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Serum Biomarkers of Polyfluoroalkyl Compound Exposure in Young Girls in Greater Cincinnati and the San Francisco Bay Area, USA

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Abstract

PFC serum concentrations were measured in 6–8 year-old girls in Greater Cincinnati (GC) (N=353) and the San Francisco Bay Area (SFBA) (N=351). PFOA median concentration was lower in the SFBA than GC (5.8 vs. 7.3 ng/mL). In GC, 48/51 girls living in one area had PFOA concentrations above the NHANES 95th percentile for children 12–19 years (8.4 ng/mL), median 22.0 ng/mL. The duration of being breast fed was associated with higher serum PFOA at both sites and with higher PFOS, PFHxS and Me-PFOSA-AcOH concentrations in GC. Correlations of the PFC analytes with each other suggest that a source upriver from GC may have contributed to

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exposures through drinking water, and water treatment with granular activated carbon filtration resulted in less exposure for SWO girls compared to those in NKY. PFOA has been characterized as a drinking water contaminant, and water treatment systems effective in removing PFCs will reduce body burdens.

Keywords

Polyfluoroalkyl compounds (PFCs); Human milk; Biomonitoring; Drinking water contaminants; Children

Background

Some polyfluoroalkyl compounds (PFCs) and their derivatives, such as perfluorooctanoate (PFOA) and perfluorooctane sulfonate (PFOS), are surfactants that have wide consumer and industrial applications as well as known environmental persistence. PFOS-related substances, including PFOA, are used in metal plating, semi-conductors, film processing and fire-fighting foams. PFOA can be found as a residual impurity in some paper coatings used on containers for processed food. Some PFCs have been detected in wildlife as widespread as polar bears in Greenland and giant pandas in China (Giesy and Kannan, 2001; Dai et al., 2006). In the United States, in serum samples collected from 1562 participants of the 1999–2000 National Health and Nutrition Examination Survey (NHANES), males and females age 12 years and older, both PFOA and PFOS were detected in every sample analyzed (geometric mean values: PFOS, 30.4 ng/mL and PFOA, 5.2 ng/mL) and other PFCs were detected in over 90% of the study population (Calafat et al., 2007a). In 2120 samples collected from NHANES participants in 2005–2006, after changes in the manufacturing practices for some PFCs, serum concentrations of PFCs had decreased, but PFOA, PFOS, and other PFCs were still detected in over 98% of the samples (CDC, 2012). The New Jersey Department of Environmental Protection measured PFCs in untreated water samples in 2006 and detected PFOA in 78% and PFOS in 57% of the 23 water treatment plants sampled (New Jersey Department of Environmental Protection, 2007). In 2009, water concentrations of PFOA in the Ohio River ranged from 2.5 ng/L in Pittsburgh, Pennsylvania (upstream of a plant processing PFCs), to 35.2 ng/L in Ravenwood West Virginia, and 13.1 ng/L in Cincinnati, Ohio at two locations downriver (Emery et al., 2010).

Species variation in the biological half-life of PFCs is substantial, from hours in some rodent strains to several years in humans (Kudo and Kawashima, 2003; Olsen et al., 2007). The perfluorinated portions of these molecules have extreme resistance to environmental and metabolic degradation; the longer the carbon chain of the PFC, the greater the persistence. PFOA and PFOS, with 7 and 8 carbon chains, have greater environmental and biological persistence in humans (about 3–4 years) than those with shorter chains. The exception is perfluorohexane sulfonate (PFHxS), with 6 carbons, and a half-life of 7.3 year (Olsen et al., 2007). PFCs have been detected in cord blood, breast milk, infant formula and food (Llorca et al., 2010; Karrman et al., 2007; Antignac et al., 2013; Kubwabo et al., 2013) and cord blood and breast milk concentrations are correlated with maternal serum concentrations (Karrman et al., 2007; von Ehrenstein et al., 2009; Mondal et al., 2012; Lee et al., 2013; Ode et al., 2013).

The PFC exposure assessment reported here was carried out as part of the puberty cohort studies of the National Institute of Environmental Health Sciences and National Cancer Institute Breast Cancer and the Environment Research Program (BCERP). The objective of these studies is to elucidate influences of environmental factors on early pubertal development in girls, and thereby possible future risk for breast cancer and other chronic

diseases among women (Hiatt et al., 2009). For this purpose, the research design employs biomarkers to assess a variety of environmental exposures. We previously published the results of the urinary exposure biomarkers (Wolff et al., 2010) and some of the persistent organo-halogenated compounds in serum (Windham et al., 2010) showing broad exposure. In this report, we describe the serum concentrations of PFCs measured among the puberty study participants. We conducted analyses to determine if factors such as location and years of residence, drinking water source and being breastfed were predictors of the serum PFC concentration.

Methods

Data and biospecimen collection: Of the three BCERP puberty cohort studies, only two collected blood serum: Greater Cincinnati (GC) (Cincinnati Children's Hospital Medical Center (CCHMC) and University of Cincinnati (UC) College of Medicine) and the San Francisco Bay Area (SFBA) (Kaiser Permanente of Northern California and University of California, San Francisco). Study participants at the GC Center were recruited from public and parochial schools in GC, through letters to parents, and through the Breast Cancer Registry of Greater Cincinnati. Informed consent was obtained from parents and child assent was verified. The SFBA study group was recruited through the Kaiser Permanente Health Plan membership in the SFBA, and consent and assent also were obtained. Serum samples were collected at the time of the first or second year clinical study visit, using a collection and processing protocol and sampling materials provided by the Centers for Disease Control and Prevention (CDC) laboratory conducting the analyses (CDC IRB #4824 and #4769). Serum was aliquotted into 2mL polypropylene cryovials and stored frozen until shipment. PFCs were measured in the serum of 704 6–8 year old girls. An additional 119 girls participated in the study, but refused blood collection. Most biospecimens of the GC girls were collected between February 2005 and December 2006 (81.2%), but a few as late as October 2007. Biospecimens of the SFBA girls were collected primarily from February 2005 until December 2007 (89.2%), but some as late April 2009.

