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Persistent organic pollutant concentrations in first birth mothers across Mexico

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This project was initiated by the North America Commission for Environmental Cooperation (CEC). Its main purpose was to obtain an initial profile on pregnant woman's exposure to persistent organic pollutants (POPs) in North America (Canada, the United States and Mexico). Persistent organic pollutants are transferred to the fetus via the placenta during the pregnancy or to the infant via maternal milk; therefore, the pregnant woman's body burden is important because of the higher exposures and potential health effects in the fetus and infant. This paper presents the results from 240 pregnant women in 10 Mexican cities, and includes the concentrations of various POPs such as polychlorinated biphenyls (PCBs), organochlorine pesticides and polychlorinated dibenzo dioxins and furans (PCDDs and PCDFs) in maternal plasma. We found concentrations of p,p′-DDE in maternal samples from Coatzacoalcos to be ~60% higher than those found in Ciudad Obregon, which had the second highest concentration. Pregnant women from Merida had higher mean concentrations of PCBs than all women in other regions. Results for PCDDs and PCDFs plus dioxin-like PCBs data were only available on the basis of composite samples, and their concentrations are similar in most cities except for Coatzacoalcos, which had more than double the concentration found in other cities. Although this study provides useful information on the variability of POPs in specific populations and possible regional/local differences, these results cannot be generalized to the entire Mexican population because of differences in age, gender, sources of exposure and nonrandom nature of the sample.
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Introduction

Persistent organic pollutants (POPs) are degradation-resistant anthropogenic compounds that accumulate in the food chain and in adipose tissue. Many POPs are widely disseminated in the environment because of their mobility, and because of their toxicity may pose a risk to the health of humans and wildlife (Albert, 2004). POPs, such as organochlorine pesticides, polychlorinated biphenyls (PCBs) and polychlorinated dibenzo-p-dioxins and furans (PCDDs and PCDFs), can be found in human blood, adipose tissue and breast milk (Solomon and Weiss, 2002; Eskenazi et al., 2003; Guvenius et al., 2003; Doucet et al., 2009; Hedgeman et al., 2009). Organochlorine pesticides, PCBs, PCDDs and PCDFs accumulating in the maternal body are transferred to the fetus via placenta during the pregnancy or to the infants via maternal milk; therefore, the pregnant woman's body burden is important because of the higher exposures and the potential health effects in the fetuses and infants. (Todaka et al., 2010; Wang et al., 2009).

The United Nations Environment Programme Stockholm Convention (SC) in 2001 established procedures to eliminate and/or control 12 POPs, 9 of which are pesticides (aldrin, chlordane, dichlorodiphenyltrichloroethane (DDT), dieldrin, endrin, heptachlor, hexachlorobenzene (HCB), mirex and toxaphene); others include PCBs, which were used in a variety of industrial/commercial applications, and the PCDDs and PCDFs that are released during combustion/production of several chemical compounds containing chlorine. Mexico signed the SC in 2001, and ratified it in 2003 (Secretaria de Medio Ambiente y Recursos Naturales, 2007).

In 1994, Canada, United States and Mexico created the North American Commission for Environmental Cooperation (CEC), based on the provisions of the North American Free-Trade Agreement. The purpose of the CEC was to address environmental issues of common concern, contribute

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to preventing potential environmental conflicts arising from trade relations of the three countries and promote effective application of environmental legislation. Mexico has made a concerted effort to enhance the development of monitoring and analytical capabilities. Regional Action Plans are currently in place for PCBs, chlordane, PCDDs, PCDFs and HCB, and are implemented with three main objectives in mind as follows: the elimination of the use of these compounds, environmentally correct handling of PCB inventories throughout their life cycle and the gradual withdrawal and destruction of these pollutants (Commission for Environmental Cooperation, 2003).

This monitoring project was initiated by the human biomonitoring subgroup of the CEC's Sound Management of Chemicals program and its main purpose is to obtain an initial profile on pregnant womens' exposure to different persistent organic compounds in North America (Canada, the United States and Mexico).

This paper provides the results for Mexico. This work establishes an initial baseline for POP concentrations in pregnant women in Mexico.

Materials and methods

Population

Between November 2005 and March 2006, 240 pregnant women from 10 Mexican sites were invited to participate in a study designed to monitor contaminants in maternal blood. The 10 selected sites were Queretaro, Tultitlan, Merida, Salamanca, Monterrey, Guadalajara, Hermosillo, Cordoba, Coatzacoalcos and Ciudad (Cd.) Obregon; some of these cities are characterized by their industrial activity, and others for their agricultural practices with a significant use of pesticides. These sites are located in the northern, central and southern Mexico (Figure 1). The rationale for each site is provided in Table 1.

This study was conducted after obtaining the approval of the Institutional Ethical, Research and Biosecurity boards of the National Institute of Public Health of Mexico. Selection criteria for this study included women in their first pregnancy with no complications, those who had lived at the area for at least 10 years and given their informed, written consent. The women were selected after their last scheduled prenatal visit to their family doctor in public hospitals. Blood samples

Table 1. Characteristics of the study cities.

Site	Population and possible sources
Ciudad (Cd.) Obregon, Sonora	Urban area close to an agricultural/organochlorine insecticide use
Salamanca, Guanajuato	Urban area /industry, refineries and organochlorine processing plants
Tultitlan, State of Mexico	Urban/contaminated sites. 'Cromatos de México' is an example.
Cordoba, Veracruz	Urban/possible dioxin/furan contamination
Coatzacoalcos, Veracruz	Urban and rural/ national petrochemical hub, other chemical industry center and pesticides
Merida area	Urban area/propose nonhotspot, possible DDT and POPs presence
Monterrey area	Urban area/nonhot spot site for POPs
Guadalajara area	Urban area/nonhot spot site for POPs
Hermosillo area	Urban area/nonhot spot site for POPs
Queretaro area	Urban area/nonhot spot site for POPs

Figure 1. Site of study.

were collected during the third trimester of pregnancy. A total of 25 women from each site were selected (except Guadalajara, where only 15 were available).

