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Predictors of Serum Dioxin, Furan and PCB Concentrations among Women from Chapaevsk, Russia

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Abstract

INTRODUCTION—Dioxins, furans and polychlorinated biphenyls (PCBs) are persistent and bioaccumulative toxic chemicals that are ubiquitous in the environment. We assessed predictors of their serum concentrations among women living in a Russian town contaminated by past industrial activity.

METHODS—Blood samples from 446 mothers aged 23–52 years were collected between 2003–2005 as part of the Russian Children's Study. Serum dioxin, furan and PCB concentrations were quantified using high-resolution gas chromatography-mass spectrometry. Potential determinants of

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exposure were collected through interviews. Multivariate linear regression models were used to identify predictors of serum concentrations and toxic equivalencies (TEQs).

RESULTS AND DISCUSSION—The median total PCB concentrations and total TEQs were 260 ng/g lipid and 25 pg TEQ/g lipid, respectively. In multivariate analyses, both total PCB concentrations and total TEQs increased significantly with age, residential proximity to a local chemical plant, duration of local farming, and consumption of local beef. Both decreased with longer breastfeeding, recent increases in body mass index, and later blood draw date. These demographic and lifestyle predictors showed generally similar associations with the various measures of serum dioxins, furans, and PCBs.

Introduction

Dioxins, furans and polychlorinated biphenyls (PCBs) are classes of structurally similar chemicals. Dioxin exposure has been linked to cancer (1–2), diabetes (1, 3–4), and endocrine disruption (5), while PCBs are classified as probable human carcinogens (6) and have been linked to impaired cognitive development in children (7). Dioxins, furans and PCBs are persistent and bioaccumulative, and their elimination from the body can take years or even decades (8). Non-occupational exposure is primarily through dietary intake. Human body burdens of dioxins, furans and PCBs in developed countries are decreasing over time due to bans on PCB production, and decreased generation of dioxins during the production of other chemicals (9). However, there are specific locations worldwide where elevated levels persist, due to either past or current industrial activity (10–12).

In the present study, we assessed predictors of dioxin, furan and PCB concentrations in serum (the primary measure of human exposure to these chemicals) in adult women living in an area of elevated exposure, the town of Chapaevsk, Russia. Until 2003 this town, located approximately 1000 kilometers southeast of Moscow, was the site of chlorinated chemical production at the Middle Volga Chemical Plant, i.e. SVZH (also referred to as ‘Khimprom’ in prior publications (13–14)). Dioxins were generated as unwanted by-products of chemical syntheses (15). PCBs were typically used in electrical capacitors and transformers, although their specific use at SVZH is unknown. Environmental release of these chemicals most likely resulted from improper disposal of hazardous waste from the plant, including incineration. Data on the women were collected as part of the Russian Children’s Study, whose primary aim is to assess pubertal maturation and growth in a prospective cohort of boys recruited at 8 or 9 years of age (the sons of the women in this analysis). These results complement a recent publication describing predictors of dioxins, furans and PCBs among the 8–9 year-old boys (13).

Methods

Study population

The Russian Children’s Study is an ongoing prospective cohort of 499 peri-pubertal boys (including 7 sibling pairs) and their 492 mothers in Chapaevsk, Russia. 572 eligible boys aged 8 or 9 years were identified using the town-wide health insurance information system and recruited between 2003 and 2005; 90% agreed to participate (16). The study was approved by the Human Studies Institutional Review Boards of the Chapaevsk Medical Association; Harvard School of Public Health; University of Massachusetts Medical School; and Brigham and Women’s Hospital. Prior to participation the parent or guardian signed an informed consent and the boy signed an assent form.

A health and lifestyle questionnaire developed with Russian collaborators (14, 17) was administered by a nurse to each boy’s mother or guardian. Data collected on the mothers

included reproductive, medical, residential, and occupational histories; socioeconomic measures such as household income and education; and lifestyle information such as duration of gardening, farming, and smoking. Household education was classified as the higher of the education levels achieved by the mother or her partner. Farming was defined as having a plot where domestic animals were raised for consumption, whereas gardening referred to growing fruits and vegetables. In addition, each mother was asked about her current height and weight, as well as her pre-pregnancy weight for the study son, 8 or 9 years previously. From this information we calculated both the current and prior BMI (kg/m^2), and the percent change in BMI since pregnancy (using the past BMI as the denominator).

