Serum Concentrations of Selected Persistent Organic Pollutants in a Sample of Pregnant Females and Changes in Their Concentrations during Gestation

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OBJECTIVES: In this study we evaluated the concentrations of selected persistent organic pollutants in a sample of first-time pregnant females residing in the United States and assessed differences in these concentrations in all pregnant females during gestation.

METHODS: We reviewed demographic and laboratory data for pregnant females participating in the National Health and Nutrition Examination Survey, including concentrations of 25 polychlorinated biphenyls (PCBs), 6 polychlorinated dibenzo-p-dioxins (PCDDs), 9 polychlorinated dibenzofurans (PCDFs), and 9 organochlorine pesticides. We report serum concentrations for first-time pregnant females (2001–2002; n = 49) and evaluate these concentrations in all pregnant females by trimester (1999–2002; n = 203) using a cross-sectional analysis.

RESULTS: The chemicals with ≥ 60% detection included PCBs (congeners 126, 138/158, 153, 180), PCDDs/PCDFs (123, 3, 4, 6, 7, 8-heptachlorodibenzo-p-dioxin (1234678HpCDD), 2,3,6,7,8-hexachlorodibenzo-p-dioxin (123678HpCDD), 1,2,3,4,6,7,8-heptachlorodibenzo-p-dioxin (1234678HpCDF), 1,1′-(2,2-dichlorohydroxylene)-bis(4-chlorobenzene) (p,p′-DDE), and trans-nonachlor. The geometric mean concentration (95% confidence intervals) for 1234678HpCDD was 15.9 pg/g lipid (5.0–50.6 pg/g); for 123678HpCDD, 9.7 pg/g (5.5–17.1 pg/g); and for 1234678HpCDF, 5.4 pg/g (3.3–8.7 pg/g). The differences in concentrations of these chemicals by trimester were better accounted for with the use of lipid-adjusted units than with whole-weight units; however, the increase in the third-trimester concentration was greater for PCDDs/PCDFs (1234678HpCDD, 1234678HpCDF) than for the highest concentration of indicator PCBs (138/158, 153, 180), even after adjusting for potential confounders.

CONCLUSION: The concentrations of these persistent organic pollutants in a sample of first-time pregnant females living in the United States suggest a decline in exposures to these chemicals since their ban or restricted use and emission. The redistribution of body burden for these and other persistent organic pollutants during pregnancy needs to be more carefully defined to improve the assessment of fetal exposure to them based on maternal serum concentrations. Additional studies are needed to further the understanding of the potential health consequences to the fetus from persistent organic pollutants.

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Persistent organic pollutants are chemicals with notable environmental persistence and the potential for long-range transport, bioaccumulation, and toxic effects. In 2001, the Stockholm Convention identified 12 of these chemicals, including polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), and selected organochlorine pesticides such as dichlorophenyltrichloroethane (DDT) (United Nations Environment Program 2001). Although the use and emission of these chemicals in the United States were discontinued or restricted in the mid-to late 1970s, the general population is still being exposed to them at low levels, predominantly by the dietary route (Centers for Disease Control and Prevention [CDC] 2005a).

The pregnant woman’s exposure to persistent organic chemicals is of much interest because of exposures to the fetus and breast-fed infant and potential subsequent health effects. During pregnancy, the disposition of chemicals can be affected by physiologic changes, such as increased renal perfusion, increased volume of distribution, and increased serum lipids. The 200–400% increase of serum triglyceride concentration (Montes et al. 1984; Sattar et al. 1997) can cause the redistribution of lipophilic chemicals stored in adipose tissue to the blood compartment (Phillips et al. 1989). The significance of understanding the changes of these chemicals during gestation is to appropriately classify the fetus’s level of exposure based on the sampling period during gestation (Longnecker et al. 1999), and to determine whether there are different risks to the fetus based on the exposure to these chemicals during certain gestational periods. Previous studies with pregnant females have demonstrated inconsistent trends of blood concentrations of PCBs and selected organochlorine pesticides [1,1′-(2,2-dichlorohydroxylene)-bis(4-chlorobenzene) (p,p′-DDE), trans-nonachlor, hexachlorobenzene, and β-hexachlorocyclohexane (β-HCH)] throughout the trimesters (Jarrell et al. 2005; Longnecker et al. 1999; Talser et al. 2005). Potential delays in growth and neurodevelopment in the fetus and breast-fed infant from exposure to persistent organic pollutants (Jacobson and Jacobson 1996; Koopman-esseboom et al. 1994; Patandin et al. 1999; Siddiqui et al. 2003) have been studied; the results suggest that these health effects can be related to late gestational exposure, although these findings are inconclusive, and additional studies are necessary to better characterize these risks to the newborn. Because these chemicals tend to accumulate in the body over a person’s lifetime, women of childbearing age should consider their exposure to these chemicals as they plan their reproductive future.

