Polychlorinated Biphenyls in the Blood Plasma: Current Exposure of the Population in Germany

Ursel Heudorf,[1] Jürgen Angerer[2] and Hans Drexler[2]

[1]*Public Health Department City of Frankfurt, Frankfurt;* [2]*Institute for Occupational, Social, and Environmental Medicine, University Erlangen-Nürnberg, Erlangen, Germany*

ABSTRACT

Until the 1970s, polychlorinated biphenyls (PCB) were used as industrial chemicals for diverse commercial applications, leading to a ubiquitous contamination of nature and man. In the 1980s, PCBs were prohibited by law in many industrialized countries. Hence, in recent years a steady decline in PCB levels has been seen. Here we report on PCB plasma levels in children and adults in Germany in 1998. *Participants and methods*: 130 children/youth (0 to <18 y) and 494 adults (18 to 65 y) living in an urban environment participated in this study. Occupational exposure to PCBs was excluded by questionnaire. Gas chromatography/electron capture detection was used to analyze blood plasma samples. *Results*: In all blood specimens, PCB congeners 28, 52, and 101 were below the limit of quantification (<0.1 µg/L) and only the congeners 138, 153, and 180 were detected. The 95th percentiles in the age groups 0 to <6y, 6 to <12y, 12 to <18y, 18 to 25 y, 26 to 35 y, 36 to 45 y, 46 to 55 y, and > 55 y were as follows: PCB 138: 1.02; 1.05; 0.61; 1.01; 1.22; 1.44; 2.23; 2.94 µg/L plasma; PCB 153: 1.47; 1.23; 0.59; 1.26; 1.53; 2.11; 3.27; 3.98 µg/l plasma; PCB 180: 0.88; 1.23; 0.39; 0.88; 1.16; 1.71; 2.16; 3.31 µg/L. *Discussion*: In adults, plasma levels of PCBs increased with age. In comparison with published reference values on internal PCB exposure in the population in Germany, based on data obtained in 1991/4 and 1994/5, the steady decline in PCB levels reflects the falling external and internal PCB exposure after the ban on PCB. For the first time, current PCB exposure during childhood and adolescence in Germany is provided here. In childhood, internal PCB exposure declined with age, especially in children who had been breastfed. An impact of breastfeeding on internal PCB exposure was found in age groups up to 12 years old.

KEYWORDS

PCBs, human biomonitoring, blood plasma levels, reference values, children, adults

INTRODUCTION

From about 1920 up to 1970 polychlorinated biphenyls (PCBs) had been widely used as industrial chemicals for diverse commercial applications, such as dielectric fluids for capacitators and transformers, as plasticizers in sealants. Because of their unusually

Reprint requests to: Dr. Ursel Heudorf, Department for Environmental Medicine and Hygiene, Public Health Authorities, Braubachstr. 18-22, D-60311 Frankfurt am Main, Germany; e-mail: ursel.heudorf@stadt-frankfurt.de

high chemical stability, PCBs do not readily break down and therefore remain in the environment for a long time. This property has led to a ubiquitous contamination in nature and, consequently, to bioaccumulation and enrichment in the food chain. Thus, the highest levels of PCB contamination can be found in man. As higher chlorinated PCBs remain virtually unmetabolized and are only minimally excreted, they are stored in fatty tissues throughout the body. High levels are found in mothers' milk /1–7/.

Today, the main route of human exposure to PCBs is via the diet. The major dietary sources of PCBs are fish, meat, and dietary products /5, 7/. Formerly, when PCBs were used as flame retardants or as plasticizers in sealants in buildings, indoor air could become contaminated with PCB up to the range of 1–10 $\mu g/m^3$. Nevertheless, people living or working in such buildings never exhibited a significantly increased internal exposure when compared to that of control persons /8–15/. In certain special cases, however, living adjacent to a PCB-contaminated waste site can cause additional significantly increased internal exposure /16/.

