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High Breast Milk Levels of Polychlorinated Biphenyls (PCBs) among Four Women Living Adjacent to a PCB-Contaminated Waste Site

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As a consequence of contamination by effluents from local electronics manufacturing facilities, the New Bedford Harbor and estuary in southeastern Massachusetts is among the sites in the United States that are considered the most highly contaminated by polychlorinated biphenyls (PCBs). Since 1993, measures of intrauterine PCB exposure have been obtained for a sample of New Bedford area infants. Among 122 mother–infant pairs, we identified four milk samples with total PCB levels that were significantly higher than the rest, with estimated total PCBs ranging from 1,100 to 2,400 ng/g milk fat compared with an overall mean of 320 ng/g milk fat for the 122 women. The congener profile and history of one case was consistent with past occupational PCB exposures. Otherwise, the source of PCB exposures in these cases was difficult to specify. Environmental exposures including those from fish consumption were likely, whereas residence adjacent to a PCB-contaminated site was considered an unlikely exposure source. In all four cases, the infants were full-term, healthy newborns. Because the developing nervous system is believed to be particularly susceptible to PCBs (for example, prenatal PCB exposures have been associated with prematurity, decrements in birth weight and gestation time, and behavioral and developmental deficits in later infancy and childhood, including decrements in IQ), it is critical to ascertain if breast-feeding is a health risk for the women's infants. Despite the potential for large postnatal PCB exposures via breast milk, there is limited evidence of significant developmental toxicity associated with the transmission of moderate PCB concentrations through breast milk. Breast-feeding is associated with substantial health benefits including better cognitive skills among breast-fed compared with formula-fed infants. We conclude, based on evidence from other studies, that the benefits of breast-feeding probably outweigh any risk from PCB exposures via breast milk among the four New Bedford infants. In this case report, PCB analysis of breast milk and infant cord serum was a research tool. PCB analysis of milk is rarely done clinically, in part because it is difficult to use the results of such analyses to predict health risks. Substantial effort is needed to achieve a better understanding of the clinical and public health significance of PCB exposures, particularly among potentially susceptible groups such as infants and children. Such efforts are critical to improving the clinical and public health management of widespread and ongoing population exposures to PCBs. *Key words*: breast milk, infancy, organochlorines, PCBs, polychlorinated biphenyls, prenatal exposure. *Environ Health Perspect* 106:513–518 (1998). [Online 14 July 1998]
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Case Presentation

As a consequence of contamination by effluents from local electronics manufacturing facilities, the New Bedford Harbor and estuary in southeastern Massachusetts is among the sites in the United States that are considered the most highly contaminated by polychlorinated biphenyls (PCBs). In 1979 the contaminated estuary and harbor were closed to fishing and in 1982 the site was placed on the EPA's National Priority List for hazardous waste cleanup (Fig. 1). In 1993 a study was begun to survey levels of intrauterine PCB exposure and to assess the relationship of biomarkers of intrauterine PCB exposure to infant development among a sample of New Bedford area infants. As part of this ongoing work, congener-specific PCB concentrations and total PCB concentrations are measured in serum from infant cord blood samples collected at birth and from maternal milk samples collected at approximately 2 weeks postpartum. The PCB congener profile characteristics of the serum and milk samples are also assessed.

Among 122 mother–infant pairs in whom both breast milk and infant cord serum samples were available, we identified four milk samples with total PCB levels that were significantly higher than the rest. The summed concentrations of 49 individual PCB congeners for these four samples ranged from 1,100 to 2,400 ng/g milk fat, compared with an overall mean of 320 ng/g milk fat for the 122 women. In addition, two of the four samples had a distinct congener profile pattern that differed noticeably from that of the overall study population in their unusually high proportion of congener number 28 (Fig. 2, Subjects A and B). Subject A's milk sample also had a high proportion of congener number 74 (Fig. 2).

The cases associated with the four milk samples were evaluated in detail (Table 1). The four women were older mothers (age >30 years). One woman had worked in occupations associated with PCB exposure, and two women reported eating an average of greater than one serving per day of fish or seafood, including local fish for Subject C. The fourth woman had no occupational or dietary risk factors for PCB exposure.

In all four cases, the infants were full-term, healthy newborns, according to a review of hospital birth records, the Brazelton Neonatal Assessment (*1*) at birth and age 2 weeks, and height, weight, and head circumference measurements at birth. No values outside accepted ranges were found for the four infants.