A brief dietary questionnaire collected information on the frequency of maternal consumption of poultry, beef, pork, lamb or goat, fish, eggs, dairy products, butter, vegetable oil, vegetables, fruits, and 'oily foods' (a well-understood dietary category in Russia referring to foods that are fried or use a mayonnaise base). The five food consumption frequency categories were: never; several times per year or more but less than once a month; once per month or more but less than once a week; once per week or more but not every day; and every day. For consistency, all dietary variables were analyzed as $\geq$ once/week vs. less, unless the number of participants in the former group was <5 in which case the higher group was expanded to include $\geq$ once/month. Information was collected separately for food of 'local' or 'any' origin. The straight line distance from the current residence to the center of the SVZH plant was calculated using ArcView GIS 3.0 (ESRI, Redlands, CA, USA). A map of Chapaevsk has previously been published (13).

Analysis of blood samples

Samples were centrifuged and the serum was aliquoted and stored at -35°C until shipment on dry ice to the Centers for Disease Control and Prevention (CDC) for chemical analyses (performed in 2008) by the National Center for Environmental Health, CDC, Atlanta, Georgia. Serum samples were spiked with a mixture of $^{13}\text{C}_{12}$ -labeled PCDDs/PCDFs and C-PCBs as internal standards, and the analytes were isolated from serum by a C18 solid phase extraction (SPE) followed by a multicolumn automated cleanup and enrichment procedure (18). Samples were processed in batches of 10, which included a method blank and two quality control samples that were aliquots of pooled bovine sera spiked with PCDDs, PCDFs, and C-PCBs.

The analytes were separated on a DB-5 MS capillary column [Agilent JW Scientific DB-5ms (p/n 122-5532); Agilent Technologies, Santa Clara, CA] and quantified using selected-ion-monitoring, high-resolution (10,000 resolving power) mass spectrometry (19). Quantification was by isotope dilution mass spectrometry using calibration standards containing ^{13}C -labeled and unlabeled analytes. For specific PCDDs, PCDFs, and C-PCBs that lack their own labeled standard, a labeled congener with the same degree of substitution and a similar retention time was used. Mono-*ortho* PCBs (M-PCBs) and non-dioxin-like PCBs were extracted from an aliquot (1 g) of sample by SPE extraction (18). Total cholesterol and triglycerides were measured enzymatically, and the serum total lipid content was calculated as in Phillips et al (20). All dioxin, furan and PCB measurements are presented as lipid-adjusted.

Congener groupings

Dioxin-like compounds include polychlorinated dibenzo-*p*-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and co-planar polychlorinated biphenyls (C-PCBs). Serum levels of dioxin-like compounds can be summarized both by their concentrations and in toxic equivalents (TEQs), in pg TEQ/g lipid. The latter measure assigns a weighting

factor (toxic equivalency factor; TEF) to each congener according to its aryl hydrocarbon receptor-mediated toxicity relative to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD), the most toxic congener (21). PCBs, in addition to the C-PCBs, also include the non-dioxin-like PCBs (with TEFs of 0), as well as the mono-*ortho* polychlorinated biphenyls (M-PCBs), which all have very low TEFs of 0.00003. We assessed concentrations of 7 PCDD congeners, 10 PCDFs, 4 C-PCBs, 6 M-PCBs, and 29 non-dioxin-like PCBs.

Predictors of the following congener groupings were analyzed:

- The concentrations of total PCDDs; total PCDFs; total C-PCBs, and total M-PCBs
- The concentrations of total PCBs (sum of total M-PCBs and non-dioxin-like PCBs)
- The total PCDD TEQs; total PCDF TEQs; total C-PCB TEQs; total M-PCB TEQs
- Total TEQs (sum of all PCDD, PCDF, C-PCB, and M-PCB TEQs)

Statistical analysis

Univariate regression models were first constructed for each predictor and each of the log₁₀-transformed dioxin, furan and PCB variables. Each predictor with $p < 0.2$ was then separately added to an initial multivariate model containing age and duration of lifetime breastfeeding (both of which were included in this model because they are well-established predictors of dioxin, furan and PCB concentrations). All predictors with $p < 0.1$ in the initial multivariate model were included together in a second multivariate model for that outcome, but only retained if their p -value in the latter model remained < 0.1 . Finally, to maximize comparability, a single final model was selected and applied to every dioxin, furan and PCB measure. All predictors with $p < 0.05$ for at least one dioxin, furan or PCB measure were included in this model, with the exception of 4 variables included because of *a priori* interest, despite being only marginally significant: employment at SVZH, and consumption of oily foods, fish, and local dairy. To explore the linearity of the association between breastfeeding duration and the serum dioxin, furan and PCB levels, breastfeeding was successively included in the final multivariate model as a linear term, and grouped into categories. The best-fitting model (with breastfeeding in 3 categories) was selected based on having the lowest Akaike Information Criterion.

