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*Published in:*
Chemosphere

*DOI:*
10.1016/j.chemosphere.2005.06.063

*Publication date:*
2006

*Document version*
Publisher's PDF, also known as Version of record

*Citation for pulished version (APA):*
Barr, D. B., Weihe, P., Davis, M. D., Needham, L. L., & Grandjean, P. (2006). Serum polychlorinated biphenyl and organochlorine insecticide concentrations in a Faroese birth cohort. Chemosphere, 62, 1167-1182. DOI: 10.1016/j.chemosphere.2005.06.063

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# Serum polychlorinated biphenyl and organochlorine insecticide concentrations in a Faroese birth cohort

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**ABSTRACT**

A prospective birth cohort of 1,022 participants was established in the Faroe Islands over a 21-month period during 1986–1987. We collected questionnaire data on potential persistent organic pollutant (POP) concentration predictors, such as duration of breastfeeding and blubber consumption. To assess the participants' exposure from *in utero* to 14 years of age to polychlorinated biphenyls (PCBs) and the insecticide p,p'-DDT and its primary degradate p,p'-DDE, we measured 37 PCB congeners in 316 umbilical cord samples taken from participants at birth, in 124 serum samples collected from participants at approximately 7 years of age, and in 795 serum samples collected from participants at 14 years of age. Measurements of higher chlorination PCB congeners made on individuals' serum samples collected at 7 years and 14 years were highly correlated (typically $r>0.5$, $p>0.01$), although their concentrations at 7 years were generally two to three times higher than at 14 years. Similarly, umbilical cord PCB concentrations were correlated with PCB concentrations in both 7- and 14-year serum samples. Sex-specific differences in higher chlorination PCB and p,p'-DDE concentrations were found at 14 years but not at 7 years, although a sex interaction with blubber consumption and nursing duration was observed at both ages. Both duration of breastfeeding and consumption of blubber were significant predictors of serum ΣPCB concentrations at 7 and 14 years. Multivariate analyses showed that breastfeeding duration was the primary contributor to serum ΣPCB concentrations at 7 years, and blubber consumption was the primary contributor at 14 years. These data suggest that infant exposures from breastfeeding were sufficiently large so that continued exposures to PCBs, p,p'-DDT, and p,p'-DDE through the diet have not fully diluted their contribution to the ΣPCB and p,p'-DDE body burden of the children.

Keywords: PCB; organochlorine; DDE; serum; Faroe Islands; children; breastfeeding; blubber

## INTRODUCTION

Polychlorinated biphenyls (PCBs) and organochlorine insecticides are man-made chemicals that are pervasive in our environment (Erickson, 2001). Although originally produced for a variety of commercial applications, such as heat transfer liquids or dielectric fluids, PCBs remain persistent in the environment either from use or careless disposal practices (Erickson, 2001). Similarly, the extensive use of the insecticide p,p'-dichlorodiphenyltrichloroethane (p,p'-DDT) in the mid-20th century for vector-borne disease control and residential and agricultural applications has created a reservoir of these chemicals in our environment (Barr and Needham, 2002). p,p'-DDT and most PCBs are considered persistent organic pollutants (POPs) in the environment; thus, they have long environmental half-lives, undergo long range transport, and tend to bioaccumulate and bioconcentrate in the fatty tissues of humans and other animals (Borga et al., 2001; Strandberg et al., 1998; United Nations Environment Program, 2001).

Serum or plasma concentrations of PCBs have been used as exposure biomarkers in studies evaluating exposure sources and potential adverse health effects (Dorgan et al., 1999; Grandjean et al., 2001a; Grandjean et al., 2001b; Hoyer et al., 1998). Similarly, p,p'-DDT analogues, primarily its main degradate and metabolite p,p'-dichlorodiphenyldichloroethene (p,p'-DDE), have been measured in serum or plasma as markers of exposure to p,p'-DDT or p,p'-DDE. Because p,p'-DDE and many PCB congeners have long biologic half-lives (Shirai and Kissel, 1996), their serum or plasma concentrations are believed to represent a long-term accumulated burden. However, their concentrations can be altered by changes in the diet and changes in the volume of distribution and storage matrices, such as blood and adipose tissue. For breastfed children, intake via breast milk usually represents a much greater exposure pathway than other pathways during the early years of childhood (LaKind and Filser, 1999; Schecter et al., 1998). However, the impact of breastfeeding on serum PCB and p,p'-DDE concentrations will tend to disappear with time, as contributions from other sources are accumulated, and because the child grows and expands the distribution volume (Klaassen, 2001).

Several studies have investigated serum or plasma concentrations of POPs in residents of the Faroe Islands (Burse et al., 2000; Grandjean et al., 1995; Grandjean et al., 2001a; Grandjean et al., 2001b; Steuerwald et al., 2000). The Faroese are a small, stable, and relatively homogenous North Atlantic population of Scandinavian origin (Grandjean et al., 1995). Many Faroese include pilot whale as a traditional food item in their marine diet. Pods of this small whale species are occasionally caught, and the meat and blubber are shared locally (Bloch et al., 1990).

PCB concentrations in whale blubber are high, ranging from 17 μg/g to 39 μg/g wet weight (Fromberg et al., 1999). A questionnaire study of Faroese adults showed a mean daily consumption of 7 g of blubber, 12 g of pilot whale muscle, and 72 g of fish (Vestergaard and Zachariassen, 1987); thus, the potential for dietary exposure to these chemicals is high. In addition, exposure to infants from breastfeeding is high. In a previous study of four Faroese milk pools collected in 1987, the ΣPCB concentrations were 1.8 μg/g–3.5 μg/g lipid with the largest contributors to total milk PCBs being congeners 153, 180, and 138 (Grandjean et al., 1995). Subsequent analyses of milk and maternal serum have confirmed the high levels of potential exposures to infants (Steuerwald et al., 2000).

We measured PCB and p,p'-DDE concentrations in 316 umbilical cords collected at delivery in a prospective cohort of Faroese children. In addition, we measured serum concentrations of PCBs in a subset of the same children at two different points of time. We measured PCBs in 124 serum samples collected from this Faroese cohort at age 7 years and 795 serum samples collected at age 14 years. We also measured p,p'-DDE in the samples collected at 14 years. We report PCB and p,p'-DDE distributions and intercorrelations in this cohort. In addition, we evaluate the biologic measurements in relation to two of the potential exposure pathways: breastfeeding and blubber consumption.

## MATERIALS AND METHODS

### Study Cohort

A cohort of 1,022 singleton births was assembled in the Faroe Islands during a 21-month period during 1986–1987 (Grandjean et al., 1992). All protocols were reviewed and approved by the Faroese ethical review committee and were found to comply with international institutional guidelines for the protection of human subjects. According to routine obstetric procedures, the umbilical cord was clamped one minute after delivery. A 5-cm piece of the cord was cut off with a pair of scissors, stored in a glass vial, and frozen. Sufficient tissue for analysis was available from 316 participants. A brief questionnaire asked for the number of dinners of pilot whale meat consumed per month during pregnancy (Grandjean et al., 1992).

As an integral part of the Faroese health care system, district health nurses visit the family soon after a child has been born and repeatedly during the following months. The nurses completed a brief questionnaire that included questions on the duration of exclusive and partial breastfeeding. Because of a shortage of district health nurses, this information was incomplete. We obtained questionnaire information for 583 children. For the remainder of the children, this information was sought from the mothers in connection with the examination of the child at age 7 years.

When the cohort members were about 7 and 14 years old, they were invited for a thorough health examination with voluntary venipuncture to collect blood samples for PCB and p,p'-DDE measurements (Grandjean et al., 2001b). Questionnaire information was obtained from participants at both ages about the frequency of whale meat dinners and blubber consumption. A total of 917 of the children at age 7 years completed the examinations, but sufficient serum for PCB measurements was available for only 124 children. A total of 878 fourteen-year-old subjects was examined, and a blood sample was obtained from 795 subjects.

After collection of the blood samples, the blood was allowed to clot for approximately 30 minutes and then spun at 10,000 rpm for 30 minutes to separate the serum portion of the blood. The serum was transferred to clean cryovials and hand-carried frozen to the Centers for Disease Control and Prevention. Samples were stored at -70ºC until analyzed.

### Laboratory Analysis

Umbilical cord samples were analyzed using the method of Burse et al. (Burse et al., 2000). The analytical method consisted of homogenization of the umbilical cords,

partitioning the PCBs into an organic solvent, followed by a microsilica gel column chromatography cleanup. Umbilical cord extracts were analyzed using dual-column capillary gas chromatography with electron capture detection. Quantification was achieved using 1,2-dichloronaphthalene as an internal standard, but it was added just prior to gas chromatography. Thus, the final results were not corrected for recovery. The median recovery of the PCB congeners measured was 77%. Several quality control parameters were followed to monitor the performance of the method.

Serum samples collected from subjects at 7 years and 14 years of age were analyzed using two different analytical methods. Samples collected from 7-year-old participants were typically analyzed in batches of 10, including 1 quality control sample and one blank sample using an established method (DiPietro et al., 1997). Each serum sample (1 g) was enriched with isotopically labeled analogues of PCB congeners and then equilibrated. The serum was extracted using C18 solid phase extraction then cleaned over a series of columns (neutral silica and carbon) connected in tandem. The PCBs were eluted from the carbon column in the forward direction using dichloromethane: cyclohexane (1:1). After evaporation, we used gas chromatography-high resolution mass spectrometry (10,000 resolution) with isotope dilution quantification to analyze the samples.

Samples collected from 14-year-old subjects were typically analyzed in batches of 20 unknown samples using methods previously established (Barr et al., 2003). We included quality control materials and blank samples in each analytical run to ensure proper operation of the method. Briefly, 1 g serum was enriched with isotopically labeled analogues of the target analytes and then applied to hydromatrix in a stainless steel extraction cell. We lyophilized the serum to remove all traces of water and extracted the PCBs into 20% dichloromethane in hexane using pressurized fluid extraction. The extract was purified during extraction with a Florisil® bed in the extraction cell to capture polar interferents. The cleaned extract was further purified using high resolution gel permeation chromatography and then concentrated for analysis. We analyzed the extracts using gas chromatography-high resolution mass spectrometry at 10,000 resolution with isotope dilution calibration.