First-time pregnant females are considered a reliable index of exposure among pregnant females because of the lack of potential confounding variables, such as parity and prior breastfeeding (James et al. 2002; Sarcinelli et al. 2003), and they have been used in international studies to monitor the entire population’s exposure to these chemicals [World Health Organization (WHO) 2007]. We evaluated the concentrations of persistent organic pollutants in a sample of first-time pregnant females residing in the United States and the changes of these concentrations during gestation for all pregnant women participating in National Health and Nutrition Examination Survey (NHANES) 1999–2002.

Methods

We selected participants in this study from NHANES (1999–2000, 2001–2002), which used a complex, stratified, multistage, probability sampling designed to be representative of the civilian, noninstitutionalized U.S. population based on age, sex, and race/ethnicity (CDC 2004). We selected all females 16–59 years of age from these two survey periods and categorized them as pregnant or nonpregnant based on a urine pregnancy test that was used to screen participants for exclusion from a dual-energy X-ray absorptiometry scan. We analyzed the data for clinical chemistries and selected PCDDs, PCDFs, non-ortho-substituted or

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by trimester. The median ages in years for all females in this study by parity were, for nulliparous, 18.0; primiparous, 26.0; and multiparous, 41.0 (data not shown). The minimum and maximum ages for first-time pregnant females and all pregnant females in this study were 16–38 and 16–50 years, respectively. Only one participant was 50 years of age.

The pregnant females demonstrated differences in physiologic parameters that were consistent with their gestational stage by trimester, which supported the use of these females as a model for gestation. For example, we observed the GMs for the following variables by trimester (first, second, third): BMI (27.05 kg/m², 28.52 kg/m², 31.1 kg/m²), serum triglycerides (102.43 mg/dL, 148.19 mg/dL, 185.38 mg/dL), serum total lipids (593.91 mg/dL, 701.60 mg/dL, 790.75 mg/dL), hemoglobin (12.88 g/dL, 11.36 g/dL, 11.91 g/dL), serum albumin (3.98 g/dL, 3.67 g/dL, 3.30 g/dL), and serum creatinine (0.53 mg/dL, 0.43 mg/dL, 0.45 mg/dL). The apparent progressive increase in BMI throughout gestation is primarily attributed to increases in total body water and adipose tissue. Increased total body water accounted for the dilutional effect seen with hemoglobin and serum albumin concentrations, and increased cardiac output and renal perfusion led to increased creatinine clearance. During the second and third trimesters, fetal growth and the preparation for lactation, dilution of serum lipids; the triglycerides concentrations, and increased cardiac output and renal perfusion led to increased creatinine clearance. The pregnant females demonstrated differences in the chemical concentrations during gestation. The median ages in years for all females in this study by parity were, for nulliparous, 18.0; primiparous, 26.0; and multiparous, 41.0 (data not shown). The minimum and maximum ages for first-time pregnant females and all pregnant females in this study were 16–38 and 16–50 years, respectively. Only one participant was 50 years of age.

