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Concentrations of select persistent organic pollutants across pregnancy trimesters in maternal and in cord serum in Trujillo, Peru

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Abstract

Although the production and use of some persistent organic pollutants (POPs) have been banned or highly restricted, human exposure remains a subject of investigation due to their environmental persistence. Physiological changes during pregnancy may affect the disposition of POPs in the mother's body, and thus fetal exposure. Changes in serum concentrations of organochlorine pesticides (OCPs) and polychlorinated biphenyls (PCBs) across pregnancy trimesters, and trans-placental transfer to the fetus were investigated. Seventy-nine pregnant women in Trujillo, Peru were recruited in the first trimester of pregnancy, and provided blood samples for the analysis of 35 PCB congeners, 9 OCPs, and 11 polybrominated biphenyl diethers (PBDEs). Subsequently,

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Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the Centers for Disease Control and Prevention (CDC) or the Agency for Toxic Substances and Disease Registry (ATSDR). The use of trade names and commercial sources is for identification only and does not constitute endorsement by the US Department of Health and Human Services, CDC, or ATSDR.

We herein declare that there are no competing financial interests.

Study review and approval

This study was reviewed and approved by the Institutional Review Boards (IRBs) from the University of Georgia, the Centers for Disease Control and Prevention (CDC), and health authorities at the Trujillo City Hall.

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maternal blood samples were collected in the second (n = 64) and third trimesters (n = 59), and cord blood samples (n = 50) were collected at delivery. There were statistically significant changes across trimesters (p <0.05) for both fresh weight (increase) and lipid adjusted concentrations (decrease) of hexachlorobenzene (HCB), 2,2-Bis(4-chlorophenyl)-1,1-dichloroethene (p,p′-DDE), PCB-74, 118, 138–158, 153, 170, 180 and 194. Fresh weight concentrations of these POPs increased from first to third trimester by 10–28%. On the other hand lipid adjusted concentrations decreased from first to third trimester by 16–28%. Serum lipids increased from first to third trimester by 53% indicating the dilution of the POPs in the lipids. Concentrations of 2,2-Bis(4-chlorophenyl)-1,1,1-trichloroethane (p,p′-DDT), its metabolite p,p′-DDE, PCB-118, 138-158, 153, 170 and 180 above their limits of detection were measured in >60% of cord serum samples. Intra-individual correlations in maternal serum concentrations were high for most of the POPs (ρ = 0.62–0.99; p <0.05) while correlations between maternal and cord serum concentrations were also high (ρ = 0.68–0.99; p < 0.05). Results indicate that the disposition in the body and blood concentrations of POPs may change during pregnancy, and show trans-placental transfer of DDT, DDE and PCBs.

Keywords

Persistent organic pollutants; Polychlorinated biphenyls; Organochlorine pesticides; Pregnancy; Trimesters

1. Introduction

Persistent organic pollutants (POPs) are man-made chemicals with high chemical and biological stability. They persist in the environment, are lipophilic, and accumulate in biological tissues (Kelly et al., 2007). Organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), and polybrominated diphenyl ethers (PBDEs) are among the most notable POPs.

PCBs were produced in large quantities between the 1930s and the 1970s (Breivik et al., 2002), while OCPs were used extensively for pest control between the 1940s and 1970s (Li and Macdonald, 2005). Except for DDT which continues to be used against mosquitoes in several countries for malaria control (Stockholm Convention, 2008a), production and use of both classes of POPs have largely stopped and multinational efforts through the Stockholm Convention are underway to eliminate the production of some PBDEs. However, humans and wildlife exposures to these chemicals continue due to their environmental persistence.

Human exposures have been associated with various health effects, including immune suppression, endocrine disruption, neurological effects, diabetes and cancers (WHO, 2003, 2010). Fetal exposure to POPs is of much interest because of the vulnerability of the fetus at critical periods of development. In-utero exposure to DDT, its metabolite 2,2-Bis(4-chlorophenyl)-1,1-dichloroethene (DDE), PCBs, and PBDEs has been associated with effects on neurodevelopment (Eskenazi et al., 2006; Longnecker et al., 2003; Herbstman et al., 2010).

Few studies have assessed the changes in POPs in the blood across pregnancy (Longnecker et al., 1999; Jarrell et al., 2005; Bloom et al., 2007, 2009; Wang et al., 2009; Hansen et al., 2010; Glynn et al., 2011). In general, the results of the studies show instability in the serum concentrations of PCBs and OCPs across pregnancy; although, fresh weight levels tend to increase during pregnancy, results suggest the dilution of the POPs in serum lipids as pregnancy progresses. However, POPs were analyzed every trimester during pregnancy in only one study in which samples had been collected within 5 years of those in the current study (Glynn et al., 2011). No inventory data were found for POPs in the literature for Peru except for PCBs for which 1000 tons have been estimated to have been used (Gevao et al., 2010). Peru ratified the Stockholm Convention in 2005 (Stockholm Convention, 2008b). Nonetheless, the women in our study are expected to be exposed to POPs due to their ubiquity and persistence in the environment. Data on human POP levels in Peru are rare (Barra et al., 2006); only the levels of perfluorinated chemicals were found in the literature (Calafat et al., 2006). Concentrations and frequencies of detection of the perfluorinated compounds were much lower than those reported for residents in the United States (Calafat et al., 2006). Exposure to nine OCPs, 35 PCBs and 11 PBDEs in pregnant women living in the province of Trujillo, Peru, and in utero exposures of their babies were assessed in the current study. The current study was primarily designed to investigate changes in POP concentrations across pregnancy trimesters. Secondarily, comparisons were made between POP levels in maternal and cord serum in order to assess trans-placental transfer from mother to child. Finally, inter-trimester correlation of the various POPs was assessed.