Thirty-seven biologically relevant PCB congeners and the insecticide p,p'-DDE were measured in each sample. The PCB congeners measured were 11, 18, 28, 44, 49, 53, 74, 87, 99, 105, 110, 118, 128, 138, 146, 149, 151, 153, 156, 157, 158, 167, 170, 172, 177, 178, 180, 183, 187, 189, 194, 195, 196, 201, 203, 206, and 209. Of these congeners, two isomeric pairs, 138 and 158, and 196 and 203, were indistinguishable because they coeluted and were not differentiated by mass; thus, a single concentration was reported for congeners 138/158 and 196/203. Although different methods were used for analyzing the serum samples collected at the two time points, agreement of the two methods was positively established to be within an average of ± 4%. The average limit of detection (LOD) of the individual PCB congeners at 7 years was 5 pg/g serum and at 14 years was 0.98 ± 1.24 pg/g serum. The average LOD of individual PCB congeners in umbilical cord was 77.5 ± 44 pg/g cord. The average LOD of p,p'-DDE in umbilical cord and 14-year serum samples was 60 pg/g cord and 1.45 ± 1.80 pg/g serum, respectively; p,p'-DDE was not measured at 7 years. The relative standard deviation of each PCB congener in positive control samples was generally below 20%.

We used standard clinical enzymatic methods (Roche Chemicals, Indianapolis, Indiana) to determine total cholesterol and triglycerides in serum. Total lipids were calculated using the summation method reported by Phillips et al. (Phillips et al., 1989a). Because limited serum was available from the collection of samples from 7-year-old participants, lipids were not determined for these samples. Instead, each PCB congener was lipid-adjusted using an average lipid value representing 0.6% of the serum. Total lipids in umbilical cords were determined gravimetrically (Burse et al., 2000)

The laboratory and all analytical methods were certified according to guidelines set forth in the Clinical Laboratory Improvement Amendment of 1988.

**Statistical Analysis**

All data were evaluated using SAS statistical software release 8.02 (SAS Institute, Cary, North Carolina) or SPSS Sigma Plot version 7.0 (RockWare Inc., Golden, Colorado). Pearson correlation analyses were used to determine intercorrelations of the PCB congeners with a detection frequency greater than 90%. A general linear model (GLM) was used to determine the least squares geometric means (LSGMs) of each variable tested while correcting for covariates. For statistical analyses where the specific congener was detected in at least half of the samples analyzed, all values below the LOD were substituted with a value equal to the LOD divided by the square root of 2. For those congeners that were detected less frequently, values below the LOD were substituted with zero. Other methods were also evaluated for the treatment of data below the LOD (i.e., imputing all values with LOD/square root of 2, imputing all values to zero, or imputing all values with LOD/2). Similar results were obtained regardless of the method used, likely because of the relatively high frequency of detection for most PCB congeners. The variables tested in the GLM analysis were duration of breastfeeding, regular blubber consumption at age 7 or 14 years, body mass index (BMI), and sex. BMI and nursing duration were evaluated as categorical and continuous variables, both giving similar findings. In the final model, all variables were categorical except BMI which was continuous. Almost all children within the cohort were breastfed to some extent. Nursing duration was considered short if the child was nursed exclusively up to 1 month and the total time nursed did not exceed 2 months. For evaluation of the general distribution and GLM of low chlorination PCBs, PCB congeners 18, 28, 44, 49, 53, and 74 were summed. For evaluation of the general distribution and GLM of high chlorination PCBs, PCB congeners 118, 138/158, 146, 153, 170, 180, 187, 194, and 201 were summed. Three different approaches were used to determine ΣPCB concentrations: (1) the 11 PCB congeners with the highest median concentrations (i.e., PCB 74, 99, 118, 138/158, 146, 153, 170, 180, 187, 194, and 201), which also represented the most frequently detected congeners, were summed; (2) PCB congeners 138/158, 153, and 180 were added and the sum was multiplied by 2 (Grandjean et al., 1995); and (3) using the equation of Schulte and Malisch (Schulte and Malisch, 1984): ΣPCB = ((PCB138*7.03)+(PCB153*6.64)+(PCB180*11.86))/3. The latter approach for summing PCB concentrations was also evaluated because this equation is still used to derive ΣPCB in some studies. All PCB and p,p'-DDE concentration data were $\log_{10}$ transformed prior to analysis, except for generation of distribution data. Geometric means (GM) were reported only for PCB congeners that were detected in more than 50% of the samples analyzed. Statistical significance was set at $p \leq 0.05$ (two-sided). Differences were

considered marginally significant when the p value was less than 0.10 but greater than 0.05.

**RESULTS**

Table 1 presents characteristics of the children in the Faroese cohort in 1986–1987 and those of the children whose serum samples were analyzed for PCBs at each time point. The cohort consisted of approximately equal numbers of males and females. More than 95% of the children were breastfed to some extent with the average nursing time being about 7 months. By age 7 years, almost 50% of the children regularly consumed blubber; by age 14 years, the percentage had increased to 63%. About 30% consumed blubber regularly at both time points. The average BMIs at ages 7 and 14 years were 16 $kg/m^2$ and 20 $kg/m^2$, respectively.

The distributions of selected PCB congeners and p,p'-DDE in umbilical cord and children at age 7 and age 14 years are shown in Table 2 (wet weight; pg/g serum) and Table 3 (lipid-adjusted; ng/g lipid). The ΣPCB concentrations evaluated using three different approaches were reasonably similar, although the summation of the 11 most prevalent congeners was consistently lower for each person than the other estimation methods (Table 2). The sum of the predominant PCB congeners 138/158, 153, and 180 comprised 75 ± 13%, 65 ± 9%, and 65 ± 4% of the total PCB concentration (calculated as Σ of 11 predominant congeners) for umbilical cord and serum from 7- and 14-year-olds, respectively. The percent contribution of each PCB congener to the ΣPCB concentrations in the serum of 7- and 14-year-olds is shown in Figure 1. The PCB congener 153 was detected in the highest concentrations, followed by PCBs 180, 138/158, and 187. The patterns we found were similar regardless of whether the samples were stratified by potential exposure pathways (blubber consumption or breastfeeding duration).

The intercorrelations of the p,p'-DDE and PCB congeners detected in more than 90% of the analyzed samples from the 14-year-olds are shown in Table 4. In general, the most highly chlorinated PCBs, especially pentachlorinated and higher, were strongly intercorrelated, but showed poor correlations with the less chlorinated PCBs. p,p-DDE was highly correlated with the mono-*ortho* substituted PCBs 105 and 118; however, the correlations with PCBs 153 and 180 were much lower. Similar correlations were seen among the PCBs measured from subjects 7 years of age; however, the magnitude of the intercorrelations among the less chlorinated PCBs was much lower. Too few of the lower chlorination congeners were detected in sufficient quantity to do a similar analysis on umbilical cord data; however, the higher chlorination PCBs showed similar intercorrelations.

Most PCB congeners concentrations measured from participants at age 7 were highly correlated with measurements from those at age 14 (Table 5). Similarly, many PCB congeners in umbilical cords were correlated with serum concentration in 7- and 14-year-old subjects. The higher chlorination PCB congeners, including the mono-*ortho* chlorinated congeners, had significant correlations greater than 0.50 (Figure 2). The average correlation among serum samples was 0.55; however, the magnitude of PCB concentrations measured in serum samples collected from participants at 7 years of age was about two to three times the concentrations measured in the same children at 14 years of age. The average correlations between umbilical cord PCB concentrations and PCB concentrations at 7 or 14 years were 0.24 and 0.32, respectively. The correlation between

p,p'-DDE concentrations in umbilical cord and 14-year serum samples was 0.39. All correlations in serum and umbilical cords were similar regardless of whether the data were evaluated on a lipid adjusted or wet weight basis.

We evaluated the average concentrations of p,p'-DDE and PCB congeners, both individually and as groupings based upon their intercorrelations, and their association with nursing duration, blubber consumption, and sex (Table 6). The coefficients for each variable in the GLM analysis for data for participants at ages 7 and 14 years are shown in Table 7. For ΣPCB concentrations determined using any of the three approaches on samples collected from 14-year-old subjects, we observed a strong positive association with blubber consumption. Those children who reported at ages 7 and 14 years of age to have consumed blubber regularly had higher ΣPCB concentrations (885 ng/g lipid) than those who reported at one age (either at 7 or 14 years) to have consumed blubber regularly (613 ng/g lipid) and those who reported at both ages not to have consumed blubber at all (373 ng/g lipid); the trend and individual differences were significant ($p<0.0001$). Similarly, children who reported at ages 7 and 14 years to have consumed blubber regularly had higher p,p'-DDE concentrations (781 ng/g lipid) than those who reported at one age (either 7 or 14 years) to have consumed blubber regularly (494 ng/g lipid) and those who reported at both ages not to have consumed blubber at all (278 ng/g lipid); the trend and individual differences were significant ($p<0.0001$). For blubber consumption at one time point, the association with ΣPCB concentrations and p,p'-DDE was independent of which time point (i.e., 7 or 14 years) was indicated. When the individual PCB congeners were considered, the most highly chlorinated congeners, such as 105, 118, 153, 138/58, 180, and 187 that are prevalently found in humans showed significant associations with blubber consumption. For example, PCB 153 mean concentrations were 276 ng/g lipid for those who reported at ages 7 and 14 years to consume blubber regularly, 200 ng/g lipid for those who reported at only one age to consume blubber regularly, and 119 ng/g lipid for nonconsumers (individual p values $<0.001$ and $p<0.001$ for trend).

When grouped by PCB homologs, associations between blubber consumption and total homolog PCB concentrations were clearly apparent for tetrachlorinated PCBs and higher, but generally lacking for the trichlorinated homologs. Regular blubber consumption was also associated with ΣPCB concentrations in the samples collected from 7-year-old subjects. The total PCB concentration of those who consumed blubber (1,140 ng/g lipid) was clearly larger than the concentration of those who did not consume blubber (875 ng/g lipid) ($p=0.008$). The effect of blubber consumption on the concentrations of the higher chlorination PCBs was also significant (1,078 ng/g versus 825 ng/g lipid; $p=0.008$); however, the difference in lower chlorination PCBs was not significant (33 ng/g versus 28 ng/g lipid; $p=0.17$). The mono-*ortho* chlorinated PCBs 105 and 118 were significantly associated with blubber consumption ($p=0.0018$ and $p=0.0064$, respectively).

