breast-feeding" as an analytic category may dilute the true association between intentions of pregnancy and breast-feeding because of the heterogeneous nature of that category. In our study, however, the same associations were observed for both any breast-feeding and exclusive breast-feeding.

This study highlights the importance of identifying women with unplanned pregnancies and specifically targeting that group for breast-feeding promotion interventions. Finally, the study provides yet further evidence that children born to women who did not intend to become pregnant are at higher risk than other children of not having sufficient resources—in this instance, the benefits of breast-feeding—for healthy development.[4] □

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Plasma Polychlorinated Biphenyl Levels in Dutch Preschool Children Either Breast-Fed or Formula-Fed during Infancy

Svati Patandin, MD, Nynke Weisglas-Kuperus, MD, PhD, Maria A. J. de Ridder, MSc, Corine Koopman-Esseboom, MD, PhD, Wija A. van Staveren, RD, MSc, PhD, Cornelis G. van der Paauw, and Pieter J. J. Sauer, MD, PhD

ABSTRACT

Objectives. This study examined the influence of lactational and in utero exposure to polychlorinated biphenyls (PCBs) on plasma PCB levels in children.

Methods. Plasma PCB levels were measured in 173 children at 3.5 years, of whom 91 were breast-fed and 82 were formula-fed in infancy.

Results. Median plasma PCB levels were 3.6 times higher in breast-fed children (0.75 μg/L) than in their formula-fed peers (0.21 μg/L). Breast-feeding period and breast-milk PCB levels were important predictors for PCB levels in the breast-fed group. For children in the formula-fed group, PCB levels were significantly related to their maternal plasma PCB levels.

Conclusions. PCB levels in Dutch preschool children are related to transfer of maternal PCBs; therefore, strategies should be aimed at reducing maternal PCB body burden. (*Am J Public Health.* 1997;87:1711–1714)

Introduction

Polychlorinated biphenyls (PCBs), polychlorinated dibenzo-para-dioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs) are widespread environmental contaminants.[1] In Dutch infants, subtle signs of neurological dysfunctioning,[2] small delays in psychomotor development,[3] and alterations in thyroid hormone[4] and immunological status[5] during infancy are associated with perinatal exposure to PCBs and PCDDs/PCDFs.

Human exposure to PCBs and PCDDs/PCDFs is mainly through the food chain, for example, dairy products, fish, and meat.[6,7] The Netherlands is among the countries with the highest environmental levels of PCBs and PCDDs/PCDFs as measured in breast milk.[8] In breast-fed infants, daily PCB and PCDD/PCDF intake is 20 times higher than the tolerable daily intake of 10 pg toxic equivalent per kilogram per day.[6,9]

We report plasma PCB levels measured in Dutch children at 3.5 years and the contribution of in utero and lactational exposure to PCBs. Furthermore, we relate plasma PCB levels in these children to their dietary intake of PCBs and PCDDs/PCDFs and to their body fat.

Svati Patandin, Nynke Weisglas-Kuperus, Corine Koopman-Esseboom, and Pieter J. J. Sauer are with the Department of Pediatrics, Division of Neonatology, Erasmus University and University Hospital/Sophia Children's Hospital, Rotterdam, the Netherlands. Maria A. J. de Ridder is with the Institute of Epidemiology and Biostatistics, Erasmus University, Rotterdam, the Netherlands. Wija A. van Staveren is with the Department of Human Nutrition, Agricultural University, Wageningen, the Netherlands. Cornelis G. van der Paauw is with the Nutrition and Food Research Institute, Division of Analytical Sciences, Zeist, the Netherlands.

Requests for reprints should be sent to Svati Patandin, MD, Department of Pediatrics, Division of Neonatology, Sophia Children's Hospital, PO Box 2060, 3000 CB, Rotterdam, the Netherlands.