Results

Study population of all participants. Table 1 presents data for the female participants in this study by their age, race/ethnicity, parity, pregnancy status, and stage of gestation

Table 1. Unweighted sample sizes (no.) for pregnant and nonpregnant females by age, race/ethnicity, parity, and gestational trimester.

| Characteristic     | All females | All pregnant females | First-time pregnant females |
|-------------------|-------------|----------------------|---------------------------|
| Total             | 1,584       | 203                  | 49                        |
| Age (years)       |             |                      |                           |
| 16–19             | 534         | 21                   | 7                         |
| 20–29             | 326         | 122                  | 31                        |
| 30–59             | 724         | 60                   | 11                        |
| Race/ethnicity    |             |                      |                           |
| Non-Hispanic white| 611         | 92                   | 26                        |
| Non-Hispanic black| 352         | 30                   | 5                         |
| Mexican American  | 462         | 54                   | 13                        |
| Remaining groups  | 159         | 27                   | 5                         |
| Parity            |             |                      |                           |
| Nulliparous       | 705         | —                    | —                         |
| Primiparous       | 337         | 155                  | 49                        |
| Multiparous       | 642         | 48                   | 19                        |
| Trimester         |             |                      |                           |
| First             | 78          | 26                   |                            |
| Second            | 57          | 15                   |                            |
| Third             | 68          | 8                    |                            |

Data are for all females (16–59 years of age) who had a urine pregnancy test in NHANES 1999–2000 and 2001–2002, all pregnant females based on a urine pregnancy test in NHANES 1999–2000 and 2001–2002, and first-time pregnant females based on a urine pregnancy test in NHANES 1999–2002.
10% of the first-time pregnant females sampled in 2001–2002. We determined the GMs or medians of the serum concentrations of four PCBs, three PCDDs/PCDFs, and two organochlorine pesticides, metabolites, or degenerades; these chemicals consisted of hexa- and heptachlorinated PCBs and PCDDs/PCDFs, p,p'-DDE, and trans-nonachlor. For DDT, the parent chemical p,p'-DDT and its environmental degradate, p,p'-DDE, were detected in 12.8% and 100% of these females, respectively. The commonly detected (>50%) PCDDs/PCDFs were 123678HxCDD (80%), 1,2,3,4,6,7,8-heptachlorodibenzo-p-dioxin (1234678HpCDF: 100%), 1234678HpCDD (90%), and OCDD (51.5%).

The PCBs detected in >20% of this group of females ranged in order of chlorination from tetrachlorinated to heptachlorinated biphenyl homologs, and this distribution is consistent with the major congeners found in Aroclor. PCDDs/PCDFs were 123678HxCDD (80%), 1,2,3,4,6,7,8-heptachlorodibenzo-p-dioxin (1234678HpCDF: 100%), 1234678HpCDD (90%), and OCDD (51.5%).

Table 2. Adjusted GM (95% confidence interval) for concentrations (lipid adjusted) of persistent organic pollutants by race/ethnicity and country of birth for all pregnant females, in this study, identified from NHANES 1999–2000 and 2001–2002.

| Chemical          | Parity                  | BMI β (SE)           |
|-------------------|-------------------------|----------------------|
|                   | Primiparous             | Multiparous          |
|                   | First                   | Trimester            |
|                   | Second                  | Third                 |
|                   |                         |                      |
| PCDD-126 (pg/g)   | 11.7 (9.1–14.9)         | 9.3 (6.4–13.6)       | 10.5 (7.4–15.0)       | 12.0 (7.8–18.7) |
|                   | 10.7 (9.8–12.8)         | 9.7 (6.5–11.1)       | 9.0 (7.0–10.6)        | 9.6 (8.0–12.0) |
|                   | 14.7 (12.4–17.5)        | 12.1 (10.5–15.9)     | 11.8 (10.0–13.9)      | 13.1 (10.4–16.5) |
|                   | 6.6 (5.6–7.8)           | 5.8 (4.5–7.3)        | 4.9 (3.8–6.3)         | 7.0 (5.8–8.5)* |
|                   | 8.3 (7.1–9.8)           | 7.1 (6.0–8.4)        | 6.9 (5.9–8.0)         | 7.0 (5.6–8.7) |
| 123678HxCDD (pg/g)| 10.6 (8.7–13.4)         | 8.9 (7.2–11.0)       | 8.1 (6.3–10.4)        | 13.4 (9.9–18.3)* |
| 123678HpCDD (pg/g)| 31.7 (24.4–41.2)        | 31.9 (24.7–41.1)     | 23.4 (17.9–30.5)      | 28.5 (19.2–42.2) |
| 1234678HpCDF (pg/g)| 274.4 (219.7–342.7)     | 217.5 (173.1–267.0)  | 262.7 (180.1–354.5)   | 159.1 (128.5–196.8) |
| BMI β (SE)        |                         |                      |                      |                  |