Blood Samples

To obtain the necessary plasma, blood samples were collected from an antecubital vein into a 10 ml purple-top, EDTA-containing Vacutainer tubes. The tubes were centrifuged at 2400 r.p.m. The plasma was then pipetted into glass vials and frozen at $-20\,^{\circ}$C until analysis.

All quality control (QC) concentration levels were characterized to determine the mean concentrations, and the 95th (1.96σ) and 99th (2.58σ) control limits by consecutive analysis of 20 samples of each QC level. QC data within each analytical run were compared with the control limits to evaluate the validity of analyses using the Westgard rules (Westgard, 2002).

Determination of PCBs, Organochlorine Pesticides and PCDDs/PCDFs

The samples were analyzed for various organochlorine pesticides (aldrin, chlordane derivatives (alpha-chlordane, *cis*-Nonachlor, gamma-chlordane, oxychlordane, *trans*-Nonachlor), hexachlorocyclohexane (HCH) derivatives (gamma-HCH and beta-HCH), mirex, HCB, p,p′-DDT, dichlorodiphenyldichloroethylene (p,p′-DDE), 19 PCBs congeners (28, 52, 99, 101, 105, 114, 118, 123, 128, 138, 153, 156, 157, 163, 167, 170, 180, 183 and 189), plus PCDDs and PCDFs.

Pesticide and PCB levels were measured by high-resolution gas chromatography/low-resolution mass spectrometry at the INSPQ's Toxicology Laboratory in Quebec City, Canada, using an in-house, ISO-17025 accredited method, adapted from Mes (1990). Plasma samples were extracted through a solid-phase extraction (SPE) column. The resulting extracts were purified in a Florisil column, and concentrated to a final volume of 100 μl, before the GC-MS determination Accuracy controls were carried out with the serum, certified by the US National Institute of Science and Technology. Accuracy was periodically verified by participation in two external quality evaluation programs. Detection limits (DLs) varied between 0.005 and 0.09 μg/l, depending on the analyte. Aroclor 1260 was calculated by summing congeners 138 and 153 and multiplying the total by 5.2 (Schulz et al., 1989).

PCDDS, PCDFs and co-planar PCB levels were measured on composite plasma pools (two composite plasma samples were prepared for each of the 10 sites, by each mother contributing $\sim$2 ml of plasma for a total of 20 composite samples). Plasma pools of equal volume were randomly allocated for the two samples for each site, aliquoted into vials and stored at $-20\,^{\circ}$C. These samples were analyzed using high-resolution gas chromatography/isotope-dilution high-resolution mass spectrometry. Plasma samples were spiked with carbon-13 labeled ($^{13}C_{12}$) internal standards and extracted using a C_{18} SPE or liquid–liquid extraction procedure followed by a multicolumn automated cleanup and enrichment procedure (Patterson et al., 1987; Turner et al., 1997).

2,3,7,8 TCDD toxic equivalents (TEQs) were calculated by multiplying the individual concentrations of dioxin, furan or dioxin-like PCB congeners with the 2005 World Health Organization toxic equivalency factor (Van den Berg et al., 2006) to obtain the TEQ for each of these chemicals; these TEQs were summed for the TEQs of dioxins, furans, mono-ortho PCBs and co-planar PCBs, and for the total TEQs.

Wet weight concentrations were converted to lipid weight for the final analysis. The total lipid (TL) concentration of each sample was calculated by summing the measured concentrations of the plasma lipid components. The following lipid components were measured by the standard clinical chemistry enzymatic methods: total cholesterol (TC), free cholesterol (FC), triglycerides (TGs) and phospholipids (PLs). Total lipid concentration was calculated as:

$$\mathrm{TL} = 1.677 * (\mathrm{TC} - \mathrm{FC}) + \mathrm{FC} + \mathrm{TG} + \mathrm{PL}$$

(Atkins et al., 1989).

Statistical Analysis

Wet weight data are summarized as maximum and minimum concentrations, geometric mean, percentiles and percentage of the detected samples. Values below the DL were set at one-half the DL.

For pollutants with more than 70%-detected values, further statistical analysis was carried out on lipid-normalized data. The DDT/DDE ratio was calculated by dividing plasma levels of p,p′-DDT by p,p′-DDE. In the human body, DDE half-life is longer than that of DDT; consequently, a higher DDT/DDE ratio may indicate a more recent exposure, whereas a lower DDT/DDE ratio may indicate a more distant/weathered exposure (Trichopoulus et al., 1995) (Koepke et al., 2004). Tests for normality were performed on these data and the contaminants did not show a normal distribution. Consequently, all data were log transformed and were tested for normality of the residuals before the final analysis. Analysis of variance was used to assess differences between the various sites ($\alpha < 0.05$) and the Scheffe's test was used to adjust for the multiple pairwise comparisons. The body mass index (BMI) was calculated by dividing the pre-pregnancy weight in kilograms by the height in square meters (kg/m^2) and was transformed as a categorical variable. Womens' pre-pregnancy BMI were classified as follows: underweight (BMI < 18.5), normal (18.50–24.99), overweight (25.0–29.99) and obese ($\geq$30.00) (World Health Organization, 1997). We categorized age to match the distribution and use of DDT in Mexico during 1971–1991 (López-Carrillo et al., 1996). The age groups correspond to different stages in the use of DDT in Mexico, from maximal use to minimal use: (1971–1981, 1982–1986 and 1987–1990).

All statistical analyses were performed using the Stata Version 9.2 (StataCorp., College Station, TX, USA).

Results

Sociodemographic Characteristics

Pregnant women participating in the study were young (mean age = 21 years old with a range = 15–33 years), and only a small proportion had finished junior high school (28%). Of these women, 40% smoked at least once in their life, 33% quit smoking when they got pregnant and only 7% smoked during pregnancy.