2. Materials and methods

2.1. Study location

The study took place during May, 2004 through February, 2005 in the province of Trujillo located in Region La Libertad, Peru. Trujillo, the provincial capital is an arid coastal city in northwestern Peru. Agriculture, dominated by sugar cane production, has been and remains the major industrial activity around the study area. The residential locations of the study participants included seven districts within 10 miles of the city of Trujillo: Trujillo, La Esperanza, El Porvenir, Florencia de Mora, Moche, El Milagro, and Alto Trujillo.

2.2. Subject selection

A convenience sample of 100 non-smoking pregnant women was recruited to participate in a larger study focusing on the assessment of various environmental exposures including other POPs and indoor air pollution due to biomass smoke. Seventy-nine of the women volunteered to give blood samples. All the women were recruited during the first trimester after 8 weeks of pregnancy from health clinics throughout Trujillo. Their pregnancies were confirmed with the doctors who attended to the women. Subjects were enrolled subsequent upon visits to their homes, the explanation of the study to them, and the receipt of informed consent. The study was approved by Institutional Review Boards (IRBs) from the University of Georgia, the Centers for Disease Control and Prevention (CDC), and health authorities at the Trujillo City Hall.

2.3. Questionnaires

Questionnaires were administered to the women in Spanish during the first trimester and used to obtain information on demographics and exposure to indoor air pollution. Questionnaire items included the type of cooking fuel used by the subjects, their socioeconomic status (SES), education, age, and other relevant exposure information such as pesticide use. Most participants in this study did not report an actual income; therefore, SES was determined mainly by assessing residential characteristics.

2.4. Serum sample collection

One sample of 40 mL of antecubital venous blood was collected once during each pregnancy trimester from each subject at the Trujillo City Hall by qualified, local health professionals. Additionally, 40 mL of cord blood was collected at delivery. Maternal and cord blood was drawn using 21-gauge butterfly needles and stored in Vacutainer® collection vials (Becton–Dickinson, Franklin Lakes, NJ). After allowing to clot at room temperature for 20–30 min, the blood samples were centrifuged for 15 min at a force of 1000 g (Hermle/Labnet, model Z 200 A). The resulting serum was transferred into pre-screened amber glass vials with Teflon-lined screw caps. The remaining red blood cells/serum in the Vacutainer® collection vials were then centrifuged for an additional 10 min in order to collect all possible serum. The serum samples were then separated into multiple aliquots and frozen. The aliquots were temporarily placed in a large refrigerator/freezer located within the Trujillo City Hall and later stored in a freezer at −30 °C. All frozen serum samples were transported from Trujillo, Peru to Athens, GA in coolers containing dry ice. Upon arrival in the US, the samples were stored at −30 °C and ultimately shipped to the CDC in Atlanta, GA for laboratory analysis and stored at −70 °C until analyzed. Participant information was not available to CDC researchers.

2.5. Laboratory analysis

Serum concentrations were measured at the CDC's National Center for Environmental Health at the Division of Laboratory Sciences. The laboratory analysis procedures used are presented elsewhere (Sjodin et al., 2004). Briefly, the methodology used included automatic fortification of the samples with internal standards as well as addition of formic acid and water for denaturation and dilution of the samples using a Gilson 215 liquid handler (Gilson Inc.; Middleton WI). The target analytes were then extracted by solid phase extraction (SPE) using a Rapid Trace modular SPE system (Caliper Life Sciences; Hopkinton, MA). Removal of coextracted lipids was performed on a silica/sulfuric acid column using the Rapid Trace equipment for automation. Final analytical determination of the target analytes was performed by gas chromatography isotope dilution high resolution mass spectrometry (GC-IDHRMS) employing a MAT95XP instrument (ThermoFinnigan MAT, Bremen, Germany). All concentration data were corrected for the average amount present in blank samples. Three blanks and three quality control (QA/QC) samples were included in every set of 30 samples. The limit of detection was defined as three times the standard deviation of the blank samples. The quality assurance procedure has been published previously (Sjodin et al., 2004). Levels of serum POPs are presented as fresh weight (pg g^{-1} serum) and lipid adjusted concentrations (ng g^{-1} lipid). The serum lipid concentrations were determined using

commercially available kits from Roche Diagnostics Corp. (Indianapolis, IN) for the quantitative determination of total triglycerides (Product No. 0110028303-600) and total cholesterol (Product No. 011573303-0600). Final determinations were made on a Hitachi 912 Chemistry Analyzer (Hitachi; Tokyo, Japan). Serum concentration (mg dL^{-1}) of total lipids was calculated as:

Total lipids (mg dL^{-1}) = 62.3 + triglycerides (mg dL^{-1}) + (2.27 – × total cholesterol (mg dL^{-1})) (Wang et al., 2009).

2.6. Statistical analysis

Repeated measures analysis of variance, using linear mixed effect models, was conducted to analyze the differences in fresh weight and lipid adjusted POP concentrations across trimesters, and to compare concentrations in maternal serum and cord blood serum. The age group of the subject (<20, 20–24, 25–29, and ⩾ 30 years), highest grade of education (primary, secondary, and superior), SES (lower and middle/upper), and the district where the subject lived (central – Trujillo; north – La Esperanza, El Porvenir, Florencia de Mora, and El Milagro; and south – Moche and Alto Trujillo) were included as covariates in each model. The models allowed a general, unstructured within-subject variance–covariance matrix to allow for possible correlation and non-constant variance among each subject's repeated measures across the three trimesters and in cord blood. The concentrations were log transformed before inclusion in the models, and concentrations below the limits of detection (LOD) were given a value equal to $\mathrm{LOD}/\sqrt{2}$ (Hornung and Reed, 1990). The models were run to analyze the change across pregnancy trimesters for compounds that had concentrations above the LOD in >60% of the maternal samples. The difference between maternal and cord serum concentrations were analyzed if >60% of both the maternal and cord serum samples had concentrations above the LOD. The 60% threshold is set according to the practice of the CDC (Sjödin et al., 2008; Wang et al., 2009). Posthoc pairwise comparisons of the means across trimesters and cord blood, age groups and education status were done using Tukey's honest significant difference (HSD) procedure in order to control for the strong familywise error rate – the probability of making type 1 errors when making multiple comparisons. Percentage changes in the POP concentrations across the trimesters were calculated from the model estimated differences in the log concentrations.

