Halogenated POPs and PAHs in Blood Plasma of Hong Kong Residents

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ABSTRACT: The objective of this study was to quantify organic chlorinated pesticides (OCPs), polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), and polycyclic aromatic hydrocarbons (PAHs) in blood plasma collected from 111 healthy residents in Hong Kong to assess the levels of these pollutants in the general population during the period of March to April, 2008. Concentrations of these residues in blood plasma obtained from the Hong Kong Red Cross Blood Transfusion Service were determined by gas chromatography—mass spectrometry. Naphthalene, phenanthrene, p,p′-DDE, PCB-180, and PBDE-47 were detected in 100% of the participants. Females had significantly greater concentrations of acenaphthylene (female: 93.3 ng/g lipid; male: 39.8, p < 0.05), anthracene (22.3, 15.3, p < 0.05), fluoranthene (138, 125, p < 0.05), p,p′-DDE, p,p′-DDT, PCB-183, BDE-99 than males. Blood of smokers contained significantly greater (p < 0.05) concentrations of acenaphthene, benzo(a)pyrene, p,p′-DDE, p,p′-DDT, PCB-138, BDE-47, and BDE-99 than did blood of nonsmokers. Positive correlations were found between concentrations of each class of pollutant, with respect to seafood diet habit, Body Mass Index (BMI), and age. Concentrations of HCHs and DDTs in blood plasma of healthy Hong Kong residents were greater than those of other countries, and it was found that smoking, consumption of a seafood diet, BMI, and age could influence concentrations in human blood.

INTRODUCTION

Due to rapid industrial development in China, there is an urgent need to study the relationship between environmental pollution and human health.¹ POPs such as OCPs, PCBs, PBDEs, in addition to PAHs have become major human health concerns. Their ubiquitous environmental occurrence, biochemical and toxic effects, linking to human exposure and health risk have been investigated.²⁻³ The results of a previous study revealed that significantly greater (p < 0.05) concentrations of DDTs, HCHs, PCBs, PAHs, and PBDEs were detected in the subcutaneous fat of patients with uterine leiomyomas (UL) when compared with those of the control group and that OCPs, PCBs, PAHs, and PBDEs may be correlated with UL for Hong Kong residents.⁴ It has also been suggested that DDTs and HCHs may increase a woman’s risk of breast cancer in China.⁵ Moreover, exposure to DDTs and HCHs was associated with adverse developmental outcomes, including fetal death, intrauterine growth restriction, preterm birth, and birth defects.⁶

There has been wide historical use of OCPs, PCBs, and PBDEs. For example, OCPs such as DDTs and HCHs were produced and used extensively to increase agricultural production⁷ while PCBs were often used in transformers, hydraulic fluids, printing, and other applications⁸ and PBDEs continue to be used as additive flame-retardants in plastic materials, paints, and textile fabrics in certain regions of the world resulting in wide occurrence in the environment, leading to elevated concentrations in human milk.⁹,¹⁰ Although DDTs and HCBs were banned in 1983 for agricultural application in China, their residues are still found in some areas, including the Pearl River Delta.¹¹,¹² PCBs were banned in a number of countries since the 1970s¹³ and also in China (since early 1980s).¹⁴ PAHs are mainly produced from incomplete combustion of different fuels such as oil, petroleum gas, coal, and wood and also through cigarette smoke and barbecue.¹⁵ PAHs are ranked in the top 8 of the 2007 list of the most hazardous substances in the environment, prepared by the Agency for Toxic Substances and Disease Registry,¹⁶ with benzo[a]pyrene (BaP) topping the list. Our previous studies have also indicated that common marine and freshwater fish collected from various freshwater fish ponds and...
mariculture sites around the Pearl River Delta (including Hong Kong) were grossly polluted by DDTs, PCBs, and greater concentrations of these contaminants detected in human milk were significantly correlated with consumption of fish by the mothers.17,18 Most of these pollutants are toxic, persistent, bioaccumulative, and lipophilic. If they enter into food chains, they are biomagnified, with all the halogenated POPs stored in the lipid for a long time resulting in great concentrations in the human body.19

Although a number of studies reported the contaminations of POPs in different environmental compartments, human body burdens of these pollutants can better reflect their toxicities on human health.20,21 There have been a number of studies which have investigated chemical contaminations of POPs in human populations using human adipose tissues, milk, and blood. Adipose tissues could be obtained during surgery, but this matrix is not readily available. A limitation to the use of human milk is that it can only be obtained from the female population and only during lactation in the reproductive age. Blood samples, however, are more readily available and recruitment is easier, and blood can be obtained from both genders of a wide age range.