Table 3. Adjusted GM (95% confidence interval) for concentrations (lipid adjusted) of persistent organic pollutants by race/ethnicity and country of birth for all pregnant females, in this study, identified from NHANES 1999–2000 and 2001–2002.

| Chemical          | Race/ethnicity          | Country of birth     |
|-------------------|-------------------------|----------------------|
|                   | Non-Hispanic white      | United States        |
|                   | Non-Hispanic black      | Non-Hispanic white   |
|                   | Mexican American        | Mexican American     |
|                   |                         |                      |
| PCDD-126 (pg/g)   | 13.9 (12.4–15.6)        | 20.3 (16.9–24.5)*    | 15.9 (12.4–17.7)      |
|                   | 16.2 (15.1–17.3)        | 21.7 (19.4–24.2)*    | 13.9 (12.6–15.4)*     |
|                   | 22.8 (21.5–24.2)        | 30.5 (28.9–32.3)*    | 18.2 (16.5–20.5)*     |
|                   | 10.9 (9.9–12)           | 13.4 (12.1–14.9)*    | 9.8 (8.7–10.2)        |
|                   | 14.1 (13.2–15.2)        | 17.2 (16.1–18.4)*    | 12.3 (11.5–13.2)*     |
|                   | 30.9 (27.8–34.2)        | 44.2 (39.2–49.8)*    | 39.3 (36.3–43.9)*     |
|                   | 14.1 (12.4–16)          | 20.4 (16.3–25.4)*    | 16.3 (14.7–18.2)      |
| 1234678HpCDF (pg/g)| 6.6 (5.9–7.3)           | 9.8 (8.7–11.1)*      | 6.7 (5.1–7.5)         |
| 1234678HpCDD (pg/g)| 260 (235.3–287.3)       | 372 (333.2–415.2)*   | 324.2 (295.7–356.5)*  |
| BMI β (SE)        |                         |                      | 350.7 (310.7–395.7)   |
| p,p'-DDE (ng/g)   | 177.2 (156.7–200.3)     | 311.6 (253.2–383.4)* | 806.8 (674.6–964.8)*  |
| trans-Nonachlor (ng/g)| 13.9 (12.7–15.2) | 18.2 (16.2–20.8)*    | 14.8 (13.2–16.7)      |

Sample size varied from 147 to 178, depending on the chemical. The model was adjusted for parity, trimester, age, BMI, race/ethnicity, U.S. birth, fish and shellfish eaten in the last 30 days, number of children breast-fed ≥1 month, and serum cotinine as independent variables. Log of serum concentration (lipid adjusted) of the chemical was the dependent variable. Remaining data for the model are provided in Supplemental Material, Tables 5–6 (doi:10.1289/ehp.0803138.S1).

*Statistically significantly different from 0 at α = 0.05. **Statistically significantly different from primiparous females at α = 0.05. *Statistically significantly different from second trimester at α = 0.05.
Discussion

This convenience sample of first-time pregnant females living in the United States in 2001–2002 includes the initial report of PCDDs/PCDFs in these females.