Partial Pearson correlation was used to estimate the intra-individual correlation for each of the POPs, and the correlation between the different POPs during each trimester and in cord blood serum. The two covariates that significantly affected POP concentrations, age and highest grade of education, were controlled for in the partial correlation analyses. Statistical significance for all analyses was set at $p < 0.05$. All analyses were done using SAS version 9.1 (Cary, NC).

3. Results

3.1. Study participants

The 21 women who were recruited for the larger exposure study but did not participate in the biomarker study were similar with regards to fuel type and education, but tended to be

younger (age – mean ± SD: 22 ± 5 years vs. age: 26 ± 6 years; range: 14–46 years). Of the 79 women who participated in the biomarker study, 64 provided additional blood samples in the second trimester and 61 in the third. Cord blood samples were obtained from 50 subjects. Subjects were lost due to relocation and miscarriages. Other characteristics of the subjects are presented in Table 1.

3.2. POP levels

Seventeen of the POPs (3 OCPs and 14 PCBs) had concentrations above the LOD in >60% of the samples with detectable concentrations in each of the trimesters and were analyzed for changes in maternal serum concentration across pregnancy trimesters. The 60% threshold was met for β-HCCH and o,p′-DDT in maternal serum samples, but they were excluded from analyses because concentrations were not reportable in <60% in at least two of the three trimesters. Two OCPs (p,p′-DDT and p,p′-DDE) and five PCBs (PCBs 118, 138–158, 153, 170, and 180) had concentrations above the LOD in >60% of the cord serum samples and were also analyzed for the comparisons of POPs in maternal and cord serum. Chemical names, LODs and descriptive statistics of all 55 POPs are presented in Supplementary Materials; Tables 1 and 2.

3.3. Changes in POP concentrations across trimester, by age and educational status

Serum concentrations of both total cholesterol and triglycerides changed significantly across the pregnancy trimesters ($p < 0.0001$) with increasing serum concentrations of both cholesterol and triglycerides from the first to the third trimester (Table 2). While lipid adjusted POP concentrations tended to significantly ($p < 0.05$) decrease from the first to the third trimester (except for PCB-99), fresh weight concentrations (except for p,p′-DDT, p,p′-DDE, and PCB-105, 138–158, 146, 183, 187, 196–203 and 199) tended to increase ($p < 0.05$). The percentage change in fresh weight POP concentrations from the first to the third trimesters ranged from 12% to 28% except for p,p′ -DDE, p,p′-DDT, PCB-99, 146, 187, and 196–203 (9.3%, 10%, 40%, 36%, 2%, and 11% respectively). Corresponding changes for lipid adjusted concentrations were between 16% and 28% except for PCB-99, 146 and 187 (9%, 32% and 34% respectively). Concentration of total lipid increased from the first to the third trimester by 53%.

The mean concentrations of the POPS by trimester and in cord serum were estimated based on the fitted linear mixed models and appear in Table 2. In fitting these models both age and education were found to be significant predictors of the mean response and retained in the model, so the estimates in Table 2 are made marginally, for a population of subjects of the mean age and educational status. In addition, estimates are presented conditionally at specific levels of these covariates in Tables 3 and 4.

Note that for one compound, fresh weight PCB-138-158, it was necessary to simplify the linear mixed effect model in order to fit it. In particular, for this response variable a compound symmetric variance-covariance structure with non-constant variance was assumed.

3.4. POP concentrations in cord serum

Overall (the 3 trimesters combined) and third maternal trimester fresh weight serum concentrations were significantly higher than the levels in the cord serum for the 7 POPs that had detection frequencies >60% in both maternal and cord serum samples. The average cord to third maternal trimester serum ratios of the fresh weight concentrations were: PCB-118: 0.32 (95% confidence limits: 0.22, 0.41); PCB-138-158: 0.41 (0.32, 0.50); PCB-153: 0.24 (0.16, 0.31); PCB-170: 0.30 (0.21, 0.29); PCB-180: 0.21 (0.12, 0.29); p,p′-DDT: 0.20 (0.11, 0.30); and p,p′-DDE: 0.25 (0.17, 0.33). The difference between the third trimester maternal and cord serum was absent only for p,p′-DDE, PCB-138-158 and 170 when lipid adjustment was applied.

3.5. Intra-individual correlation

The intra-individual correlations of the lipid adjusted concentrations of the POPs across the trimesters were positive, moderate to high, and significant (Table 5). The intra-individual correlations across the trimesters for the POPs were between 0.51 and 0.98 except for first and third trimester PCB-105 concentrations ($\rho = 0.30$), and first and second trimester PCB-183 concentrations ($\rho = 0.46$). Results of the correlation analyses were similar for fresh weight POP concentrations.

4. Discussion

4.1. Exposure levels

Three classes of POPs: OCPs, PCBs, and PBDEs were measured in pregnant women across pregnancy trimesters and in their babies' cord serum in Trujillo, Peru. The frequencies of detection for the PBDEs in the study were very low; below 20% except for PBDE-153 (38%) in maternal serum samples. Consistent with other studies, p,p′-DDE was the most abundant OCP, while PCB-153, 180 and 138–158 were the most abundant PCBs (Rollin et al., 2009; Hansen et al., 2010; Llop et al., 2010; Glynn et al., 2011; Rudge et al., 2011). The low serum levels of PBDEs in this study indicate little or no exposure to PBDE containing products/materials in the indoor environment which has been suggested as the most likely dominant pathway of human exposure (Sjödin et al., 2008).