Several previous studies have used PCBs and DDTs in human blood as exposure biomarkers for evaluating exposure sources and potential adverse health effects. However, the contaminations of POPs in blood plasma of humans in Hong Kong have not been reported. Since blood samples can cover a wide range of age and both genders, it was used as a medium to assess the levels of these pollutants in the general population of Hong Kong and their health effects. Therefore, the objectives of this study were to determine the contaminations of PCBs, OCPs, PBDEs, and PAHs in blood plasma from 111 people in Hong Kong through the Hong Kong Red Cross and to study the association of concentrations of POPs with age, Body Mass Index (BMI), seafood diet habit, and smoking habit.

**Experimental Section**

**Sampling and Preparation.** A total of 111 participants (blood donors) were recruited during March to April, 2008 and grouped under different age groups 20—30, 31—40, 41—50, and 51—60 years old. All participants were eligible as blood donors based on their health history status and screening by a nurse at the Red Cross before recruitment into the study. Informed consent was then obtained from each participant, together with a short questionnaire (given by staff of Hong Kong Baptist University, self-reported by participant) recording details on age, weight, height, and number of seafood meals per week for the association study.

**Analyses of POPs.** The methods were based on previous studies with some modifications. Before extraction, the surrogates m-terphenyl, 13C-β-HCH, 13C-p-p′-DDT, 13C-labeled PCB 28, 52, 101, 138, 153, 180, 209, unlabeled BDE 77, 116, and 126 (50 ng) were spiked separately into the blood plasma samples and kept at 4 °C overnight for equilibrium before sample extraction. The solid phase extraction (SPE) column was washed with DCM and activated with methanol and Milli-Q water. After conditioning, the SPE column was not allowed to dry, and 2 mL plasma was added into column. The column was then dried for 15 min by aspiration of ambient air. Subsequently, 50 mL of DCM:n-hexane (1:1, v/v) was added to the column for elution. The extract was further cleaned up by Florisil column (modified from USEPA 3620C) and concentrated to 0.5 mL before analysis by Gas Chromatography—Mass Spectrometer (GC-MS). Concentrations of PAHs, OCPs, PBDEs, and low molecular weight PBDEs were determined with a Hewlett-Packard (HP) 6890 N gas chromatograph (GC) coupled with a HP-5973 mass selective detector (MSD) and a 30 m × 0.25 mm × 0.25 μm DB-5 capillary column (J & W Scientific Co. Ltd., USA). BDE-209 was analyzed with a 15 m DB-SHT capillary column (0.25 mm i. d., 0.1 μm film thickness). Internal standards acenaphthene-d10, phenanthrene-d10, chrysene-d12, perylene-d12 for analysis of PAHs, OCPs, deuterated PBDEs (phenanthrene-d10, chrysene-d12 and perylene-d12), and PCB 209 for analysis of PCBs, 13C-labeled PBDE 3, 15, 28, 47, 99, and 153 for analysis of PBDEs were added respectively. Total lipids in plasma were determined gravimetrically (details in the Supporting Information).

**Quality Assurance/Quality Control.** For every sequence of 10 samples, a solvent blank and a procedural blank were added to ensure that the samples and the analysis process were free of contamination. Four quality control criteria were used to ensure the identification of POPs congeners in the plasma samples. First, retention times matched with those of the authentic reference compounds. Second, the ratios of the two characteristic ions were within 15% of the theoretical values. Third, the signal-to-noise (S/N) ratio was greater than three for the selected ions. Fourth, the amount of the analytes in the sample had to be at least two times that in the blank sample if there were interferences. If any of these four criteria failed, the congener was excluded. The average procedural blank value was subtracted from each sample when appropriate. The limit of detection (LOD) (in ng/g lipid) of PAHs, OCPs, PCBs, and PBDEs defined as standard deviation from mean blank (n = 3) was 1–5, 2, 0.6, 0.2, respectively. The recoveries of spiked plasma samples for PAHs ranged from 79 to 98%, PCBs from 75 to 92%, HCHs and DDTs from 82% to 103%, and PBDEs from 79 to 107%. If a congener was below the LOD, its concentration was assumed to be LOD/2. Reported concentrations were not corrected with recovery rates. Six-point calibration curves were constructed for the quantification, with good to excellent linearity (r² > 0.99).