Differences in PCB and p,p'-DDE concentrations due to nursing duration were clearly apparent in samples collected from participants at both 7 years and 14 years. Children who nursed for a shorter duration had lower concentrations of total PCBs than did children who nursed for a longer duration in samples collected from both 7-year-old participants (1,200 ng/g versus 752 ng/g lipid; $p<0.0001$) and 14-year-old participants (654 ng/g versus 448 ng/g lipid; $p<0.0001$). Children who nursed for a shorter duration

had lower concentrations of p,p'-DDE than did children who nursed for a longer duration in samples collected at 14 years (486 ng/g versus 399 ng/g lipid; $p<0.0075$). Multivariate analyses showed that breastfeeding duration was a greater contributor to serum total PCB concentrations at 7 years, while blubber consumption was the greater contributor at 14 years. The effect of nursing duration on the concentration of total PCBs was primarily from the contributions of the higher chlorination PCBs. Concentrations of the lower chlorination PCBs were not associated with breastfeeding at either age ($p>0.1$). In addition, the mono-*ortho* chlorinated PCBs 105 and 118 ($p=0.66$ and 0.22, respectively) were not associated with nursing duration at 14 years of age; however, PCB118 was associated with nursing duration at 7 years of age ($p=0.0192$), but PCB105 was not ($p=0.11$).

PCB concentrations were significantly different between males and females at age 14, but no differences were observed at age 7. Similarly, p,p'-DDE concentrations were significantly higher in males than in females. However, when evaluating the demographic characteristics collectively, we observed a statistically significant sex interaction in the serum samples collected from both 7- and 14-year-old subjects (Figures 3a and 3b). Not surprisingly, in the samples from both the 7- and 14-year-olds, both males and females who nursed for a longer duration and consumed blubber as children and adolescents had significantly higher ΣPCB concentrations than all other groups ($p<0.0001$). At 7 years, both nursing and blubber consumption were individual predictors of ΣPCB concentrations, although nursing alone appeared to be a larger contributor to the ΣPCB concentrations than blubber consumption. Possessing both predictor variables did not result in a cumulative estimate of ΣPCB concentrations. At 7 years, nursing was a much larger contributor to ΣPCB concentrations in females than was blubber consumption. Females at 14 years showed a similar pattern as females at 7 years, though the overall concentrations of PCBs were much lower than those in males. Conversely, in 14-year-old males, consuming blubber at only one time point or nursing for longer durations were similarly associated with ΣPCB concentrations. Likewise, ΣPCB concentrations were similar when possessing any two predictor variables (i.e., blubber consumption at two time points; nursing a long duration and consuming blubber at one time point). This sex interaction was also observed for p,p'-DDE at 14 years (Figure 4).

## DISCUSSION

The concentrations of individual PCB congeners and ΣPCBs measured in serum in the present study were generally higher than those reported in samples taken from the general population elsewhere in Europe and in North America. For example, the 95th percentiles of ΣPCB concentrations in adolescents and adults in the U.S. population during 1999–2000 were about half of the GM concentrations in 7-year-old Faroese children, whether compared on a lipid adjusted or wet weight basis (Needham et al., 2004), and the GM of 14-year-old Faroese children was similar to the upper bound of the U.S. data. Similarly, the Faroese children median ΣPCB concentrations were much higher than median concentrations in some of the more recent U.S. studies evaluating targeted populations (Darvill et al., 2000; Fitzgerald et al., 2004; Hoppin et al., 2000; Korrick, 2004). Faroese child median ΣPCB concentrations were similar to those of

other recent fish-eating populations and non-fish-eating populations that were sampled when PCBs were still in use (Jacobson and Jacobson, 1996; Longnecker et al., 2003). The concentrations, though, were about one half of those observed in samples collected from Great Lakes fish eaters around the time of discontinuation of PCB manufacturing in the United States (Humphrey et al., 2000).

Of interest, larger PCB concentrations, roughly a factor of 2–3, were observed in samples collected from 7-year-olds than in samples from the same children at 14 years of age. This is consistent with those results obtained by Jacobson and Jacobson. (Jacobson and Jacobson, 1996; Jacobson and Jacobson, 2001a) where serum concentrations at 4 years of age were about four times greater than those collected at 11 years of age. Because the serum lipid content is relatively similar at these age periods (Behrmen et al., 2000), the difference is unlikely caused by age-related differences in lipid concentrations. However, as a child grows and the blood volume and distribution/deposition matrices expand, the concentrations of contaminants in serum are often diluted (Jacobson and Jacobson, 2001a). Likely, the differences we observed between the 7-year time points were due at least partially to this phenomenon. Given that the median weight at 14 years of age (53.9±11 kg) in our cohort was about double of that at age 7 (23.9±5), this explanation seems plausible, especially for the higher chlorination PCBs. However, for the low chlorination PCB congeners, metabolism and elimination must be considered a supplementary explanation.

The most prevalent PCBs found in our population are the same as reported elsewhere. However, the congener pattern was slightly different than that reported for Michigan fish eaters in which the highest concentrations observed were for PCB138. Regardless, at least eight of the most prevalent PCB congeners detected in the Faroese cohort were the same as those most frequently observed in most populations (Hoppin et al., 2000; Humphrey et al., 2000; Jacobson and Jacobson, 1996; Longnecker et al., 2003). Furthermore, the patterns of the higher chlorination PCBs were similar to those described in long-finned pilot whale pods caught at the Faroes (Dam and Bloch, 2000). The lower chlorination PCB concentrations represented a larger proportion of the ΣPCB concentration in pilot whales than in humans, which is consistent with the difference between the fish and human half-lives of these PCBs (Gooch and Hamdy, 1982; Phillips et al., 1989b).

As would be expected, concentrations of the higher chlorination PCBs were highly correlated. Interestingly, the concentrations of PCBs of lower chlorination were highly intercorrelated with each other as well. This is in contrast to the observations of Gladen et al. (Gladen et al., 2003), who reported no correlations for the lower chlorination PCBs, albeit their analysis was on a data set generated from breast milk samples. Our data suggest that the lower chlorination PCBs are likely handled differently in the body than higher chlorination PCBs. Lower chlorination PCBs, although minimally metabolized and excreted in fish, are more rapidly metabolized and eliminated in humans (Gooch and Hamdy, 1982; Phillips et al., 1989b). Thus, those lower chlorination PCBs that were highly correlated likely had similar half-lives that were very different from those of the higher chlorination PCBs. The pattern of PCB congeners in pilot whale blubber (Fig. 1) suggests that blubber ingestion resulted in much lower serum concentrations of lower chlorination PCBs than of congeners with a greater degree of chlorination. This difference could very well be due to a difference in toxicokinetics, i.e.,

a more rapid elimination of the lower chlorination congeners.

Because of the high correlation between selected higher chlorination PCB congeners (e.g., 74, 99, 105, 118, 138/158, 153, 180, 170), one or more of them would be reasonably representative of the ΣPCB concentration. PCB 153 comprised about 25% of the ΣPCB concentration. The sum of 138/158, 153, and 180 comprised about 65% of the ΣPCB concentration and about 74% of the total umbilical cord concentration. Those figures are somewhat higher than the 50% contribution of these congeners observed in Faroese breast milk pools, perhaps in part because the milk pools included several additional congeners not detected in the analyses presented here (Grandjean et al., 1995). Thus, it is not surprising that the summation method that doubles the sum of PCBs 138/158, 153, and 180 and the Schulte and Malisch summation method overestimates the ΣPCB concentration. Instead, multiplying this sum by a factor of about 1.5 would more closely approximate the true ΣPCB concentration.

Though the umbilical cord lipids were low when compared to the lipids in serum samples (i.e., 20%–30% of the lipid content of serum samples), we still observed significant associations between ΣPCB concentrations measured in all samples at all time points. Previous analyses had already shown that PCB concentrations in cord and cord blood correlated well (Grandjean et al., 2001b). Because the umbilical cord data, likely representative of maternal exposures, were more highly associated with the serum concentrations from participants 14 years of age than those from participants 7 years of age, the data suggest that Faroese adolescents share exposures, likely dietary, with their mothers.

Both blubber consumption and nursing duration were significant predictors of ΣPCB concentrations at ages 7 years and 14 years and p,p'-DDE concentrations at 14 years. A significant association between ΣPCB concentrations and blubber consumption was expected when data were stratified in the samples collected from participants at ages 7 years and 14 years. Because as children grow, and in particular as they enter adolescence, the amount of fatty tissues (e.g., adipose tissue, blood serum) available for distribution increases, often disproportionately to age, we would have expected the changes in distribution to obscure any remaining differences based upon nursing duration. Therefore, the clear differentiation between adolescents who were breastfed as infants for a long duration from those who were breastfed for a short duration was unexpected, though certainly consistent with PCB findings in prepubescents (Jacobson and Jacobson, 1996; Jacobson and Jacobson, 2001b; Karmaus et al., 2001; Link et al., 2005) and breastfed and formula-fed preschool children (Patandin et al., 1997). Further, our findings are consistent with the body burdens of another POP, 2,3,7,8-tetrachlorodibenzodioxin, in breastfed and formula-fed infants whose initially high levels begin to blur in adolescence between 15 years and 20 years of age (as cited in (Lorber, 2002)). These data suggest that infant exposures from breastfeeding were sufficiently large so that continued exposures to PCBs and p,p'-DDE through the diet and the increasing volume of bodily tissues did not dilute or blur their contribution to the ΣPCB or p,p-DDE body burden of the children. The expected half-life of PCB congeners in adults considered here is estimated to be between 2 years and 6 years (Masuda et al., 1995; Phillips et al., 1989b; Shirai and Kissel, 1996; Wolff et al., 1992), and the half-lives of PCBs in the Faroese children are assumed to be similar. Therefore, the children's PCB concentrations during infancy and early childhood, a period of large developmental

changes, may have been more than 10 times greater than their concentrations at age 14, potentially ranging above 10 μg/g lipid in some cases.