At both sites, baseline and yearly questionnaires were administered to the girls' parents or guardians. These included items about potential sources of environmental exposures (e.g. drinking water source and residential history) and the health histories of the girl and her parents. At each study visit, research staff, trained and certified through a common protocol, measured height and weight using calibrated stadiometers and scales. Body mass index (BMI) was calculated as $\text{weight}/(\text{height})^2$ in kilograms/meter², and then related to age- and sex-specific percentiles using the CDC growth charts (CDC, 2000). BMI was categorized as either < or the 85th percentile. BMI percentile was included in the calculation of geometric mean, but not included in regression models because, in other studies, PFOA has been found to be related to lower birth weight in infants (Maisonet, 2012; Halldorsson, 2012; Lee, 2013) and higher BMI in adults (Maisonet et al., 2012; Ji et al., 2012). For the purpose of this analysis, race/ethnicity has been categorized as Hispanic, Black, non-Hispanic White, and Asian.

Serum analysis

Concentrations of PFCs in all blood sera were measured at the CDC, using methods published previously (Kuklenyik et al., 2005; Kato et al., 2011). Briefly, after dilution with formic acid (and without protein precipitation), one aliquot of 100 μL serum was analyzed by online solid-phase extraction high performance liquid chromatography – tandem mass spectrometry to measure trace concentrations of eight PFCs including PFOS and PFOA. Perfluorodecanoic acid (PFDeA) was not measured for the early sample analyses. Most analyses incorporated isotopically-labeled internal standards for PFOS, PFOA and 2-(N-methyl-perfluorooctane sulfonamide) acetate (Me-PFOSA-AcOH), 2-(N-ethyl-

perfluorooctane sulfonamide) acetate (Et-PFOSA-AcOH) and perfluorononanoate (PFNA). The CDC laboratory is certified according to the Clinical Laboratories Improvement Amendments, and procedures incorporate quality control (QC) measures to ensure accuracy and precision of results, including annual proficiency testing compliance. A laboratory batch must meet QC criteria, including acceptable blanks, or the batch is entirely reanalyzed (Caudill et al., 2008). Results are blank-corrected if applicable. For all our statistical analyses, we used PFC measurements from the first serum sample collected from all girls.

Statistical methods

We examined possible environmental and lifestyle factors to determine if they could explain the variation in PFOA concentrations. Questionnaire data were used to determine the proportion of water consumed by the girl that came from bottled water, parity of the mother, history and duration of being breast fed, and education of the parents. After first conducting these analyses on all girls, we then performed the analyses separately on the site specific sub-cohorts. For the girls from the GC area, we incorporated information on residence location and number of years at each residence. Parts of the GC metropolitan area where the girls resided are served by two different water treatment systems. The GC municipal water departments provided information about their water distribution systems and the zones serviced by each of the water treatment plants. Residential history information from the questionnaires was used to assign each GC study participant to a water treatment plant for each address.

All statistical analyses were conducted using SAS (version 9.2, SAS Institute, Cary, NC). We calculated Pearson correlation coefficients for the relationships between each of the eight PFC serum concentrations with each other. For analytes detected in >60% of the samples (all except Et-PFOSA-AcOH), we then performed multivariate analyses to calculate geometric means adjusted for age at blood sample, race/ethnicity, BMI, and study site using the general linear model (GLM) procedure, and tested for differences in the adjusted geometric means for levels of categorical variables using the least squares geometric means (LSMEANS) option of the GLM procedure. We conducted linear regression analyses to determine if any of these factors were predictors of the serum PFC concentrations. In parametric analyses, we used log-transformed values of the serum PFC concentrations to normalize the distributions, and we substituted the value LOD/ 2 for concentrations below the LOD following the CDC practice (Wolff et al., 2005). All terms were included in the full model analyses. We conducted a forward stepwise elimination procedure using GLM, which accommodates unbalanced designs, with hand fitting to include terms by order of statistical significance. Age at sample and drinking water provider (where data were available) were always included, and other terms were retained in the final model if they were significant ($p < 0.05$) or caused a >10% change in the effect estimate for either age or water source provider. Effect estimates of change in log-transformed PFOA concentrations, from the regression models, were back transformed for the description of the findings.

Results

Demographic characteristics and PFC Concentrations

Participants were distributed across four racial groups (51.7% non-Hispanic White, 13.9% Hispanic, 27.8% Black and 6.5% Asian); most of the Asian and Hispanic participants were located at the SFBA site (Table 1). Most girls (70.6%) had a BMI below the 85th percentile for their age (CDC, 2000) with a BMI percentile median value of 49.6; the median BMI percentile value was 94.9 for those 85th percentile. Mean age at date of sample collection was 7.8 years. Duration of being breast fed was categorized as >0–3, 4–6, 7–9, 10–12, and 13+ months versus not breast fed (group N's for GC are 74, 60, 32, 35, 27, and 107; for

SFBA are 61, 51, 43, 53, 117 and 22). Being breast fed and the number of months of being breast fed was correlated with race at both sites (Spearman $p < 0.05$) but not the ordinal levels of breast feeding months groups ($p = 0.91$); there was no correlation with education level (HS, some college/technical school, BS, MS+).

Descriptive statistics for the eight PFCs are shown in Table 2. Four PFCs were detected in >99% of the samples (PFHxS, PFNA, PFOA and PFOS), and one (Me-PFOSA-AcOH) was detected in 95% while Et-PFOSA-AcOH was detected in only 14.6%. Median concentrations of some PFCs significantly differed by study site, notably PFOA. PFOA serum concentrations exceeded the NHANES 2005–2006 95th percentile value in 38.6% of the GC site girls (136/352) and in 14% of the SFBA girls (50/351). Girls from the GC site lived in either Southwestern Ohio (SWO) or in Northern Kentucky (NKY). A highly significant difference ($p < 0.0001$) in median serum PFOA concentrations was found between girls living in NKY (22.0 ng/mL) and SWO (6.8 ng/mL); 48/51 NKY girls had concentrations above the NHANES 2005–2006 95th percentile value. A significant difference in medians among girls living in these two areas also existed for PFOS (17.7 ng/mL vs. 13.2 ng/mL; $p = 0.02$) but not for Me-PFOSA-AcOH, PFNA, PFDeA or PFHxS.