While Peru has ratified the Stockholm Convention and no evidence of current use of any of the POPs measured in this study was found in the literature, indirect exposure to residues of POPs in the environment is still expected. Diet, especially the consumption of fatty fish, has for instance been identified as a major source of exposure (Glynn et al., 2007; Llop et al., 2010). The concentrations of PCBs in this study were lower than those measured within five years of the current study in pregnant women in Western Europe, Canada and the United States (Jarrell et al., 2005; Wang et al., 2009; Hansen et al., 2010; Llop et al., 2010; Glynn et al., 2011). The United States levels are from serum samples collected from pregnant women at different pregnancy time points between 1999 and 2002 for National Health and Nutrition Examination Survey (NHANES) (Wang et al., 2009). The low amount of PCBs that was used in Peru (Gevao et al., 2010) could have contributed to the lower serum PCB concentrations that were observed in this study relative to those measured in pregnant women in Europe and the United States.

Contrarily, geometric mean level of p,p′-DDE in pregnant women in this study was multiple times higher than that measured in the pregnant women in NHANES (except when compared to Mexican American women), Canada, Norway and Spain. This may reflect the possibility that DDT use in Peru continued much longer than in the United States and the other developed countries. While DDT application was stopped in most industrialized countries in the 1970s (Zumbado et al., 2004, 2009; USEPA, 2009), Peru only ratified the Stockholm Convention in 2005 (Stockholm Convention, 2008b). However, the fairly high average p,p′ -DDE:p,p′-DDT ratio of 11:1 in the maternal serum samples indicates that the women were not exposed to recently applied DDT (Johnson-Restrepo et al., 2007). A high DDE:DDT ratio has been reported to be an indication that DDT is no longer entering the environment (Harris et al., 1999). Nonetheless, dietary exposure through consumption of fatty fish may still occur. Interestingly it was identified that commercially produced chickens were commonly fed with a feed containing fish meal, hence, the consumption of meat and eggs from chicken may also be a source of POP exposure in this population (Hirai et al., 2004).

4.2. POPs levels across pregnancy trimesters

As expected, the concentration of total lipids in maternal serum increased significantly from first to third pregnancy trimester. Increasing lipid content of the blood during pregnancy is thought to be related to the maintenance of nourishment to mother and fetus (Glynn et al., 2011). While fresh weight concentrations of the POPs tended to increase from the first through the third trimester, lipid adjustment of the concentrations tended to reverse the trend (Table 2). The increase in the fresh weight concentrations may have been the corollary of the increase in serum lipid concentrations as pregnancy progressed. Indeed, the possibility of using fresh weight concentrations of serum organochlorines as an indicator of lipidemia during pregnancy has been suggested (Hansen et al., 2010). Changes in the fresh weight POP concentrations across pregnancy time periods could be particularly important with regards to periods of vulnerability of the fetus during pregnancy for particular adverse outcomes. As such, sample collection outside the relevant pregnancy time window and/or inconsistent sampling time could result in exposure misclassification. On the other hand, the decrease across trimesters of the lipid adjusted concentrations was most likely due to dilution by the gain in weight as pregnancy progressed (Glynn et al., 2007, 2011). In cross-sectional studies of pregnant women conducted in the United States and Sweden, lipid adjusted serum PCB and DDE concentrations were found to be negatively associated with body mass index (BMI) (Glynn et al., 2007; Wang et al., 2009), and with weight gain during pregnancy in the Sweden study (Glynn et al., 2007).

Only a few studies have investigated women’s concentrations of POPs across pregnancy trimester. While no change was reported for lipid adjusted concentrations of OCPs and PCBs across various pregnancy time points in some of the studies (Jarrell et al., 2005; Wang et al., 2009), Longnecker et al. (1999) and Hansen et al. (2010) had observed an increase in fresh weight concentrations across pregnancy. The increasing trends was either reversed or no longer apparent when lipid adjusted concentrations were used instead of fresh weight concentrations in both studies. Glynn et al. (2011) had reported results similar to those in the current study for lipid adjusted concentrations of PCBs for a study including ten pregnant

women. They observed a decline in lipid adjusted concentrations of PCBs across pregnancy trimesters among pregnant women in their study. Results from their study also showed nonsignificant increases in fresh weight PCBs across pregnancy trimesters, possibly due to the small sample size ($N = 10$).

There are significant differences between the studies that reported no trend in lipid adjusted concentrations of OCPs and PCBs across pregnancy time points and the current study. Wang et al. (2009) did not collect serial measurements from the women in their study but used a population based sample from NHANES. Although, Longnecker et al. (1999) analyzed POPs in samples that were serially collected (once every trimester), samples were collected between 1959 and 1965 when PCBs were still produced and used in large quantities. Jarrell et al. (2005) measured OCPs and PCBs in blood samples collected during the second trimester and at delivery. Results of the current study suggest that the largest decline in serum adjusted lipid concentrations of the OCPs and PCBs occurred between the first and second trimesters as observed for PCBs by Glynn et al. (2011).

4.3. POP concentrations in cord serum

The detection of POPs in cord serum and average cord to maternal serum (third trimester) ratio of the fresh weight concentrations indicate there is substantial trans-placental POP transfers from mother to fetus during pregnancy. Similar results have been reported in another study (Covaci et al., 2002).

4.4. Effect of age and education status

Consistent with results from other studies (Glynn et al., 2007; Hansen et al., 2010; Llop et al., 2010), age was positively associated with POP concentrations. Being older would allow for a larger exposure period to these bioaccumulating compounds. Furthermore, subjects in the oldest age category were born in the 1960s and 1970s when the production and use of OCPs and PCBs were at their peaks (Breivik et al., 2002; Li and Macdonald, 2005). The only other factor that was associated with POP serum concentrations was the women's education status. Exposure increased with increasing level of education, especially for the more abundant PCBs. The reason for this is unclear.

4.5. Intra-individual correlations

The high intra-subject correlations across the trimesters for p,p′-DDT and p,p′-DDE and the more abundant PCBs indicate that measurements of these pollutants for epidemiological exposure assessment may be made at any stage of pregnancy without the risk of exposure misclassification, as long as the measurements of all subjects were collected within a narrow time period. Similar findings have been reported by others (Longnecker et al., 1999; Glynn et al., 2011). The significant correlation between the POPs (results not presented) also suggests that they have similar exposure routes/sources.