Since the serum concentrations used in the regression models were log₁₀-transformed, for ease of interpretation each regression coefficient is presented as a percent change (equal to $100 \times (10^\beta - 1)$, where β is the regression coefficient for a given predictor). For continuous predictors, this represents the percent change in the dioxin, furan or PCB serum concentration associated with a one-unit increase in the predictor (adjusting for all other variables in the regression model). For categorical predictors, this percent change describes the relative difference between the serum concentrations at each level of the predictor compared to the reference category.

Pearson correlations were used to assess the associations between log₁₀-transformed measures of dioxins, furans and PCBs. Serum concentrations of dioxins, furans and PCB congeners below the limit of detection (LOD) were assigned a value equal to the LOD divided by the square root of 2 (22–23). Participants with a non-reported value for an individual congener concentration were assigned a missing value for each dioxin or PCB sum to which that congener's average percent contribution was over 5% among reported values. Missing indicator variables were used in the regression models for demographic or lifestyle variables missing among two or more mothers.

Results

Study population

446 serum samples were included in this analysis, after excluding the first of two serum samples from each of 3 mothers with two sons in the study who gave blood twice. Of the 46 mothers (9%) without serum samples, 37 did not accompany the son to the initial interview when the samples were collected; and 9 were present but declined to give a sample.

The descriptive statistics for demographics and key predictors among the 446 mothers who provided blood sample are shown in Table 1. The mean age at interview was 33 years. 27% of mothers were overweight (BMI 25–30) and 15% were obese (BMI >30). 92% reported at least 1 month of lifetime breastfeeding, and 84% reported living in Chapaevsk for 10 years or more. Local food consumption was reported by 44% for eggs, 62% for dairy, 15% for beef, and 91% for fruit. 19% currently lived within 2 km of the SVZH plant, and 6% reported ever working there.

Serum dioxins, furans and PCBs

The mean, standard deviation, and percentiles of selected dioxin, furan and PCB variables are shown in Table 2 (individual dioxin, furan and PCB congener values are shown in Supporting Information Tables S1 and S2). Pearson correlations between all log₁₀-transformed dioxin, furan and PCB summary variables are shown in Supporting Information Table S3, and were moderate to strong. The correlations between concentrations of PCDDs, PCDFs, C-PCBs, and M-PCBs ranged from 0.29 to 0.58. Similarly, correlations between the TEQs of the classes ranged from 0.46 to 0.79. The correlations of concentrations of total PCBs with C-PCBs and M-PCBs were 0.40 and 0.91, respectively. The correlation between total PCBs and total TEQs was 0.74.

The individual congeners with an average contribution of >5% for each dioxin, furan and PCB summary measure are shown in Supporting Information Figure S1. The largest contributors to the total TEQ were PCB 126 (32%), 1,2,3,7,8-PeCDD (18%), 2,3,4,7,8-PeCDF (14%), and TCDD (12%). The largest contributors to the total PCBs were PCB 153 (18%), PCB 138/158 (16%), PCB 118 (13%), PCB 180 (8%), and PCB 99 (7%).

Predictors

The results of the final multivariate model for each dioxin, furan and PCB concentration are shown in Table 3, and results for TEQs are shown in Table 4. The model results for M-PCBs are not shown since they correlate highly with total PCBs (Pearson correlation = 0.91), and thus are similar. The percent of variation (R^2) explained by each model ranged from 0.13 to 0.41 (for total C-PCBs and total TEQs, respectively).

Since the serum concentrations used in the regression models were log₁₀-transformed, each parameter estimate is presented as a percent increase. For example, the mean serum TCDD concentration of women living <2 km from the SVZH plant was 72% higher than those of women living >5 km away, adjusting for all other predictors ($p < 0.01$; Table 3).

The following well-established predictors were significantly associated with all dioxin, furan and PCB measures (except total C-PCBs): age, lifetime breastfeeding duration, and the percent change in BMI over the previous 8 to 9 years (Tables 3 and 4). Each additional year of age was associated with increases in dioxins, furans and PCBs of up to 4.6% (for TCDD, $p < 0.0001$). Each 10% increase in BMI since pregnancy was associated with an average decrease in dioxins, furans and PCBs of up to 0.8% (for TCDD, $p < 0.05$). Lifetime breastfeeding for ≥ 21 months was associated with significant decreases in all dioxins, furans

and PCB measures (except total C-PCBs) of up to 55% (for TCDD, $p < 0.0001$). Lifetime breastfeeding of less than 10 months did not decrease mean serum levels for any dioxin, furan or PCB measure (results not shown).