Although PCBs exhibit low acute toxicity, the main problem is the potential for bioaccumulation and chronic toxicity, with effects on the liver, skin, immune system, thyroid, and the neurodevelopment of children, especially from perinatal exposure /1, 4–7/. PCBs have been categorized as animal carcinogens and probable human carcinogens /2, 3/.

Between 1980 and 1990, PCBs were prohibited by law in many industrialized countries. Hence, in recent years, a steady decline in PCB levels has been seen in outdoor air, food stuff, human blood /7, 17–23/ and human fat /24/, as well as in mothers' milk /25–30/. In Germany, PCB levels declined 80% in children's adipose tissue between 1985 and 1995 /24/. A reduction of PCB levels in mothers' milk to about the half was found between about 1984/5 and 1995/7 /25–30/. In the past 15 years, a significant decline (> 50%) occurred in cord blood of neonates /17–20/. In adults, the mean reduction of PCB levels in blood plasma was up to 30% between 1991 and 1998 /7, 21–23/.

In Germany, the Commission on Human Biological Monitoring of the German Federal Environmental Agency published reference levels for PCB in mothers' milk /31/, as well as for adult internal PCB exposure /7/. In children, however, reference levels for PCB in blood plasma have not yet been published. Here, we present data on current PCB exposure in children and adults in an urban population in Germany.

METHODS

The participants comprised 494 adults (18–65 years) and—with the informed consent of their parents—130 children and adolescents (0–18 years) took part in this investigation, conducted in 1998. All participants lived in the former American Forces housing estates in Frankfurt am Main, Germany. In children and adolescents, breastfeeding history was obtained by parent interview. Occupational exposure to PCBs was excluded by questionnaire. Venous blood was withdrawn using EDTA syringes and centrifuged. The supernatant liquid was analyzed for PCBs by capillary gas chromatography and electron capture detection, a well established method, approved by the Deutsche Forschungsgemeinschaft, Germany. Analyses were made for PCB cogeners 28, 52, 101, 138, 153, and 180 /32/.

RESULTS

Comparable with former studies, the PCB congeners 28, 52, and 101 were below the limit of quantification in all blood specimens and only the PCB congeners 138, 153, and 180 were detected. The statistical data are presented in Table 1.