Discussion

PCBs are widely occurring environmental contaminants. They are a family of 209 structurally related congeners that have a common biphenyl structure but differ in the number and position of chlorine substitutions. PCBs are lipophilic, bioconcentrate in the food

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Figure 1. View of a New Bedford, Massachusetts, neighborhood adjacent to the PCB-contaminated New Bedford harbor estuary. Notices posted along the shore advise "Warning, hazardous waste, no wading, fishing, shellfishing per order US EPA."

Table 1. Characteristics of four New Bedford, Massachusetts, women with high breast milk polychlorinated biphenyl (PCB) concentrations

Subject	Milk PCBs (ng/g fat)[a]	Prior breast-feeding	In New Bedford area before 1979	History of occupational risk	>1 serving/ day fish or seafood	Infant cord serum PCBs (ng/g)[b]
A	2,379	No	Yes	Yes	No	6.1
B	2,071	No	No	No	Yes	4.6
C	1,432	Yes	Yes	No	Yes	1.4
D	1,107	Yes	No	No	No	1.1

[a]Nonoccupationally exposed population background levels are generally ≤2,500 ng/g milk fat (*19*).
[b]The mean cord serum total PCB concentration was 0.8 ng/g for the 122 New Bedford infants. There are no background standards for cord serum PCB concentrations. On average, adult serum PCB concentrations are higher than those in cord serum and have background levels of up to 20 ng/g (*19*).

chain, and are present in detectable amounts in the fat of all human populations for whom monitoring data are available (*2*). Commercial mixtures of PCB congeners, Aroclors, were manufactured in the United States for almost 50 years for use as nonflammable dielectrics in electronic parts, lubricants, plasticizers in caulking compounds, paints, adhesives and sealants, vehicles for pesticide application, and pigment suspension agents in carbonless copy paper. Commercial use of PCBs was banned in the United States in 1977, but because of their resistance to degradation and metabolism and their bioaccumulation, exposures still occur. Dietary intake is the main source of nonoccupational PCB exposure, particularly from animal fat or fish harvested in contaminated water. PCBs readily cross the placenta, and maternal exposures are a potential source of intrauterine PCB exposure. Because PCBs are lipophilic, they concentrate in fatty tissue including breast milk, which in turn can be a major source of postnatal PCB exposure during infancy.

Clinical assessment of PCB exposure risk should include a careful occupational and dietary history. Other potential environmental risk factors include the condition and age of household appliances, fluorescent lighting fixtures, and other electrical equipment. A history of electrical repair work involving old transformers, capacitors, or other components that may contain PCBs should be reviewed, as should the possibility of accidental or unusual exposure circumstances (transformer fires, for example).

Independent of exposure source, PCBs that are commonly found in human tissue (serum, milk, or fat, for example) are those that are more lipophilic, are resistant to biotransformation, and have *para* and *ortho* substitutions—for example, International Union of Pure and Applied Chemists (IUPAC) (*3*) congener numbers 28, 74, 99, 118, 128, 138, 153, 156, 170, and 180 (*4,5*) (Fig. 3). In general, less chlorinated PCBs are more rapidly metabolized, although half-lives of 3 and 8 years, respectively, have been estimated for the less chlorinated PCBs 28 and 74 (*6*). Estimated half-lives of more chlorinated congeners such as PCBs 138 and 153 are 16 and 28 years, respectively (*7*).

Exposure Assessment and Apportionment by PCB Congener Profiling

The concentrations of 49 individual PCB congeners or coeluting congener pairs (IUPAC numbers 6, 8, 18, 16, 31, 28, 33, 22, 52, 49, 44, 37, 74, 70, 66, 95, 84, 101, 99, 97, 87, 136, 77/110, 151, 135, 149, 118, 153, 105, 141, 138, 187, 183, 128, 167, 174, 177, 171, 156, 157/201, 180, 170, 199, 196/203, 189, 195, 194, 206, 209) and their sum, an estimate of total PCB content, were calculated for the maternal milk and infant cord blood samples in these analyses, as was the congener weight percent, the relative contribution by weight of each congener to the sum of PCBs in the sample (*8*). Specific patterns of congener weight percent have been described in association with particular exposure sources: relatively high prevalence of congeners 28 and 74 is often associated with long-term occupational PCB exposures (*4,9*), and congeners 138, 153, and 156 may predominate in exclusively environmental exposures (*9*).