Exposure levels. Overall, the concentrations of these chemicals in this study suggest a decline in the exposure to persistent organic pollutants in pregnant females residing in the United States since their ban or restricted use and emission in the late 1970s, which is consistent with the observed trend for the general population in previous reports (Patterson et al. 1994; CDC 2005a). More specifically, the concentrations of the indicator PCBs (congener 138/150, 153, and 180) in first-time pregnant females in this study are lower than those reported for pregnant females who participated in the Collaborative Perinatal Project from 1959 through 1966 (Niswaner and Gordoni 1972). In an approximately one-third subset of first-time pregnant females, their median serum concentrations of PCB-153 was 140 ng/g lipid adjusted (Daniels et al. 2003) (vs. 8.0 ng/g lipid adjusted for this study) and for p,p’-DDE was 25 ng/mL whole weight (Longnecker et al. 2001) (vs. 113.0 ng/g lipid adjusted for this study). The rate of decline in the PCB-153 concentration from 1959–1966 to 1999–2002 appears to be consistent with the estimated half-life of approximately 10 years for these chemicals (Yukushii et al. 1984). The concentrations of PCDDs/PCDFs in adipose tissue were reported for females in the National Human Adipose Tissue Survey from 1986 to mid-1990 (Orban et al. 1994; Reynolds et al. 2005) and comparative data on these chemicals suggest a more gradual rate of decline than for the PCBs.

Human milk concentrations of these chemicals were measured in two pooled collections obtained from first-time mothers in the United States in 2002–2003 as part of the third round of the WHO-coordinated exposure study on the levels of PCBs, PCDDs, and PCDFs in human milk (PCB-153, 15.9 and 24.2 ng/g lipid; 1234678HpCDD, 16.0 and 12.9 pg/g lipid; 1234678HpCDF, 3.1 and 1.5 pg/g lipid; p,p’-DDE, 248 and 123 ng/g lipid) (Wang and Needham 2003, 2004). These concentrations are comparable to those for the first-time pregnant females in this study and lower than those measured in two pooled milk samples from U.S. women participating in a similar WHO survey conducted in 1989 (PCB-153, 80 and 88 ng/g lipid; 1234678HpCDF, 34 and 50 pg/g lipid; 1234678HpCDF, 2.4 and 5.7 pg/g lipid) (Vijanekilli 1989). The direct comparison of concentrations of higher chlorinated PCDDs/PCDFs of serum to milk specimens is limited by the diminished ability of these chemicals to transfer from blood to milk due to size exclusion (Wittsipe et al. 

Table 4. Serum concentrations for first-time pregnant females in this study, identified from NHANES 2001–2002.

| Chemical (μg/g lipid) | LOD below LOD | Whole weight | Lipid adjusted | Whole weight | Lipid adjusted |
|-----------------------|---------------|--------------|----------------|--------------|----------------|
| 1234678HpCDD | 0.0038 | 12.0 | 104.4 (36.6–298.0) | 15.9 (5.0–50.6) | 12.4 (5.4–56.0) |
| 1234678HpCDF | 0.0017 | 11.4 | 32.7 (23.7–37) | 33.7 (23.8–39) | 30.8 (27.9–35) |
| 1234678HpCDD | 0.0017 | 8.6 | 8.6 (8.6–9) | 7.3 (8.6–8) | 7.8 (6.8–9) |
| 1234678HpCDF | 0.0012 | 280.6 (229.8–342.6) | 214.3 (187.6–244.7) | 220.9 (192.5–253.6) | 14.2 (12.6–16.1) |

Sample size varied from 23 to 39, depending on the chemical. Estimates were not calculated (NC) when either the proportion of results below the LOD was too high to provide a valid result or the estimate of the percentile was below the maximum LOD.