Later blood draw dates were associated with significantly lower average concentrations of all dioxin, furan and PCB measures (except for PCDD TEQ which was marginally significant, $p = 0.06$), suggesting decreasing levels of external exposure over this time period. Each additional year since the beginning of the study was associated with a mean decrease in concentrations of up to 16% (for total PCDDs, $p < 0.0001$).

Consumption of certain local foods, especially eggs and beef, was associated with increases in some (but not all) dioxin, furan and PCB concentrations. For example, consuming local eggs $\geq$ once/week was associated with increases of 53% for mean total PCDFs ($p < 0.0001$), but did not significantly increase total PCDD concentrations (Table 3). Similarly, consuming local beef $\geq$ once/month was associated with an 83% increase in mean total PCDD TEQs ($p < 0.05$), but did not significantly increase total PCDF TEQs (Table 4). However, consumption of the various local foods was highly correlated, and the magnitude and significance of the associations was sensitive to which foods were included in the multivariate regression models. Although no associations with eating fish $\geq$ once/week were significant, additional analyses showed that mean levels were higher in the 17 women who reported eating fish every day (e.g. 35% higher total TEQs, $p < 0.01$), compared to all other women.

Various residential, occupational, lifestyle, and socioeconomic factors also significantly predicted dioxin, furan and PCB levels (Tables 3 and 4). Currently living within 2 km of SVZH was significantly associated with increases in all dioxins, furans and PCBs except C-PCBs, ranging from 21% greater mean concentrations of total PCBs ($p < 0.01$) to 72% greater concentrations of TCDD ($p < 0.01$). Each additional year of local farming (defined as having a plot where domestic animals are raised for consumption) was associated with increased concentrations of all dioxins, furans and PCBs (up to 3.4% higher for PCDF TEQs, $p < 0.0001$). Additional years of local gardening were not significantly associated with any measures of dioxin, furan and PCB concentrations (results not shown). Each additional year of residence in Chapaevsk was also associated with significantly higher concentrations of total PCDDs, total PCDD TEQs, total PCDF TEQs, and total TEQs (up to 2.3% greater for PCDD TEQs, $p < 0.0001$). Women who reported ever doing laundry by hand had lower mean concentrations of most dioxins, furans and PCBs, although statistical significance was reached only for PCDD TEQs, PCDF TEQs, C-PCB TEQs, and total TEQs. This result is based on a comparison with only 13 women who never did laundry by hand. The 27 women who reported ever working at SVZH had modest and only marginally significant increased concentrations of total PCDDs, total PCBs and C-PCB TEQs ($p = 0.10$, 0.054, and 0.09, respectively). The 34 women in households with the lowest education (i.e. neither they nor their partners educated above secondary school) had significantly higher mean concentrations of total PCDFs and PCDF TEQs (33% and 32% higher, respectively, $p < 0.01$).

Sensitivity analyses

Two of the continuous variables had right-skewed distributions (farm plot use duration, and smoking duration); however log-transforming the variables to improve their normality did not change their statistical significance.

Discussion

This study investigated demographic and lifestyle predictors of serum dioxin, furan and PCB concentrations among adult women of reproductive age living in Chapaevsk, Russia, a town contaminated by previous industrial activity.

Dioxins, furans and PCBs share the properties of being lipophilic chemicals with long half-lives, and consistent with this fact, we found that factors related to bioaccumulation or lipid distribution (i.e. age, duration of breastfeeding, and recent increase in BMI) were significantly associated with serum concentrations of almost all groupings of dioxins, furans and PCBs. In addition, certain external factors were similarly associated with all dioxin, furan and PCB concentrations (i.e. current residential distance from SVZH, and farm plot use duration), suggesting that some exposure pathways are shared by these different classes of chemicals. The moderate to strong correlations between dioxin, furan and PCB concentrations (similar to those reported by other studies (9, 24)) are indeed consistent with their having a broadly similar set of predictors in Chapaevsk. However, these chemicals also have some different sources: dioxins were produced as by-products of industrial activities and incineration, whereas PCBs are released into the environment consequent to their past industrial use. This may explain why certain factors were only significantly associated with a subset of dioxin, furan and PCB concentrations (e.g. duration of local residence, and consumption of various local foods), suggesting the existence of some chemical-specific exposure pathways in this community.