Because the correlations of serum concentrations of the polyfluoroalkyl compounds with each other can assist in identifying a possible source, we examined the correlations by site, and by the two areas within the GC site. At both GC and SFBA sites, strong correlations (Pearson, log-transformed PFC) existed between PFOA and PFOS concentrations (GC $R = 0.62$, SFBA $R = 0.60$), PFOS and PFHxS concentrations ($R = 0.74$, $R = 0.69$), and PFNA and PFDeA concentrations ($R = 0.60$, $R = 0.58$), all with $p < 0.0001$ (Supplemental Table 1). However, among the NKY girls, we noted a more moderate correlation of PFOA with PFOS ($R = 0.38$, $p < 0.013$) than among the girls living in the SWO region of GC ($R = 0.75$, $p < 0.0001$) whose correlation was more similar to the SFBA girls (Supplemental Table 2). The correlation of concentrations of PFOA with PFHxS was much stronger among the SFBA girls (0.49, $p < 0.0001$) and the Cincinnati SWO girls (0.55, $p < 0.0001$) than among the fifty-four NKY girls (0.08, $p = 0.547$) (Supplemental Table 2).

Adjusted geometric mean serum concentrations (for those PFCs detected in greater than 60% of samples) reveal differences by race, site, BMI percentile and age at sample collection (Supplemental Table 3). The adjusted geometric mean concentrations of PFOS, PFOA and PFHxS were significantly lower in Black, Asian and Hispanic girls than in Whites ($p < 0.01$); however, 51/54 of the NKY girls were White and the other 3 were Asian. Girls at the GC site had significantly higher adjusted geometric mean concentrations of PFOA and PFHxS but significantly lower geometric mean concentrations of PFNA than girls in SFBA (all $p < 0.001$). Girls with BMI below the 85th percentile had significantly higher geometric mean concentrations of PFDeA and PFOS ($p < 0.01$). The geometric mean concentration of PFDeA was significantly higher in girls who had serum collected after their 7th birthday. At the GC site, residents of NKY at the time of sample collection, when compared to those living in SWO, had significantly higher geometric mean serum concentrations of PFOA (22.0 vs 6.8 ng/mL; $p < 0.0001$) and PFOS (17.7 vs. 13.1 ng/mL; $p = 0.02$) (data not shown in Supplemental Table 3). When the NKY girls (all White or Asian) were removed from the total study sample, statistically significant differences by race and site (SFBA vs. GC without NKY) for PFHxS, PFNA and PFOA still existed (p -values all < 0.0005) (not shown in Supplemental Table 3).

We have PFC measurements in two sequential samples, collected from the same girl one year apart, for 22 GC girls and 22 SFBA girls. For girls in NKY ($N = 12$), the median of the difference values between paired PFOA measures was a decrease of 32% or 7.9 ng/mL ($p < 0.0001$); for SWO ($N = 10$), the median of the difference between measures was a

decrease of 26% or 1.6 ng/mL ($p < 0.001$). For the 22 SFBA girls, the median of the difference was an increase of 14% or 0.7 ng/mL ($p = 0.007$).

Determinants of PFOA concentrations

Because the distribution of PFOA concentrations was skewed to the right, natural log-transformed PFOA was used as the dependent variable in all regression analyses of determinants. In bivariate analyses, variables related to drinking water (e.g. source of drinking water from the tap [public vs. all other such as wells or cisterns; bottled vs. all other including public water], and use of a water filter) were not significantly associated with log PFOA; all had p values > 0.3 .

Full models initially contained terms for age at serum sample collection, race, water source (bottled or not), parity of mother (1 vs. > 1), duration of being breast fed, parent attained education and study site. Among the terms retained in the final model of the analysis of combined data from both sites, factors associated with lower PFOA concentrations included being from the SFBA site, being older at time of blood sample, and being either Black, Hispanic or Asian, all with p values < 0.002 . All levels of duration of being breast fed were associated with higher PFOA concentrations (p values all < 0.001) when compared to not being breast fed, and the test for linear trend across increasing duration of being breast fed was significant ($p < 0.0001$).

We then conducted site-specific analyses (Tables 3 and 4) because for the GC site we had the information to link each address to a water purification plant and calculate the number of years of that drinking water source for each girl. Since girls in the NKY area were all White or Asian, race was confounded with location within the GC site and not included in the GC site model. Age at sample collection was not related to PFOA serum concentration in the SFBA girls (Table 3) but inversely related to PFOA serum concentration for the GC girls (Table 4). At the SFBA site, breast feeding duration was significantly associated with higher PFOA concentration, and also with a significant linear trend ($p = 0.02$) (Table 3). For the GC girls, we modeled the number of years of drinking water from either the NKY water distribution system or one of the SWO water distribution zones (three separate model terms, Table 4), with five interval levels of breast feeding duration compared to not being breast fed. With this better characterization of drinking water exposure, PFOA serum concentration was highly associated ($p < 0.001$) with cumulative years of drinking water from the NKY water distribution zone but not associated with years of drinking water from either of the other two SWO water distribution zones (Table 4). Being breast fed was positively associated with PFOA serum concentrations in GC, with all groups having p values < 0.04 , and the longest duration category of 13+ months having a p value of < 0.0001 ; a test for linear trend of β estimates over the increasing duration categories was significant ($p < 0.0001$). Median breast feeding duration was greater for NKY girls (9 months vs. 6 months for SWO girls). The final model for GC data explained 64% of the variability in log PFOA (Table 4, $R^2 = 0.64$). When a term for race was included in the GC model, the terms for breast feeding duration or drinking water from the NKY water distribution system remained significant (data not shown). When we replaced the terms for water distribution zone-years with just the water distribution zone at enrollment (allowing inclusion of 79 girls without detailed residential history data), the terms for NKY water district at enrollment, breast feeding duration and age at sample remained significant ($p < 0.0001$, $p < 0.0001$ and $p = 0.006$ respectively).

For the GC girls, living in NKY at birth was highly associated with PFOA serum concentration ($p < 0.0001$) in regression models containing residence location at birth and being breast fed. For girls who were not breastfed, living in NKY at birth resulted in a 7.7 ng/mL increase in serum PFOA over living elsewhere. Among girls who were breast fed,

living in NKY at birth was associated with an estimated 10.8 ng/mL increase in serum PFOA, compared to living elsewhere at birth and being breast fed. Moreover, among girls who lived in SWO at birth, being breast fed resulted in a 1.4 ng/mL increase in serum PFOA. GC girls who were breast fed and lived in NKY at birth had a 12.2 ng/mL increase in serum PFOA when compared to GC girls who were not breast fed and did not live in NKY. We conducted linear regression analyses of the other PFCs with the same terms in the models and found evidence of an association of breast feeding with serum concentrations of Me-PFOA-AcOH, PFHxS, and PFOS in GC girls (Figure 1 and Supplemental Table 4) where the linear test for trend was at least $p < 0.002$ for all of these PFCs.

