Human plasma levels of POPs, and diet among native people from Uelen, Chukotka

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Some of the people living in the Chukotka Peninsula of Russia depend heavily on marine mammals, but little is known of the exact dietary patterns and plasma levels of POPs among these populations. In this study, POPs levels in plasma from 50 participants from the isolated community of Uelen (Bering Strait) were determined and related to dietary information obtained through a food frequency questionnaire. The intake of marine mammals was high and the combined intake of blubber from walrus, seal and whale was a significant predictor ($p < 0.01$) of plasma concentrations of sum PCBs and borderline for sum CDs ($p = 0.02$) and sum DDTs ($p = 0.04$). There was a significant gender difference in the levels of POPs, and among women there was a significant increase with age. Extensive breastfeeding and lower blubber intake among women could be possible explanations for this gender difference. Despite the high intake of blubber the plasma levels of PCBs and DDTs were lower than some of those reported for the East Coast of Greenland. The geometric mean values for sum PCBs (17 congeners) and sum DDTs were 1316 ng g^{-1} lipids and 563 ng g^{-1} lipids, respectively. PCB 163, which partly co-eluted with PCB 138, was found in high concentrations (40% of PCB 138). This raises questions regarding the validity of using PCB 138 and PCB 153 to calculate the level of Arochlor 1260. The geometric mean of sum CDs was 518 ng g^{-1} lipids. Concentrations of β-HCH (geometric mean; 410 ng g^{-1} lipids) were higher than observed for other native populations depending on marine mammals. Transportation of β-HCH by ocean currents through the Bering Strait into the Arctic Ocean or regional point sources might explain these elevated levels.

Introduction

Polychlorinated biphenyls (PCBs) and other halogenated aromatic hydrocarbons are ubiquitous environmental contaminants that accumulate in lipid-rich body tissues.[1] The lipophilicity and resistance to biodegradation are responsible for the bioaccumulation in the food web, and in particular the aquatic food web.[2] In humans, biological half-lives of several years or longer have been reported for many organochlorines.[3,4]

Present levels of persistent organic pollutants (POPs) in the Arctic cannot generally be related to known use and/or release from local sources, and can therefore only be explained by long-range transport from lower latitudes.[5–7] The long-range transport of POPs to the Arctic is well-documented.[8] However, for α-HCH the Arctic Ocean appears now also to act as a source by revolatilization of long-range transported material previously deposited.[9] Several review papers and reports have also indicated a non-uniform distribution of POPs in the Arctic.[10,2,5,11,12]

High intake of blubber from marine mammals, by humans in Greenland, northern-Canada and the Faeroe Islands have been found to lead to elevated blood levels of POPs in humans, especially PCBs and the metabolite *p,p′*-dichlorodiphenylethylene (*p,p′*-DDE).[5,13–15] In men from Scoresbysund in Greenland, the average amount of sum PCBs and sum DDTs in plasma was found to be 41 μg L^{-1} and 11.1 μg L^{-1}, respectively.[13] In Scandinavia and most areas in northwest Russia, where people eat small amounts of marine mammals, the concentrations of PCBs are low. In Norwegian women, the mean sum PCBs concentration in plasma has been reported to be 4.0 μg L^{-1}, while sum DDT was 0.9 μg L^{-1}.[5] However, high levels of *p,p′*-dichlorodiphenyltrichloroethane (*p,p′*-DDT) and *β*-HCH have been found in human plasma from residents of the town of Nikel and city of Arkhangelsk indicating the presence of *de nova* local sources at these sites in western Russia;[5,16] their exact origin have thus far not been identified.

The information on plasma levels of POPs and in diet in northeast Russia is very limited in comparison to other Arctic countries. This is also highlighted in the 1998 AMAP report and Chukotka Peninsula is now one of the key areas in the future work of AMAP.[5,17] Several of the communities in the Chukotka Peninsula depend heavily on marine mammals, although the concentrations of POPs in the seals from that region have been reported to be lower than in other arctic areas such as Spitsbergen, Eastern Greenland and northwest Russia.[5] The levels of β-HCH have, on the other hand, been reported to be high in polar bears from the Chukotka Peninsula.[17] Further, there is no information on the possibility of local point sources in this remote region as compared to northwest Russia.

The data presented here clarify these various conflicting observations. We report plasma concentrations of POPs for 50 participants from Uelen in the Chukotka Peninsula, and examine the link to dietary intake of marine mammals and other traditional foods.

Methods

The joint RAIPON/AMAP/GEF† study of pregnant women and their neonates was initiated in 2001. Four regions are involved in the project: the Kola Peninsula, Pechora Basin, Taimyr Peninsula and Chukotka Peninsula. During the fieldwork, additional participants from the general population were interviewed and blood samples were collected from them. In Uelen, situated by the Bering Strait and Chukotka Sea, the intake of marine mammals was known to be considerable. A total of 250 adults were interviewed and who donated blood. The 250 participants were all the people available, from an adult population of 374, at the time of the fieldwork. Of these 250 samples, 50 were selected at random (corresponding to every 5th donor) and analysed to get a first indication of the human POP content among the general population of Uelen. The samples were collected in July and August of 2001 and the weight and the height of the participants were measured at the time of the interview. Specimens of antecubital vein blood were taken in EDTA tubes with standard vacutainer equipment. The blood was centrifuged and plasma was immediately stored at −20 °C and kept frozen until analysis.