There were substantially fewer significant predictors for the total C-PCB concentrations than for any other dioxin, furan, or PCB variable, as well as a low model R^2 of 0.13. This may be due to the large percent contribution by PCB 77 (mean contribution = 48%), which has a half-life of only 0.1 years (8), and therefore may vary on a shorter time-scale than the predictors measured here. In contrast, the total C-PCB TEQ is on average 90% PCB 126, whose relatively longer half-life of 1.6 years (8) may explain the greater number of significant predictors for this variable, and higher model R^2 of 0.28. The C-PCBs may also have different exposure patterns that were not adequately captured by our data; for example, total C-PCBs and C-PCB TEQs were the only measures that were not associated with closer residence to SVZH.

A later date of blood draw was associated with lower dioxin, furan and PCB concentrations in multivariate analyses adjusting for age (approximately 10% lower for each additional year for most dioxins, furans and PCBs). This suggests a decreasing trend in exposure over time, which is consistent with decreasing production at the SVZH plant since 1991 (14) and cessation in 2003, as well as with the measured decline in dioxin levels in Chapaevsk soil samples between 1994 and 2006 (25). However, temporal trends in other lifestyle and behavioral predictors of serum dioxin, furan, and PCB concentrations (such as local food consumption), may have contributed to the association of blood draw date with serum concentrations, and may not have been adequately controlled for in our statistical models.

Previous research in other populations has shown that diet is an important source of non-occupational exposure to dioxins and PCBs (26). In this study, consumption of local eggs or fruit at least once/week, and of local beef at least once/month, was associated with significantly higher concentrations of certain dioxins, furans and PCBs, although the strong correlations between the consumption of various types of local foods makes it difficult to reach definitive conclusions about which are most responsible for dioxin, furan and PCB intake. Although elevated dioxin levels have been found in fish from Chapaevsk (25), no associations with eating fish $\geq$ once/week were significant. However, additional analyses showed that total TEQs were elevated in the 17 women who reported eating fish every day

($p < 0.01$), compared to all other women. This finding indicates that within low and moderate fish consumption categories there is wide variability in serum concentrations of dioxins, furans, and PCBs, which provides insufficient power to detect all but the largest differences between groups.

Limitations of our study include that all dietary data was self-reported, and also that no information was collected on the species of fish consumed. In addition, only the current residential distance from SVZH was available, precluding examination of whether distance from SVZH in certain historical eras was more strongly associated with serum dioxin, furan, and PCB concentrations.

One unexpected finding is that doing laundry by hand was associated with lower serum dioxin, furan and PCB concentrations. This finding was based on a small reference group of only 13 women who reported not doing laundry by hand, and could be due to unknown additional demographic or lifestyle characteristics of these women, or represent a chance finding resulting from the large number of associations that were examined. However, the magnitude of the association was relatively consistent across dioxin, furan and PCB measures, and the relationship could be plausible if doing laundry cleaned the hands of contaminated soil, and therefore decreased incidental ingestion.

Smoking was significantly associated only with lower concentrations of C-PCB TEQs and total TEQs. It has been suggested that cigarette smoke accelerates the elimination of dioxins (8), possibly due to the induction of the enzyme CYP1A2, which sequesters dioxins into the liver, leading to faster elimination. However, the exact mode of action remains unknown. Several recent studies have suggested stronger inverse associations between smoking and levels of C-PCBs than of PCDDs and PCDFs (27–28), however other studies have reported that PCDD and PCDF half-lives were also shorter among smokers (29).

Research by Wolff et al (30) has suggested that increased adiposity can affect lipid concentrations of organochlorines either by reducing their elimination or by providing a larger volume of distribution. Our results are consistent with this observation, as increases in the woman's BMI were significantly associated with lower serum concentrations of all dioxins, furans, and PCBs (except for C-PCB concentrations), whereas the only significant association with BMI at the time of blood draw was with increased C-PCB TEQs, possibly reflecting slower elimination in individuals with higher BMI.

Comparison of dioxin, furan and PCB concentrations in this population to other studies

The serum dioxin, furan and PCB concentrations seen in this cohort are elevated compared to the US general population. Both the 90th percentile total TEQ and the median total PCBs in these women were higher than among the 20–39 year old US population in 2003–2004 (90th percentile total TEQ: 51 vs. 16 pg TEQ/g lipid; median total PCBs: 260 vs. 75 ng/g lipid; (31); the 90th percentile was shown for total TEQs since median values were not available for the US population due to the high percentage of non-detects). The women in this cohort also have similarly elevated 90th percentile TEQs of total PCDDs, PCDFs, C-PCBs, and M-PCBs compared to the 20–39 year old female US population in 2001–2002 (23 vs. 14, 9.0 vs. 4.3; 14 vs. 4.8, 3.2 vs. 1.1 pg TEQ/g lipid, respectively; (32)).