Discussion and Conclusions

In this study, five of the eight PFCs were measured in almost all 6–8 year old girls in our study sample, and the serum concentrations (with the exception of PFOA) were generally similar to those reported for 2005–2006 NHANES boys and girls, age 12–19 years (CDC, 2012). PFOA serum concentrations were slightly higher overall in SWO girls (median 6.8 ng/mL) and the SFBA girls (5.8 ng/mL) and much higher in girls living in the NKY area of the GC site (22.0 ng/mL) than the median reported for children 12–19 years in the NHANES 2005–2006 (3.8 ng/mL). Of the three girls from NKY whose serum concentration was not above the NHANES 2005–2006 95th percentile, one did not live in NKY from mid-1999 to 2003, one was born in Asia, and the third did live in NKY since birth but the family used bottled water for a portion of their drinking water. We know of no PFC compound manufacturing sites in the GC area. One limitation of this study was our inability to capture individual information on all possible sources of PFCs, especially contamination present in food items (Begley et al., 2005; D'Hollander et al., 2010) and perhaps exposure to children through house dust containing PFCs (Knobeloch et al., 2012; Xu et al., 2013). There also is emerging evidence suggesting that biotransformation of fluorotelomer commercial products and their residuals may be a continuing source of PFOA and PFDeA (D'eon and Mabury, 2011). However, the regression model for the determinants of serum PFOA concentration in GC, with terms for water distribution zones, explained 64% of the variance without any estimation of exposure from food or dust sources; the model for SFBA explained only 8% suggesting that there were other sources of exposure not captured in our analyses.

The rigorous methods of this study for data and biospecimen processing lend strength to this research. The serum samples were collected and processed specifically for biomarker measurement, following a well-established protocol developed by CDC. We also measured height and weight under a research protocol and collected questionnaire data on race, residential history, drinking water source, parity and breast feeding prior to the PFC measures. Use of bottled water by mothers was not ascertained, but the NKY population had the highest education level and their daughters had the highest level of bottled water use.

Among the girls living in NKY, 94% had serum PFOA concentrations above the 95th percentile concentration for older children (boys and girls) in the 2005–2006 NHANES (CDC, 2012). Moreover, our study population contained only girls, and several other US studies have noted that concentrations are higher in males than in females. Higher geometric mean PFOA concentrations were found in boys than in girls in children age 2–12 years (40.1 ppb vs 35.2 ppb, Olsen et al., 2004), in children <12 years in the C-8 cohort (39.1 vs 34.8 ng/mL, Frisbee, 2009), and among Texas children 6–9 years (median 3.75 vs 2.90 ng/mL, Schecter et al., 2012). If there is a gender difference in children, with males having higher concentrations, then the concentrations we found in our girls may represent an even greater deviation from the reported NHANES cohort levels.

This is the first published report of a direct relationship between the duration of being breast fed and the child's serum PFOA concentration, and also the first to report a relationship between being breast fed and serum concentrations of other PFCs. In exposure pathway models developed by Haug et al. (2011), for breast fed infants, breast milk was the single most important source of PFCs. Transfer of PFOA to breast milk from serum was more than 2 times that for PFOS. Jain (2013), using NHANES data, found that mothers who breast fed at least one child had significantly lower PFOA serum concentrations and Javins (2013) recently reported that pregnant women have lower PFOA and PFOS concentrations in peripheral blood than non-pregnant women.

Serum concentrations of PFOA in GC girls in both SWO and NKY appear to be decreasing over time in a one year period from 2005–2006, and in similar proportions, 26% and 32% respectively. In the NHANES studies, the decrease in geometric mean concentration in the general population over four years between the 1999–2000 and 2003–2004 studies was approximately 25% (Calafat et al., 2007a; Calafat et al., 2007b) although the 2005–2006 data show a very small decrease (CDC, 2012). In our regression analyses, among GC area girls there was a strong inverse relationship between the PFOA concentrations and the age at serum sample collection, suggesting that serum concentrations in our study participants were substantially higher when they were younger. In girls from the SFBA, however, there was no relationship between age at sample and serum PFOA concentration, which suggest a continuous source. The SFBA is known for its electronics industry, and in an area of similar industry in Taiwan, river water receiving waste was noted contain PFOA as the most significant PFC (Lin et al., 2009).

The serum concentrations of PFOA measured in the NKY girls are similar to those reported for other exposed study populations. In Arnsberg, Germany, where industrial waste contaminated with PFCs was mixed with soil and used by farmers, causing contamination of surface and drinking water and fish, the geometric mean plasma PFOA concentration in children was 25.3 ng/mL (Holzer et al., 2008). Some of the highest PFOA serum concentrations measured in persons living in a community were found in 2005 in Ohio and West Virginia residents, with drinking water exposures from an industrial facility in West Virginia. The average PFOA concentration in the treated drinking water in that area in 2002–2005 was 3.55 ng/mL or 3550 ng/L (Emmett et al., 2006). This facility is about 285 miles upriver from the GC area, and may represent a potential source of exposure via the Ohio River for the girls from NKY. As a result of a legal settlement, in 2005–2006 the C8 Health Project measured PFCs in a large population of community residents, and found that the median serum concentration of PFOA for females < 12 years was 30.7 ng/mL (Frisbee et al., 2009). When two water treatment districts in this area surrounding the industrial facility began using granular activated carbon filtration (GAC) in 2007, the average decrease in serum PFOA concentration over one year was 26% (Bartell et al., 2010). Concentrations of PFCs in untreated Ohio River water, measured in 2009, were reported by the Ohio River Valley Water Sanitation Commission (Emery et al., 2010). In single grab samples collected by ORSANCO in 2009, levels of PFOA progressively decreased with increasing distance downriver from Parkersburg WV to the Greater Cincinnati area, whereas levels of PFOS did not (Supplemental Table 5). We know of no other local industrial source in the Greater Cincinnati area which could provide inhalation exposure as has been described by other studies where the industrial source was within 4.5 km (2.8 miles) of the study population (Niisoe et al., 2010).