Another unusual finding was the sex-related difference between associations with blubber consumption and nursing duration. ΣPCB concentrations were comparable for males and females 7 years of age, although a combination of breastfeeding and blubber consumption had a larger effect on females. By age 14, the difference in ΣPCBs and p,p'-DDE in males and females were significant and the sex-related contributions of the predictor variables were still apparent. The sex-related differences in serum concentrations may be attributable to different fat accumulation during adolescence. If females begin to accumulate body fat as a higher percentage of their body weight at this age, the equilibrium between adipose tissue and blood serum may favor increased deposition in adipose tissue. Indeed, ΣPCB concentrations were significantly inversely associated with BMI. Further, females had significantly higher BMIs both at age 7 years (16.8 $kg/m^2$ versus 16.0 $kg/m^2$; $p=0.008$) and 14 years (21.0 $kg/m^2$ versus 19.9 $kg/m^2$; $p<0.0001$). Further evaluation of this sex-related difference, especially in relation to body mass index, is warranted.

Childhood PCB exposure in the Faroe Islands has been associated with adverse effects on postnatal growth (Grandjean et al., 2003), lipid metabolism (Grandjean and Weihe, 2003), neurobehavioral development (Grandjean et al., 2001b), and antibody response to childhood vaccinations (Heilmann et al., 2003). Other adverse effects ranging from endocrine modulation to cancer have also been associated with PCB exposures (Longnecker, 2001). Given the relatively high level of childhood PCB exposures in the Faroese population and the continuous replenishment of PCB body burden through its traditional diet, PCB exposure-related effects in this population will likely continue unless prenatal and postnatal exposures can be reduced. Although the most recent data suggest that blubber consumption in the Faroes is declining, serum PCB concentrations in pregnant women have not begun to decrease (Weihe et al., 2003).

Our study is limited in several ways. Ideally, we would have been able to acquire a complete set of biologic samples at each collection period. Unfortunately, only about one tenth of the cohort provided serum samples at 7 years, leaving a limited number of samples we could compare across time points. Additionally, only a small volume of serum was collected at 7 years, which prevented the analysis of p,p'-DDE and serum lipids at this time point. Thus, the lipid-adjusted concentration data presented for 7-year serum samples were adjusted to the average serum concentration found at 14 years. The average lipid content of umbilical cords was much lower than the lipid content generally found in serum. Because PCBs and p,p'-DDE tend to sequester into the lipid stores, the absolute amounts of PCBs and p,p'-DDE in the umbilical cord samples were lower than the amounts in serum, often precluding the detection of less prevalent PCB congeners. Also, in our analysis, breastfeeding duration was classified according to the duration in months; thus the amount of milk consumed by each child was not considered during the analysis.

## CONCLUSIONS

In the Faroe Islands, the effect of infant PCB and p,p'-DDE exposure during breastfeeding was still apparent more than 12 years after its cessation. The PCB exposures from breastfeeding were more pronounced when the subjects were 7 years old

than when they were 14. For males, these exposures were similar to those from blubber consumption, though the effects were not additive. For females, nursing duration was a greater predictor of ΣPCB concentrations. Significant differences in serum ΣPCBs and p,p'-DDE were also observed between males and females at age 14, but not at age 7.

ΣPCB concentrations in umbilical cord samples were associated with serum ΣPCB concentrations from subjects 7 and 14 years of age. Because the serum concentrations in the group of 14-year-olds correlate more highly with the umbilical cord levels which represent maternal exposures, these data suggest that by the time the child is 14 years of age, the exposures begin to mimic those of the mother, likely derived from the diet.

The lower chlorination PCBs share a common characteristic in being less accumulative than the higher chlorination PCBs. Our data suggest that the lower chlorination PCB congeners that are present in the traditional Faroese diet are more rapidly eliminated than the higher chlorination PCBs; thus, the lower chlorination PCB congeners were not as apparently associated with the ΣPCB concentration predictors. Given the high levels in 14-year-olds still associated primarily with breastfeeding, total infant PCB concentrations could have been several times higher.

**ACKNOWLEDGMENTS**

This study was supported by the U.S. National Institute of Environmental Health Sciences (ES09797) and the Danish Medical Research Council. The study was carried out in accordance with the Helsinki convention and with the approval of the ethical review committee for the Faroe Islands and the institutional review board in the United States. We thank Don Patterson, Wayman Turner, Virlyn Burse, Cynthia Williams, Cheryl McClure, William Roman-Esteva, Courtney Sandau, Lawrence Wilson, Arnetta Thomas, Jim Preau, Angelina Sclafani, and Kerry Preston for their work in sample analysis. We also thank Peter Fürst for suggesting the need to compare various alternatives for calculating total PCB concentrations.

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Table 1. Characteristics of the children in the Faroese birth cohort

| Group | Variable | Variable type | Characteristic | N | Median | Range |
|---|---|---|---|---|---|---|
| Entire cohort (N=1022) * | Sex | Categorical | Male | 459 | NA | NA |
| | | | Females | 458 | NA | NA |
| | Nursing duration | Categorical | > 3 months (long) | 583 | NA | NA |
| | | | ≤ 3 months (short) | 329 | NA | NA |
| | Blubber consumption | Categorial | Yes at 7 years | 416 | NA | NA |
| | | | No at 7 years | 390 | NA | NA |
| | | | Yes at 14 years | 330 | NA | NA |
| | | | No at 14 years | 522 | NA | NA |
| | Body mass index (kg/m$^2$) | Continuous | 7 years | 905 | 15.9 | 12.9-79.2 |
| | | | 14 years | 872 | 19.7 | 14.6-42.3 |
| Age 7 years (N=124) | Sex | Categorical | Male | 71 | NA | NA |
| | | | Females | 51 | NA | NA |
| | Nursing duration | Categorical | > 3 months (long) | 79 | NA | NA |
| | | | ≤ 3 months (short) | 42 | NA | NA |
| | Blubber consumption | Categorial | Yes | 63 | NA | NA |
| | | | No | 45 | NA | NA |
| | Body mass index (kg/m$^2$) | Continuous | 7 years | 123 | 16 | 13.3-22.2 |
| | | | 14 years | 109 | 19.4 | 15.1-30.8 |
| Age 14 years (N=796) | Sex | Categorical | Male | 378 | NA | NA |
| | | | Females | 366 | NA | NA |
| | Nursing duration | Categorical | > 3 months (long) | 478 | NA | NA |
| | | | ≤ 3 months (short) | 262 | NA | NA |
| | Blubber consumption | Categorial | At 2 timepoints | 206 | NA | NA |
| | | | At 1 timepoint | 217 | NA | NA |
| | | | No | 243 | NA | NA |
| | Body Mass index (kg/m$^2$) | Continuous | 7 years | 737 | 16 | 12.8-25.9 |
| | | | 14 years | 777 | 19.7 | 10-42.3 |

NA = not applicable; * not all information was obtained from each participant so the numbers may not necessarily add up to the total N of the cohort

Table 2. Distribution of selected PCB congeners and p,p'-DDE in Faroese children at age 7 and 14 years. Units are pg analyte per g serum/umbilical cord.

| Age | Analyte | N | Detection Frequency (%) | Geometric Mean | Arithmetic Mean | Standard Deviation | 10th percentile | Median | 90th percentile |
|---|---|---|---|---|---|---|---|---|---|
| Cord | PCB105 | 316 | 26 | <LOD | <LOD | 49.9 | <LOD | <LOD | 70.0 |
| | PCB118 | 316 | 82 | 143 | 162 | 168 | <LOD | 130.0 | 350 |
| | PCB138/158 | 316 | 97 | 300 | 400 | 337 | 70 | 320 | 750 |
| | PCB153 | 316 | 98 | 408 | 540 | 482 | 140 | 420 | 1060 |
| | PCB170 | 316 | 81 | 130 | 127 | 123 | <LOD | 110 | 250 |
| | PCB180 | 316 | 93 | 194 | 253 | 257 | <LOD | 190 | 500 |
| | ΣPCB [1] | 316 | NA | 1710 | 2390 | 2120 | 540 | 1830 | 4640 |
| | ΣPCB [2] | 316 | NA | 1070 | 1500 | 1340 | 290 | 1190 | 2900 |
| | ΣPCB [3] | 316 | NA | 2230 | 3130 | 2820 | 672 | 2410 | 6040 |
| | p,p'-DDE | 433 | 99 | 1290 | 1760 | 1525 | 380 | 1320 | 3620 |
| 7 years | PCB18 | 82 | 57 | 5.20 | 24.3 | 33.8 | 10.0 | 2.50 | 70.4 |
| | PCB28 | 97 | 71 | 16.5 | 60.7 | 63.9 | 34.0 | 49.5 | 149 |
| | PCB44 | 80 | 71 | 5.50 | 13.8 | 16.3 | 4.0 | 10.0 | 36.0 |
| | PCB74 | 124 | 100 | 101 | 123 | 72.5 | 40.0 | 115 | 234 |
| | PCB105 | 124 | 100 | 57 | 72.7 | 51.2 | 24.0 | 62.0 | 137 |
| | PCB118 | 124 | 100 | 300 | 373 | 262 | 118 | 317 | 387 |
| | PCB138/158 | 115 | 100 | 1180 | 1470 | 959 | 446 | 1290 | 2870 |
| | PCB153 | 124 | 100 | 1760 | 2250 | 1610 | 656 | 1880 | 4520 |
| | PCB156 | 124 | 100 | 115 | 155 | 1302 | 40.0 | 115 | 304 |
| | PCB157 | 122 | 98 | 39.2 | 55.4 | 46.1 | 14.5 | 44.0 | 104 |
| | PCB170 | 124 | 100 | 389 | 515 | 415 | 144 | 433 | 986 |
| | PCB180 | 119 | 100 | 1095 | 1440 | 1150 | 396 | 1290 | 2700 |
| | ΣPCB [1] | 119 | NA | 7120 | 9430 | 7230 | 3260 | 7760 | 18900 |
| | ΣPCB [2] | 119 | NA | 5990 | 7390 | 5210 | 2280 | 6120 | 14200 |
| | ΣPCB [3] | 119 | NA | 11000 | 14200 | 10500 | 4350 | 12000 | 29100 |
| 14 | PCB18 | 778 | 100 | 11.1 | 15.1 | 25.7 | 5.75 | 9.60 | 24.2 |