The individual congeners comprising the highest percentage of the total TEQ were TCDD, 12378-PeCDD, 23478-PeCDF, and PCB 126 (mean contribution of 76% from these 4 congeners). These predominant congeners are similar to those reported in a national representative sample of the US population (32), as well as in the University of Michigan Dioxin Exposure Study (33), which described a population with potential non-occupational

exposure to dioxins from a Dow Chemical plant, as well as a comparison population living approximately 100 miles away.

Comparison of predictors in mothers and sons

Predictors of maternal serum dioxin, furan and PCB concentrations are similar to those identified among their sons in our recent publication (13). Maternal employment at SVZH was more strongly associated with the sons' dioxin, furan and PCB concentrations than with the mothers' levels. For the sons the percent increases in total PCBs and total TEQs associated with maternal SVZH employment were 29% ($p = 0.02$) and 26% ($p = 0.05$), respectively, whereas for the mothers they were 17% ($p = 0.054$) and 11% ($p = 0.28$). Possible explanations for the difference include higher background dioxin, furan and PCB concentrations among the mothers, or the greater number of covariates included in our analysis of the mothers' samples.

Public health recommendations

Our finding that average serum concentrations of dioxins, furans and PCBs decreased in the course of this study is an encouraging sign that exposure in this region may be trending downward. Certain modifiable factors were nonetheless associated with higher concentrations of dioxins, furans and PCBs, especially residential distance from SVZH, duration of farm plot use, and consumption of local foods. In spite of our findings about local diet, it would be premature to suggest that intake of local foods or fish should be reduced without a fuller assessment of the net health tradeoffs of such a recommendation, especially in a relatively resource-poor environment such as Chapaevsk. Alternate possible ways to reduce dioxin, furan and PCB intake, without potential unintended adverse effects on local nutrition, include remediation of contaminated soil, shifting farm plots to less contaminated locations, or thorough washing of fruits and vegetables before consumption.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Appendix A: Abbreviations

BMI	Body mass index
C-PCB	Coplanar polychlorinated biphenyl
M-PCB	Mono- <i>ortho</i> polychlorinated biphenyl
PCB	Polychlorinated biphenyl
PCDD	Polychlorinated dibenzo- <i>p</i> -dioxin

PCDF	Polychlorinated dibenzofuran
SVZH	Middle Volga Chemical Plant
TCDD	2,3,7,8-tetrachlorodibenzo- <i>p</i> -dioxin
TEQ	Toxic equivalents
WHO	World Health Organization

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Table 1

Demographic and lifestyle characteristics of 446 mothers from the Russian Children's Study

Continuous variables	Median	Percentiles		
		25 th	75 th	90 th
Age (years)	31	29	35	40
Breastfeeding duration (months)	6	3	17	30
Duration of residence in Chapaevsk (years)	28	15	31	35
Farm plot use duration (years)	0	0	1	8
Body Mass Index (kg/m ²)	24	21	28	32
BMI change since pregnancy with study son (%)	11	3	24	37
Duration of smoking (years)	0	0	2	10
Categorical variables	N	%		
Breastfeeding duration (≥21 months)	281	(63)		
(11–20 months)	83	(19)		
(0–10 months)	82	(18)		
Distance from SVZH (<2 km)	85	(19)		
(2–5 km)	202	(46)		
(5+ km)	157	(35)		
Maximum household education (≤Secondary school)	34	(8)		
(≥Some university)	411	(92)		
Ever employed at SVZH	27	(6)		
Ever do laundry by hand	433	(97)		
Local Eggs ≥ once/week	38	(9)		
Local Dairy ≥ once/week	78	(19)		
Local Beef ≥ once/month ^a	14	(3)		
Local Fruit ≥ once/week	140	(34)		
Oily Food ≥ once/week	363	(88)		
Fish ≥once/week	170	(41)		

Missing information: Age (n = 1), Residence duration (n = 1), BMI (n = 22), BMI change (n = 53), Smoking duration (n = 30), Distance from SVZH (n = 2), Maximum household education (n = 1), Dietary variables (n = 32).

BMI = body mass index; SVZH = Middle Volga Chemical Plant.

^aLocal beef consumption was grouped as ≥once/month since only 4 women consumed ≥once/week.

Table 2
Distribution of serum dioxin, furan, and PCB concentrations among 446 mothers in the Russian Children's Study.