NKY and SWO are serviced by different water treatment systems, but both use the Ohio River as a primary water source. Prior to our serum sample collection, the water from the Ohio River in SWO, but not in the portion of NKY where the study girls were living, was treated with GAC filtration, which could be a plausible explanation for the differences we

found in serum concentrations of PFOA and PFOS. GAC treatment of Ohio River water by the SWO water treatment system began in January 1992 (Chowdhury, 2013; Westerhoff, 2009). Water at a second SWO water treatment plant, which originates from the Great Miami aquifer, is not treated with GAC (GCWW, 2012). Within the NKY water treatment system, there are two water treatment plants within the water distribution zone but serum concentrations were not related to which water treatment plant served the girls' residences. GAC treatment was initiated at both NKY plants in 2012 (Northern Kentucky Water District, 2012).

The correlations of the serum concentrations of the polyfluoroalkyl compounds with each other in the NKY girls, similar to those in the C-8 project community in southwestern Ohio, also suggest a common source for PFOA and the Ohio River as the water pathway. Pearson correlations of PFOA and PFOS were $R=0.75$ ($p < 0.0001$) in SWO girls and $R=0.38$ ($p=0.013$) in NKY girls (Supplemental Table 2). The moderate correlation of PFOA and PFOS found in NKY girls was reported as a Spearman's correlation of PFOA and PFOS ($R=0.30$) in the exposed population of the C-8 project (Frisbee, 2009). The strong correlations in SWO and SFBA girls ($R=0.60$) are expected for samples from the general population, consistent with that reported for American children (Olsen et al., 2004; Schecter et al., 2012), and in the NHANES 2003–2004 population (Calafat et al., 2007b). In NKY girls, the correlation between PFOA and PFHxS serum concentrations was minimal ($R=0.08$, $p=0.547$). Although this correlation in the C-8 project was moderate (Spearman $R=0.30$), it was much stronger in SWO ($R=0.55$, $p < 0.0001$) and SFBA girls ($R=0.49$, $p < 0.0001$). Correlations between PFOA or PFOS and the other PFCs did not substantially differ between SWO and NKY girls (Supplemental Table 2).

The findings from this study suggest that exposure to PFCs is widespread in our population of young girls, and varies by race or ethnic group. Despite the many health benefits of breast feeding to both child and mother, our study is the first to report that being breast fed is associated with higher serum PFC concentrations in the child. Our results suggest that a source upriver from the GC area may have contributed to exposures in girls from NKY through their drinking water, while girls in SWO had lesser exposure because of the use of granular activated carbon filters for water treatment. PFOA has been characterized as an emerging drinking water contaminant (Post et al., 2012), and water treatment systems able to remove PFOA and other emerging PFCs will reduce body burdens of both mother and child and may decrease the risk of health effects.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

- Antignac JP, Veyrand B, Kadar H, Marchand P, Oleko A, Bizec BL, Vandentorren S. Occurrence of perfluorinated alkylated substances in breast milk of French women and relation with socio-demographical and clinical parameters: Results of the ELFE pilot study. *Chemosphere*. 2013; 91:802–808. [PubMed: 23473698]
- Bartell SM, Calafat AM, Lyu C, Kato K, Ryan PB, Steenland K. Rate of decline in serum PFOA concentrations after granular activated carbon filtration at two public water systems in Ohio and West Virginia. *Environ Health Perspect*. 2010; 118(2):222–228. [PubMed: 20123620]
- Begley TH, White K, Honigfort P, Twaroski ML, Neches R, Walker. Perfluorochemicals: potential sources of and migration from food packaging. *Food Addit Contam*. 2005; 22(10):1023–1031. [PubMed: 16227186]
- Calafat AM, Kuklenyik Z, Reidy JA, Caudill SP, Tully JS, Needham LL. Serum concentrations of 11 polyfluoroalkyl compounds in the US population: Data from the National Health and Nutrition Examination Survey (NHANES). *Environ Sci Technol*. 2007a; 41(7):2237–2242. [PubMed: 17438769]
- Calafat AM, Wong L, Kuklenyik Z, Reidy JA, Needham LL. Polyfluoroalkyl chemicals in the US population: Data from the National Health and Nutrition Examination Survey (NHANES) 2003–2004 and comparisons with NHANES 1999–2000. *Environ Health Perspect*. 2007b; 115(11):1596–1602. [PubMed: 18007991]
- Caudill SP, Schleicher RL, Pirkle JL. Multi-rule quality control for the age-related eye disease study. *Stat Med*. 2008; 27(20):4094–4106. [PubMed: 18344178]
- CDC (Centers for Disease Control and Prevention). CDC Growth Charts. Atlanta, GA: Centers for Disease Control and Prevention; 2000. Available: <http://www.cdc.gov/growthcharts/>.
- CDC (Centers for Disease Control and Prevention). Atlanta, GA: Division of Laboratory Sciences, National Center for Environmental Health, Centers for Disease Control and Prevention; 2012. Fourth National Exposure Report, Updated Tables, September 2012. Available: http://www.cdc.gov/exposurereport/pdf/FourthReport_UpdatedTables_Sep2012.pdf. [Accessed May 17, 2013]
- Chowdhury, ZK.; Summers, RS.; Westerhoff, GP., et al. Activated carbon: Solutions for Improving Water Quality. Denver: American Water Works Association; 2013.
- Dai J, Li M, Jin Y, Saito N, Xu M, Wei F. Perfluorooctanesulfonate and perfluorooctanoate in red panda and giant panda from China. *Environ Sci Technol*. 2006; 40(18):5647–5652. [PubMed: 17007121]
- D'eon JC, Mabury SA. Is indirect exposure a significant contributor to the burden of perfluorinated acids observed in humans? *Environ Sci Technol*. 2011; 45(19):7974–7984. Epub 2011 Jun 1. [PubMed: 21630688]
- D'Hollander W, de Voogt P, De Coen W, Bervoets L. Perfluorinated substances in human food and other sources of human exposure. *Rev Environ Contam Toxicol*. 2010; 208:179–215. [PubMed: 20811865]
- Emery, E.; Spaeth, J.; Mills, M.; Nakayama, S.; Frommel, J. A Screening Study Investigating the Presence of Emerging Contaminants within the Ohio River Basin. Cincinnati, OH: The Ohio River Valley Water Sanitation Commission (ORSANCO) and United States Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory; 2010. <http://www.orsanco.org/images/stories/files/publications/biological/orsanco%20screening%20study%20investigating%20emerging%20contaminants%20reduced%20.pdf>. [Accessed May 17, 2013]
- Emmett EA, Shofer FS, Zhang H, Freeman D, Desai C, Shaw LM. Community exposure to perfluorooctanoate: Relationships between serum concentrations and exposure sources. *J Occup Environ Med*. 2006; 48(8):759–770. [PubMed: 16902368]
- Frisbee SJ, Brooks AP Jr, Maher A, Flensburg P, Arnold S, Fletcher T, et al. The C8 health project: Design, methods, and participants. *Environ Health Perspect*. 2009; 117(12):1873–1882. [PubMed: 20049206]
- Giesy JP, Kannan K. Global distribution of perfluorooctane sulfonate in wildlife. *Environ Sci Technol*. 2001; 35(7):1339–1342. [PubMed: 11348064]