The general distribution of the maternal POPs data on a wet-weight basis in plasma is outlined in Table 2 (minimum, maximum, percentile distribution, geometric mean and % detected). Results for 13 pesticides and 19 PCB congeners are presented. Aroclor 1260, a measure of total PCBs, is also presented to enable comparison with older/historical data. The only POP found in all the maternal samples was p, p′-DDE. Beta-HCH, oxychlordane and PCB153 were detected in more than 90% of the samples. PCBs 138 and 180, HCB and *trans*-Nonachlor were detected in more than 70% of samples, and all compounds with more than 70% detected were lipid adjusted before further statistical analysis (Table 3).

Polychlorinated Biphenyl

Merida had higher concentrations of PCB congeners 138, 153 and 180 than all the other cities (Table 4). We found

Table 2. Maternal plasma concentrations of POPs (μg/l plasma)[a].

Contaminant	Minimum	Percentiles				Maximum	GM	% Detected
		25	50	75	90			
Aldrin	ND	NA	NA	NA	NA	ND	NA	0
Alpha-chlordane	ND	NA	NA	NA	NA	ND	NA	0
Gamma-chlordane	ND	NA	NA	NA	NA	ND	NA	0
Alpha-HCH	ND	NA	NA	NA	NA	0.02	NA	0.4
Gamma-HCH	ND	NA	NA	NA	NA	NA	0.005	2.9
Beta-HCH	ND	NA	0.06	0.1	0.2	1.8	0.07	98.7
Hexachlorobenzene	ND	NA	0.06	0.1	0.2	1.7	0.06	70.8
Mirex	ND	NA	NA	NA	NA	0.07	0.05	2.1
Oxychlordane	ND	0.08	0.01	0.02	0.03	0.1	0.01	95.4
Cis-Nonachlor	ND	NA	NA	NA	NA	0.01	0.01	12.5
Trans-Nonachlor	ND	0.01	0.02	0.03	0.05	0.2	0.02	85.4
p,p′-DDT	ND	NA	NA	0.10	0.3	26.0	0.06	38.3
p,p′-DDE	0.48	1.3	2.4	4.2	11.0	160.0	2.67	100
Polychlorinated biphenyls (PCBs)								
PCB 28	ND	NA	NA	NA	NA	0.2	0.02	5.4
PCB 52	ND	NA	NA	NA	NA	ND	NA	0
PCB 101	ND	NA	NA	NA	NA	0.01	NA	0.4
PCB 105	ND	NA	NA	NA	NA	0.1	0.005	3.7
PCB 114	ND	NA	NA	NA	NA	0.01	NA	0.4
PCB 118	ND	NA	0.01	0.01	0.02	0.4	0.01	54.2
PCB 123	ND	NA	NA	NA	NA	0.2	NA	0.4
PCB 128	ND	NA	NA	NA	NA	0.02	NA	0.4
PCB 138	ND	0.01	0.02	0.03	0.05	0.4	0.02	84.6
PCB 153	ND	0.02	0.03	0.05	0.08	0.5	0.03	95.4
PCB 156	ND	NA	NA	NA	0.02	0.06	0.006	14.2
PCB 157	ND	NA	NA	NA	NA	0.01	NA	0.4
PCB 163	ND	NA	NA	NA	0.01	0.3	0.006	15.4
PCB 167	ND	NA	NA	NA	NA	0.2	NA	0.8
PCB 170	ND	NA	NA	0.01	0.02	0.07	0.009	48.7
PCB 180	ND	NA	0.01	0.02	0.03	0.05	0.02	79.2
PCB 183	ND	NA	NA	NA	NA	0.05	0.005	4.2
PCB 187	ND	NA	NA	NA	0.02	0.2	0.006	21.2
PCB 189	ND	NA	NA	NA	NA	ND	NA	0
Arochlor 1260[b]	ND	NA	0.2	0.42	0.7	4.0	0.2	90.8

Abbreviation: GM, geometric mean.
[a] $N = 240$.
[b] Arochlor 1260 was calculated by adding PCB 138 and PCB 153 and multiplying the total by 5.2 (Schulz et al., 1989).

Table 3. Maternal plasma concentrations of POPs (ng/g lipids)[a].

Contaminant lipid adjusted	Minimum	Percentiles				Maximum	GM	% Detected
		25	50	75	90			
Beta-HCH	ND	NA	8.1	16.3	32.4	209.7	8.3	98.7
Hexachlorobenzene	ND	NA	7.3	14.7	25.8	152.4	7.9	70.8
Oxychlordane	ND	1.0	1.7	2.3	3.6	15.0	1.6	95.4
Trans-nonachlor	ND	1.5	2.7	3.8	5.5	21.3	2.4	85.4
p,p'-DDE	46.5	159.	297.	544.	1466	19,753	336	100.
Polychlorinated biphenyls (PCBs)								
PCB138	ND	1.4	2.3	3.9	5.9	50.7	2.4	84.6
PCB 153	ND	2.2	3.4	5.8	9.9	72.5	3.6	95.4
PCB 180	ND	NA	2.0	3.5	5.4	43.6	2.1	79.2
Arochlor 1260[b]	ND	NA	30.0	51.2	78.9	547.2	31.1	90.8

Abbreviation: GM, geometric mean.
[a]$N=240$.
[b]Arochlor 1260 was calculated by adding PCB 138 and PCB 153 and multiplying the total by 5.2 (Schulz et al., 1989).

significantly higher concentrations of PCB 138 in Merida compared with Cordoba, Hermosillo, Guadalajara Monterrey or Cd. Obregon. We found significantly higher concentrations of PCB 153 in Merida compared with Queretaro, Salamanca, Cordoba, Guadalajara, Monterrey Cd. Obregon or Hermosillo and finally Merida had significantly higher concentrations of PCB 180 than Cordoba, Cd. Obregon, Monterrey Hermosillo or Guadalajara (Table 4). The lowest concentrations of PCBs were, in general, seen in Cd. Obregon, Monterrey, Guadalajara and Hermosillo.