**Statistical Analyses.** Data were presented as median, mean ± SD, and analyzed using SPSS 16.0 software. Inspection of a normal probability plot (Q-Q plot) and the Shapiro-Wilk statistic were used to test the normality of primary data. The data were log-transformed prior to conducting statistical tests. The effects of age and cofactors sex and seafood diet on pollutants body burden were determined by two-way ANOVA model. Student t test was used to compare the concentrations of pollutants between female and male, smokers and nonsmokers. Duncan’s Multiple Range Test was performed for investigating the bivariate relationships between seafood diet habit, BMI, age, and concentrations of pollutants after one-way ANOVA test. Correlation analysis between concentrations of pollutants and amount of seafood consumed, BMI, and age was conducted using Pearson’s correlation method.

**Results and Discussion**

**POPs Concentrations.** PAHs, OCPs, PCBs, and PBDEs concentrations were detected in human blood plasma (Figure 1 and Table 1). While exposure to PAHs is usually monitored through the measurement of hydroxylated metabolites in urine, parent compounds of PAHs can also be detected in blood plasma. Among individual PAHs, naphthalene...
Figure 1. Box plots of total PAHs, DDTs, HCHs, PCBs, and PBDEs concentrations in female and male blood plasma. Total HCHs refer to the sum of β-HCH + γ-HCH. Total DDTs refer to the sum of pp-DDE and pp-DDT. Total PAHs, PCBs, and PBDEs represent the sum of all the compounds.

(female: 305 ng/g lipid; male: 310) and phenanthrene (430; 316) were the dominant congeners detected in both females and males, followed by pyrene (193; 215), fluorene (160; 130). Individual PAH compounds such as naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, and chrysene were detected in more than 90%, while benzo(b+k)fluoranthene and benzo(a)pyrene in about 60% of the samples from both female and male participants. These compounds are the main byproduct of pyrolytic processes, such as incomplete combustion of organic materials during the processing of coal and crude oil, combustion of natural gas, including vehicle traffic, cooking, and tobacco smoking.33 Females showed significantly greater concentrations of acenaphthylene (female: 93.3; male: 39.8, p < 0.05), anthracene (22.3; 15.3, p < 0.05), and fluoranthene (138; 125, p < 0.05) than males, while males accumulated significantly greater pyrene (193; 215, p < 0.05) than females.

HCHs and p,p'-DDE were detected in the blood plasma of 100% of the samples, while p,p'-DDT and HCB in about 90% and 80%, respectively. p,p'-DDE was the most abundant congener of the DDTs detected in both females and males. Previous studies also revealed that DDE is the most commonly detected congener of DDTs in the general population (UK;25 Southern Spain34). Samples of blood from females contained significantly greater concentrations of p,p'-DDE (female: 1219; 961, p < 0.05) and p,p'-DDT (63.7; 60.3, p < 0.05) than did that of males.

PCB congeners 118, 180, 153, and 138 were detected in more than 90% of the blood samples, with PCB-180 being the predominant congener in both females (49.5 ng/g lipid) and males (43.8). It has been reported that PCB-153, -180, and -138 were the dominant congeners (Thomas et al.25 and Petrik et al.35). Blood of female participants contained greater PCB-183 (2.31; 2.05, p < 0.05) concentrations than did those of males.

PBDE-47 and -153 were detected in 100% of the blood samples, with BDE-47 being the most dominant congener. BDE-209, the predominant congener in the deca-BDE commercial product, was found in half of the blood samples. This result is consistent with the results of other studies in the US and Norway.36 This may be due to the fact that less brominated BDEs have longer half-lives (years) and could be formed through debromination of more brominated congeners.37 The finding that females accumulated higher concentrations of PAHs, DDTs, PCBs, and PBDEs than males was in line with a previous study26 and may have resulted from differences in dietary exposure or metabolism.