- GCWW (Greater Cincinnati Water Works). [accessed 29 August 2013] Water Quality Report 2012. 2012. Available: <http://www.cincinnati.oh.gov/water/linkservid/2408CCBD-F4E7-CECD-6D65691748988CB0/showMeta/0/>
- Haug LS, Huber S, Beecher G, Thomsen C. Characterisation of human exposure pathways to perfluorinated compounds – comparing exposure estimates with biomarkers of exposure. *Environ Int.* 2011; 37(4):687–693. [PubMed: 21334069]
- Hiatt RA, Haslam SZ, Osuch J. The Breast Cancer and the Environment Research Centers: Transdisciplinary research on the role of the environment in breast cancer etiology. *Environ Health Perspect.* 2009; 117:1814–1822. [PubMed: 20049199]
- Hölzer J, Midasch O, Rauchfuss K, Kraft M, Reupert R, Angerer J, et al. Biomonitoring of perfluorinated compounds in children and adults exposed to perfluorooctanoate-contaminated drinking water. *Environ Health Perspect.* 2008; 116(5):651–657. [PubMed: 18470314]
- Jain R. Effect of Pregnancy on the levels of selected perfluoroalkyl compounds for females aged 17–30 years: Data from the national Health and Nutrition Examination Survey 2003–2008. *J Tox Env Health.* 2013; 76(7):409–421.
- Javins B, Hobbs G, Ducatman AM, Pilkerton C, Tacker D, Knox SS. Circulating maternal perfluoroalkyl substances during pregnancy in the C8 Health Study. *Environ Sci Technol.* 2013; 47:1606–1613. [PubMed: 23272997]
- Ji K, Kim S, Kho Y, Paek D, Sakong J, Ha J, Kim S, Choi K. Serum concentrations of major perfluorinated compounds among the general population in Korea: dietary sources and potential impact on thyroid hormones. *Environ Int.* 2012; 45:78–85. [PubMed: 22580293]
- Karrman A, Ericson I, van Bravel B, Darnerud PO, Aune M, Glynn A, Linell S, Lindstrom G. Exposure of Perfluorinated Chemicals through Lactation: Levels of matched human milk and serum and a temporal trend, 1996–2004, in Sweden. *Environ Health Perspect.* 2007; 115(2):226–230. [PubMed: 17384769]
- Kato K, Basden BJ, Needham LL, Calafat A. Improved selectivity for the analysis of maternal serum and cord serum for polyfluoroalkyl chemicals. *Journal of Chromatography A.* 2011; 1218:2133–1237. [PubMed: 21084089]
- Knobeloch L, Imm P, Anderson H. Perfluoroalkyl chemicals in vacuum cleaner dust from 39 Wisconsin homes. *Chemosphere.* 2012; 88(7):779–783. Epub 2012 Apr 27. [PubMed: 22542201]
- Kubwabo C, Kosarac I, Lalonde K. Determination of selected perfluorinated compounds and polyfluoroalkyl surfactants in human milk. *Chemosphere.* 2013; 91:771–777. [PubMed: 23498060]
- Kudo N, Kawashima Y. Toxicity and toxicokinetics of perfluorooctanoic acid in humans and animals. *J Toxicol Sci.* 2003; 28(2):49–57. [PubMed: 12820537]
- Kuklennyik Z, Needham LL, Calafat AM. Measurement of 18 perfluorinated organic acids and amides in human serum using on-line solid-phase extraction. *Anal Chem.* 2005; 77(18):6085–6091. [PubMed: 16159145]
- Lee YJ, Kim MK, Bae J, Yang JH. Concentrations of perfluoroalkyl compounds in maternal and umbilical cord sera and birth outcomes in Korea. *Chemosphere.* 2013; 90(5):1603–1609. [PubMed: 22990023]
- Lin AY, Panchangam SC, Lo CC. The impact of semiconductor, electronics and optoelectronic industries on downstream perfluorinated chemicals contamination in Taiwanese rivers. *Environ Pollut.* 2009; 157(4):1365–1372. [PubMed: 19117653]
- Llorca M, Farré M, Picó Y, Teijón ML, Alvarez JG, Barcelo D. Infant exposure to perfluorinated compounds: Levels in breast milk and commercial baby food. *Environment International.* 2010; 36:584–592. [PubMed: 20494442]
- Maisonet M, Terrell ML, McGeehin MA, Christensen KY, Holmes A, Calafat AM, Marcus M. Maternal concentrations of polyfluoroalkyl compounds during pregnancy and fetal and postnatal growth in British girls. *Environ Health Perspect.* 2012; 120(10):1432–1437. [PubMed: 22935244]
- Mondal D, Lopez-Espinosa MJ, Brmstrong B, Stein CR, Fletcher T. Relationships of perfluorooctanoate and perfluorooctane sulfonate serum concentrations between mother-child pairs in a population with perfluorooctanoate exposure from drinking water. *Environ Health Perspect.* 2012; 120(5):752–757. [PubMed: 22271837]