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TABLE 1—Characteristics and Polychlorinated Biphenyl (PCB) Levels of Formula-Fed and Breast-Fed Children at 3.5 Years of Age, Rotterdam Area, the Netherlands, 1994

	Formula-Fed Group	Breast-Fed Group	P[a]
n	93	100	
Male, no. (%)	43 (46%)	61 (61%)	.04
Firstborn, no. (%)	44 (47%)	53 (53%)	NS
Age, y, mean ± SD	3.54 ± 0.10	3.53 ± 0.08	NS
Weight, kg, mean ± SD	17 ± 2.1	16.5 ± 2.0	NS
Body fat, %, mean ± SD	20.4 ± 3.5	19 ± 3.0	.007
Maternal age, y, mean ± SD	28.9 ± 4.2	28.8 ± 3.2	NS
Dietary intake of TEQ,[b] pg/d, mean ± SD	104 ± 33.4	107 ± 38.8	NS
ΣPCB[c] (μg/L), median (range)	0.210 (0.08–0.46)	0.750 (0.23–5.90)	<.0001

[a]Student's *t* test or chi-squared test.
[b]TEQ = toxic equivalent of dioxin-like PCBs and 2, 3, 7, 8 tetra chloro dibenzo-dioxin.
[c]Sum of PCBs, International Union of Pure and Applied Chemistry numbers 118, 138, 153, and 180 in plasma.

TABLE 2—Multiple Linear Regression Analysis with Plasma ΣPCB[a] at 3.5 Years of Age as Dependent Variable

	Regression Coefficient (SE)	Standardized Regression Coefficient	P
Breast-fed group (n = 81)[b]			
Constant	−0.938 (0.572)		.10
Weeks of breast-feeding	0.030 (0.003)	0.64	<.0001
Breast milk ΣPCB, ng/g fat	1.031 (0.448)	0.30	.02
Maternal plasma ΣPCB, μg/L	0.088 (0.081)	0.15	.28
Maternal age, y	0.03 (0.015)	0.02	.85
Weight of child, kg	−0.055 (0.024)	−0.17	.02
Dietary intake of total TEQ, pg/d	0.002 (0.001)	0.13	.09
Formula-fed group (n = 79)[c]			
Constant	−1.434 (0.461)		.003
Maternal plasma ΣPCB, μg/L	0.121 (0.045)	0.29	.009
Maternal age, y	0.020 (0.011)	0.20	.07
Weight of child, kg	−0.07 (0.02)	−0.38	.0002
Dietary intake of total TEQ, pg/day	0.003 (0.001)	0.20	.04

Note. TEQ = toxic equivalent.
[a]Sum of polychlorinated biphenyls, International Union of Pure and Applied Chemistry numbers 118, 138, 153, and 180.
[b]R^2 = 0.63; multiple R = 0.79.
[c]R^2 = 0.36; multiple R = 0.60.

Methods

From 1990 to 1992 this study enrolled 207 children, of whom 105 were breast-fed and 102 were formula-fed during infancy. Subjects were living in Rotterdam or its surroundings, an industrialized and densely populated area in the Netherlands. The formula consumed in the formula-fed group was from one batch (Almiron M2, Nutricia NV, the Netherlands) and had negligible concentrations of PCBs and PCDDs/PCDFs. The study was approved by the Medical Ethical Committee of the University Hospital Rotterdam. The study design and chemical analysis methods are described elsewhere.[3,10]

In 1994, at 3.5 years of age, children were visited at home for a parental interview, a food questionnaire, and their developmental follow-up. Blood collection for PCB analysis and measurement of weight, height, and skinfold thickness took place at the Children's Hospital.

Analysis of four PCB congeners, International Union of Pure and Applied Chemistry (IUPAC) numbers 118, 138, 153, and 180, was performed at the Nutrition and Food Research Institute, Zeist, the Netherlands. The same method was used for PCB analysis in maternal and cord plasma.[10,11] PCB values in plasma are reported on a volume basis (μg/L), and the PCB sum (ΣPCB) was calculated by adding up the four congeners in each plasma sample.