	N	Mean	SD	Min.	Percentiles						Max.
					10 th	25 th	50 th	75 th	90 th		
TCDD	445	3.6	3.4	0.1	0.4	0.8	3.3	4.8	6.7	43	
Total PCDD	443	133	93	11	58	79	109	160	227	1194	
Total PCDF	442	50	80	3.3	19	25	35	48	65	953	
Total C-PCB	405	259	168	89	143	168	221	289	378	1647	
Total M-PCB	446	62	37	11	30	39	53	72	108	318	
Total PCB	446	302	172	60	153	196	260	362	498	2007	
Total PCDD TEQ	445	12	10	0.6	1.7	4.5	10	16	23	88	
Total PCDF TEQ	445	6.7	11	0.3	2.4	3.2	4.6	6.2	9.0	147	
Total C-PCB TEQ	444	9.3	5.4	2.3	4.5	6.0	8.0	11	14	46	
Total M-PCB TEQ	446	1.9	1.1	0.3	0.9	1.2	1.6	2.2	3.2	9.5	
Total TEQ	444	30	21	4.6	12	17	25	36	51	173	

All units are pg/g lipid, except total M-PCBs and total PCBs are ng/g lipid Total PCBs do not include C-PCBs.

TEQs are WHO 2005 (21)

Samples sizes fluctuate due to non-reported congener values

SD = standard deviation; TCDD = tetrachloro-dibenzo-*p*-dioxin; PCDDs = polychlorinated dibenzo-*p*-dioxins; PCDFs = polychlorinated dibenzofurans; C-PCBs = co-planar polychlorinated biphenyls; M-PCBs = mono-*ortho* polychlorinated biphenyls; TEQs = toxic equivalents; WHO = World Health Organization.

Multivariate predictors (percent change) of log₁₀ serum concentrations of dioxins, furans and PCBs among mothers in the Russian Children's Study.

Table 3

	TCDD N = 442	Total PCDD N = 440	Total PCDF N = 439	Total C-PCB N = 402	Total PCB N = 443
Age (years)	4.6% ^{**}	1.4% ^{**}	1.9% ^{**}	0.7%	3.1% ^{**}
Breastfeeding duration (≥21 months)	-55.4% ^{**}	-21.4% ^{**}	-27.3% ^{**}	-9.9% [§]	-30.8% ^{**}
(11–20 months)	-22.2% ^{§*}	-6.7%	-17.2% ^{**}	4.5%	-13.1% ^{**}
(0–10 months) (reference)	--	--	--	--	--
BMI at blood draw (kg/m ²)	0.2%	0.2%	0.3%	0.4%	-0.6%
BMI increase since pregnancy ^a	-0.8% [*]	-0.4% [*]	-0.6% ^{**}	-0.1%	-0.6% ^{**}
Blood draw date (years) ^b	-15.7% [*]	-16.0% ^{**}	-11.1% ^{**}	-8.4% [*]	-9.8% ^{**}
Duration of residence in Chapaevsk (years)	0.7%	1.2% ^{**}	0.3%	0.2%	0.2%
Residence distance from SVZH (<2 km)	72.1% ^{**}	52.3% ^{**}	55.6% ^{**}	8.1%	21.3% ^{**}
(2–5 km)	26.7% [*]	12.7% [*]	20.8% ^{**}	-3.7%	-2.6%
(5+ km) (reference)	--	--	--	--	--
Ever employed at SVZH	3.7%	17.8% [§]	5.1%	0.9%	17.0% [§]
Low education (≤secondary school vs. higher) ^c	-0.8%	7.6%	32.8% ^{**}	-8.1%	6.2%
Duration of smoking (years)	0.8%	-0.3%	-0.4%	-0.5%	0.2%
Farm plot use duration (years)	2.5% [*]	1.2% ^{**}	3.1% ^{**}	1.6% ^{**}	1.6% ^{**}
Local ≥Eggs once/week	27.1%	4.9%	53.1% ^{**}	1.4%	14.7% ^{§*}
Local ≥Dairy once/week	8.5%	4.0%	7.2% [*]	5.1%	3.4%
Local ≥Beef once/month ^d	16.9%	0.1%	0.5%	9.5%	35.8% ^{**}
Local ≥Fruit once/week	31.5% [*]	6.7%	0.2%	4.2%	1.0%
Oily Food ≥once/week	32.9% [§]	11.4%	12.5%	-3.0%	9.7% [§]
Fish ≥once/week	10.5%	-3.7%	0.7%	7.4%	0.3%
Laundry by hand (Ever vs. never)	-42.0% [§]	-23.4% [§]	-26.0% [§]	-4.3%	-15.4%
Overall Model R ²	0.24	0.31	0.31	0.13	0.36

[§] $p < 0.1$;

* $p < 0.05$;
 ** $p < 0.01$;
 *** $p < 0.0001$

^a Per 10% increase in BMI since pregnancy with study son, 8 or 9 years before blood draw.