- New Jersey Department of Environmental Protection. Trenton, NJ: Bureau of Safe Drinking Water, Division of Water Supply, New Jersey Department of Environmental Protection; 2007. Determination of Perfluorooctanoic Acid (PFOA) in Aqueous Samples: Final Report. Available: http://www.nj.gov/dep/watersupply/pdf/final_pfoa_report.pdf. [Accessed September 4, 2013]
- Niisoe T, Harada KH, Ishikawa H, Koizumi A. Long-Term Simulation of Human Exposure to Atmospheric Perfluorooctanoic Acid (PFOA) and Perfluorooctanoate (PFO) in the Osaka Urban Area, Japan. *Environ Sci Technol*. 2010; 44(20):7852–7857.
- Northern Kentucky Water District. 2012 Water Quality Report. 2012 Available: <http://www.nkywater.org/ccr.pdf>.
- Ode A, Rylander L, Lindh CH, Kallen K, Jonsson BAG, Gustafsson P, Olofsson P, Ivarsson SA, Rignell-Hydbom A. Determinants of maternal and fetal exposure and temporal trends of perfluorinated compounds. *Environ Sci Pollut Res*. 2013 Epub 24 Feb 2013.
- Olsen GW, Burris JM, Ehresman DJ, Froehlich JW, Seacat AM, Butenhoff JL, et al. Half-life of serum elimination of perfluorooctanesulfonate, perfluorohexanesulfonate, and perfluorooctanoate in retired fluorocarbon production workers. *Environ Health Perspect*. 2007a; 115(9):1298–1305. [PubMed: 17805419]
- Olsen GW, Church TR, Hansen KJ, Burris JM, Butenhoff JL, Mandel JH, et al. Quantitative evaluation of perfluorooctanesulfonate (PFOS) and other fluorocarbon chemicals in the serum of children. *J Child Health*. 2004; 2(1):53, 53–76.
- Post GB, Cohn PD, Cooper KR. Perfluorooctanoic acid (PFOA), an emerging drinking water contaminant: A critical review of recent literature. *Environmental Research*. 2012; 116:93–117. [PubMed: 22560884]
- Schechter A, Malik-Bass N, Calafat AM, Kato K, Colacino JA, Gent TL, Hynan LS, Harris TR, Malla S, Birnbaum L. Polyfluoroalkyl compounds in Texas children from birth through 12 years of age. *Environ Health Perspect*. 2012 Apr; 120(4):590–594. [PubMed: 22182702]
- Von Ehrenstein OS, Fenton SE, Kato K, Kuklenyik Z, Calafat AM, Hines E. Polyfluoroalkyl chemicals in the serum and milk of breastfeeding women. *Reproductive toxicology*. 2009; 27:239–245. [PubMed: 19429402]
- Westerhoff, G.; Atha, K.; Pohlman, R. [accessed 4 April 2013] The Cincinnati GAC experience: Improving water quality and public trust in Ohio; Government Engineering March–April. 2009. p. 30–32. Available: <http://www.govengr.com/ArticlesMar09/Cincinnati.pdf>
- Windham GC, Pinney SM, Sjödin A, Lum R, Jones RS, Needham LL, Biro FM, Hiatt RA, Kushi LH. Body burdens of brominated flame retardants and other persistent organo-halogenated compounds and their descriptors in U.S. girls. *Environmental Research*. 2010; 110(3):251–257. Epub 2010 Mar 22; [PubMed: 20129604]
- Wolff MS, Teitelbaum SL, Lioy PJ, Santella RM, Wang RY, Jones RL, et al. Exposures among pregnant women near the World Trade Center site on 11 September 2001. *Environ Health Perspect*. 2001; 113(6):739–748. [PubMed: 15929898]
- Wolff MS, Teitelbaum SL, Pinney SM, Windham G, Liao L, Biro F, et al. Investigation of Relationships between Urinary biomarkers of phytoestrogens, phthalates, and phenols and pubertal stages in girls. *Environ Health Perspect*. 2010; 118(7):1039–1046. Epub 2010 Mar 22; [PubMed: 20308033]
- Xu Z, Fiedler S, Pfister G, Henkelmann B, Mosch C, Völkel W, Fromme H, Schramm KW. Human exposure to fluorotelomer alcohols, perfluorooctane sulfonate and perfluorooctanoate via house dust in Bavaria, Germany. *Sci Total Environ*. 2013 Jan 15; 443:485–490. Epub 2012 Dec 4. [PubMed: 23220138]

Highlights

- PFC serum concentrations were measured in 6–8 year-old girls.
- Study sites in Greater Cincinnati (N=353) and the San Francisco Bay Area (N=351).
- The duration of being breast fed was associated with higher serum PFOA.
- Lower PFOA in girls living in areas with granular activated carbon water treatment.

Figure 1.
Regression β Estimates for the Duration of Breastfeeding, by PFC and Site

Table 1

Study Population Characteristics

Characteristic	Greater Cincinnati		SF Bay Area		SF Bay Area	
	N	%	N	%	N	%
Number of Subjects	353	50.1%	351	49.9%	704	100.0%
Age at sample collection (years)						
6.0–6.9	59	16.7%	62	17.7%	121	17.2%
7.0–7.9	137	38.8%	176	50.1%	313	44.5%
8.0	157	44.5%	113	32.2%	270	38.4%
Race/Ethnicity						
Asian	5	1.4%	41	11.7%	46	6.5%
Black	119	33.7%	77	21.9%	196	27.8%
Hispanic	14	4.0%	84	23.9%	98	13.9%
White	215	60.9%	149	42.5%	364	51.7%
BMI For Age						
Below the 85th Percentile	250	70.8%	247	70.4%	497	70.6%
At or Above the 85th Percentile	103	29.2%	104	29.6%	207	29.4%
Sample Collection Time						
June–August	22	6.2%	27	7.7%	49	7.0%
September–May	331	93.8%	324	92.3%	655	93.0%
Ever Used Bottled Water^a	234	66.3%	238	67.8%	472	67.0%
Parity of mother at child's birth^a						
1	105	29.7%	142	40.5%	247	35.1%
More than 1	218	61.8%	209	59.5%	427	60.7%
	229	64.9%	329	93.7%	558	79.3%
Child Breast Fed^a						
Parental Education^a						
Grade School (1–8), Some High School (9–11) or a High School Diploma/GED	33	9.3%	65	18.5%	98	13.9%
Some College/Technical/Trade/Vocational School or an Associate's Degree	116	32.9%	110	31.3%	226	32.1%
Bachelor's Degree	103	29.2%	101	28.8%	204	29.0%
Master's Degree or Higher	83	23.5%	44	12.5%	127	18.0%

Note:

^a Data is missing for some participants

Table 2

Distribution of serum PFC concentrations (ng/mL) for study population and by site.