4.6. Limitations

Because this study was primarily designed to measure the exposure of the women to indoor and environmental pollutants, no information was collected on some factors that may be associated with serum concentrations of POPs. These include diet, parity, lactating history

BMI, and weight gain during pregnancy. However, the findings of the study with regards to the decreases in lipid adjusted concentrations from the first to the third trimester were similar to those reported for PCBs by Glynn et al. (2011). Moreover, repeated measurements were taken from the study participants with each woman effectively serving as her own control. Additionally, when changes for the individual were considered, there was decrease in at least 70% of the women for the POPs from the first to the second trimester (except for PCB-183 – 59%, PCB-187 – 69%, and PCB-99 – 67%) and from the first to the third trimester (except PCB-99 – 67%). This indicates consistency in the results among the study participants and that the inclusion of the other factors in our analyses may not have influenced our results. A convenience sample was used in this study, limiting the generalization of the results.

5. Conclusion

Results of this study suggest that the disposition of POPs in the body may change during pregnancy, and that the direction of the change of serum POPs across pregnancy trimesters may be affected by how their concentrations are expressed. Fresh weight concentrations of PCBs, p,p′-DDT and p,p′-DDE increased in blood serum as pregnancy progressed, most likely as a result of the increase of lipids in the serum. However lipid adjustment of the concentrations tended to reverse the trend, probably due to dilution by weight gain as pregnancies progressed. As indicated in this study, change in lipid concentration affects the serum concentrations of POPs. Consequently, lipid adjusted concentrations are used for the assessment of prenatal exposures in order to reduce variations within persons. The findings in this study demonstrate that OCPs and PCBs were ubiquitously present in the Peruvian environment prior to 2004–2005. The detection of DDT, DDE and PCBs in cord serum suggests substantial trans-placental transfer of these POPs from the mother to the fetus.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.chemosphere.2013.01.043.

Abbreviations

POP	persistent organic pollutant
PCB	polychlorinated biphenyl
OCP	organochlorine pesticide
PBDE	polybrominated biphenyl diether
DDE	2,2-Bis(4-chlorophenyl)-1,1-dichloroethene
DDT	2,2-Bis(4-chlorophenyl)-1,1,1-trichloroethane
HCB	hexachlorobenzene
LOD	limit of detection

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HIGHLIGHTS

- Fresh weight serum PCBs and pesticides in increased across pregnancy trimesters.
- Lipid adjusted PCBs and pesticides in decreased across pregnancy trimesters.
- Trans-placental transfer of PCBs, DDT and DDE was apparent in the subjects.
- PCB were lower in pregnant women in Peru compared to levels in developed countries.
- DDT and DDE were higher compared to levels in developed countries.

Table 1

Number and percentage of women stratified by demographic sub-categories. The average age was 26 ± 6 years (range: 14–46).

Demographic	***N* (%)**
Highest education obtained	
Primary	16 (20)
Secondary	46 (58)
Superior	17 (22)
Fuel type used for cooking	
Gas	27 (35)
Wood	12 (6)
Kerosene	4(5)
Vegetable carbon/carbon briquettes	11 (14)
Combo with gas	19 (24)
Combo without gas	4 (5)
Electric	1 (1)
Unknown	1 (1)
Socioeconomic status	
Poor	50 (63)
Middle	27 (34)
Affluent	2 (3)

Table 2

Model derived concentrations of fresh weight and lipid adjusted concentrations of POPs in maternal and cord serum across trimesters.

Compound	First trimester	Second trimester	Third trimester	Cord blood	N persons (1st, 2nd, 3rd trimester, cord)
Fresh weight POP (95% confidence limits) (pg g^{-1} serum)					
p,p′-DDT[##]	239 (158, 362)	261 (166, 408)	261 (165, 409)	47 (29, 75)	76, 46, 44, 47
p′,p′-DDE[**,##]	3560 (2310, 5470)	4930 (2530, 6110)	4920 (2410, 6380)	898 (534, 1510)	76, 62, 59, 47
HCB[**]	24 (19, 30)	23 (18, 29)	29 (23, 36)		58, 62, 55, –
PCB-74[**]	6.5 (5.0, 8.4)	7.0 (5.4, 9.2)	8.4 (6.4, 11)		76, 62, 59, –
PCB-99[**]	8.1 (6.2, 11)	10 (7.9, 13)	11 (8.6, 15)		76, 62, 59, –
PCB-105	7.9 (6.3, 10)	9.5 (7.3, 12)	9.4 (7.0, 13)		76, 62, 59, –
PCB-118[**,##]	22 (18, 28)	23 (18, 29)	27 (21, 35)	4.7 (3.6, 6.2)	76, 62, 59, 48
PCB-138–158[**,##]	52 (43, 63)	59 (49, 73)	59 (45, 76)	12 (8.1, 16)	76, 62, 59, 48
PCB-146	11 (8.9, 15)	10 (7.8, 14)	12 (8.8, 16)		76, 62, 59, –
PCB-153[**,##]	73 (57, 92)	80 (64, 102)	88 (68, 114)	16 (12, 22)	76, 62, 59, 48
PCB-170[**,##]	26 (20, 33)	29 (23, 37)	31 (24, 41)	7.5 (5.8, 9.8)	76, 62, 59, 48
PCB-180[**,##]	58 (46, 73)	65 (52, 82)	72 (56, 91)	13 (10, 16)	76, 62, 59, 48
PCB-183	6.6 (4.9, 8.7)	7.4 (5.4, 10)	7.5 (5.5, 10)		76, 62, 59, –
PCB-187	18 (14, 24)	22 (17, 30)	19 (13, 26)		76, 62, 59, –
PCB-194[*]	8.2 (6.3, 11)	8.9 (6.7, 12)	10 (7.7, 13)		76, 62, 59, –
PCB-196–203	8.8 (6.8, 11)	8.7 (6.6, 12)	9.8 (7.4, 13)		76, 62, 59, –
PCB-199	7.8 (6.0, 10)	8.2 (6.3, 12)	8.9 (6.8, 12)		76, 62, 59, –
Lipid (95% confidence limits) (mg dL^{-1})					
Total Cholesterol[**,##]	179 (167, 191)	239 (223, 256)	268 (248, 289)	60 (55, 66)	76, 62, 59, 48
Triglycerides[**,##]	137 (122, 154)	202 (182, 225)	263 (236, 293)	35 (31, 39)	76, 62, 59, 48
Lipid adjusted POPs (95% confidence limits) (ng g^{-1} lipid)					
p′,p′-DDT[##]	39 (26, 59)	32 (20, 51)	29 (18, 45)	20 (12, 33)	76, 46, 44, 47
p,p′-DDE[**]	581 (373, 906)	486 (310, 762)	418 (255, 686)	383 (225, 652)	76, 62, 59, 47
HCB[**]	3.9 (3.1, 4.9)	2.8 (2.3, 3.5)	3.0 (2.4, 3.8)		58, 62, 55, –