| Age | Analyte | N | Detection Frequency (%) | Geometric Mean | Arithmetic Mean | Standard Deviation | 10th percentile | Median | 90th percentile |
|---|---|---|---|---|---|---|---|---|---|
| years | | | | | | | | | |
| | PCB28 | 792 | 100 | 31.2 | 41.5 | 63.1 | 17.6 | 27.0 | 61.6 |
| | PCB44 | 661 | 99 | 6.70 | 11.9 | 40.6 | 0.5 | 5.90 | 16.3 |
| | PCB74 | 795 | 100 | 60.5 | 74.7 | 52.9 | 25.7 | 60.6 | 139 |
| | PCB105 | 737 | 99 | 24.1 | 35.9 | 34.4 | 7.60 | 24.7 | 78.5 |
| | PCB118 | 788 | 99 | 129 | 185 | 171 | 41.2 | 133 | 384 |
| | PCB138/158 | 787 | 100 | 320 | 436 | 365 | 109 | 336 | 867 |
| | PCB153 | 792 | 100 | 960 | 1330 | 1150 | 335 | 1010 | 2610 |
| | PCB156 | 782 | 100 | 54.9 | 77.6 | 72.7 | 16.7 | 57.2 | 156 |
| | PCB157 | 720 | 99 | 19.0 | 27.4 | 26.0 | 0.5 | 20.5 | 54.9 |
| | PCB170 | 790 | 100 | 191 | 265 | 238 | 62.6 | 197 | 527 |
| | PCB180 | 795 | 100 | 548 | 787 | 724 | 174 | 588 | 1560 |
| | ΣPCB [1] | 795 | NA | 3680 | 5080 | 4410 | 1270 | 3820 | 10200 |
| | ΣPCB [2] | 795 | NA | 2860 | 3910 | 3350 | 986 | 2920 | 7930 |
| | ΣPCB [3] | 795 | NA | 5100 | 7040 | 6160 | 1730 | 5250 | 14060 |
| | p,p-DDE | 788 | 100 | 2420 | 4040 | 4930 | 657 | 2460 | 8800 |

NA = not calculated; <LOD = calculated value less than the analytic limit of detection; p,p'-DDE = p,p'-dichlorodiphenyldichloroethene.

[1] = sum calculated by adding PCB congeners 138/158, 153, and 180 then multiplying the sum by 2.

[2] = sum calculated by adding the 11 most prevalent congeners for serum (PCBs 74, 99, 118, 138/158, 146, 153, 170, 180, 187, 194, and 201) and the 6 most prevalent congeners for umbilical cord (PCBs 105, 118, 138/158, 153, 170, and 180).

[3] = sum calculated using the equation of Schulte and Malisch 1984: total PCB=((pcb138*7.03)+(pcb153*6.64)+(pcb180*11.86))/3

Table 3. Distribution of selected PCB congeners and p,p'-DDE in Faroese children at age 7 and 14 years. Units are ng analyte per g lipid.

| Age | Analyte | N | Detection Frequency (%) | Geometric Mean | Arithmetic Mean | Standard Deviation | 10th percentile | Median | 90th percentile |
|---|---|---|---|---|---|---|---|---|---|
| Cord | PCB105 | 316 | 26 | NA | 1.61 | 7.43 | <LOD | <LOD | 2.85 |
| | PCB118 | 316 | 82 | 7.70 | 12.0 | 43.4 | <LOD | 6.79 | 23.3 |
| | PCB138/158 | 316 | 97 | 15.9 | 27.5 | 87.6 | 4.12 | 16.7 | 48.2 |
| | PCB153 | 316 | 98 | 21.6 | 33.6 | 68.6 | 6.00 | 21.6 | 63.3 |
| | PCB170 | 316 | 81 | 6.82 | 7.86 | 17.5 | <LOD | 5.69 | 14.0 |
| | PCB180 | 316 | 93 | 10.3 | 16.1 | 36.4 | 1.00 | 10.0 | 30.0 |
| | ΣPCB [1] | 316 | NA | 90.7 | 155 | 382 | 23.2 | 100 | 288 |
| | ΣPCB [2] | 316 | NA | 56.3 | 98.7 | 256 | 14.1 | 63.8 | 176 |
| | ΣPCB [3] | 316 | NA | 118 | 203 | 497 | 29.8 | 133 | 373 |
| | p,p'-DDE | 316 | 99 | 68.1 | 110 | 211 | 17.8 | 71.3 | 211 |
| 7 years[4] | PCB18 | 82 | 57 | 0.88 | 3.22 | 5.27 | 1.71 | 0.12 | 11.5 |
| | PCB28 | 97 | 71 | 2.80 | 7.72 | 10.5 | 5.81 | 1.20 | 23.6 |
| | PCB44 | 80 | 71 | 0.94 | 2.28 | 2.78 | 0.68 | 1.20 | 6.20 |
| | PCB74 | 124 | 100 | 17.2 | 20.8 | 12.5 | 6.84 | 19.5 | 40.0 |
| | PCB105 | 124 | 100 | 9.80 | 12.3 | 8.80 | 4.10 | 10.4 | 23.3 |
| | PCB118 | 124 | 100 | 51.2 | 63.3 | 45.0 | 20.2 | 53.5 | 117 |
| | PCB138/158 | 115 | 100 | 202 | 245 | 160 | 76.3 | 220 | 454 |
| | PCB153 | 124 | 100 | 302 | 378 | 278 | 120 | 311 | 760 |
| | PCB156 | 124 | 100 | 19.7 | 25.6 | 22.4 | 6.84 | 19.5 | 51.6 |
| | PCB157 | 122 | 98 | 6.70 | 9.30 | 7.90 | 2.48 | 7.4 | 17.8 |
| | PCB170 | 124 | 100 | 77.6 | 84.5 | 71.9 | 25.7 | 70.5 | 168 |
| | PCB180 | 119 | 100 | 187 | 241 | 194 | 67.7 | 220 | 457 |
| | ΣPCB [1] | 119 | NA | 1024 | 1290 | 886 | 557 | 1100 | 2420 |
| | ΣPCB [2] | 119 | NA | 696 | 879 | 615 | 390 | 799 | 1650 |
| | ΣPCB [3] | 119 | NA | 1880 | 2440 | 1800 | 744 | 2050 | 4980 |
| 14 | PCB18 | 778 | 100 | 2.10 | 2.87 | 4.88 | 1.09 | 1.87 | 4.70 |

| Age | Analyte | N | Detection Frequency (%) | Geometric Mean | Arithmetic Mean | Standard Deviation | 10th percentile | Median | 90th percentile |
|---|---|---|---|---|---|---|---|---|---|
| years | | | | | | | | | |
| | PCB28 | 792 | 100 | 5.92 | 8.00 | 12.21 | 3.22 | 5.31 | 12.2 |
| | PCB44 | 661 | 99 | 1.26 | 1.93 | 7.05 | 0.08 | 0.98 | 2.87 |
| | PCB74 | 737 | 99 | 11.5 | 14.1 | 9.68 | 4.99 | 11.3 | 25.7 |
| | PCB105 | 788 | 99 | 4.53 | 6.71 | 6.17 | 1.39 | 4.71 | 15.3 |
| | PCB118 | 787 | 100 | 24.4 | 34.5 | 31.1 | 7.94 | 24.6 | 72.0 |
| | PCB138/158 | 792 | 100 | 60.4 | 81.4 | 66.5 | 21.0 | 63.3 | 169 |
| | PCB153 | 782 | 100 | 182 | 250 | 208 | 64.4 | 193 | 505 |
| | PCB156 | 720 | 99 | 10.4 | 14.3 | 13.3 | 3.48 | 10.7 | 28.9 |
| | PCB157 | 790 | 100 | 3.57 | 4.68 | 4.79 | 0.09 | 3.43 | 10.3 |
| | PCB170 | 795 | 100 | 35.1 | 49.4 | 43.5 | 12.0 | 36.7 | 99.8 |
| | PCB180 | 795 | 100 | 105 | 147 | 132 | 33.2 | 109 | 298 |
| | ΣPCB [1] | 795 | NA | 709 | 1040 | 859 | 239 | 808 | 2100 |
| | ΣPCB [2] | 795 | NA | 643 | 861 | 703 | 183 | 665 | 1730 |
| | ΣPCB [3] | 795 | NA | 966 | 1320 | 1120 | 326 | 1020 | 2690 |
| | p,p'-DDE | 788 | 100 | 462 | 762 | 467 | 123 | 467 | 1750 |

NA = not calculated; <LOD = calculated value less than the analytic limit of detection; p,p'-DDE = p,p'-dichlorodiphenyldichloroethene.

[1] = sum calculated by adding PCB congeners 138/158, 153, and 180 then multiplying the sum by 2.

[2] = sum calculated by adding the 11 most prevalent congeners for serum (PCBs 74, 99, 118, 138/158, 146, 153, 170, 180, 187, 194, and 201) and the 6 most prevalent congeners for umbilical cord (PCBs 105, 118, 138/158, 153, 170, and 180).

[3] = sum calculated using the equation of Schulte and Malisch 1984: total PCB=((pcb138*7.03)+(pcb153*6.64)+(pcb180*11.86))/3

[4] Serum samples collected at 7 years lipid-adjusted based upon an average lipid content of 0.6%.