Prenatal PCB exposure was estimated from the ΣPCB in maternal plasma collected during the last trimester of pregnancy and in cord plasma.[10] Postnatal PCB exposure was estimated by the ΣPCB of the same four congeners in breast milk and number of weeks of breast-feeding. Total toxic equivalent in breast milk was calculated from 8 dioxin-like PCBs and 17 PCDDs/PCFFs according to the World Health Organization and S. H. Safe.[10,12,13]

Dietary intake of PCBs and PCDDs/PCDFs at preschool age was assessed by a validated food questionnaire developed by the Agricultural University Wageningen, the Netherlands. Comparison of the results of the questionnaire with the dietary history as a reference showed a good agreement between the mean intakes (r = .58 for PCDDs/PCDFs and r = .40 for PCBs). The total toxic equivalent intake was calculated in each food item by means of reference data for food products provided by the Dutch National Institute of Public Health and Environmental Protection (RIVM).[6,14]

Weight (kg), height (m), and skinfold thickness (mm) at four sites—bicipital, tricipital, subscapular, and suprailiacal skinfolds—were measured according to Tanner.[16] Total body fat percentage was calculated from four skinfolds as described by Weststrate and Deurenberg.[16]

Plasma PCB levels were normalized by natural logarithmic transformation. Median and range of the ΣPCB are reported. The Student's t test and the chi-squared test were used to compare differences between the breast-fed and the formula-fed group. Multiple linear regression analysis was performed separately for the two groups. Plasma ΣPCB levels at 3.5 years of age were entered as dependent variables. The PCB levels in breast milk and duration of breast-feeding in weeks were entered as exposure variables for the breast-fed group. The ΣPCB levels in maternal plasma were

entered as prenatal exposure in both groups. Results were statistically significant at a $P \leq .05$. Data analysis was performed with SPSS.[17]

Results

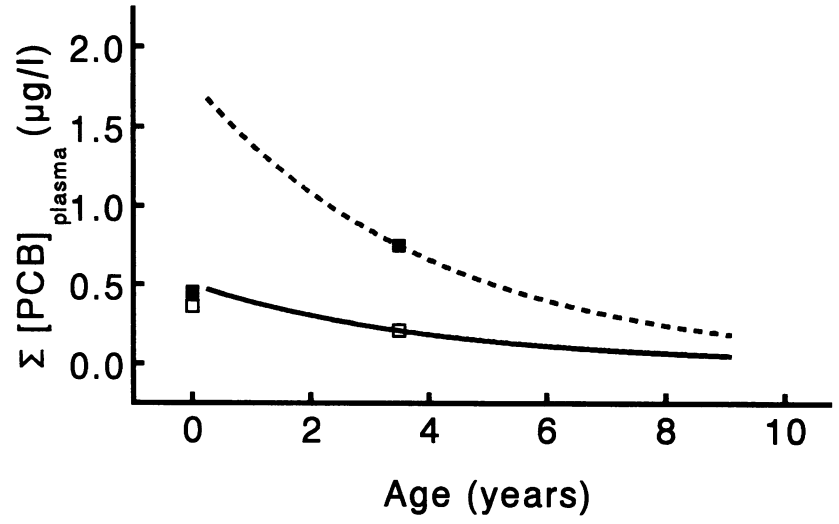
Of the original 207 infants, 193 were examined at 3.5 years (100 breast-fed and 93 formula-fed). Fourteen infants were lost to follow-up, owing to lack of interest (n = 10) and emigration (n = 4). Polychlorinated biphenyl levels were measured in plasma of 173 children (91 breast-fed and 82 formula-fed).

In the breast-fed group, there were slightly more boys ($P = .04$) and the total body fat percentage was lower ($P = .007$) compared with the formula-fed group. Children in the breast-fed group had significantly higher median PCB levels in plasma ($P < .0001$) than children in the formula-fed group. Dietary intake of total toxic equivalents did not differ in the two groups (Table 1).

Levels of PCBs, measured in cord plasma and in 3.5-year-old plasma, were available for 155 children (81 breast-fed and 74 formula-fed). Plasma ΣPCB levels at 3.5 years of age in the breast-fed group were significantly higher than their levels in cord plasma (median = 0.75 vs 0.45 μg/L; $P = .001$), whereas in the formula-fed group, plasma ΣPCB levels were significantly lower than their levels in cord plasma (median = 0.21 vs 0.35 μg/L; $P = .003$).

PCB levels in maternal and cord plasma were significantly correlated with the PCB levels at 3.5 years in the breast-fed group ($r = .40$ for maternal plasma; $r = .37$ for cord plasma) as well as in the formula-fed group ($r = .44$; $r = .35$). In the breast-fed group, PCB levels were significantly correlated with the period of breast-feeding ($r = .63$), milk PCB levels ($r = .39$), and the total toxic equivalent in breast milk ($r = .36$).