Analyte	N	% above LOD	Median (ng/mL)	Geometric Mean (GSD) ^b (ng/mL)		Range (ng/mL)	
				Mean	Max	Min	Max
Total Study Population							
Et-PFOSA-AcOH	704	14.6%	<LOD			<LOD	3.1
Me-PFOSA-AcOH	704	95.6%	0.7	0.7 (2.3)		<LOD	14.6
PFDeA ^a	641	77.4%	0.3	0.3 (1.7)		<LOD	1.2
PFHxS	704	99.9%	3.5	3.9 (2.9)		<LOD	192.0
PFNA	704	99.9%	1.5	1.6 (1.6)		<LOD	15.5
PFOSA	704	14.5%	<LOD			<LOD	1.6
PFOS	704	99.9%	13.1	13.2 (1.8)		<LOD	104.0
PFOA	704	99.9%	6.4	6.7 (1.7)		<LOD	55.9
Cincinnati Only							
Et-PFOSA-AcOH	353	14.4%	<LOD			<LOD	1.2
Me-PFOSA-AcOH	353	94.9%	0.7	0.7 (2.4)		<LOD	8.1
PFDeA ^a	293	75.8%	0.3	0.3 (1.7)		<LOD	1.0
PFHxS	353	99.7%	5.2	5.1 (2.9)		<LOD	185.0
PFNA	353	99.7%	1.4	1.4 (1.5)		<LOD	6.8
PFOSA	353	19.0%	<LOD			<LOD	0.7
PFOS	353	99.7%	13.6	13.2 (1.9)		<LOD	96.0
PFOA	353	99.7%	7.3	7.8 (1.9)		<LOD	55.9
SF Bay Area Only							
Et-PFOSA-AcOH	351	14.8%	<LOD			<LOD	3.1
Me-PFOSA-AcOH	351	96.3%	0.6	0.7 (2.2)		<LOD	14.6
PFDeA ^a	348	78.7%	0.3	0.3 (1.7)		<LOD	1.2
PFHxS	351	100.0%	2.3	3.0 (2.9)		0.3	192.0
PFNA	351	100.0%	1.6	1.7 (1.7)		0.6	15.5
PFOSA	351	10.0%	<LOD			<LOD	1.6
PFOS	351	100.0%	12.5	13.2 (1.7)		3.8	104.0
PFOA	351	100.0%	5.8	5.7 (1.4)		2.4	18.2

Notes:^a PFDeA was not measured in the samples sent to CDC as part of the pilot study (for both sites, N=55) nor in the additional 30 samples sent from Cincinnati for the follow-up study

^b Geometric means were not calculated for analytes where the proportion of samples with values below the LOD was greater than 40%

Table 3

Determinants of PFOA serum concentration in the San Francisco Bay Area

	Full Model		Final Model	
	β estimate	p-value	β estimate	p-value
Total Number of Girls			351	351
Girls Used in Analysis			316	347
R-Square		0.10		0.08
Model Parameters				
Intercept	2.32	0.01	1.99	0.03
Log Age at Sample (months)	-0.14	0.50	-0.08	0.70
Highest Provider Education				
<i>Grade School, Some High School, or High School Diploma/GED</i>	-0.11	0.07		
<i>Bachelor's Degree</i>	-0.02	0.67		
<i>Master's Degree or Higher</i>	0.06	0.39		
<i>Some College/Technical/Trade/Vocational School or an Associate's Degree</i>	0.00			
Race/Ethnicity				
<i>Black</i>	-0.15	0.01	-0.14	0.01
<i>Hispanic</i>	-0.06	0.28	-0.11	0.02
<i>Asian</i>	-0.22	0.00	-0.24	0.00
<i>White</i>	0.00		0.00	.
Breastfeeding Duration ^a				
<i>Breastfed for 1–3 Months</i>	0.12	0.18	0.18	0.04
<i>Breastfed for 4–6 Months</i>	0.17	0.07	0.22	0.02
<i>Breastfed for 7–9 Months</i>	0.12	0.22	0.19	0.05
<i>Breastfed for 10–12 Months</i>	0.16	0.09	0.23	0.01
<i>Breastfed for 13+ Months</i>	0.15	0.08	0.20	0.02
<i>No Breastfeeding</i>	0.00		0.00	
Parity				
<i>1</i>	-0.03	0.51		
<i>2+</i>	0.00			

Note:

$\alpha_{\text{Test for Linear Trend: Full Model p-value}=0.1033; \text{Final Model p-value}=0.0209$

Table 4

Determinants of PFOA serum concentration in Greater Cincinnati

	Full Model		Final Model	
	β estimate	p-value	β estimate	p-value
Total Number of Girls	353		353	
Girls Used in Analysis	237		250	
R-Square	0.6484		0.6366	
Model Parameters				
Intercept	5.811	<.0001	5.863	<.0001
Years drinking from a water distribution zone				
Cumulative NKY Water Years	0.141	<.0001	0.140	<.0001
Cumulative Bolton Water Years	0.006	0.6462	0.005	0.6879
Cumulative Miller Water Years	-0.002	0.9035	-0.006	0.6677
Log Age at Sample (months)	-0.889	0.0009	-0.899	0.0004
Highest Provider Education				
Grade School, Some High School, or High School Diploma/GED	0.131	0.2278		
Bachelor's Degree	0.058	0.3388		
Master's Degree or Higher	0.123	0.0837		
Some College/Technical/Trade/Vocational School or an Associate's Degree	0.000			
Breastfeeding Duration ^a				
Breastfed for 1–3 Months	0.150	0.0363	0.139	0.0387
Breastfed for 4–6 Months	0.135	0.0721	0.174	0.0126
Breastfed for 7–9 Months	0.178	0.0483	0.201	0.0199
Breastfed for 10–12 Months	0.292	0.0016	0.308	0.0004
Breastfed for 13+ Months	0.488	<.0001	0.537	<.0001
No Breastfeeding	0.000		0.000	
Bottled Water Use				
Yes	-0.052	0.3537		
No	0.000			
Parity				
1	-0.038	0.4743		

2+ 0.000

Note:

α_{Test} for Linear Trend: Full Model p-value < 0.0001; Final Model p-value < 0.0001