TABLE 1

PCB levels in blood plasma of children and adults, Germany, 1998

Subjects		PCB concentrations (μg/L)					Reference values	
age	number	mean ± SD	range	P 5	P50	P95	1994/5 /1, 19/	1991/4 /10/
PCB 138								
0–<6 y	30	0.35±0,27	<LOD-1.33	0.04	0.29	1.02	-	-
6–<12y	60	0.38±0.28	<LOD-1.06	0.05	0.28	1.05	-	-
12–<18 y	40	0.22±0.18	<LOD0.92	<LOD	0.19	0.61	-	-
18–25 y	28	0.30±0.24	<LOD-1.19	<LOD	0.26	1.01	0.8	1.3
26–35 y	205	0.50±0.34	<LOD-2.28	0.07	0.43	1.22	1.5	1.9
36–45 y	200	0.66±0.40	<LOD-2.41	0.15	0.60	1.44	2.2	2.3
46–55 y	50	0.88±0.61	0.29-3.40	0.30	0.69	2.23	3.0	2.7
>55 y	11	1.05±0.78	0.26-2.94	0.26	0.71	2.94	3.7	4.9
PCB 153								
0–<6 y	30	0.51±0.38	<LOD-1.65	0.06	0.40	1.47	-	-
6–<12y	60	0.51±0.39	<LOD-2.00	0.12	0.40	1.23	-	-
12–<18 y	40	0.28±0.16	<LOD-0.68	<LOD	0.28	0.59	-	-
18–25 y	28	0.38±0.31	<LOD-1.63	<LOD	0.31	1.26	1.0	1.8
26–35 y	205	0.71±0.49	<LOD-3.70	0.15	0.61	1.53	1.9	2.4
36–45 y	200	0.97±0.59	<LOD-3.56	0.23	0.90	2.11	2.8	2.9
46–55 y	50	1.26±0.80	0.45-3.84	0.49	0.92	3.27	3.7	4.2
>55 y	11	1.59±1.01	0.51-3.98	0.51	1.40	3.98	4.6	6.1
PCB 180								
0–<6 y	30	0.31±0.24	<LOD-1.03	0.03	0.25	0.88	-	-
6–<12y	60	0.35±0.35	<LOD-1.84	0.07	0.23	1.23	-	-
12–<18 y	40	0.19±0.11	<LOD-0.47	<LOD	0.15	0.39	-	-
18–25 y	28	0.24±0.22	<LOD-1.20	<LOD	0.19	0.88	0.8	1.3
26–35 y	205	0.50±0.35	<LOD-3.00	0.12	0.42	1.16	1.5	1.6
36–45 y	200	0.76±0.49	<LOD-2.46	0.15	0.69	1.71	2.2	2.4
46–55 y	50	0.96±0.64	0.30-3.71	0.30	0.76	2.16	2.9	3.3
>55 y	11	1.48±0.84	0.42-3.31	0.42	1.40	3.31	3.5	4.3
PCB-sum								
0–<6 y	30	1.18±0.86	<LOD-4.01	0.13	1.01	3.28	-	-
6–<12y	60	1.25±0.99	<LOD-4.90	0.32	0.92	3.51	-	-
12–<18 y	40	0.69±0.36	<LOD-1.51	<LOD	0.66	1.34	-	-
18–25 y	28	0.92±0.74	<LOD-4.02	0.04	0.75	3.03	3.2	4.2
26–35 y	205	1.72±1.10	<LOD-7.46	0.42	1.47	3.89	5.6	5.8
36–45 y	200	2.40±1.43	<LOD-8.43	0.62	2.21	4.87	7.6	7.6
46–55 y	50	3.10±0.97	1.17-10.13	1.19	2.47	7.85	10.0	10.2
>55 y	11	4.13±2.28	1.61-9.36	1.61	4.04	9.36	12.2	15.5

TABLE 2

PCB levels in blood plasma of children and adolescents with regard to their breastfeeding history

Age (years)	Breastfeeding history	number	PCB 138 (µg/l)		PCB 153 (µg/l)		PCB 180 (µg/l)		PCB sum (µg/l)	
			Median	Max.	Median	Max.	Median	Max.	Median	Max.
0–< 6	Yes	19	0.30	1.33	0.58	1.65	0.27	1.03	1.33	4.01
	No	4	0.17	0.25	0.17	0.41	0.09	0.34	0.46	0.95
6–<12	Yes	43	0.30	1.06	0.41	0.75	0.38	1.94	0.97	4.90
	No	5	0.25	0.72	0.36	0.60	0.40	0.58	0.77	2.05
12–<18	Yes	25	0.20	0.62	0.27	0.60	0.15	0.40	0.66	1.27
	No	9	0.13	0.31	0.29	0.47	0.16	0.33	0.56	0.99

In children, the concentrations of all PCB congeners decreased with age up to 18 y, whereas in adults (> 18 years), all PCB congeners increased with age (Fig. 1, A–D). In comparison with published reference values on internal PCB exposure in the adult population in Germany, however, based on data obtained in 1991/4 /10/ and 1994/5 /1, 19/, an overall decline is seen (Table 1).

Children (< 12 years of age) having a history of breastfeeding exhibited higher internal PCB levels than did formula-fed children (Table 2). Significant correlations were found between the children's internal PCB levels and the data on whether and for how long the children had been breast fed. The effect of breast feeding was found in the age groups up to 12 years old, but was no longer detectable in the older age group.