Table 4. Pearson correlation coefficients of p,p'-DDE and PCB congeners detected in over 90% of the analyzed samples at age 14 (N=782). All correlations were significant except those shown in italics. All correlations over 0.80 are bolded.

| Analyte | PCB11 | PCB18 | PCB28 | PCB53 | PCB66 | PCB74 | PCB99 | PCB105 | PCB118 | PCB138/158 | PCB146 | PCB153 | p,p'-DDE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PCB11** | | | | | | | | | | | | | 0.33 |
| **PCB18** | 0.76 | | | | | | | | | | | | *0.03* |
| **PCB28** | 0.77 | **0.93** | | | | | | | | | | | *0.06* |
| **PCB53** | **0.88** | **0.93** | **0.9** | | | | | | | | | | 0.11 |
| **PCB66** | **0.9** | 0.77 | **0.84** | **0.85** | | | | | | | | | 0.30 |
| **PCB74** | 0.56 | 0.24 | 0.32 | 0.33 | 0.61 | | | | | | | | **0.85** |
| **PCB99** | 0.54 | 0.14 | 0.19 | 0.25 | 0.5 | **0.89** | | | | | | | **0.85** |
| **PCB105** | 0.56 | 0.1 | 0.17 | 0.22 | 0.58 | **0.85** | **0.89** | | | | | | 0.53 |
| **PCB118** | 0.52 | 0.09 | 0.17 | 0.21 | 0.55 | **0.89** | **0.9** | **0.98** | | | | | **0.50** |
| **PCB138/158** | 0.42 | *0.05* | 0.1 | 0.15 | 0.38 | **0.9** | **0.93** | **0.81** | **0.85** | | | | **0.40** |
| **PCB146** | 0.35 | *0.02* | *0.05* | 0.11 | 0.3 | **0.85** | **0.83** | 0.69 | 0.76 | **0.95** | | | **0.32** |
| **PCB153** | 0.36 | *0.03* | 0.07 | 0.12 | 0.34 | **0.86** | **0.87** | 0.75 | **0.81** | **0.97** | **0.93** | | 0.34 |
| **PCB156** | 0.36 | *0.06* | 0.1 | 0.21 | 0.36 | 0.78 | 0.7 | 0.58 | 0.65 | **0.88** | **0.89** | **0.93** | **0.33** |
| **PCB157** | 0.38 | *0.06* | 0.11 | 0.23 | 0.4 | **0.8** | 0.72 | 0.6 | 0.67 | **0.9** | **0.92** | **0.94** | **0.36** |
| **PCB170** | 0.3 | *0.02* | *0.07* | 0.1 | 0.28 | **0.81** | 0.76 | 0.62 | 0.7 | **0.91** | **0.92** | **0.95** | **0.97** |
| **PCB172** | 0.28 | *-0.01* | *0.01* | 0.1 | 0.17 | 0.48 | 0.46 | 0.33 | 0.4 | 0.58 | 0.64 | 0.55 | 0.84 |
| **PCB177** | 0.44 | *0.05* | 0.1 | 0.17 | 0.35 | **0.85** | **0.88** | 0.77 | 0.79 | **0.93** | **0.91** | **0.88** | **0.89** |
| **PCB178** | 0.42 | *0.06* | 0.1 | 0.25 | 0.37 | **0.81** | 0.74 | 0.6 | 0.65 | **0.91** | **0.96** | **0.89** | **0.93** |
| **PCB180** | 0.31 | *0.03* | 0.07 | 0.11 | 0.29 | **0.81** | 0.76 | 0.63 | 0.71 | **0.92** | **0.92** | **0.96** | **0.98** |
| **PCB194** | 0.29 | *0.02* | 0.06 | 0.1 | 0.38 | 0.77 | 0.73 | 0.61 | 0.69 | **0.88** | **0.88** | **0.94** | **0.95** |
| **PCB196/203** | 0.14 | *0.01* | 0.03 | 0.05 | 0.32 | 0.37 | 0.37 | 0.3 | 0.35 | 0.44 | 0.43 | 0.46 | 0.46 |
| **PCB201** | 0.31 | *0.04* | 0.07 | 0.12 | 0.26 | 0.78 | 0.72 | 0.57 | 0.63 | **0.89** | **0.94** | **0.89** | **0.92** |
| **PCB206** | 0.35 | *0.05* | 0.1 | 0.14 | 0.34 | 0.79 | 0.77 | 0.7 | 0.77 | **0.87** | **0.83** | **0.92** | **0.93** |
| **PCB209** | 0.36 | *0.04* | 0.1 | 0.14 | 0.35 | 0.77 | 0.77 | 0.72 | 0.79 | **0.84** | **0.77** | **0.88** | **0.88** |

p,p'-DDE = p,p'- dichlorodiphenyldichloroethene

Table 5. Correlations of selected PCB congeners in umbilical cords and serum samples taken from same children at age 7 and 14 years.

| Analyte | Umbilical cord and 7 year serum samples[A] | | Umbilical cord and 14 year serum samples | | 7 year and 14 year serum samples | |
|---|---|---|---|---|---|---|
| | **Pearson Correlation** | **p value** | **Pearson Correlation** | **p value** | **Pearson Correlation** | **p value** |
| PCB18 | NA | NA | NA | NA | -0.14 | 0.16 |
| PCB28 | NA | NA | NA | NA | -0.14 | 0.17 |
| PCB44 | NA | NA | NA | NA | -0.13 | 0.19 |
| PCB105 | -0.09 | 0.65 | -0.08 | 0.22 | 0.48 | <0.0001 |
| PCB118 | 0.20 | 0.065 | 0.30 | <0.0001 | 0.51 | <0.0001 |
| PCB138/158 | 0.27 | 0.004 | 0.35 | <0.0001 | 0.33 | 0.0005 |
| PCB153 | 0.30 | 0.001 | 0.33 | <0.0001 | 0.58 | <0.0001 |
| PCB156 | NA | NA | NA | NA | 0.56 | <0.0001 |
| PCB157 | NA | NA | NA | NA | 0.57 | <0.0001 |
| PCB170 | 0.04 | 0.66 | 0.29 | <0.0001 | 0.23 | 0.020 |
| PCB180 | 0.20 | 0.040 | 0.31 | <0.0001 | 0.56 | <0.0001 |
| p,p'-DDE | NA | NA | 0.39 | <0.0001 | NA | NA |

NA = not available

[A] Serum samples collected at 7 years were lipid-adjusted based upon an average lipid content of 0.6%.

Table 6. Least squares geometric mean concentrations of selected PCB congeners, homologues and specified congener groups at age 7 and 14 years stratified by regular blubber consumption, nursing duration, sex, and body mass index. PCB concentrations are listed in ng/g lipid units and are corrected for all covariates. § in the analyte column indicates that the PCB is significantly associated with BMI.

| Age | Analyte | Regular Blubber Consumption at ages 7 and 14 years [A] | | | Nursing duration [B] | | Sex | |
|---|---|---|---|---|---|---|---|---|
| | | At 7 and 14 years | At only one timepoint | At neither timepoint | Long | Short | Male | Female |
| 7 years | PCB28 | NA | 2.64 | 2.38 | 2.58 | 2.44 | 2.97 | 1.98 |
| | PCB105 | NA | 13.2 [C] | 8.19 | 11.6 | 9.65 | 9.98 | 12.2 |
| | PCB118 | NA | 64.0 [C] | 44.7 | 60.1 [C] | 46.9 | 49.6 | 64.1 |
| | PCB138/158 § | NA | 110 [C] | 91.2 | 111 [C] | 87.9 | 91.9 | 118 |
| | PCB153 § | NA | 346 [C] | 268 | 367 [C] | 233 | 286 | 354 |
| | PCB170 § | NA | 66.1 [C] | 53.5 | 68.7 [C] | 47.6 | 49.6 | 81.3 |
| | PCB180 § | NA | 163 [C] | 126 | 165 [C] | 118 | 131 | 172 |
| | TriCBs | NA | 4.69 | 4.96 | 4.63 | 5.09 | 5.35 | 4.10 |
| | TetraCBs § | NA | 24.2 [C] | 19.8 | 24.6 [C] | 18.3 | 20.6 | 24.8 |
| | PentaCBs § | NA | 124 [C] | 89.2 | 119 [C] | 90.5 | 102 | 118 |
| | HexaCBs § | NA | 665 [C] | 510 | 700 [C] | 435 | 552 | 665 |
| | HeptaCBs § | NA | 390 [C] | 315 | 407 [C] | 277 | 303 | 451 |
| | OctaCBs § | NA | 70.0 [C] | 50.8 | 72.7 [C] | 43.7 | 57.5 | 67.4 |
| | NonaCB § | NA | 4.63 [C] | 3.17 | 4.43 [C] | 3.17 | 3.57 | 4.56 |
| | DecaCB | NA | 2.91 [C] | 2.31 | 2.64 | 2.58 | 2.44 | 3.04 |
| | Sum PCBs [F] § | NA | 1140 [C] | 875 | 1200 [C] | 752 | 938 | 1160 |
| | High PCBs [G] § | NA | 1080 [C] | 825 | 1130 [C] | 708 | 882 | 1100 |
| | Low PCBs [H] | NA | 33.0 | 28.4 | 32.8 | 28.0 | 30.2 | 32.4 |
| 14 years | PCB28 | 6.3 [C] | 5.6 | 5.8 | 6.0 | 5.7 | 5.8 | 6.0 |
| | PCB105 | 8.1 [C,D] | 4.9 [E] | 2.6 | 4.6 | 4.5 | 4.8 | 4.3 |
| | PCB118 | 41.7 [C,D] | 27.1 [E] | 14.4 | 24.9 | 23.2 | 25.3 | 23.3 |
| | PCB138/158 § | 94.7 [C,D] | 65.9 [E] | 37.9 | 66.5 [C] | 48.4 | 65.9 [C] | 53.6 |
| | PCB153 § | 276 [C,D] | 200 [E] | 119 | 206 [C] | 142 | 203 [C] | 160 |
| | PCB170 § | 55.1 [C,D] | 39.5 [E] | 23.9 | 43.2 [C] | 25.7 | 40.6 [C] | 31.9 |

| Age | Analyte | Regular Blubber Consumption at ages 7 and 14 years [A] | | | Nursing duration [B] | | Sex | |
|---|---|---|---|---|---|---|---|---|
| | | At 7 and 14 years | At only one timepoint | At neither timepoint | Long | Short | Male | Female |
| | PCB180 § | 164 [C,D] | 114 [E] | 66.9 | 125 [C] | 73.4 | 116 [C] | 92.7 |
| | TriCBs | 8.6 [C] | 7.6 | 8.1 | 8.2 | 7.9 | 8.1 | 8.2 |
| | TetraCBs § | 28.6 [C,D] | 19.8 [E] | 15.6 | 21.7 [C] | 17.3 | 21.6 [C] | 18.8 |
| | PentaCBs § | 87.2 [C,D] | 61.0 [E] | 35.7 | 61.1 | 54.5 | 62.2 ** | 55.6 |
| | HexaCBs § | 530 [C,D] | 396 [E] | 274 | 445 | 368 | 475 [C] | 367 |
| | HeptaCBs § | 396 [C,D] | 277 [E] | 192 | 313 [C] | 208 | 318 [C] | 238 |
| | OctaCBs § | 55.7 [C,D] | 38.4 [E] | 24.0 | 43.3 [C] | 26.5 | 41.8 [C] | 32.1 |
| | NonaCB § | 4.1 [C,D] | 2.8 [E] | 1.7 | 2.9 [C] | 2.1 | 2.9 [C] | 2.3 |
| | DecaCB § | 2.3 [C,D] | 1.6 [E] | 1.0 | 1.6 [C] | 1.4 | 1.7 [C] | 1.3 |
| | Sum PCBs [F] § | 885 [C,D] | 613 [E] | 373 | 654 [C] | 448 | 635 [C] | 515 |
| | High PCBs [G] § | 833 [C,D] | 578 [E] | 352 | 619 [C] | 418 | 598 [C] | 484 |
| | Low PCBs [H] | 35.8 [C,D] | 26.1 | 23.6 | 29.0 [C] | 24.8 | 28.9 | 26.3 |
| | p,p'-DDE | 782 [C,D] | 494 [E] | 278 | 486 [C] | 399 | 521 [C] | 394 |