Organochlorine Pesticides

The concentrations of various organochlorine pesticides in maternal plasma samples from each city are summarized in Table 5. The highest concentrations of p,p′-DDE were found in mothers from Coatzacoalcos and these were approximately 60% higher than those found in mothers from Cordoba (1072 *vs* 615 ng/g lipid), which had the second highest concentration and was two- to sevenfold higher than the other sites. The overall mean DDT/DDE ratio was 0.03 ± 0.04, with the highest ratio being found in Coatzacoalcos (Table 5). Ciudad Obregon had higher maternal plasma concentrations of HCB than other cities, and was statistically greater than all the other cities except Hermosillo (34.9 *vs* 14.8 ng/g lipid). Salamanca had the highest maternal plasma concentrations of beta-HCH (Table 5). In Table 6, data are stratified by age group and BMI. We found that for p,p′-DDE, beta-HCH, PCB 138, 153 and 180, women between the age of 24 and 33 years had significant higher concentrations than younger women. For p,p′-DDE and beta-HCH, higher concentrations were found in the obese group, and for p,p′-DDE we found statistically significant differences between the obese group and underweight group (BMI <18.5) in Table 6.

PCDDs, PCDFs and Dioxin-like PCBs

PCDDs, PCDFs and dioxin-like PCB results were only available for two composite samples per city because of cost and larger volumes required for these chemical analyses. The total TEQ levels of PCDD, PCDF and DL-PCBs are presented in Table 7. 2,3,7,8 TCDD-TEQ concentrations in the composite maternal plasma samples were very similar in all cities except Coatzacoalcos, where the PCDD-TEQ concentrations were more than double of those found in other cities (Table 8). The dioxin congener with the highest concentration in Coatzacoalcos was 1,2,3,7,8-PePCDD (8.3 pg/g lipid; data not shown).

Discussion

This study measured current human concentrations of pesticides, PCBs and PCDDs/PCDFs in pregnant women across several regions of Mexico. The hypothesized exposure scenario to POPs in Mexico, outlined in Table 1, was not supported by the data we found. Higher concentrations of various contaminants were found in cities such as Merida and Monterrey that we had thought would be background sites (i.e. nonhotspots). This indicates that sources of exposure may be more varied than we previously realized.

PCBs were used extensively as heat-exchange agents in electric capacitors and transformers, as hydraulic lubricants, heat transfer fluids and pesticide extenders (Giesy and Kannan, 1998), and are likely to be widespread in the Mexican environment. Toxicological effects of PCBs have been observed in animal studies that include carcinogenesis, reproductive problems, neurodevelopment anomalies and immunological deficiencies (Liu et al., 2010; Seelbach et al., 2010). However, not all of these effects have been observed in humans (Park et al., 2007), but this information continues to

Table 4. Maternal plasma concentrations of polychlorinated biphenyls (PCBs; ng/g lipids) by city.

Contaminant	City	Geometric mean	95% CI	Minimum	Maximum	Significant difference[a]
PCB138	Merida	4.6	(3.7–5.6)	1.2	13.3	a
	Tultitlan	3.7	(2.8–5.0)	1.3	19.7	ab
	Coatzacoalcos	3.2	(2.3–4.5)	0.8	50.7	abc
	Queretaro	3.1	(2.3–4.2)	0.6	14.4	abc
	Salamanca	2.6	(2.0–3.5)	0.7	14.5	abcd
	Cordoba	1.9	(1.2–1.3)	0.6	32.8	bcd
	Hermosillo	1.7	(1.4–2.0)	0.6	3.6	bcd
	Guadalajara	1.5	(1.1–2.4)	0.6	15.7	bcd
	Monterrey	1.5	(1.2–2.0)	0.5	4.8	cd
	Cd. Obregon	1.4	(1.4–1.1)	0.6	5.8	d
PCB153	Merida	9.1	(7.4–11.2)	3.1	25.5	a
	Coatzacoalcos	6.0	(4.7–7.7)	2.1	43.7	ab
	Tultitlán	4.9	(3.8–6.3)	1.8	21.1	abc
	Queretaro	3.9	(3.0–5.0)	1.2	12.4	bcd
	Salamanca	3.8	(2.9–4.9)	1.6	25.4	bcd
	Cordoba	3.1	(2.2–4.4)	0.9	72.5	bcd
	Guadalajara	2.8	(2.0–3.8)	1.4	15.7	bcd
	Monterrey	2.3	(1.7–3.1)	0.5	7.5	cd
	Cd. Obregón	2.2	(1.6–2.9)	0.6	9.5	d
	Hermosillo	2.1	(1.8–2.6)	0.6	4.9	d
PCB180	Merida	4.9	(3.8–6.2)	1.2	14.7	a
	Coatzacoalcos	3.0	(2.4–3.7)	0.8	7.7	ab
	Tultitlán	2.9	(2.2–3.8)	0.6	10.8	ab
	Salamanca	2.9	(1.9–4.3)	0.7	43.6	abc
	Queretaro	2.0	(1.6–2.6)	0.5	6.2	abc
	Cordoba	1.5	(1.0–2.2)	0.5	36.9	bc
	Cd. Obregon	1.5	(1.0–1.6)	0.6	14.8	bc
	Monterrey	1.4	(1.0–1.8)	0.5	5.7	bc
	Hermosillo	1.3	(1.0–1.7)	0.5	3.7	bc
	Guadalajara	1.2	(0.8–1.7)	0.5	3.3	c
	Merida	71.3	(58.1–87.6)	23.8	180.0	a
	Coatzacoalcos	48.5	(37.1–63.4)	17.9	493.0	ab
Aroclor 1260[a,b]	Tultitlan	45.2	(34.7–58.7)	16.9	210.5	ab
	Queretaro	37.1	(28.5–48.2)	11.1	133.3	abc
	Salamanca	34.2	(17.0–36.1)	14.9	209.0	abc
	Cordoba	24.8	(17.0–36.1)	7.6	547.2	bc
	Guadalajara	22.1	(14.9–32.7)	6.6	171.4	bc
	Monterrey	20.0	(15.2–26.3)	5.2	64.6	c
	Hermosillo	19.5	(16.0–23.9)	6.4	42.5	c
	Cd. Obregon	17.5	(13.0–23.7)	5.9	79.0	c