DISCUSSION

In Germany, the reference values and human biological monitoring values (HBM values) for given environmental toxins are published by the Commission on Human Biological Monitoring of the German Federal Environmental Agency /33/. HBM values are derived from human toxicological and epidemiologic studies and are intended for use as a basis for a health related evaluation of human biological monitoring data. For lack of appropriate data, the Commission has not yet been able to establish HBM values for PCB levels in blood (plasma) /7/. Reference values are intended to indicate the upper margin of the current background exposure of the general populations to a certain toxin at a given time. Ideally, reference values should be based on large (representative)

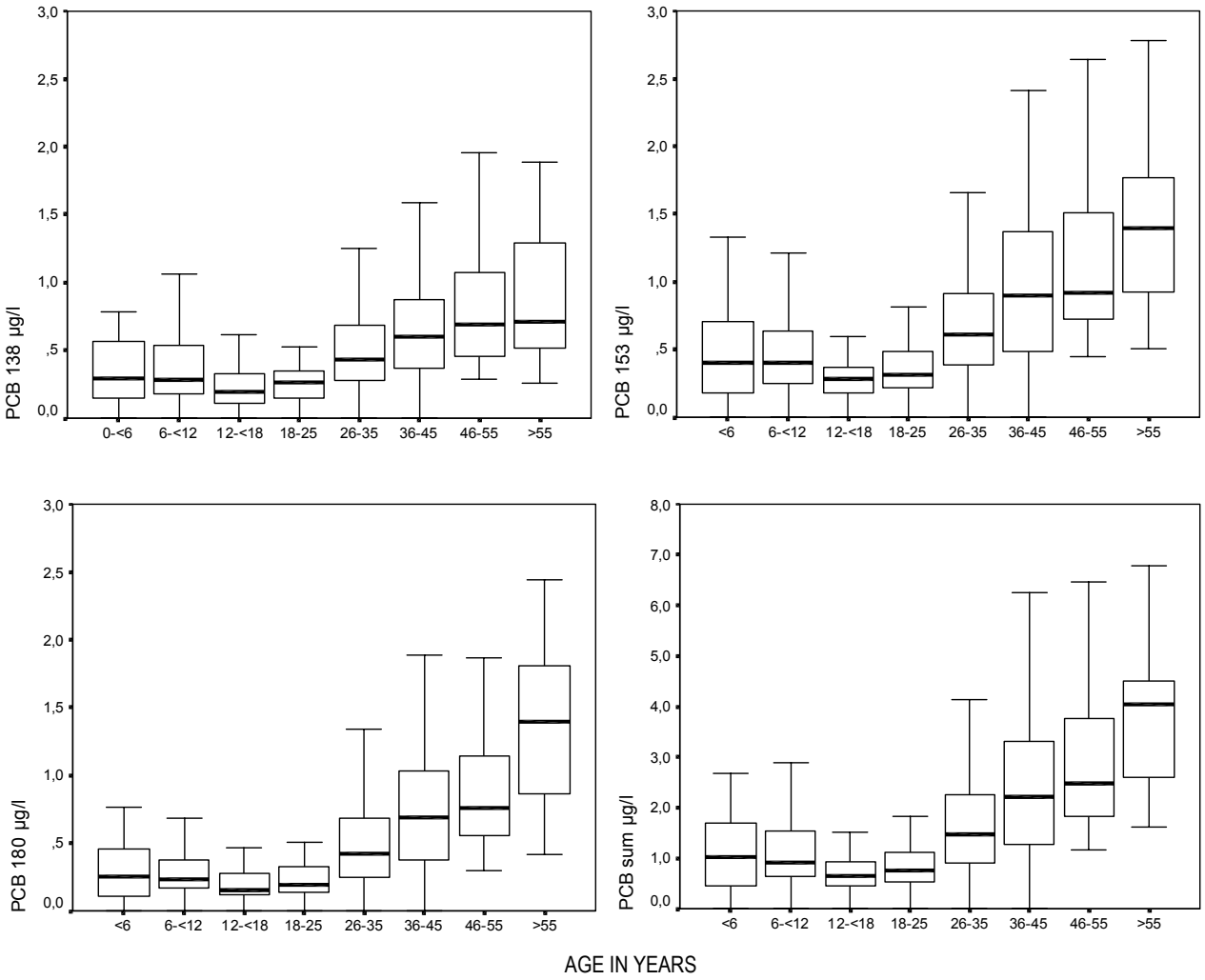

Fig. 1: PCB-levels (µg/L) in blood plasma of children and adults living in Frankfurt am Main, 1998 (median, 25th, 75th, 10th, and 90th percentile). PCB cogener: A – 138 (upper left); B – 153 (upper right); C-180 (lower left); D-PCBs sum (lower right).

population studies. For several environmental toxins (including PCB), however, data from representative studies are not available. In such cases, reference values had been based on data from smaller studies /7, 21, 22/. Up to now, however, data on PCB exposure during childhood and adolescence have not been available in Germany at all.

Furthermore, reference values must be revised according to changes in the background exposure of the general population /33/. Here, we report the current internal exposure in Germany, 1998. In comparison with published reference values on internal PCB exposure in the adult population in Germany, based on data obtained in 1991/4 /21/ and 1994/5 /7, 22/, the present steady decline in

plasma PCB levels reflects falling external and internal PCB exposure after the ban on PCBs. Therefore, for lack of representative data on current PCB exposure in the population, the data presented here could be used as 'provisional reference values'.

Because of their tendency for accumulation, plasma PCBs are known to increase with age in adults /7, 21–23/. In the children and adolescents tested in our investigation, however, PCB levels decreased with age. This result was mainly due to decreasing blood plasma levels in children with a positive history of breastfeeding. In the small group of children who had not been breastfed, however, a slight increase with age was seen.