The distribution of congeners in the sample with the highest breast milk PCB concentrations was consistent with occupational PCB exposure, which was confirmed by history but had ceased by the time of the study (Table 1, Fig. 2, Subject A). The PCB congener patterns of the other three samples were less consistent with a dominant exposure source, although environmental exposures including dietary exposures are a likely explanation (*9*). Despite a high proportion of congener 28 for one of these women (Fig. 2, Subject B), none of the women had occupational risk factors for PCB exposure, although two were heavy fish or seafood eaters (Table 1). PCB excretion via prior breast-feeding, interindividual variability in PCB metabolism, the possibility of childhood exposures, or other unidentified dietary or environmental risk factors for PCB exposure may have determined the total PCB concentrations and congener patterns in these three women.

An important but difficult question in this case is what role, if any, residency adjacent to a PCB-contaminated site plays in PCB exposures. In surveys of residents of communities with PCB-contaminated sites, including New Bedford, population mean PCB concentrations have not exceeded those of control populations (*10,11*). High levels of PCBs have only been found among the subset of the population with occupational exposures or identifiable high risk behaviors (fishing and consuming fish from polluted waters, for example) (*10,11*). Consistent with past surveys of serum samples in this community, the average breast milk PCB concentrations among the 122 New Bedford women were comparable to, if not lower than, those described in other populations without occupational or unusual dietary risk factors for PCB exposure [Table 2 (*12,13*)]. The available evidence from the current and past surveys suggests that, in the absence of high risk behaviors, residency adjacent to a PCB-contaminated site is unlikely to be a major contributor to

total PCB concentrations in breast milk among the New Bedford women.

The four women identified in this report had significantly higher milk PCB concentrations than the average in the New Bedford women sampled and than the average for other population-based samples (Table 2). However, cross-study comparisons of total PCB concentrations are difficult because of differences in techniques for PCB identification and quantification, which can account for as much as 2- to 10-fold differences in estimates of total PCB concentration (*14*). Furthermore, in many populations, human milk and serum PCB concentrations have been gradually declining since the early 1980s (*14,15*). With these caveats in mind, none of the four women had breast milk total PCB concentration estimates in excess of maximum population total PCB levels described previously of >6,000 ng/g milk fat (*16–18*). All of the milk concentrations were within published so-called background ranges of total PCBs of up to approximately 2,500 ng/g milk fat (*19*). However, two of the samples had higher concentrations than were described among more recently studied (1988–1990) women in southern Quebec, whose breast milk maximum total PCB concentrations were approximately 1,900 ng/g milk fat (*15*). In addition, these two samples exceeded the Food and Drug Administration's (FDA) currently recommended tolerance for total PCBs in commercial milk of 1,500 parts per billion (fat basis) (*20*). Of note, in populations surveyed in the past in Michigan, up to 50% of breast milk PCB concentrations exceeded the FDA tolerance level (*21*).

PCB-contaminated Breast Milk as a Health Risk

Clinical intervention, if any, in these cases must be based on the possible health risks associated with the milk PCB concentrations. Indeed, PCBs have wide-ranging potential health effects including hepatotoxicity, neurotoxicity, and immunotoxicity. PCBs are hepatic carcinogens in experimental ani-