The breast-feeding period ($P < .0001$) and ΣPCB level in breast milk ($P = .02$) were important predictors for plasma PCB levels at 3.5 years in the breast-fed group. In the formula-fed group, PCB levels at 3.5 years were significantly associated with their maternal ΣPCB levels ($P = .009$) and daily total toxic equivalent intake through diet ($P = .04$). A higher body weight of the child was significantly associated with lower plasma PCB levels at 3.5 years in both groups (Table 2). The same was true for body fat when this was entered in the regression analysis. The standardized regression coefficient increased to −0.51 and −0.31 for the breast-fed and formula-fed groups, respectively.



Note. Estimated PCB values are calculated from measured PCB values at 3.5 years of age and based on the assumption that the half-life of PCBs is 2.8 years. The dashed line represents estimated values for children from the breast-fed group, and the solid line, estimated values for children from the formula-fed group. Measured values have been marked with closed squares (breast-fed group) and open squares (formula-fed group).

FIGURE 1—Estimated polychlorinated biphenyl (PCB) levels from infancy to school age for children breast-fed or formula-fed during infancy.

Figure 1 gives an estimate of plasma PCB levels from birth to school age that is based on the assumption that the half-life for plasma PCBs is 2.8 years in children[18] and that the dietary intake of PCBs after weaning is negligible compared with the prenatal and lactational exposure. On the basis of these assumptions and the measured PCB levels at 3.5 years, PCB levels in infants during breast-feeding must have reached levels as high as their mother's.

Discussion

Our study demonstrates that plasma PCB levels of preschool children breast-fed in infancy are 3.6 times higher than those of their formula-fed peers. Plasma PCB levels in the breast-fed group are 167% of their cord plasma levels, compared with 60% in the formula-fed group. To our knowledge, no other study has measured plasma PCB levels in children—either formula-fed or breast-fed during infancy—in relation to environmental exposure to PCBs.

In agreement with studies performed in children concerning populations either accidentally or occupationally exposed[18,19] to PCBs, or populations living on farms with PCB-contaminated silos or consuming contaminated fish,[20,21] PCB levels in Dutch breast-fed children were significantly related to the period of breast-feeding and PCB levels in breast milk. A German study measured PCBs in adipose tissue of infants and toddlers; however, the study estimated the quantity of breast milk consumed, not the PCB levels in breast milk.[22] In contrast to our study, comparison with a formula-fed group was not performed in these studies.

Jacobson et al. could detect PCB levels in half of the samples tested in 4-year-old children whose mothers were exposed by either contaminated fish or farm products.[20] In our study, PCB levels were detectable in all children. This might be due to higher exposure in our group; however, it is more likely due to a more accurate laboratory technique[10,11] used in our study.

We were not able to estimate the dietary intake of the four PCB congeners measured in plasma. Instead the total toxic equivalent intake was measured. There is, however, a good correlation between total toxic equivalent intake and individual congeners.[10] The dietary toxic equivalent intake had a small but significant effect on the plasma PCB levels in the formula-fed group, but not in the breast-fed group. This difference can be

explained by the high intake of PCBs and total toxic equivalent through breast milk.

The observed negative association between total body fat (body weight) and plasma PCB levels is in agreement with two other studies.[18,19] PCBs are distributed over all fat-containing components in the body. Lower PCB levels in children with a higher total body fat most likely concerns a dilutional effect. The total body burden of infants with a high fat content might even be higher than that of leaner children. To calculate total body burden, PCBs should be expressed per gram of fat in plasma or adipose tissue, and total body fat should be estimated.

We conclude that plasma PCB levels in Dutch preschool children are the result of exposure through breast milk and in utero exposure. The influence of dietary intake of PCBs after weaning is small compared with the intake during breastfeeding. To lower PCB levels in childhood, future mothers will have to reduce their long-term intake of PCBs years before pregnancy in order to lower both in utero and lactational transfer. Strategies should be aimed at reducing PCB accumulation in the food chain. □

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