When interpreting these data, growth phenomena occurring during childhood must not be neglected. Apart from a nonlinear increase in body weight (birth weight about 3 kg, doubled up to 6 mo and tripled up to 1 y, followed by an increase of about 2.5 kg/y up to 10 y), age-dependent percentages in body fat must be taken into account as well (body fat percentage about 15% in newborns, 25% in 6-mo-old infants, decreasing to 20% in 3-y-old and to 15% in 8–10 y-old children). Thus, decreasing blood plasma PCB levels in formerly breastfed children are the consequence of increasing body fat deposits rather than a decreased total internal PCB load via metabolism and excretion /34, 35/. The trend for increasing PCB blood levels in children without a history of breastfeeding must be considered with respect to the tenfold increase in total body fat occurring during this time.

Children who had been breastfed exhibited higher internal PCB exposure than did children without a history of breastfeeding. The effects of breastfeeding could be found not only in the age group 0 – 6 years old but also in the children 6 –12 years old; in the older age group (12–<18 years) it was no longer detectable, thus confirming results of earlier studies in infants. At the age of 4 y, American children with a history of breastfeeding for more than 6 mo exhibited higher PCB plasma levels (5.1 ± 3.9 µg/L) than did children who were breastfed for less than 6 mo (1.2 ± 1.6 µg/L) or who were formula fed (0.3 ±0.7 µg/L) /36/. In the Netherlands, blood PCB levels of 3.5-y-old children who had been breastfed were 3.6-fold higher (median 0.78 µg/L vs. 0.20 µg/L) than those of formula fed children /37/. And even in two studies with pupils 12–14 years old who had been exposed to PCB in their schools, the impact of breast feeding remained evident /38, 39/.

Hence, we conclude that today, breastfeeding continues to make a major contribution to internal PCB exposure in children; in teenagers, however, this effect may be exceeded by PCB intake with normal food. With less PCB contamination in breast milk resulting from the ban on PCBs, however, the effect of persistent pollutants in breast milk should decrease further, and the difference between children who were breastfed and those who were not should decline as well.