Comparison among Concentrations of POPs in Blood of Humans in Different Countries. Concentrations of OCPs in human blood from different countries were compared (Table S1 Supporting Information). Concentrations of p,p'-DDE in blood of people from Mexico (2770 ng/g lipid)39 were greatest, while the least concentrations were observed in blood of people living in Japan (93.0).24 The concentration of p,p'-DDE (1057) observed in the present study was similar to that detected in Thailand (1191).40 The greatest concentration of p,p'-DDT was observed in Bangladesh (1340),41 while the least were found in Japan (2.40).42 The ratio of p,p'-DDE/p,p'-DDT is an indicator of whether the DDT observed was recently released from technical material or had been weathered in the environment. In general, a lesser p,p'-DDE to p,p'-DDT ratio is an indication of more recent exposure to DDT; conversely, a greater ratio indicates that the DDT complex had been more weathered.42 The greatest ratio of p,p'-DDE/p,p'-DDT was observed in Slovakia (41.5),35 while Bangladesh (1.19)41 had the least ratio. This indicated a more recent exposure to DDT. The ratio observed in the present study (16.8) was least among these countries, which is consistent with the conclusion that people in Hong Kong are exposed to more recently applied DDT.

Alternatively, blood samples from Hong Kong (206 ng/g lipid) contained the greatest concentration of HCHs, with the least concentration in Poland (2.00).23 China is the largest producer and user of technical HCHs in the world, with the total production of HCH estimated to be 4.9 million tonnes,
The concentrations of PCBs in human blood from Hong Kong was similar to Bangladesh (91.7) but less than that observed in the Europe countries. In the present study was four times greater than the country's average annual application having the greatest rates of pesticide application in the country.

<table>
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<tr>
<th>compound</th>
<th>female (n = 51)</th>
<th>male (n = 60)</th>
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<tbody>
<tr>
<td>naphthalene</td>
<td>316 ± 131</td>
<td>343 ± 106</td>
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<td>124 ± 60.6</td>
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<td>phenanthrene</td>
<td>366 ± 233</td>
<td>303 ± 126</td>
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<tr>
<td>fluoranthene</td>
<td>106 ± 46.2</td>
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<tr>
<td>pyrene</td>
<td>184 ± 47.5</td>
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<td>BDE209</td>
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<td>1.03 ± 0.83</td>
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*p < 0.05, between female and male (Student t-test)." Represents information in female and male: female number is 51, BMI is 22.6 ± 3.62, age is 37.2 ± 12.2, smoking number is 6; male number is 60, BMI is 23.2 ± 3.14, age is 39.7 ± 11.7, smoking number is 9; total participant number is 111, BMI is 23.0 ± 3.61, age is 38.5 ± 11.9, smoking number is 15.

which accounts for 33% of the total world production. The Pearl River Delta in southern China is one of the most developed and prosperous regions in the country and also has a history of having the greatest rates of pesticide application in the country. The average annual application from 1980 to 1995 in the region was four times greater than the country’s average annual application and reached 37.2 kg/ha. Concentrations of PCBs in human blood were compared among countries (Table S2 in the Supporting Information). The concentrations of PCBs in human blood from Hong Kong (110 ng/g lipid) was similar to Bangladesh (91.7) but less than that observed in the Europe countries. In the present study concentrations of PCB congeners 153, 180, 138 were 11.0, 45.6, and 21.6, respectively, which were less than those observed in Sweden (296, 207, 134) and Spain (183, 120, 105). This result might be due to the relatively fewer industrial activities in Hong Kong (1970s), compared with urban areas of other developed regions (1950s and 1960s). Since the worldwide ban of PCBs around late 1970s-early 1980s, small concentrations of PCBs were detected in different food items including fish, meat, and vegetables collected from Shanghai, China. The present study also provides additional information showing that concentrations of PCBs in human blood plasma in Hong Kong were generally low.