Compound	First trimester	Second trimester	Third trimester	Cord blood	N persons (1st, 2nd, 3rd trimester, cord)
PCB-74 **	1.1 (0.83, 1.4)	0.87 (0.67, 1.1)	0.89 (0.68, 1.2)		76, 62, 59, –
PCB-99	1.3 (1.0, 1.7)	1.3 (0.97, 1.6)	1.2 (0.91, 1.6)		76, 62, 59, –
PCB-105	1.3 (1.0, 1.7)	1.1 (0.89, 1.5)	1.0 (0.75, 1.3)		76, 62, 59, –
PCB-118 **,##	3.6 (2.9, 4.5)	2.8 (2.3, 3.6)	2.8 (2.2, 3.7)	2.0 (1.5, 2.7)	76, 62, 59, 48
PCB-138–158 **,##	8.8 (7.1, 11)	7.7 (6.2, 9.6)	6.5 (4.9, 8.5)	5.1 (3.6, 7.2)	76, 62, 59, 48
PCB-146 **	1.9 (1.5, 2.4)	1.3 (1.0, 1.7)	1.3 (0.94, 1.7)		76, 62, 59, –
PCB-153 **,##	12 (9.3, 15)	9.8 (7.8, 12)	9.3 (7.2, 12)	7.0 (5.2, 9.2)	76, 62, 59, 48
PCB-170 **,#	4.2 (3.3, 5.3)	3.6 (2.8, 4.5)	3.3 (2.6, 4.3)	3.2 (2.5, 4.1)	76, 62, 59, 48
PCB-180 **,##	9.5 (7.6, 12)	8.1 (6.5, 10)	7.6 (6.0, 9.7)	5.5 (4.4, 6.9)	76, 62, 59, 48
PCB-183 *	1.1 (0.80, 1.4)	0.89 (0.65, 1.2)	0.79 (0.57, 1.1)		76, 62, 59, –
PCB-187 *	3.0 (2.3, 3.9)	2.8 (2.1, 3.6)	2.0 (1.4, 2.7)		76, 62, 59, –
PCB-194 *	1.3 (1.0, 1.7)	1.1 (0.83, 1.4)	1.1 (0.82, 1.4)		76, 62, 59, –
PCB-196–203 **	1.4 (1.1, 1.9)	1.1 (0.82, 1.4)	1.0 (0.78, 1.4)		76, 62, 59, –
PCB-199 **	1.3 (1.0, 1.6)	1.0 (0.77, 1.3)	0.94 (0.73, 1.2)		76, 62, 59, –

*Significant difference across trimester at $p < 0.05$.

**Significant difference across trimester at $p < 0.01$.

#Significant difference between maternal and cord serum at $p < 0.05$.

##Significant difference between maternal and cord serum at $p < 0.01$.

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Table 3

Model derived concentrations of fresh weight and lipid adjusted concentrations of POPs in maternal and cord serum across age group.

Compound	<20 years	20–24 years	25–29 years	⩾30 years	*N* person-trimester (<20, 20–24, 25–29, ⩾30 years)[a]
Fresh Weight POP (95% confidence limits) (pg g^{-1} serum)					
p′,p′-DDT*	124 (64, 242)	98 (55, 178)	230 (128, 410)	269 (134, 538)	38, 70, 65, 38
p′,p′-DDE	2820 (1410, 5630)	1730 (936, 3210)	2430 (1330, 4450)	4130 (2010, 8490)	44, 81, 69, 46
HCB*	20 (15, 29)	22 (16, 29)	25 (18, 33)	37 (26, 52)	30, 59, 52, 33
PCB-74*	7.1 (4.7, 10)	5.1 (3.6, 7.3)	8.0 (5.7, 11)	9.7 (6.4, 15)	35, 65, 60, 37
PCB-99	10 (6.9, 16)	7.6 (5.3, 11)	9.5 (6.7, 14)	12 (8.1, 19)	35, 65, 60, 37
PCB-105	9.7 (6.7, 14)	7.3 (5.3, 10)	8.5 (6.1, 12)	10 (7.1, 15)	35, 65, 60, 37
PCB-118	16 (11, 23)	12 (9.2, 17)	15 (11, 21)	20 (14, 21)	44, 81, 69, 46
PCB-138–158**	32 (23, 44)	31 (23, 41)	37 (28, 49)	58 (42, 80)	44, 81, 69, 46
PCB-146*	7.9 (5.3, 12)	9.8 (6.9, 14)	11 (7.4, 15)	19 (13, 29)	35, 65, 60, 37
PCB-153**	41 (28, 59)	42 (30, 58)	50 (36, 69)	97 (66, 143)	44, 81, 69, 46
PCB-170**	14 (9.3, 20)	15 (11, 21)	20 (14, 28)	43 (29, 64)	44, 81, 69, 46
PCB-180**	28 (20, 40)	32 (24, 44)	41 (30, 56)	92 (64, 134)	44, 81, 69, 46
PCB-183**	4.5 (2.9, 7.1)	5.3 (3.5, 7.8)	6.9 (4.7, 10)	16 (10, 25)	35, 65, 60, 37
PCB-187**	14 (8.7, 21)	13 (8.8, 19)	19 (14, 28)	44 (28, 69)	35, 65, 60, 37
PCB-194**	5.1 (3.5, 7.6)	6.1 (4.3, 8.7)	9.6 (6.8, 13)	22 (15, 33)	35, 65, 60, 37
PCB-196–203**	5.5 (3.7, 8.2)	6.7 (4.7, 9.6)	9.3 (6.6, 13)	20 (13, 30)	35, 65, 60, 37
PCB-199**	5.2 (3.5, 7.7)	5.9 (4.1, 8.3)	8.2 (5.8, 12)	19 (12, 28)	35, 65, 60, 37
Lipid adjusted POPs (95% confidence limits) (ng g^{-1} lipid)					
p′,p′-DDT	22 (11, 44)	19 (10, 34)	39 (22, 71)	44 (22, 88)	38, 70, 65, 38
p′,p′-DDE	487 (239, 994)	319 (169, 601)	413 (223, 769)	702 (334, 1480)	44, 81, 69, 46
HCB*	2.6 (1.9, 3.6)	2.9 (2.2, 3.9)	3.1 (2.3, 4.1)	4.6 (3.3, 6.4)	30, 59, 52, 33
PCB-74	0.90 (0.61, 1.3)	0.71 (0.50, 1.0)	1.0 (0.72, 1.4)	1.2 (0.79, 1.8)	35, 65, 60, 37
PCB-99	1.3 (0.88, 2.0)	1.0 (0.72, 1.5)	1.2 (0.85, 1.7)	1.5 (1.0, 2.3)	35, 65, 60, 37
PCB-105	1.2 (0.84, 1.8)	1.0 (0.72, 1.5)	1.1 (0.79, 1.5)	1.3 (0.88, 1.9)	35, 65, 60, 37