[a]a,b,c,d comparisons are one-way ANOVA with Scheffe's test for multiple comparisons, where the groups that do not have a common letter are significantly different.
[b]Sum of PCBs expressed as Aroclor 1260 = 5.2(PCB 138 + 153).

stimulate concern about present human body burdens. PCB concentrations (expressed as Aroclor 1260) in our study were lower than those found in breast cancer patients and controls from public hospitals of Mexico city (López-Carrillo et al., 2002). This might be expected, as the breast cancer cases and controls are older than the mothers in this study, and concentrations of PCBs in human beings are decreasing in many parts of the world over the time period between these two studies. Concentrations of PCBs 138, 153 and 180 in Mexican primiparous mothers were close to one quarter to those seen in the United States primiparous mothers as reported by Wang et al. (2009), even although the age range were similar in both the studies. This difference could be because NHANES (1999–2000, 2001–2002) was conducted at a time when PCB concentrations in the environment were higher, hence, the women had higher exposures to PCBs. A more recent study of pregnant mothers in NHANES (2003–2004) indicates that the Mexican women in our study had only one half the concentrations of PCB 153 and 180 than those seen in the United States (Woodruff et al., 2011). In this case, the difference is less because the participants selected from the NHANES (2003–2004) were closer to this sampling time point 2006–2007, although the Mexican mothers continue to be lower.

Table 5. Chlorinated organic pesticide concentrations in maternal plasma (ng/g lipid).

Contaminant	*City*	*Geometric mean*		*95% CI*	*Minimum*	*Maximum*	*Significant difference*[a]
Beta-HCH	Salamanca	19.9		(15.1–26.2)	4.1	67.9	a
	Merida	16.7		(11.6–24.1)	4.9	209.7	ab
	Coatzacoalcos	14.1		(8.7–22.9)	2.6	180	ab
	Cordoba	13.0		(8.6–19.6)	1.6	68.8	abc
	Queretaro	9.9		(6.8–14.4)	2.2	123.7	abc
	Guadalajara	7.6		(5.5–10.3)	3.1	18.8	abcd
	Tultitlan	7.5		(5.9–9.57)	2.2	20.7	bc
	Monterrey	6.2		(4.8–4.10)	1.5	32.9	cd
	Hermosillo	2.9		(2.3–3.6)	1.3	10.7	d
	Cd. Obregon	2.6		(1.8–3.7)	0.633	56.8	d
Hexachloro benzene	Cd. Obregon	34.9		(24.8–49.1)	3.5	135.8	a
	Hermosillo	14.8		(10.1–21.7)	2.6	152.4	ab
	Coatzacoalcos	10.3		(7.9–13.4)	2.9	30.0	b
	Guadalajara	7.8		(5.7–10.7)	2.4	18.8	bc
	Tultitlan	7.0		(5.2–9.2)	2.2	19.0	bc
	Salamanca	6.7		(5.0–9.0)	2.0	20.2	bcd
	Queretaro	6.6		(5.0–8.8)	1.7	22.4	bcd
	Monterrey	6.4		(4.8–8.7)	2.1	21.1	bcd
	Merida	3.7		(3.0–4.5)	1.5	10.4	cd
	Cordoba	3.1		(2.6–3.8)	2.0	9.0	d
Oxychlordane	Guadalajara	2.6		(1.9–3.6)	1.3	15.1	a
	Salamanca	2.3		(1.7–2.9)	0.7	14.8	a
	Hermosillo	2.1		(1.7–2.6)	1.0	7.9	ab
	Monterrey	1.9		(1.4–2.4)	0.5	7.9	ab
	Cd. Obregon	1.9		(1.4–2.5)	0.4	7.5	ab
	Queretaro	1.7		(1.4–2.1)	0.7	6.8	ab
	Coatzacoalcos	1.5		(1.1–1.9)	0.5	4.1	ab
	Merida	1.2		(1.0–1.6)	0.6	4.4	ab
	Cordoba	1.1		(0.9–1.4)	0.3	4.2	b
	Tultitlan	1.0		(0.9–1.3)	0.3	2.4	b
trans-Nonachlor	Hermosillo	4		(3.2–4.9)	1.9	13.8	a
	Monterrey	3.5		(2.5–4.9)	0.5	21.3	a
	Guadalajara	3.3		(2.4–4.5)	1.6	18.3	ab
	Cd. Obregon	2.7		(2.0–3.6)	0.7	14.8	ab
	Salamanca	2.6		(2.0–3.4)	0.5	8.7	ab
	Queretaro	2.4		(1.9–3.2)	0.6	12.0	ab
	Coatzacoalcos	2.4		(1.8–3.3)	0.7	11.9	ab
	Merida	2.2		(1.6–2.9)	0.6	7.1	ab
	Cordoba	1.4		(1.0–2.0)	0.5	13.1	b
	Tultitlan	1.3		(1.1–1.7)	0.5	3.4	b
p,p′-DDE	Coatzacoalcos	1072	0.07[b]	(754–1522)	200	4300	a
	Cordoba	615.3	0.02[b]	(426.7–887.4)	94.3	2166.7	ab
	Cd. Obregon	529.7	0.04[b]	(296.2–947.1)	87.3	19,753.0	abc
	Monterrey	363.6	0.01[b]	(254.2–519.9)	99.9	2903.2	bcd
	Merida	291.0	0.04[b]	(207.1–409.0)	60.5	1122.4	bcd
	Hermosillo	233.2	0.02[b]	(185.9–292.3)	96.2	666.7	cd
	Queretaro	226.9	0.04[b]	(154.4–333.5)	50.0	2166.7	cd
	Salamanca	218.7	0.03[b]	(169.8–281.9)	67.0	1077.8	cd
	Tultitlan	209.9	0.02[b]	(165.7–266.1)	58.7	867.6	cd
	Guadalajara	144.2	0.03[b]	(94.4–220.1)	46.5	520	d

[a]a,b,c,d comparisons are carried out by one-way ANOVA by Scheffe's test, where the groups which do not have a common letter are significantly different.
[b]Ratio DDT/DDE.