Table 5. Adjusted GM (95% confidence interval) for concentrations (lipid adjusted) of persistent organic pollutants and regression coefficient for number of breast-fed children for at least 1 month, parity, and pregnancy status for all females in this study, identified from NHANES 1999–2000 and 2001–2002.

| Chemical | Nulliparous | Parity | Multiparous | Pregnant |
|----------|-------------|--------|-------------|----------|
| PCB-12B | 16.7 (13.7–20.5) | 16.6 (13.4–20.8) | 14.6 (11.7–18.1) | 12.3 (10.3–13.7) |
| PCB-138/153 | 17.4 (15.3–19.9) | 17.1 (15.1–19.5) | 15.8 (14.7–17.9) | 13.3 (11.4–15.8) |
| PCB-153 | 24.9 (22.4–27.6) | 24.3 (21.6–27.3) | 21.5 (19.4–23.9) | 18.5 (15.8–21.8) |
| PCB-169 | 11.5 (10.2–13.1) | 11.8 (10.4–13.3) | 10.7 (9.3–12.4) | 8.3 (6.7–10.1) |
| PCB-180 | 15.8 (13.4–17.5) | 14.9 (13.1–17.1) | 12.9 (11.8–14.2) | 11.6 (10.2–13.3) |

Sample size varied from 779 to 1088, depending on the chemical. The model was adjusted for parity, trimester, pregnancy status, age, BMI, race/ethnicity, country of birth, fish and shellfish eaten in the last 30 days, number of children breast-fed ≥ 1 month, and serum cotinine as independent variables. Log of serum concentration (lipid adjusted) chemical was the independent variable. Remaining data for the model are provided in Supplemental Material, Tables 6 and 7 (doi:10.1289/ehp.0800315). 

**Statistically significantly different than nulliparous females at α = 0.05. ***Statistically significantly different than nulliparous females at α = 0.05. ****Statistically significantly different than 0 at α = 0.05. **Statistically significantly different than nulliparous females at α = 0.05.
the use of first-time pregnant females and human milk as a matrix to monitor the population’s trend in exposure to persistent lipophilic chemicals, although the exposure level only reflects that of females of reproductive age (Wang et al. 2005). The added benefit of using milk as an exposure matrix includes the ability to assess the breast-fed infant’s intake of these chemicals.

Maternal parity, age, BMI, prior breastfeeding, and dietary intake of fish and shellfish are predictors for the serum concentrations of these chemicals, and differences in exposure levels exist among race/ethnicities. Differences in the concentrations of PCBs among groups in this study are likely attributable to variations in the dietary intake of fatty foods and the exposure to different PCB mixtures, such as the Aroclor mixtures (1260, 1254, 1248), which were produced and used in the United States. Environmental degradation and biologic metabolism of higher to lower chlorinated homologs can account for differences in PCB concentrations (e.g., PCB-169), in the population as well. In North America, the historic difference in the production and use of PCBs and DDT between Mexico and the United States may account for variations in the concentrations of these chemicals in these populations. For example, Mexico imported but did not produce PCBs and was until recently using DDT to control vectors for malaria (Chanon et al. 2003). These practices are unlike those for the United States and may account for the low indicator PCB concentrations and high p,p’-DDE concentration in the Mexican Americans in this study. Other studies have demonstrated a difference in the concentrations of PCBs and p,p’-DDE in pregnant females (Bradman et al. 2007; James et al. 2002; Wolff et al. 2005) and in other groups in the population (Finklea et al. 1972; Rogan et al. 1986) based on race/ethnicity in the United States. The higher p,p’-DDE concentration in Mexican Americans than other race/ethnic groups in this study is similar to the findings in NHANES (2001–2002) (CDC 2005a and Hispanic Health and Nutrition Examination Survey (1982–1984) (Akkina et al. 2004).

The increased concentrations of PCBs (congeners 153 and 169) and 1234678HpCDF in females who consumed a fish or a shellfish meal in the last 30 days of the survey in this study are consistent with prior reports demonstrating that these food groups can be a source of exposure to these chemicals in pregnant females and other groups in the population from regions known for their increased dietary intake of seafood, such as the Nordic countries and their territories (Glynn et al. 2007; Johansen et al. 1996) and the U.S. Great Lakes (Turyk et al. 2006). The increased consumption of crustaceans from contaminated waterways has been associated with a higher toxic equivalency concentration for PCDFs than for PCDDs, and the sum of these concentrations was higher than that for dioxin-like PCBs (Johansen et al. 1996).