Concentrations of PBDEs in human blood were compared among countries (Table S3 in the Supporting Information). The total PBDE concentration obtained in this study was similar to those observed in other countries, but less than those in Korea and the USA. In Japan, the PBDEs concentration found in 1980 (1.20 ng/g lipid) compared with...
that in 1995 (8.50) indicated that PBDE contamination had increased with time. Concentrations of PBDE in blood of Hong Kong residents (5.56) were approximately 10-fold less than the mean concentration observed in blood plasma of people from the USA (61.0). The concentration of BDE-47 (2.90) was also ten times less than in the USA (34.0). The concentration of BDE-209 measured in this study (1.59) was less than that found in the UK (83.0). This is likely due to the fact that the USA has strict fire resistance laws for furniture, and PBDEs are used as flame-retardant additives in plastics, foams, electrical appliances, television sets, computer circuit boards, and casings. The global demand for PBDEs reached 200,000 tonnes in 2003, with half of the PBDEs and 95% of the PentabDE used worldwide being consumed in North America. This then leads to greater exposure of the general population of the USA to PBDEs than people living in other countries.

**Contributing Factors to POPs Concentrations in Human Blood Plasma.** Concentrations of PAHs, OCPs, PCBs, and PBDEs in human blood plasma collected from Hong Kong residents were correlated with seafood diet. POPs concentrations in seafood (including fish, shrimp, shellfish, and mussel) were measured in samples collected from Hong Kong markets. There were statistically significant correlations between the amount of seafood in the diet and concentrations of fluorene \( r = 0.557, p < 0.05 \), p,p'-DDE \( r = 0.527, p < 0.05 \), p,p'-DDT \( r = 0.502, p < 0.05 \), DDTs \( r = 0.533, p < 0.05 \) and PCB-126 \( r = 0.579, p < 0.05 \) in human blood plasma (adjusting for age in a two-way ANOVA, seafood diet*age >0.05, Table S4 in the Supporting Information). Diet has long been believed to be the predominant source of human exposure to POPs through bioaccumulation in food chains. The average Hong Kong person consumes fish or shellfish four or more times per week, with an average mass of 164.4 g consumed per day. A previous study showed that DDT levels in fish species such as snubnose pompano (133 ng/g wet wt) and golden threadfin bream (59.8 ng/g wet wt) investigated in Hong Kong were higher than the guideline of 14.4 ng/g wet wt for human consumption. Moreover, previous studies also observed that concentrations of DDTs and PCBs in human milk and adipose tissue collected from Hong Kong were significantly correlated with frequency of fish consumption of the donors.

POPs are ubiquitous environmental pollutants. They can also be found in indoor environments and inhalation is another important exposure pathway. Concentrations of PAHs, OCPs, PCBs, and PBDEs in blood plasma were compared between smokers and nonsmokers in Hong Kong (Figure 2). Due to the limited number of smokers in this study, student t test was used to make a comparison between smokers and nonsmokers. Compounds such as acenaphthene (smoker: 84.0 ng/g lipid; nonsmoker: 49.9), benzo-(a)pyrene (15.0; 7.27), p,p'-DDE (908; 831, p < 0.05), p,p'-DDT (65.6; 62.0, p < 0.05), DDTs (973; 893, p < 0.05), PCB-138 (19.5; 14.7, p < 0.05), PBDE-47 (2.94; 2.52, p < 0.01), and PBDE-99 (0.09; 0.03, p < 0.05) were significantly greater in smokers than in blood of nonsmokers. Tobacco smoke is a major source of human exposure to PAHs. A previous study showed that the concentrations of PAHs, especially BaP (two times greater), were greater in lung tissues of smokers than those of nonsmokers. The concentrations of BaP observed in this study confirmed this finding (smoker: 15.0 ng/g lipid; nonsmoker: 7.27). The present study also showed that there were greater concentrations \( p < 0.05 \) of p,p'-DDE, p,p'-DDT, and DDTs in blood plasma of smokers. This is consistent with the findings that organochlorine concentrations in human plasma were positively correlated with smoking. It has been reported that smoking during pregnancy was associated with greater concentrations of both PCBs and PBDEs in cord blood. In recent years, it has been observed that house dust is an important source of PBDEs, and ingestion absorption is estimated to be a significant parameter in human exposure to PBDEs. The greater PCBs and PBDEs concentrations in smokers may be due to the smokers’ hand-to-mouth behavior which can
increase oral ingestion of contaminated dust in the environment. Although not readily explained, these associations between smoking and PCBs and PBDEs were consistent warranting further studies.