Of the 50 participants 92% considered themselves Chukchi, whereas the remaining were Eskimos or Evenk. There were 26 women and 24 men with an average age of 37.3 years (range, 20–70 years). Of the 50 study subjects, 36 (73.5%) may be considered to have normal weight (body mass index (BMI) = 18.5–24.9 kg m^{-2}) and the remaining 14 were overweight (BMI > 25 kg m^{-2}), based on WHO criteria. The average height was 161.9 cm (range; 132 to 180 cm). Local health professionals solicited information on breastfeeding, 6 months after the sample collection. Unfortunately, no information on time elapsed from the last period of breastfeeding was obtained.

Dietary information

The food frequency questionnaire was designed to include most food items consumed locally, registering the frequency, the amount eaten and the season for consumption. For the estimate of the frequency the following options were given to the participants: 'daily', '1–3 times per week', '2–3 times per month' or 'once per month or less'. Six trained health personnel carried out the interviews. Use was not made of models describing portion size due to very different dietary habits. For example, the hunters ate much more during the hunting season (June–Sept.). The reported intake per meal was thus estimated to the nearest 50 g. From the reported frequency of intake and portion sizes, the average consumption per day was calculated. This intake in g per day was used in the statistical models.

To facilitate the consideration of intakes of the 11 most common food articles, they were normalised by calculating the corresponding energy intake using the Norwegian Food Composition Table.[18] The energy intake values were compared to energy requirements for high physical activity calculated from 'Energy and protein requirements' according to WHO.[19] These calculations enable comparison of energy intake with other studies independent of food articles.

Despite the energy calculations, no attempts were made to validate the food questionnaire and the self estimated intakes completely. The self reported intake was used only to separate high and low consumers on a relative basis, remembering that the questionnaire has not been validated.

Analytical procedures

The plasma samples were extracted and purified according to a slightly modified method developed at the Centre of Human Toxicology (CTQ), National Institute of Public Health, Quebec,[20] and the compounds were quantified according to a method published previously.[21] In short, the plasma samples were extracted using liquid–liquid extraction with ethanol, deionised water saturated with ammonium sulfate and hexane. The POPs were separated from the lipids using a tandem florisil column manually packed with 1.5 g of 0.5% deactivated florisil with 2 g of granulated sodium sulfate on top in each of the columns. The POPs were eluted using 11 ml hexane–dichloromethane (3 + 1). The collected fraction was evaporated to 0.5 ml using a Zymark Turbovap 500 Closed Cell Concentrator (Hopkinton, USA), followed by a gentle flow of nitrogen for reduction to 100 µl. Gas chromatography (GC) was performed using a Fisons 8060 Mega Gas Chromatograph (Milan, Italy). A 30-m DB-5 MS column (0.25 mm id and 0.25 µm film thickness; J&W Scientific, CA, USA) and a deactivated guard column (0.53 mm id, 2.5 m, J&W Scientific, CA, USA) were used for all analyses. The GC was further connected to a low-resolution Fisons MD 800 Mass Spectrometer (Milan, Italy).

C-13 labelled PCB 101, 118, 141 and 178, *p,p′*-DDE and *p,p′*-DDT were used as internal standards. Octachloronaphthalene was added as a recovery standard and the recovery rates for the internal standards all were in the range of 65 to 97% (results not shown). The quantification was achieved using both positive electron-impact ionisation (EI+) and negative chemical ionisation (NCI); both were employed in the selected ion-monitoring (SIM) mode in the same instrument. The different compounds were identified from their SIM masses and retention times. Peaks with differences in isotopic ratio greater than 20% compared to the quantification standard were rejected and not quantified. For every 10 samples, a blank was analysed to assess laboratory-derived (*i.e.* inadvertent) sample contamination. The limit of detection (LOD) was calculated using three times the area of the noise or, if peaks were found in the blanks, three times the area of the blank. All levels below the LOD were set to half LOD and included as such in the statistical analyses.

PCB 138 was only partially resolved from PCB 163 and integrated as one peak, and thus was reported as PCB 138/163. Twenty samples were, however, reanalysed to determine the presence of additional PCB congeners and possible co-elutions. In these it was possible to quantify these two congeners separately due to better separation caused by minor differences in column performance. The lipid content of the plasma samples was determined enzymatically.[22]

In terms of quality control, our laboratory participates three times per year in the AMAP Human Health Ringtest for plasma samples. The ringtest includes 6 PCB congeners, *p,p′*-DDE, *p,p′*-DDT, β-HCH and oxy chlordane, and three plasma samples each round. We have been participating from the outset of this programme and performed well throughout. During 2002 our performance was 85, 95 and 89% on the three runs. (Each result within ±40% of the assigned value, gives one point. Each result also within ±20% gives an additional point. Only numerical results are counted. Laboratories must also supply results for at least 5 analytes to be graded. Scores are expressed as a percentage.)