The concentrations of PCB 153 among Mexican mothers was markedly lower than the concentrations found among Inuit mothers from arctic Canada and similar to or lower than the concentrations of Scandinavian mothers from Sweden and Norway (Van Oostdam and Donaldson, 2009).

In the 1950s, approximately 1000 tons of DDT were used each year in Mexico for agricultural and malaria vector control purposes. Owing to its toxic effects on wildlife and its high persistence in the environment and in the food chain, the use of DDT was banned in the 1970s in the United States

Table 6. Concentration of contaminant (ng/g lipid; GM) by age and body mass index.

Characteristics	p,p'-DDE	Significant difference[a]	Beta-HCH	Significant difference[a]	PCB138	Significant difference[a]	PCB153	Significant difference[a]	PCB 180	Significant difference[a]
Age (years)										
15–18	250.9	a	5.1	a	1.9	a	3.0	a	1.7	a
19–23	327.2	a	8.8	b	2.4	a	3.5	a	2.0	a
24–33	559.7	b	16.1	c	3.3	b	5.1	b	3.0	b
Pre-pregnancy BMI (kg/m²)										
Underweight <18.5	273.7	a	6.3	a	2.4	a	3.8	a	2.1	a
Normal 18.50–24.99	320.3	ab	8.0	a	2.4	a	3.8	a	2.2	a
Overweight 25.0–29.99	331.2	ab	9.4	a	2.2	a	3.1	a	1.7	a
Obese ≥30.00	539.1	b	11.4	a	2.6	a	3.8	a	2.2	a

[a]a,b,c, comparisons are carried out by one-way ANOVA by Scheffe's test, where the groups that do not have a common letter are significantly different.

Table 7. 2,3,7,8 TCDD toxic equivalents (TEQs) of PCDDs, PCDFs and dioxin-like PCBs in maternal plasma (pg/g lipid).

	Mean	Range
PCDDs TEQs	5.0	2.9–14.9
PCDFs TEQs	1.3	0.9–1.6
cPCBs TEQs	1.1	0.7–1.6
mPCBs TEQs	0.1	0.04–0.1
Total TEQs	7.5	5.2–18.0
Sum PCBs[a]	282.4	154.2–370.2

Abbreviations: cPCB, coplanar polychlorinated biphenyl; mPCB, mono-ortho polychlorinated biphenyl; PCCD, polychlorinated dibenzo-p-dioxin; PCDF, polychlorinated dibenzofuran.
[a]Sum of 19 polychlorinated biphenyls congeners.
$N=2$ Pools.

Table 8. Concentrations of PCDDs, PCDFs and dioxin-like PCBs in maternal plasma by city (expressed as 2,3,7,8 TCDD-TEQs pg/g lipid).

City	PCDD TEQ	PCDF TEQ	cPCB TEQ	mPCB TEQ	Total TEQ
Queretaro	3.5	1.0	1.1	0.1	5.7
Tultitlan	3.9	1.6	1.6	0.1	7.0
Merida	3.3	1.1	0.9	0.1	5.4
Guadalajara	4.6	1.6	1.3	0.1	7.5
Coatzacoalcos	14.9	1.5	1.4	0.1	18.0
Monterrey	5.9	1.6	1.2	0.1	8.9
Salamanca	4.4	0.9	1.3	0.1	6.7
Hermosillo	3.0	1.0	1.1	0.05	5.3
Cordoba	3.4	1.3	0.8	0.1	5.6
Cd. Obregon	2.9	1.6	0.7	0.04	5.3

Abbreviations: cPCB, coplanar polychlorinated biphenyl; mPCB, mono-ortho polychlorinated biphenyl; PCCD, polychlorinated dibenzo-p-dioxin; PCDF, polychlorinated dibenzofuran.
$N=2$ Pools.

and Canada, whereas in Mexico it was restricted to public health campaigns against vectors of malaria and dengue fever. DDT use was banned in 2000 and the remaining reserves were eliminated in 2009 (Panamerican Health Organization, 1992; Albert, 1996; Gobierno Federal, 2009). Total concentrations of DDT and DDE found in our study were lower than those seen by Torres-Sanchez et al. (2007) and Longnecker et al. (2007), but this is expected because those studies were conducted in Morelos and Chiapas where DDT was extensively used for malaria control. The DDT/DDE ratio found indicates chronic exposure, although the ratio found in Coatzacoalcos is almost 30 times higher than that found by Torres-Sanchez et al (2009) in pregnant women from Morelos (0.002 ± 0.003). This difference could be related to the highly widespread of use of DDT in the coastal areas of Mexico, where malaria is endemic (Centro Nacional de Salud Ambiental, 2000; Portillo-Galván et al., 2002). Our study finds that the concentrations of p,p′-DDE are consistent with other studies performed in Mexican women of reproductive age (Yañez et al., 2002; Flores-Luevano et al., 2003; Koepke et al., 2004; Torres-Sanchez et al., 2007). A review article by Torres-Sanchez and Lopez-Carrillo (2007) in Mexico indicates a possible link between DDE maternal contaminant concentrations and possible damage to reproductive health, and alteration in the psychomotor development of children exposed *in utero*, even though many gaps in knowledge exist concerning reproductive effects (Torres-Sanchez and López Carrillo, 2007). A pilot study carried out on Mexican woman evaluated the effect of breastfeeding on the serum levels of DDT, and concluded that breastfeeding leads to a rapid removal of p,p′-DDT from the body (Lopez-Carrillo et al., 2001). Although infant exposure may be high, it should also be noted that breastfeeding has significant nutritional, developmental and psychological benefits for the infant (Dewey et al., 1992).

Hexachlorobenzene was used in Mexico mainly as a fungicide and was manufactured in Mexico from 1970 to 1992 (Instituto de Salud Ambiente y Trabajo, 1998). Few studies have been conducted on this pollutant in Mexican women. López-Carrillo et al. (2002) observed higher mean lipid adjusted concentrations of beta-HCH and HCB in women from Mexico city, in both breast cancer cases and controls (104/93 ng/g beta-HCH and 28/28 ng/g HCB in cases/controls) than those observed among the women in our study (8.3 ng/g beta-HCH and 7.9 ng/g HCB). However, when we analyzed our data by city, Cd. Obregon had a higher concentration of HCB than Mexico city. We need to be cautious in these comparisons, as the breast cancer cases and controls would be significantly older than the first-time mothers in our study and we have shown that the concentrations of these contaminants increase with age within our group of mothers.