[A] +/+ indicates regular consumption of blubber at both 7 and 14 years of age; +/- indicates regular consumption of blubber at 7 or 14 years of age but not both; -/- indicates blubber not regularly consumed at either age

[B] Short indicates exclusive nursing ≤ 1 months and total nursing ≤ 2 months

[C] Indicates statistical significance (at $p<0.05$) between the first and second variables of a stratum

[D] Indicates statistical significance (at $p<0.05$) between the first and third variables of a stratum

[E] Indicates statistical significance (at $p<0.05$) between the second and third variables of a stratum

[F] Sum of 11 most prevalent PCB congeners

[G] Sum of PCBs 118, 138/158, 153, 170, 180

[H] Sum of PCBs 18, 28, 44, 49, 53, and 74

Table 7. Coefficients of independent variables from the general linear models of ΣPCB concentrations (dependent variable) on serum samples taken at 7 and 14 years of age. ΣPCB concentrations were determined by summing the 11 most prevalent congeners. All variables were categorical except for body mass index (BMI; $kg/m^2$). The BMI was measured at the time the serum samples were taken. The intercept is equal to a female child who did not consume blubber and nursed for only a short duration.

| Age | Variable | | B coefficient | Standard error | p value |
|---|---|---|---|---|---|
| **7 years** | **Intercept** | | **2750** | **936** | **<0.0001** |
| | **Sex** | **Male** | **-84.1** | **187** | **0.65** |
| | **Blubber consumption** | **Yes** | **393** | **188** | **0.04** |
| | **Nursing** | **Long duration** | **587** | **194** | **0.003** |
| | **BMI (continuous)** | | **-120.4** | **56.1** | **0.034** |
| | **R2 of overall regression** | | **0.23** | **NA** | **<0.001** |
| **14 years** | **Intercept** | | **1030** | **130** | **<0.0001** |
| | **Sex** | **Male** | **202** | **41.9** | **<0.0001** |
| | **Blubber consumption** | **At both ages** | **610** | **50** | **<0.0001** |
| | | **At one age** | **268** | **49** | **<0.0001** |
| | **Nursing** | **Long duration** | **245** | **42.8** | **<0.0001** |
| | **BMI (continuous)** | | **-40.0** | **5.9** | **<0.0001** |
| | **R2 of overall regression** | | **0.37** | **NA** | **<0.0001** |

NA= not applicable

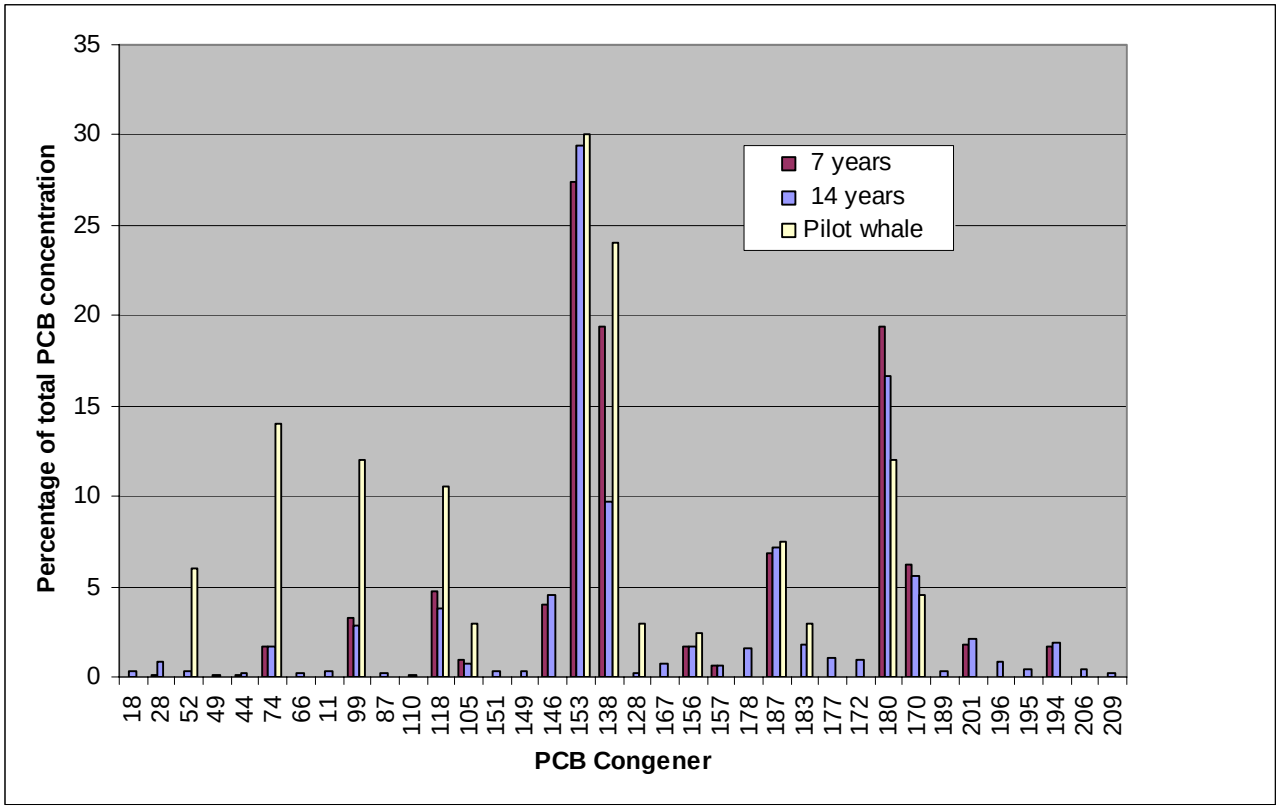
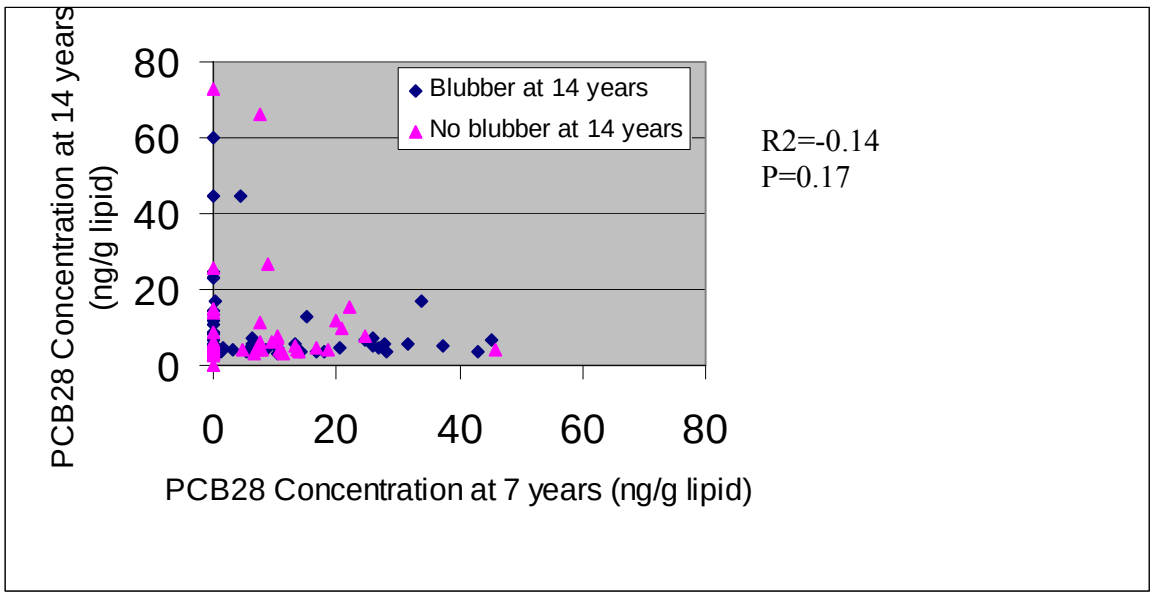



Figure 1. Contribution of each PCB congener to the ΣPCB concentration in serum samples of a Faroese birth cohort at 7 and 14 years of age. Also, approximate distributions of PCB congeners in long-finned pilot whale in the Faroe Islands [7] are shown for comparison.