^b In years since the beginning of the study.

^c Maximum education of woman or her partner.

^d Local beef consumption was grouped as $\geq$ once/month since only 4 women consumed $\geq$ once/week. For continuous predictors, each unit increase changes the serum concentration by the percent shown. For categorical predictors, the percent shown represents the relative difference in serum concentrations of those at each level compared to the reference group, adjusting for all other predictors.

BMI = body mass index; SVZH = Middle Volga Chemical Plant; TCDD = tetrachloro-dibenzo-*p*-dioxin; PCDDs = polychlorinated dibenzo-*p*-dioxins; PCDFs = polychlorinated dibenzofurans; C-PCBs = co-planar polychlorinated biphenyls.

Total PCBs do not include C-PCBs.

Table 4

Multivariate predictors (percent change) of log₁₀ serum TEQs of dioxins, furans and PCBs among mothers in the Russian Children's Study.

	Total PCDD TEQ N = 442	Total PCDF TEQ N = 442	Total C-PCB TEQ N = 441	Total TEQ N = 441
Age (years)	3.7% ***	2.3% ***	2.9% ***	2.9% ***
Breastfeeding duration (≥21 months)	-53.8% ***	-36.1% ***	-23.6% ***	-39.0% ***
(11–20 months)	-27.9% **	-23.3% **	-5.7%	-18.8% **
(0–10 months) (reference)	--	--	--	--
BMI at blood draw (kg/m ²)	-0.4%	0.2%	1.7% **	0.8%
BMI increase since pregnancy ^a	-0.7% **	-0.7% **	-0.4% **	-0.7% ***
Blood draw date (years) ^b	-11.7% §	-9.4% *	-11.7% **	-10.5% **
Duration of residence in Chapaevsk (years)	2.3% ***	0.6% *	-0.2%	0.6% **
Residence distance from SVZH (<2 km)	69.9% ***	57.0% ***	10.1%	39.7% ***
(2–5 km)	19.5% *	18.7% **	0.2%	12.2% *
(5+ km) (reference)	--	--	--	--
Ever employed at SVZH	19.8%	2.7%	16.7% §	11.2%
Low education (≤secondary school vs. higher) ^c	9.1%	32.3% **	9.7%	14.8%
Duration of smoking (years)	0.4%	-0.6%	-2.1% ***	-1.0% *
Farm plot use duration (years)	2.7% **	3.4% ***	1.2% **	2.7% ***
Local Eggs ≥ once/week	15.7%	52.1% ***	18.7% *	27.9% **
Local Dairy ≥ once/week	18.7%	10.7%	1.5%	9.1%
Local Beef ≥ once/month ^d	83.2% *	8.8%	44.3% **	41.3% *
Local Fruit ≥ once/week	23.2% *	1.3%	-2.5%	5.9%
Oily Food ≥ once/week	10.6%	13.4%	7.5%	12.9% §
Fish ≥ once/week	-0.1%	0.6%	3.1%	0.6%
Laundry by hand (Ever vs. never)	-58.7% **	-27.2% *	-26.6% *	-43.5% ***
Overall Model R ²	0.38	0.36	0.29	0.41

§ $p < 0.1$;

* $p < 0.05$;

** $p < 0.01$;

*** $p < 0.0001$

^a Per 10% increase in BMI since pregnancy with study son, 8 or 9 years before blood draw.

^b In years since the beginning of the study.

^c Maximum education of woman or her partner.

^d Local beef consumption was grouped as $\geq$ once/month since only 4 women consumed $\geq$ once/week. For continuous predictors, each unit increase changes the serum concentration by the percent shown. For categorical predictors, the percent shown represents the relative difference in serum concentrations of those at each level compared to the reference group, adjusting for all other predictors.

TEQs are WHO 2005 (Van den berg et al, 2006).

BMI = body mass index; SVZH = Middle Volga Chemical Plant; PCDDs = polychlorinated dibenzo-*p*-dioxins; PCDFs = polychlorinated dibenzofurans; C-PCBs = co-planar polychlorinated biphenyls; TEQs = toxic equivalents; WHO = World Health Organization.