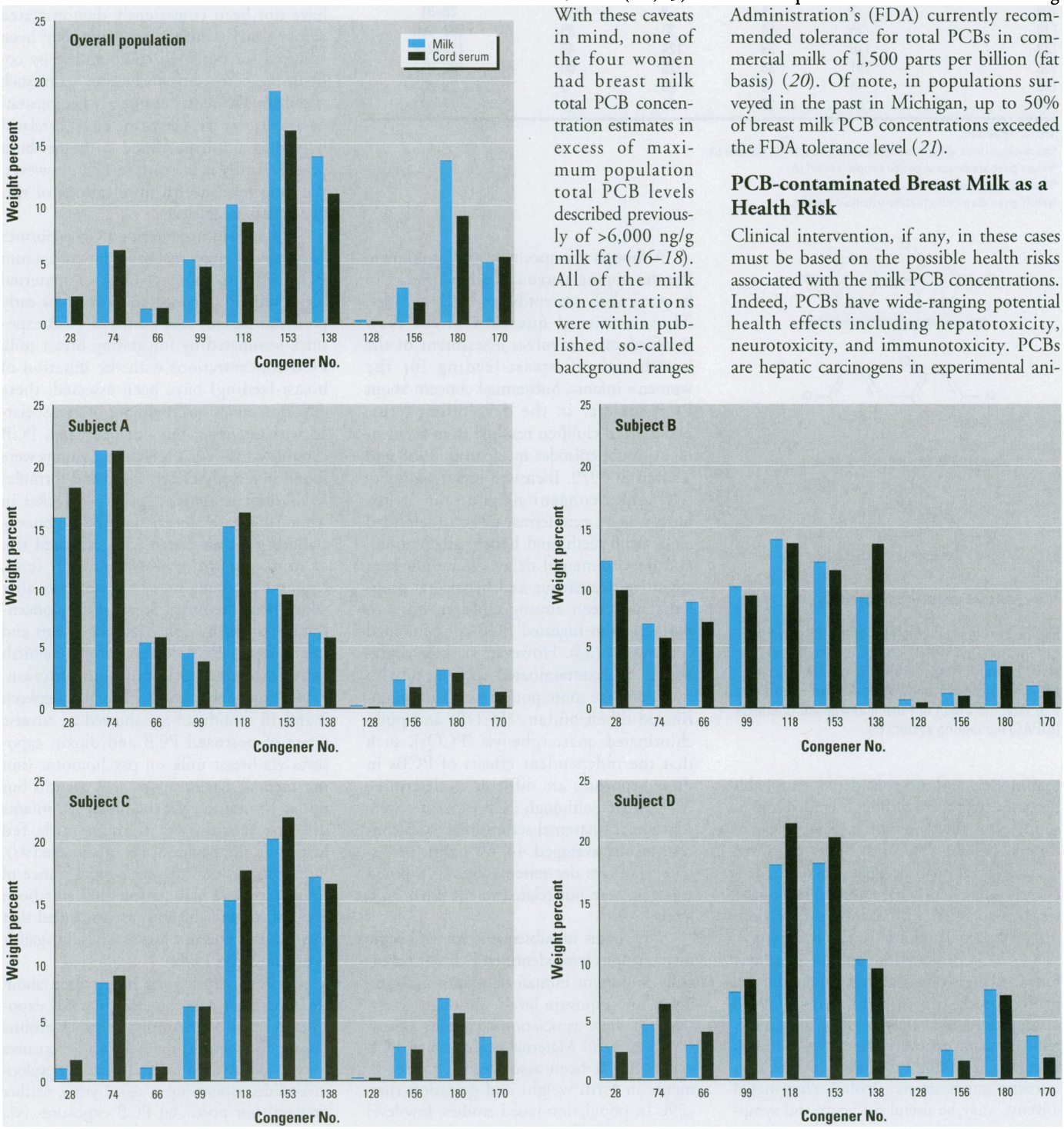
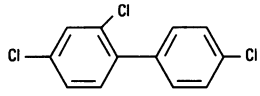


Figure 2. The relative proportion by weight (congener weight percent) of 11 of the most prevalent polychlorinated biphenyl (PCB) congeners measured in New Bedford, Massachusetts, breast milk samples. The sum of concentrations of 49 PCB congeners was used to estimate the total PCB concentration in the samples. The mean congener weight percent profile of the overall population (n = 122) is compared to the profiles of samples from Subjects A, B, C, and D. Congeners are represented using the International Union of Pure and Applied Chemists (IUPAC) numbering system (*3*).

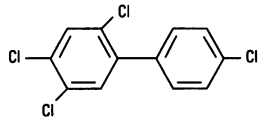
Table 2. Comparison of congener-specific breast milk polychlorinated biphenyl (PCB) concentrations among general population samples and in four New Bedford, Massachusetts, mothers with high breast milk PCB levels

	Breast milk PCB concentration (ng/g milk fat)				
Congener[a]	Sweden 1988–1989[b]	Canada 1988–1989[b]	Holland 1990–1992[c]	New Bedford 1993–1997[d]	New Bedford range of 4 high values
28	NR	NR	6	10	14–380
74	NR	NR	NR	23	52–510
105	7	5	9	6	26–81
118	25	18	33	35	202–360
138	116	39	124	42	112–245
153	151	38	175	60	202–292
156	14	8	20	9	23–56
180	64	20	71	41	74–99

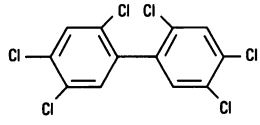
NR, not reported.
[a]International Union of Pure and Applied Chemists (IUPAC) numbers (*3*).
[b]Values given are means or pooled sample results (*12*).
[c]Values given are medians (*13*).
[d]Values given are means of 122 New Bedford samples.