(A)




(B)

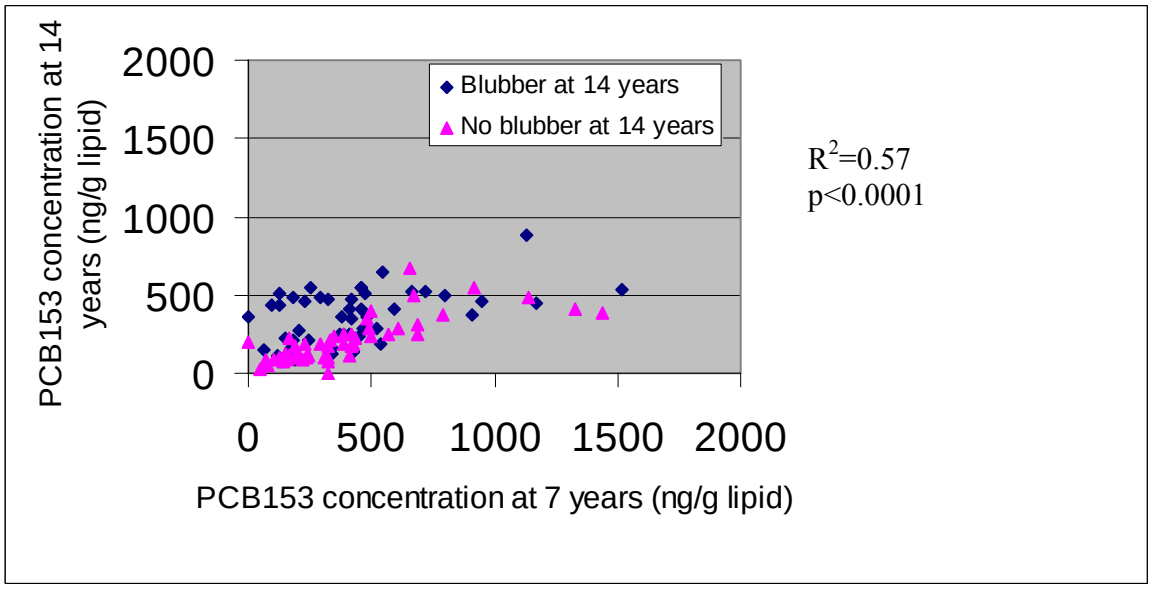
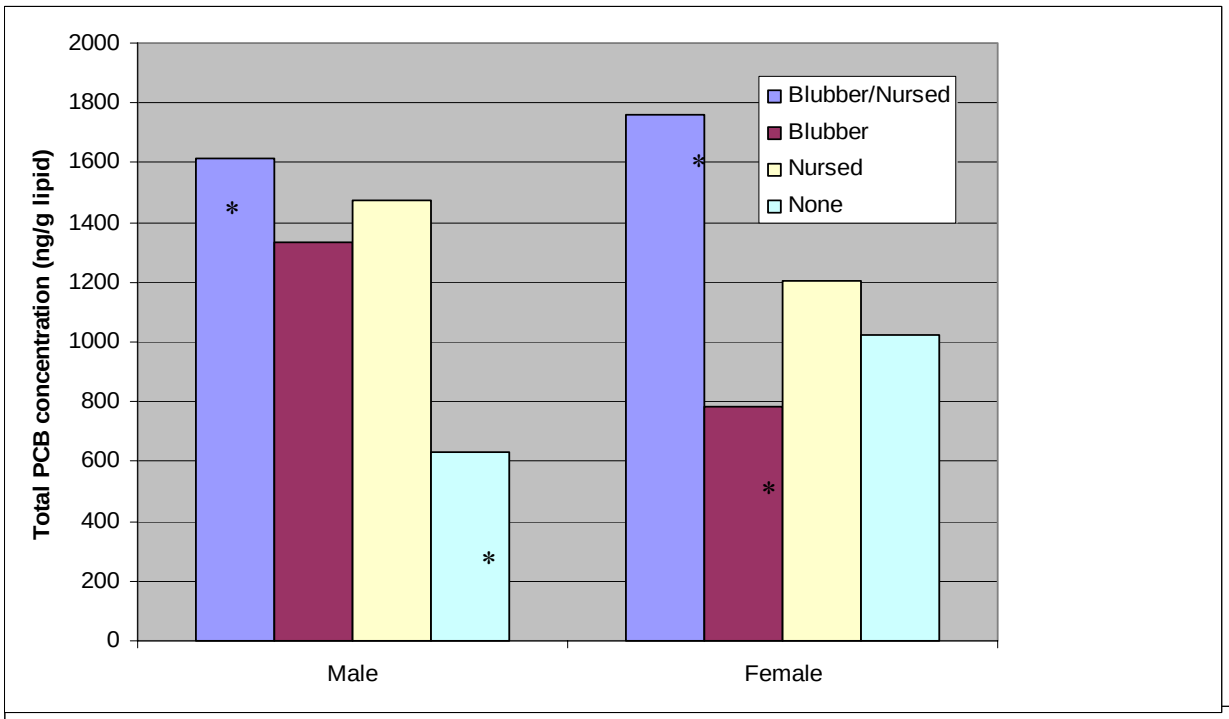



Figure 2. Correlations of PCB congeners 28 (a) and 153 (b) in serum samples collected at age 7 and 14 years. Faroese children who routinely consumed blubber at age 14 are differentiated from those who did not.

(A)




(B)

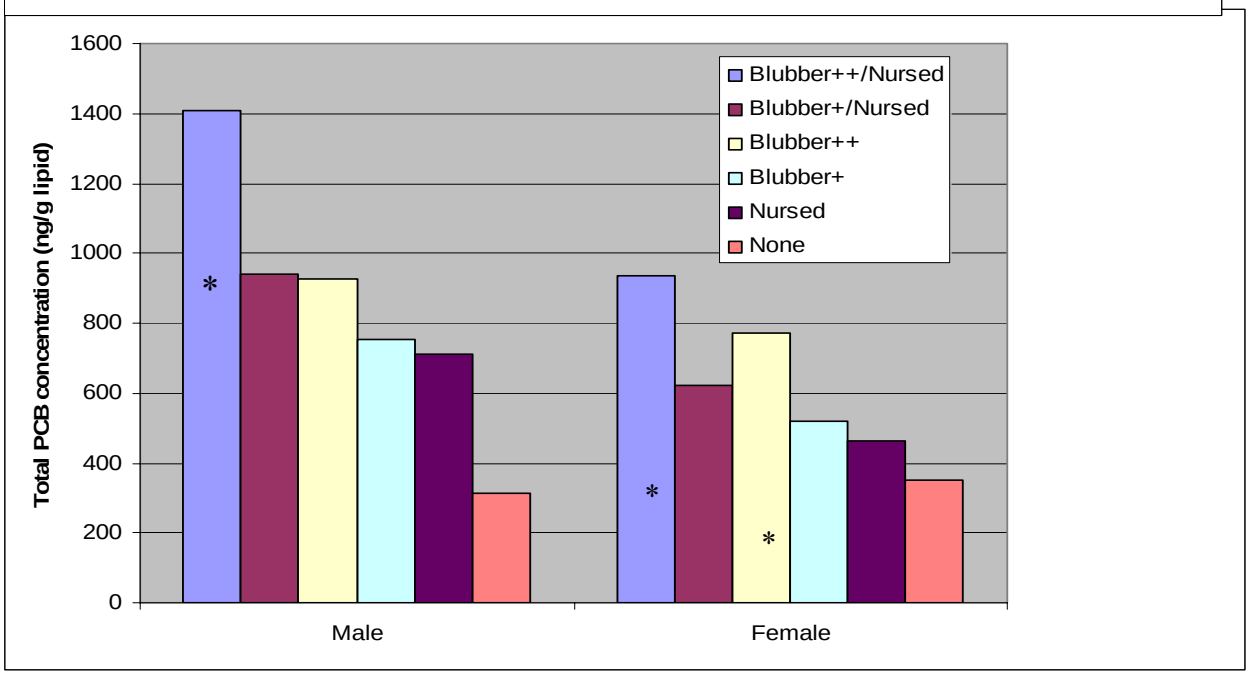



Figure 3. Effect of routine blubber consumption noted at age 7 (a) and 14 (b) years, nursing duration, and sex on ΣPCB concentrations. Differences noted with an asterisk are significant at p=0.05. Blubber++ indicates the child consumed blubber routinely at age 7 and 14 years. Blubber+ indicates the child consumed blubber routinely at only one evaluated time point. Nursed indicates that the child was nursed for a duration longer than 2 months.

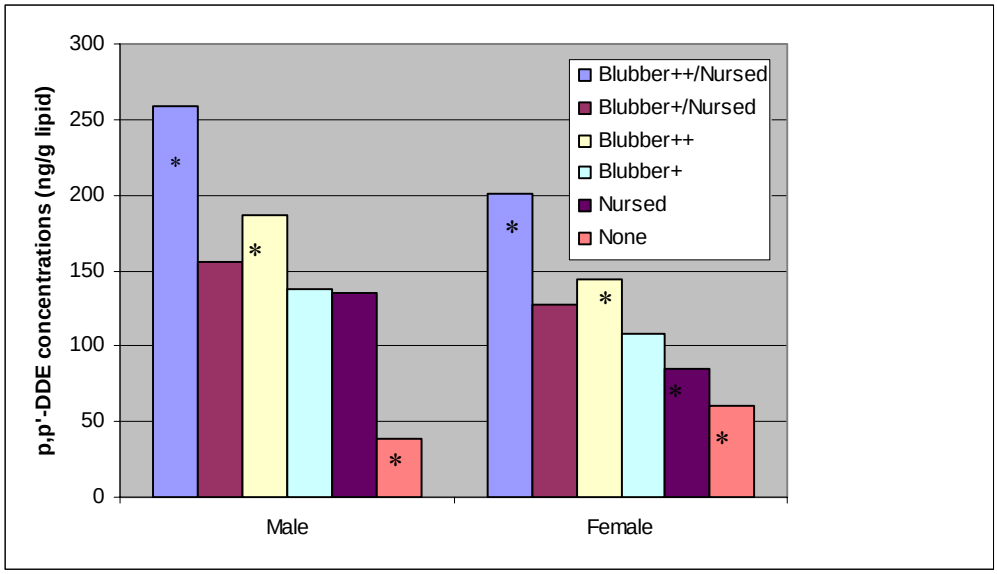



Figure 4. Effect of routine blubber consumption, nursing duration, and sex on p,p'-DDE concentrations in 14 year old Faroese. Differences noted with an asterisk are significant at p=0.05. Blubber++ indicates the child consumed blubber routinely at age 7 and 14 years. Blubber+ indicates the child consumed blubber routinely at only one evaluated time point. Nursed indicates that the child was nursed for a duration longer than 2 months.