The mean total 2,3,7,8 TCDD-TEQ of maternal blood in this study was 7.5 pg/g lipid, which is lower than what was reported in the Australian women (total TEQ 11.5 p.p.t. lipid; Harden et al., 2007). It is also lower than the mean levels of PCDD/F reported by Ferriby et al. (2007) in women from the United States (19.3 pg/g lipid). The concentration of 18.0 pg/g 2,3,7,8 TCDD-TEQs for Coatzacoalcos is higher than in Australian women.

Overall, we found that mothers from Coatzacoalcos, a center of the Mexican petrochemical industry, had the highest concentration of several POPs (p,p′-DDE, p,p′-DDT, PCDDs, mPCBs). In contrast to this we found that mothers from Merida, an urban area without major sources of contaminant exposure, had higher concentration of several other PCB congeners. We also found that concentrations of HCB in Cd. Obregon were twofold higher than the concentrations in any other city.

This study provides useful information on the variability of POPs in specific populations and possible regional/local differences, which can be used in other Mexican population biomonitoring or contaminant effect studies.

These results cannot be directly generalized to the entire Mexican population, as this is not a random sample of the population and there are significant differences in age, gender and contaminant exposures between mothers and the general population. This study provides an indication of POP levels in pregnant women in various areas of Mexico and at the same time shows the requirement for a surveillance program among vulnerable populations to pinpoint areas of higher exposure. Further research is needed because we found higher concentrations of a number of contaminants in mothers from regions that we would consider as nonhotspot or background sites. It is, thus, important to identify the source of the higher contaminant exposures in mothers from various regions of Mexico. More human biomonitoring capacity and the development of a National Biomonitoring Program in Mexico would be major steps to address this need.

Conflict of interest

The authors declare no conflict of interest.

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References

Albert L. Persistent pesticides in Mexico. *Rev Environ Contam Toxicol* 1996: 147: 141–144.

Albert L. Compuestos Orgánicos Persistentes. In: Ambiental-Albert LA, (Ed.) *Toxicología*. Universidad Autónoma de Ciudad Juárez, Ciudad Juárez Chihuahua México, 2004 pp. 377–402.

Atkins J.R., Waldrep K., and Bernet Jr J.T. The estimation of total serum lipids by a completely enzymatic "summation" method. *Clin Chim Acta* 1989: 184: 219–226.

Centro Nacional de Salud Ambiental. *Centro de Vigilancia Epidemiológica. Situación actual de la malaria y el uso de DDT en México*. Secretaria de Salud, Mexico DF, 2000.

Commission for Environmental Cooperation. The Sound Management of Chemicals (SMOC) initiative of the Commission for Environmental Cooperation of North America. Overview and Update 2003: Commission for Environmental Cooperation (CEC).

Dewey K.G., Heinig M.J., Nommsen L.A., Peerson J.M., and Lonnerdal B. Growth of breast-fed and formula-fed infants from 0 to 18 months: the DARLING Study. *Pediatrics* 1992: 89: 1035–1041.

Doucet J., Tague B., Arnold D., Cooke G.M., Hayward S., and Goodyer C. Persistent organic pollutant residues in human fetal liver and placenta from Greater Montreal, Quebeb: a longitudinal study from 1998 through 2006. *Environ Health Perspect* 2009: 117: 605–610.

Eskenazi B., et al. Maternal serum dioxin levels in birth outcomes in women of Seveso, Italy. *Environ Health Perspect* 2003: 111: 947–953.

Ferriby L.L., et al. Evaluation of PCDD/F and dioxin-like PCB serum concentration data from the 2001–2002 National Health and Nutrition Examination Survey of United States Citizens. *J Expo Sci Environ Epidemiol* 2007: 17: 358–371.

Flores-Luevano S., et al. [DDT/DDE concentrations and risk of hypospadias. Pilot case-control study]. *Salud Pública Mex* 2003: 45: 431–438.

Giesy J., and Kannan K. Dioxine-like and non-dioxin-like toxic effects of polychlorinated biphenyls (PCBs): implications for risk assessment. *Crit Rev Toxicol* 1998: 28: 511–569.

Gobierno Federal. Desarrrollo Sustentable. Tercer Informe de Gobierno. http://tercer.informe.calderon.presidencia.gob.mx/informe/pdf/4_7.pdf (accessed 26 July 2010) (Type of Medium) 2009.

Guvenius D.M., Aronsson A., Ekman-Ordeberg G., Bergman A., and Norén K. Human prenatal and postnatal exposure to polybrominated diphenyl ethers, polychlorinated biphenyls, polychlorobiphenylols, and pentachlorophenol. *Environ Health Perspect* 2003: 111: 1235–1241.

Harden F.A., Toms L.M., Paepke O., Ryan J.J., and Müller J.F. Evaluation of age, gender and regional concentration differences for dioxin-like chemicals in the Australian population. *Chemosphere* 2007: 67: 318–324.

Hedgeman E., et al. The university of Michigan dioxin study: population survey results and serum concentrations for polychlorinated dioxine, furans and biphenyls. *Environ Health Perspect* 2009: 117: 811–817.

Instituto de Salud Ambiente y Trabajo. Nomination Dossier for hexachlorobenzene: submitted by Mexico to the Sound Management of Chemicals (SMOC) Working Group. http://www.cec.org/files/pdf/POLLUTANTS/hcbmex_en.PDF (accessed 8 November 2010) (Type of Medium) 1998.