Congener 28: 2,4,4'-trichlorobiphenyl



Congener 74: 2,4,4',5-tetrachlorobiphenyl



Congener 153: 2,2',4,4',5,5'-hexachlorobiphenyl

Figure 3. The structures of 3 of the 49 polychlorinated biphenyl (PCB) congeners measured in New Bedford, Massachusetts, breast milk samples. Congeners are represented using the International Union of Pure and Applied Chemists (IUPAC) numbering system (*3*).

mal models and are considered a probable human carcinogen, although epidemiologic support for their human carcinogenicity is limited (*14,22–23*). With heavy exposures characteristic of past occupational or accidental exposures, PCBs have been most consistently associated with skin manifestations (e.g., chloracne) and liver function abnormalities (*19,23*). Although we did not assess liver function, the women described here did not present with clinical symptoms of PCB intoxication. Had they been symptomatic, removal from exposure would be the main treatment. Limiting exposure to other hepatotoxins (medications, alcohol, chlorinated solvents) may be useful for acute and symptomatic exposures, but, except via lactation, there is no means to promote PCB elimination (analogous to chelation for certain forms of metal intoxication).

Although the mechanism is unknown, the developing nervous system appears to be particularly susceptible to PCB toxicities. Thus, a critical question in the New Bedford cases involves assessment of the health risk of breast-feeding for the women's infants. Substantial concern about PCB toxicity in the developing fetus, infants, and children resulted from accidental exposure episodes in Japan in 1968 and Taiwan in 1979. Increased infant mortality (*24*) and a congenital syndrome of low birth weight, ectodermal defects (deformed nails, natal teeth, and hyperpigmentation), and developmental delay (including later cognitive decrements and behavioral problems) was seen among children born to mothers who ingested PCB-contaminated cooking oil (*25*). However, via heat degradation, the contaminated cooking oil also contained the more potent toxins polychlorinated dibenzofurans (PCDF) and polychlorinated quarterphenyls (PCQs), such that the independent effects of PCBs in these exposures are difficult to determine (*26*). In fact, although PCB exposures were substantial (maternal serum total PCB concentrations averaged 40–60 ng/g), persistent cognitive decrements among exposed children were not related to maternal PCB levels (*24*).

The results of subsequent epidemiologic investigations have identified PCBs as potentially important human developmental toxins at low exposure levels, although acceptance of these associations remains controversial (*27,28*). Maternal occupational PCB exposure has been associated with decrements in birth weight and gestation time (*29*). In population-based studies, low-level intrauterine PCB exposures have been associated with changes in fetal growth and maturation (small size and short gestation, including prematurity) (*30,31*) and behavioral and developmental deficits in infancy and childhood, including hypotonia and poor reflex functioning in the neonatal period (*32–34*), and decrements in visual memory at age 7 months (*35*), in psychomotor performance on the Bayley Scales up to age 2 years (*36,37*), in short-term memory and weight at 4 years (*38,39*), and in IQ at 11 years (*40*). However, some of these associations have not been consistently demonstrated across study cohorts, nor have they been adjusted for potential confounding by co-occurring potent organochlorine toxins such as dioxin. The most consistently demonstrated association has been that of PCB-related hypotonia and hyporeflexia in the newborn period, which is of concern (*23*); however, the long-term health implications of this association are unclear.

When both intrauterine PCB exposures (estimated by maternal or infant cord serum PCB concentrations at birth or maternal breast milk PCB concentrations in the early postnatal period) and postnatal PCB exposures (estimated by integrating breast milk PCB concentrations with the duration of breast-feeding) have been assessed, these developmental toxicities have been associated with prenatal, but not postnatal, PCB exposures (*35–40*). Notable exceptions were found in a study of breast-fed and formula-fed Dutch neonates (ages 2–4 weeks) in whom higher maternal milk PCB concentrations were associated with increased risk of minor neurologic dysfunction (e.g., hypotonia) among breast-fed neonates after adjustment for infant serum PCB concentrations at birth (*13*). Maternal serum and infant serum PCB concentrations at birth were unrelated to neurologic function. Evaluation of the breast-fed infants between 3 and 18 months of age showed an adverse effect of postnatal PCB and dioxin exposures via breast milk on psychomotor (but not mental) Bayley Scales at 7 months but not at 18 months, yet the breast-fed infants did not score lower than formula-fed infants on the Bayley Scales at any age (*41*). Furthermore, the long-term significance of these early life associations has not been established, and the authors concluded that their findings do not justify advising against breast-feeding (*13,41*).