**Trimesters.** The serum whole-weight concentrations of these chemicals are higher in the third trimester than in earlier trimesters, and this is attributed to the progressive increase in maternal serum nonpolar lipids, such as triglycerides and cholesterol esters, that occurs throughout the latter two-thirds of gestation and is primarily for milk production (Sattar et al. 1997). The apparent differences in serum concentrations of these chemicals among the trimesters in this study are consistent with the physiologic changes during gestation, which include the body’s increasing volume of distribution and serum lipid concentrations. Increased body weight and BMI have been associated with increased concentrations of PCBs and selected organochlorine pesticides during gestation (Glynn et al. 2007; James et al. 2002; Wolff et al. 2005). For example, Glynn et al. (2007) reported a decrease in the concentrations of PCBs and selected organochlorine pesticides of 16–38% per unit of body weight during gestation. These changes are likely explanations for the apparent decrease in the lipid-adjusted concentrations for PCBs (congeners 169 and 180) and PCDDs (1234678HpCDD) during the second trimester among all pregnant females in this study (see Supplemental Material, Table 2 (doi:10.1289/ehp.0800319.S1)).

The nearly complete correction of the difference in the concentrations of the indicator PCBs between the first and the third trimester in this study by using lipid-adjusted units suggests that the increase in the serum PCB concentration reflects the redistribution of PCB from tissue stores (Gallenberg et al. 1987; Phillips et al. 1989.). This observation has been demonstrated for serum total PCB concentrations in a longitudinal study of 67 pregnant females throughout their pregnancy (Longnecker et al. 1999). These changes in PCB concentrations among trimesters are presumed to be less than the amount loss by lactation (Jacobson and Jacobson 1996), which is consistent with the associations between prior breastfeeding and lower indicator PCB concentrations in this study (Table 5). However, the contribution to lower concentrations of these chemicals in females from their deposition in placental tissue or fetal tissues and organs cannot be excluded because parity remained a predictor variable for certain chemicals after adjusting for breastfeeding. The small changes in serum concentrations for certain PCDDs/PCDFs (e.g., 1234678HpCDF, 1234678OCDD) associated with prior breastfeeding among all females in this study might be attributable to the poor diffusion of these chemicals across the milk-blood barrier (Wittsiepe et al. 2007). These effects of breast-feeding and parity on the chemical concentrations support the use of first-time pregnant females as a reliable index of exposure to these chemicals among pregnant females.

**Limitations.** The findings in this study are limited by the cross-sectional design, use of self-reported data for reproductive history, and small sample size. NHANES is designed to achieve representative concentrations of these environmental chemicals in the general U.S. population by age, sex, and race/ethnicity. Thus, the estimates of the central tendencies for these chemicals in first-time pregnant females in this study are likely to be unstable and not representative of this group in the general population because the statistical weighting factor used in this analysis was not designed for these females. Also, the observed gestational trends for these
chemical concentrations need to be verified in a prospective observational study because their pregnancy价值观 might have biased the findings despite the use of statistical adjustments for potential confounders. Finally, the statistical power of the analyses to identify significant findings might have been limited because of the sample sizes, which could not be controlled because of the nature of the study design.

Conclusions

The findings from this study suggest a decline in the exposure to these persistent organic pollutants in pregnant females in the United States since their ban or restricted use and emission, which is consistent with the exposure trend for these chemicals in the general population based on past reports. The redistribution of the body burden for persistent organic pollutants in response to the change in serum lipid profile during gestation needs to be more carefully defined because the concentrations of some of these chemicals can vary on a whole-weight or lipid-adjusted basis during this period. The sampling of blood from pregnant females at a specified time during gestation and the use of lipid-adjusted units can minimize these differences and improve the interpretation of the fetus’s level of exposure to these chemicals based on maternal serum concentrations. Additional studies on the exposure and disposition of these and other persistent organic pollutants in pregnant females are needed to better understand the potential health consequences to the fetus from these exposures.

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