Concentrations of PAHs, OCPs, PCBs, and PBDEs in human blood plasma were found to be correlated with BMI (see Table S5, Supporting Information). Concentrations of chrysene (r = 0.505, p < 0.05), p,p′-DDE (r = 0.649, p < 0.05), DDTs (r = 0.613, p < 0.05), PCB-138 (r = 0.582, p < 0.05), and PCBs (r = 0.560, p < 0.05) were significantly correlated with BMI. Significant correlations between BMI and PCBs and DDTs in blood were also observed by Hanrahan et al. These results indicated that BMI is an important factor influencing the body burdens of these pollutants, possibly due to the bioaccumulative and lipophilic nature of these pollutants.

Table S6 (see Supporting Information) shows the mean concentrations of PAHs, OCPs, PCBs, and PBDEs in human blood plasma of different age groups. p,p′-DDE (female: r = 0.607, male: r = 0.729, p < 0.05), DDTs (female: r = 0.591, male: r = 0.678, p < 0.05), PCB-180 (male: r = 0.507, p < 0.05), PCBs (female: r = 0.519, male: r = 0.502, p < 0.05), BDE-209 (female: r = 0.583, male: r = 0.516, p < 0.05), and PBDEs (female: r = 0.532, male: r = 0.545, p < 0.05) were significantly correlated with age. Previous studies have reported significant correlations between pesticide levels in blood and age. A study which analyzed blood samples of thirteen family members from twelve EU countries in order to identify persistent and bioaccumulative chemicals showed that p,p′-DDE was detectable in blood samples of three generations, and the greatest found in grandmothers who had concentrations that were 2-fold greater than mothers, with the least found in their children (three times less than their mothers). No significant correlations between donor age and concentration of PBDEs were obtained in Belgium and New Zealand, but the present study indicated that the 51–60 age group contained the greatest concentrations of PBDEs. It was found that women between 20 and 40 years of age had a significantly (p < 0.05) lesser average concentration of DDTs than in women in the age groups of 41–50 and 51–60, which indicates that breast-feeding provides a possible mechanism for the elimination of organochlorine pesticides.

The greater concentrations of HCHs and DDTs detected in human blood plasma of the present study compared with other countries was linked to the great concentrations of DDTs detected in fish in Hong Kong markets because there was a significant correlation (p < 0.05) between the frequency of seafood consumption with the accumulation of DDTs and HCH in human milk and adipose of people in Hong Kong. Furthermore, relatively great concentrations of DDTs and HCHs in adipose tissue of patients in Hong Kong with UL indicated that DDTs and HCHs are great risk factors that affect human health via frequent fish intake.

There are several limitations to the present study in that blood samples were only obtained from one blood donor center; therefore, most of the donors may live or work near the center, and the study group was not a random sample of the population. There may also be characteristics of self-selected individuals that make them different from the general population, such as health, or some types of behaviors; however, it is difficult to determine what these factors might be. There was no indication from our data that the volunteers of this study were significantly different from the general population.

The volunteers examined in this study represented a broad age group, both genders, and a range of lifestyle and personal factors that may influence chemical exposure and concentrations in individuals. Our result serves as an early warning that a diet of contaminated fish, smoking, and continued environmental pollution in air and water in the Pearl River Delta will lead to the accumulation of PAHs, OCPs, PCBs, and PBDEs in the body, which is potentially harmful to health. Donor blood from the Red Cross could serve as a good benchmark matrix for future regional or global pollution surveillance studies.

ASSOCIATED CONTENT

Supporting Information. Tables S1, S2, S3, S4, S5, and S6. This material is available free of charge via the Internet at http://pubs.acs.org.

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NOMENCLATURE

BMI body mass index
GC-MS gas chromatography—mass spectrometer
OCPs organic chlorinated pesticides
PAHs polycyclic aromatic hydrocarbons
PBDEs polybrominated diphenyl ethers
PCBs polychlorinated biphenyls
POPs persistent organic pollutants
DDTs dichlorodiphenyltrichloroethane
HCBs hexachlorobenzene
HCHs hexachlorocyclohexane

REFERENCES


dx.doi.org/10.1021/es102444g | Environ. Sci. Technol. 2011, 45, 1630–1637

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(58) WWF. Generation X. Results of WWF’s European family biomonitoring survey; DETOX Campaign. 2005.