Koepke R., et al. Serum DDT and DDE levels in pregnant women of Chiapas, Mexico. *Arch Environ Health* 2004: 59: 559–565.
Liu S., Li S., and Du Y. Polychlorinated biphenyls (PCBs) enhance metastatic properties of breast cancer cells by activating rho-associated kinase (ROCK). *PLos ONE* 2010: 5: e11272.
Longnecker M.P., et al. *In utero* exposure to the antiandrogen 1,1-dichloro-2,2-bis(p-chlorophenyl)ethylene (DDE) in relation to anogenital distance in male newborns from Chiapas, Mexico. *Am J Epidemiol* 2007: 165: 1015–1022.
López-Carrillo L., López-Cervantes M., Torres-Sánchez L., Blair A., Cebrián M., and García R. Serum levels of beta-hexachlorocyclohexane, hexachlorobenzene and polychlorinated biphenyls and breast cancer in Mexican women. *Eur J Cancer Prev* 2002: 11: 129–135.
Lopez-Carrillo L., Torres-Sanchez L., Moline J., Ireland K., and Wolff M.S. Breast-feeding and serum p,p'DDT levels among Mexican women of childbearing age: a pilot study. *Environ Res* 2001: 87: 131–135.
López-Carrillo L., et al. Is DDT use a public health problem in Mexico? *Environ Health Perspect* 1996: 104: 584–588.
Mes J. Organochlorine residues in adipose tissue of Canadians bull. *Environ Contam Toxicol* 1990: 45: 681–688.
Pan American Health Organization. *Status of Malaria Programs in the Americas*. PAHO, Washington, 1992.
Park J., Linderholm L., Charles M.J., Athanasiadou M., Petrik J., and Kokan A. Polychlorinated biphenyls and their hydroxylated metabolites (OH-PCBSs) in pregnant women from Eastern Slovakia. *Environ Health Perspect* 2007: 115: 20–27.
Patterson D.J., Hampton L., Lapeza C.J., Belser W., Green V., and Alexander L. High resolution gas chromatographic/high resolution mass spectrometric analysis of human serum on a whole weight and lipid basis for 2,3,7,8 TCDD. *Anal Chem* 1987: 59: 2000–2005.
Portillo-Galván M., Jiménez-Gutierrez C., Torres Sánchez L., and Lopez-Carrillo L. [Food consumption and adipose tissue DDT levels in Mexican women]. *Cad Saúde Pública* 2002: 18: 447–452.
Schulz D.P., Patrick G., and Duiker J.C. Complete characterization of polychlorinated biphenyl congeners in commercial Aroclor and clophen mixtures by multidimensional gas chromatography-electron capture detection. *Eviron Sci Technol* 1989: 23: 852–859.
Secretaria de Medio Ambiente y Recursos Naturales. *Plan Nacional de Implementación del Convenio de Estocolmo*. Secretaria de Medio Ambiente y Recursos Naturales, México, 2007.
Seelbach M., et al. Polychlorinated biphenyls disrupt blood–brain barrier integrity and promote brain metastasis formation. *Environ Health Perspect* 2010: 118: 479–484.
Solomon G.W., and Weiss P.M. Chemical contaminants in breast milk: time trends region variability. *Environ Health Perspect* 2002: 110: A339–A347.
Todaka T., et al. Relationship between the concentrations of polychlorinated dibenzo-p-dioxins polychlorinated dibenzofurans, and polychlorinated biphenyls in maternal blood and those in breast milk. *Chemosphere* 2010: 78: 185–192.
Torres-Sanchez L., and Lopez-Carrillo L. [Human health effects and p,p'-DDE and p,p'-DDT exposure: the case of Mexico]. *Cien Saude Colet* 2007: 12: 51–60.
Torres-Sanchez L., et al. *In utero* p,p'-DDE exposure and infant neurodevelopment: a perinatal cohort in Mexico. *Environ Health Perspect* 2007: 115: 435–439.
Torres-Sanchez L., et al. Prenatal dichlorodiphenyldichloroethylene (DDE) exposure and neurodevelopment: a follow-up from 12 to 30 months of age. *Neurotoxicology* 2009: 30: 1162–1165.
Trichopoulus D., Adami H.O., Hsieh C.C., Baron J., and Lipworth L., et al. Organochlorine compounds in relation to breast cancer, endometrial cancer, and endiometrosis: an assesmment of the biological and epidemiological evidence. *Crit RevToxicol* 1995: 25: 463–531.
Turner W., DiPrieto E., Lapeza C., Green V., Gill J., and DG Jr P. A fast universal automated cleanup system for the isotope-dilution high-resolution mass spectrometric analysis of PCDDs, PCDFs, coplanar PCBs, PCB congeners, and persistent pesticides from the same serum sample. *Organohalogen Compd* 1997: 31: 26–31.
Van den Berg M., et al. The 2005 World Health Organization re-evaluation of human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds. *Toxicol Sci* 2006: 93: 223–241.
Van Oostdam J., and Donaldson, S.G. Human tissue levels of environmental contaminants. In: Hansen JC, Van Oostdam, Gilman A, Odland JO, Vaktskjold A, Dudarev A, (Eds.) *In AMAP Assessment 2009. Human Health in the Arctic*. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway, 2009 pp. 61–100.
Wang R.Y., Jain R.B., Wolking A.F., Rubin C.H., and Needham L.L. Serum concentrations of selected persistent organic pollutants in a sample of pregnant females and changes in their concentrations during gestation. *Environ Health Perspect* 2009: 117: 1244–1249.
Westgard J. *Basic QC Practices: Training in Statistical Quality Control for Health Care Laboratories* Inc., Westgard QC, Madison, WI, 2002.
Woodruff T.J., Zota A.R., and Schwartz J.M. Environmental chemicals in pregnant women in the US:NHANES 2003–2004. *Environ Health Perspect* 2011: 119: 1023–1028.
World Health Organization. *Obesity: Preventing And Managing The Global Epidemic*. In: Report of a WHO Consultation Presented at: The World Health Organization Geneva, Switzerland, 1997.
Yañez L., Ortiz-Pérez D., Batres Lilia E., Borja Aburto V., and Diaz-Barriga F. Levels of dichlorodiphenyltrichloroethane and deltametrhin in humans and environmental samples in malarious areas of Mexico. *Environ Res* 2002: 88: 174–181.