Several investigations were conducted in the United States of America—the Michigan and the North Carolina studies—and in Europe—the Dutch and the German studies—to assess the health impact of background intrauterine and lactational PCB exposure on the child's current body burden with PCB in infancy or in childhood up to the age of 11 y, especially with respect to neurological and cognitive, as well as growth, outcomes.

The Michigan Study

In the Michigan study /40–43/, 313 infants born between July 1980 and December 1981 were included; 242 born to mothers who reported moderate consumption of Lake Michigan fish contaminated with PCBs and 71 born to mothers who ate no fish. Maternal serum PCB levels were significantly higher than PCB levels in cord blood; and cord and maternal serum were highly correlated to PCB levels in mothers' milk. In 242 of the neonates, PCB levels in cord blood remained

below the limit of detection (3 µg/L), and in 75 infants the PCB levels were above 3 µg/L. The weights of exposed infants were up to 160–190 g lighter and their head circumference was about 0.5–0.6 cm less than in nonexposed neonates /41/.

At 4 years of age, PCB levels in blood were tested in 285 of these children: in 50% the PCB levels were above the limit of detection, with nursing being the principal source of this exposure /42/. McCarthy Scales of Children's abilities, Beery test of Visual Motor integration, and the Peabody Picture Vocabulary test-revised were administered: The authors stated that prenatal exposure as indicated by cord serum PCB levels—but not lactational exposure—was associated with poorer short-term memory function on both verbal and quantitative tests in a dose-dependent fashion /36/. Another battery of IQ and achievement tests was administered to 212 of those children when they were 11 years of age. After controlling for potential confounders like socioeconomic status, prenatal exposure to PCBs was associated with lower full-scale and verbal IQ scores, the strongest effects relating to memory and attention /43/.

The North Carolina Study

In the North Carolina Study, prospective birth cohort study was enrolled in about 900 families between 1978 and 1982 /44/. Birth weight, head circumference, and neonatal jaundice showed no relation with PCBs. With regard to Brazelton Neonatal Behavioral Assessment Scales—psychological and neurological tests for assessing neonates—PCBs affected general tone and activity scales, namely, were associated with hypotonicity and hyporeflexia at least in those children with the highest levels of transplacental PCB exposure (namely, > 3.5 ppm in milk fat at birth) /45/. Of these children, 802 were examined using Bayley (Bayley Scales of Infant Development) scores either at 6 mo or 12 mo or both /46/: again, higher transplacental exposure to PCBs was associated with lower psychomotor scales at 6 and 12 mo of age (difference 6 to 8 points). Exposure to PCBs via breastfeeding, however, was apparently unrelated to the Bayley scores. At 18 and 24 months of age, adjusted scores on the Bayley psychomotor scales were still 4 to 9 points lower among children in the top fifth percentile of transplacental but not lactational exposure /47/. On reexamination of 712 of these children at 3, 4, or 5 years of age, using the McCarthy Scales of Children's Abilities, a statistically significant relation between poorer grades and PCB exposure was no longer evident, neither by prenatal nor by lactational PCB exposure /48/. In 1992, a puberty follow-up of 594 of these children was obtained by questionnaire. Neither height and weight nor Tanner stages of puberty differed significantly among different levels of PCB exposure, either pre- or postnatal /49/.

Certain inconsistencies between the two studies may derive from differences in exposure levels. In the Michigan cohort, offspring of women who had eaten relatively large quantities of contaminated Lake Michigan fish were studied, whereas the North Carolina cohort was drawn from the general population. It could be assumed that via contaminated fish some other neurotoxic contaminants like mercury or lead might have been incorporated additionally. In both groups, however, effects were seen only in the most heavily exposed children; the top 3% to 5% of the North Carolina sample and the top 11% of the Michigan sample /50–52/.