There is very limited information about the long-term consequences of PCB exposures in early life. Among North Carolina infants for whom prenatal PCB exposures were associated with demonstrable developmental decrements up to age 2 years, neither prenatal nor postnatal PCB exposures (via breast-feeding) were associated with performance on McCarthy exams at 3–5 years or school performance (assessed by grades) at 8–10 years (*42*). In a follow-up evaluation

of Michigan infants at 11 years, a 6-point decline in full-scale IQ was seen in association with prenatal, but not postnatal, PCB exposures (*40*). Specifically, children whose mothers' initial postpartum breast milk total PCB concentrations were ≥1,250 ng/g milk fat or whose cord serum total PCB concentrations were ≥4.7 ng/g had lower IQs than those whose maternal milk and cord serum total PCB concentrations were <1,250 ng/g milk fat and <4.7 ng/g, respectively. These findings suggest that prenatal PCB exposures in the New Bedford infants with the three highest maternal milk and cord serum PCB concentrations are potential risk factors for poorer cognitive performance in later childhood. However, the findings of Jacobson and Jacobson (*40*) have not been replicated; their results were based on a small number of children (only 30 children were in the highest exposure category), and the most exposed children still had, on average, normal IQs. Perhaps more important, postnatal PCB exposure, estimated by integrating breast milk PCB concentrations with duration of lactation, was not associated with IQ decrements.

Thus, despite the potential for large postnatal PCB exposures via breast milk, there is currently limited evidence of developmental toxicity associated with the transmission of low to moderate PCB concentrations through breast milk, and the appropriate clinical interpretation of this evidence is unclear (*43*). Breast-feeding has been associated with substantial health benefits including better cognitive skills among breast-fed than formula-fed children (*44,45*). In fact, because of the wide-ranging and substantial health benefits of breast-feeding, the American Academy of Pediatrics recommends breast-feeding of almost all infants for the first 12 months of life, and these recommendations do not include exceptions for environmental contaminants in milk (*46*). There are no accepted guidelines for breast milk PCB concentrations that are a contraindication to breast-feeding. Anecdotal case reports include recommendations against breast-feeding in a woman with chronic occupational PCB exposures and breast milk PCB concentrations of 13,600 ng/g fat (*14*). Regulatory recommendations for limiting dietary PCB intake to 1 µg/kg/day, for example, are problematic because a substantial portion (up to 50% in some populations) of breast-fed infants exceed this limit (*47,48*). In part due to limitations in our current knowledge, risk assessment efforts in this area have been unable to propose a standard and have recommended continued promotion of breast-feeding (*14*). In the New Bedford cases, we conclude that the benefits of breast-feeding probably outweigh any risk from moderate PCB exposures via breast milk. However, the ultimate decision regarding breast-feeding rests with mothers. When specific questions regarding breast milk safety arise, decisions are probably best made on an individual basis in the context of the physician–patient relationship after discussion of the known risks and benefits.

For this case report, PCB analysis of breast milk and infant cord serum was done as a research tool. In fact, PCB analysis of breast milk or infant cord serum is rarely done clinically. These analyses are expensive, there are no defined normal values, and, in the absence of massive exposure and acute toxicities, it is difficult to use the exposure information to predict individual health risks, as is illustrated in this case report. The case report is also illustrative of several key aspects of PCB-related health risks in particular (in contrast to lead-related health risks, for example). First, the clinical implications of risks associated with low to moderate perinatal PCB exposures are not well established. Second, even where PCB-related health risks are suspected, standardized methods for exposure assessment are not available. Third, except for exposure prevention, there is no treatment for PCB exposure. Furthermore, exposure prevention is complicated by the long half-life of PCBs and the fact that there is nearly universal background exposure to these compounds. Thus, in the absence of clear occupational or accidental exposures, it is often difficult to identify major PCB exposure sources. Given their prevalence and persistence in the environment, PCB exposures are likely to continue for many decades. Substantial efforts are needed to achieve a better understanding of the clinical and public health significance of these exposures.

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