Compound	<20 years	20–24 years	25–29 years	⩾30 years	*N* person-trimester (<20, 20–24, 25–29, ⩾30 years)[a]
PCB-118	2.8 (2.0, 4.0)	2.3 (1.7, 3.2)	2.7 (1.9, 3.6)	3.4 (2.3, 4.9)	44, 81, 69, 46
PCB-138–158 *	5.8 (4.0, 8.2)	5.7 (4.2, 7.9)	6.5 (4.8, 8.9)	10 (7.1, 15)	44, 81, 69, 46
PCB-146 *	1.0 (0.69, 1.5)	1.3 (0.95, 1.9)	1.4 (0.97, 1.9)	2.3 (1.6, 3.5)	35, 65, 60, 37
PCB-153 *	7.1 (4.9, 10)	7.8 (5.6, 11)	8.6 (6.3, 12)	16 (11, 23)	44, 81, 69, 46
PCB-170 **	2.4 (1.7, 3.5)	2.8 (2.0, 3.9)	3.4 (2.5, 4.7)	6.9 (4.7, 10)	44, 81, 69, 46
PCB-180 **	5.0 (3.5, 7.1)	6.0 (4.4, 8.2)	7.0 (5.2, 9.5)	15 (11, 22)	44, 81, 69, 46
PCB-183 **	0.58 (0.37, 0.90)	0.71 (0.48, 1.1)	0.87 (0.59, 1.3)	1.9 (1.2, 3.0)	35, 65, 60, 37
PCB-187 **	1.7 (1.2, 2.6)	1.8 (1.2, 2.5)	2.5 (1.7, 3.5)	5.5 (3.6, 8.3)	35, 65, 60, 37
PCB-194 **	0.66 (0.45, 0.97)	0.84 (0.59, 1.2)	1.2 (0.87, 1.7)	2.7 (1.8, 4.1)	35, 65, 60, 37
PCB-196–203 **	0.70 (0.47, 1.0)	0.92 (0.65, 1.3)	1.2 (0.84, 1.7)	2.5 (1.6, 3.7)	35, 65, 60, 37
PCB-199 **	0.66 (0.45, 0.97)	0.80 (0.57, 1.1)	1.0 (0.75, 1.5)	2.3 (1.6, 3.4)	35, 65, 60, 37

* Significant difference across age group and education status at $p < 0.05$.

** Significant difference across age group and education status at $p < 0.01$.

[a] *N* breaks down according to trimester for each age group as follows: 1st – 15, 25, 22, 14; 2nd – 11, 20, 19, 12; 3rd – 9, 20, 19, 11; and for those with cord blood – 9, 16, 9, 9 except for HCB: 1st – 11, 22, 14, 11; 2nd – 11, 20, 19, 12; 3rd – 8, 18, 19, 10; and p,p′-DDT: 1st – 15, 25, 22, 14; 2nd – 8, 14, 16, 8; 3rd – 6, 15, 14, 9; and cord blood: 9, 16, 13, 9.

Table 4

Model derived concentrations of fresh weight and lipid adjusted concentrations of POPs in maternal and cord serum according to education status.