Dutch PCB and Dioxin Study

From 1990 to 1992, a total of 418 healthy mother child pairs were recruited; half the study population lived in Rotterdam, the other half in Groningen. In the Rotterdam group (n = 207; 105 breastfed, 102 bottle fed), birth weight and weight,

length, head circumference were measured at 10 d and at 3, 7, 18, and 42 mo of age during infancy. Infants with high cord plasma PCB levels (P 90: 0.80 µg/L) weighed 165 g less than infants with low cord plasma PCB levels (P10: 0.20 µg/L). In the formula fed group, high PCB levels in cord and maternal plasma were significantly associated with a lower growth rate (weight, length, and head circumference) from birth to 3 mo. Later on, no negative effect on growth was found up to 42 mo of age. Postnatal PCB exposure via breast milk was not negatively related with growth rate at all /53/. Higher in utero exposure to PCBs correlated with lower psychomotoric scores (Bayley Scales of Infant Development) at 3 mo of age; a doubling of the PCB load resulted in a decrease of 3 points. Although a definitely greater amount of PCB was transferred to the children via breastfeeding, breastfed infants scored significantly higher on the psychomotor scale at 7 mo of age. At 18 mo of age, neither the mental nor the psychomotor score was related to perinatal PCB exposure or to the exposure via breastfeeding /54/.

In the combined Rotterdam and Groningen groups (n = 418), neurological examination of the neonates with the Prechtl test revealed reduced neurological ability in newborns ingesting high levels of PCBs and dioxins in mothers milk /55/ The negative correlation with prenatal (but not with postnatal) PCB exposure was still evident in children at 18 mo /56/. At the age of 42 mo, neither prenatal nor postnatal PCB (and dioxin) exposure was found to be related to the neurological condition of the children /57/. Additionally, in a subgroup of 193 children, verbal comprehension was assessed with the Reynell Language Development Scales. When compared with the lowest perinatally exposed group, the highest exposed group scored 4 points lower on all 3 scales of the K-ABC. Both lactational exposure and current PCB exposure to PCBs and dioxins were not related to 42-mo cognitive tests /58/. Later on, at school age, negative effects of prenatal PCB and dioxin exposure on cognitive and motor abilities were seen only in families with less optimal parental and home characteristics but not in children raised in a better social environment /59/.

In Germany, comparable results were reported recently: A follow up of 171 healthy mother-infant pairs recruited between 1993 and 1995 showed that until 42 mo of age, prenatal PCB exposure inhibited and a favorable environment supported mental and motor development /60/. Additionally, the authors had reported a small negative effect of postnatal PCB exposure via breastfeeding at 42 mo as well, but the latter result is controversial for methodological reasons /61/.

Despite the much larger quantity of PCBs transferred postnatally via lactation than prenatally across the placenta, prenatal exposure but not exposure from nursing was related to cognitive performance or growth in all but one study /36, 37, 40–62/. Moreover, breastfeeding per se exhibited important positive influences on the neurological and cognitive development of the children /54/. In conclusion, it was stated that the recommendations for promotion and support of breastfeeding need not be altered and mothers should be supported to breastfeed their infants—also in the western industrialized part of the world /54, 62, 63/.

Prenatal PCB exposure is not only positively correlated with the age of the mother and the gestational age of the child /64/ but also with the smoking habits of the parents. Median total PCB levels neonates of active smoking mothers were found to be significantly higher than those of passive smoking mothers or of mothers in non-smoking families (1.19 µg/L vs. 0.91 µg/L, vs. 0.70 µg/L) /65/.

Although the effects of prenatal PCB exposure were small and within ‘normal’ physiological range, a WHO expert panel stated that continued and enhanced effort should be directed toward identifying and controlling the sources of environmental

input of these contaminants /63/. In consequence of the ban on these substances in the Eighties of the last century, internal exposure in the population has been declining during the last decade, and it may be assumed that this positive development will continue during the future, thus preventing negative effects on neurodevelopment in children.

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