incisors ($n = 1061$) and 5.01 µg/g for upper incisor teeth ($n = 829$). In our studies no differentiation was made between upper and lower incisors.

The blood cadmium concentrations measured were on average in the range of 0.2 µg/l, with a 95th percentile of about 0.4 µg/l. There were no detectable differences between children from rural and urban/industrial areas. Higher mean values were found, however, in children living in the close vicinity of the Stolberg lead smelter and in children from lead worker families. The data are comparable to the results obtained for children from Northern Germany (Jessen et al. 1984). Schaller et al. (1984) reported substantially higher median values for children living in different areas of Bavaria. The levels of cadmium in urine found in our studies are likewise very low indicating an upper normal value (95th percentile) of about 0.5–1.0 µg/g creatinine. No differences were found between groups of children from various areas.

The mean CdB and CdU levels in children are significantly lower than the ones we found in non-smoking adults (Brockhaus et al. 1983; Ewers et al. 1985a, b). The increase of CdB and CdU with age seems to reflect the age-dependent increase of the cadmium body burden (Hahn et al. 1987) and has also been observed in several other studies (Elinder et al. 1983; Kowal and Zirkes 1983; Watanabe et al. 1983).

Whereas the mean CdB levels do not differ between girls and boys, girls were found to have a significantly higher cadmium excretion than boys. This finding is consistent with previous reports, which indicated that women excrete more cadmium than men (Kowal and Zirkes 1983). Non-smoking females were also found to have higher CdB values than non-smoking males (Elinder et al. 1983; Watanabe et al. 1983). It has been speculated that females, as a result of their lower iron reserves, have a higher absorption rate of cadmium from food and that this might be the reason for their higher cadmium levels in blood and urine (Flanagan et al. 1978; Elinder et al. 1983). Our results show that even in childhood there is a tendency towards higher CdU levels in girls when compared to boys, but no differences were found regarding CdB. The reason for the higher cadmium excretion in girls is not known. It can be expected that, in this age group, the iron reserves do not differ in boys and girls.

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