Compound	Primary	Secondary	Superior	*N* person-trimesters (1°, 2°, 3° education)[a]
Fresh weight POP (95% confidence limits) (pg g^{-1} serum)				
p′,p′-DDT	101 (49, 210)	182 (115, 288)	248 (132, 467)	48, 110, 55
p′,p′-DDE	1430 (670, 3040)	3050 (1890, 4920)	4260 (2210, 8220)	52, 143, 50
HCB	20 (14, 29)	24 (19, 30)	34 (24, 46)	35, 104, 36
PCB-74	5.8 (3.8, 9.0)	6.9 (5.3, 9.1)	9.5 (6.5, 14)	41, 115, 41
PCB-99	8.5 (5.4, 13)	9.2 (7.0, 12)	12 (8.4, 18)	41, 115, 41
PCB-105	2.2 (1.8, 2.6)	2.2 (1.9, 2.4)	2.2 (1.8, 2.5)	41, 115, 41
PCB-118	13 (9.1, 20)	16 (12, 20)	19 (14, 27)	41, 115, 41
PCB-138–158 *	28 (20, 39)	38 (30, 48)	52 (39, 70)	52, 143, 50
PCB-146	8.4 (5.4, 13)	11 (8.2, 14)	15 (10, 22)	41, 115, 41
PCB-153 *	39 (26, 59)	51 (40, 66)	77 (54, 109)	52, 143, 50
PCB-170 *	14 (9.2, 21)	21 (16, 27)	29 (20, 42)	52, 143, 50
PCB-180 *	30 (21, 45)	43 (34, 55)	61 (44, 85)	52, 143, 50
PCB-183	5.1 (3.1, 8.3)	6.8 (5.0, 9.2)	11 (6.9, 16)	52, 143, 50
PCB-187	14 (8.8, 22)	21 (16, 28)	26 (18, 39)	41, 115, 41
PCB-194 *	5.9 (3.8, 9.0)	10 (7.7, 13)	12 (8.6, 18)	52, 143, 50
PCB-196–203	7.2 (4.6, 11)	9.4 (7.2, 12)	11 (7.6, 16)	41, 115, 41
PCB-199	6.0 (3.9, 9.3)	8.7 (6.6, 11)	11 (7.4, 16)	41, 115, 41
Lipid adjusted POPs (95% confidence limits) (ng g^{-1} lipid)				
p′,p′-DDT	18 (8.5, 37)	33 (20, 52)	43 (23, 82)	48, 110, 55
p′,p′-DDE	237 (109, 515)	542 (332, 886)	764 (389, 1500)	52, 143, 50
HCB	2.5 (1.8, 3.6)	3.1 (2.5, 3.9)	4.3 (2.1, 5.8)	
PCB-74	0.73 (0.48, 1.1)	0.92 (0.71, 1.2)	1.2 (0.84, 1.8)	41, 115, 41
PCB-99	1.1 (0.68. 1.7)	1.2 (0.92, 1.6)	1.6 (1.1, 2.3)	41, 115, 41
PCB-105	1.1 (0.75, 1.7)	1.2 (0.91, 1.5)	1.2 (0.81, 1.6)	41, 115, 41
PCB-118	2.3 (1.5, 3.4)	2.8 (2.2, 3.6)	3.3 (2.4, 4.7)	52, 143, 50
PCB-138–158 *	4.9 (3.3, 7.2)	6.8 (5.3, 8.7)	9.7 (7.0, 14)	52, 143, 50
PCB-146	1.1 (0.68, 1.6)	1.4 (1.1, 1.9)	2.0 (1.4, 2.9)	41, 115, 41
PCB-153 *	6.7 (4.5, 9.9)	9.0 (7.0, 12)	13 (9.4, 19)	52, 143, 50
PCB-170 *	2.3 (1.6, 3.5)	3.7 (2.9, 4.8)	5.2 (3.6, 7.3)	52, 143, 50
PCB-180 *	5.2 (3.6, 7.6)	7.6 (6.0, 9.6)	11 (7.8, 15)	52, 143, 50
PCB-183 *	0.63 (0.39, 1.0)	0.88 (0.66, 1.2)	1.3 (0.88, 2.0)	52, 143, 50
PCB-187	1.8 (1.1, 2.7)	2.7 (2.1, 3.6)	3.4 (2.3, 4.9)	41, 115, 41
PCB-194 *	0.74 (0.48, 1.1)	1.3 (1.0, 1.7)	1.6 (1.1, 2.3)	52, 143, 50
PCB-196–203	0.90 (0.58, 1.4)	1.2 (0.95, 1.6)	1.4 (0.99, 2.1)	41, 115, 41

Compound	Primary	Secondary	Superior	*N* person-trimesters (1°, 2°, 3° education)[a]
PCB-199	0.76 (0.50, 1.2)	1.1 (0.88, 1.5)	1.4 (0.97, 2.0)	41, 115, 41

[*] Significant difference across age group and education status at $p < 0.05$.

[a] N breaks down according to trimester for each education status as follows for all compounds: 1st – 16, 45, 15; 2nd – 13, 36, 13; 3rd – 12, 34, 13 and for those with cord blood – 11, 28, 9; except for HCB: 1st – 12, 34, 12; 2nd – 13, 36, 13; 3rd – 10, 34, 11 and p,p′-DDT: 1st – 16, 45, 25; 2nd – 10, 25, 11; 3rd: 11, 22, 11; and cord blood – 11, 28, 8.

Table 5

Intra-individual spearman rank correlation coefficients for lipid adjusted POP concentrations.

Analyte	Trimester/cord serum Pairs[a,b]						
	I–II	I–III	II–III	I–IV	II–IV	III–IV	*N*
p,p′-DDT	0.99	0.99	0.98	0.91	0.89	0.92	36
p,p′-DDE	0.99	0.98	0.98	0.99	0.99	0.97	47
HCB	0.90	0.85	0.88				38
PCB-118	0.98	0.90	0.91	0.77	0.80	0.68	47
PCB-138–158	0.98	0.93	0.93	0.73	0.74	0.74	48
PCB-153	0.98	0.96	0.96	0.90	0.90	0.90	48
PCB-170	0.99	0.95	0.95	0.85	0.82	0.82	48
PCB-180	0.99	0.97	0.98	0.89	0.90	0.88	48
PCB-74	0.85	0.82	0.77				59
PCB-99	0.92	0.83	0.85				59
PCB-105	0.85	0.53	0.68				59
PCB-146	0.92	0.87	0.89				59
PCB-183	0.86	0.82	0.85				59
PCB-187	0.94	0.87	0.91				59
PCB-194	0.87	0.80	0.82				59
PCB-196–203	0.85	0.62	0.67				59
PCB-199	0.90	0.80	0.82				59

[a] All Correlation Coefficients are significant at $p = 0.05$.

[b] I – first trimester, II – second trimester, III – third trimester and IV – cord blood.