Statistical analyses

Analyses of Variance (ANOVA), *t*-tests and linear regression models were used when assessing the predictors of POP concentrations in plasma. Shapiro-Wilks test criteria were first used to decide whether the levels of the different compounds were normally distributed. The levels of all compounds had to be log transformed to obtain a normal distribution (results not shown). All statistics was performed on lipid weight data. Pearson correlation coefficients (*r*) were calculated for linear relationships. Both genders were included in the ANOVA. To

†RAIPON: Russian Association of Indigenous Peoples of the North; AMAP: Arctic Monitoring and Assessment Programme (Arctic Council/AEPS group); GEF: Global Environment Facility.

better explore the gender differences and the effects of breastfeeding; POPs and lipid levels were compared in men and women below and above the age of 40 years. This was done using an independent sample *t*-test and ANOVA adjusting for blubber intake. Different combinations of blubber from seal, whale and walrus including their sums were used in the statistical models to find the best predictor of POPs intake.

Because of the uncertainty in data on blubber intake, it was not treated as a continuous variable. Participants were instead divided into two equal sized groups on the basis of blubber consumption: low intake and high intake. They were first divided into tertiles (results not shown), but the moderate and high consumer had very similar levels and it was thus decided to divide them into two groups. Further, they were divided into two age groups, 0–40 years and 41 years and above, and two BMI groups, 0–24.99 kg m^{-2} and 25 kg m^{-2} and above. The women were divided into two equal-sized breastfeeding groups, 0–36 months and 37 months and above, because categorical grouping (breastfed or not) was not possible as only one had not been breastfeeding her child. Smoking, also found to affect the levels of POPs,[23] was not included in the analyses because 95% of the participants were smokers and the remaining 5% were previous smokers.

All statistical analyses were done using the SAS software package, version 6.12 (SAS Institute, 1996).[24] The border for significance was set to 99% instead of more commonly used 95% due to the high number of variables and uncertainties involved in these types of analyses. Significance between 95 and 99% was considered as borderline.

Table 1 Self-reported daily intake of the 18 most common food items in Uelen ($n = 50$)

Food items (g per day)	Mean daily intake	Median daily intake	Range
Seal meat	159	79	7–1000
Walrus meat	165	105	12–800
Whale meat	32	14	0–173
Seal blubber	34	18	0–200
Walrus blubber	46	26	0–370
Whale blubber	5	12	0–132
Wheat bread	251	200	3–600
Cereal	108	100	8–500
Macaroni	113	66	26–500
Sugar	50	40	0–400
Saithe	57	26	0–345
Arctic char	31	21	0–164
Duck	26	19	0–132
Hunchback salmon	23	8	0–263
Conserved beef	17	3	0–200
Chum salmon	15	2	0–263
Hare	19	2	0–575
Polar bear meat	5	2	0–77

Results

Breast feeding

Women reported breastfeeding for a median total of 36 months (range: 0–270), and every child was breast-fed a median time of 18 months.

Diet

It must be noted that the food questionnaire has not been validated and the self reported intake is presented here just to give an impression of the relative reported intake values. The most common food items are listed in Table 1 with the median and average amounts consumed. All participants reported eating local food with marine mammals being the most important besides bread. Walrus and seal meat, as well as walrus blubber were most frequently consumed with a frequency of 8 meals per month for all three items. The median intakes were reported to be 105, 79 and 26 g per day, respectively. The intake of blubber and marine meat was highly correlated (r coefficient of 0.81 and $p < 0.001$). The most common fish, saithe, was consumed 2.7 times per month corresponding to 26 g per day.

Bread was consumed daily at an intake rate of 200 g per day. Considerable amounts of cereal and macaroni were also consumed with intakes of 100 and 86 g wet weight, respectively. Besides those items, small amounts of vegetables and other commercial goods were eaten.

The median energy intake for the 11 most common food items was found for men to be 20360 kJ per day (18–30 years) and 16357 kJ per day (31–60 years). For women 18 to 30 years and 30 to 60 years, it was found to be 9096 and 18024 kJ per day, respectively.

Persistent organic pollutants (POPs)

The limits of detection (LOD) for all compounds are shown in Table 2. Wet-weight and lipid-weight plasma concentrations of POPs are shown in Table 3 and Table 4, respectively. In Table 3 the percentage of individuals with values below the LOD is indicated. *cis*-Chlordane was also quantified, but due to isotopic interference in the chromatograms it was not reported. The compounds with the highest concentrations were PCB 153, *p,p′*-DDE, β-HCH, *trans*-nonachlor and oxy chlordane with geometric means of 538, 520, 410, 261 and 205 ng g^{-1} lipids respectively (Table 4). The geometric mean of β-HCH was 521 ng g^{-1} lipids for men and 331 ng g^{-1} lipids for women (results not shown). Toxaphene 26 (Tox 26) and 50 (Tox 50) were detected in 82% and 86% of the samples, respectively. Geometric mean levels of tox 26 + tox 50 (sum tox) was 62.7 ng g^{-1} lipids. The DDE:DDT ratio was found to be 15.4. Both mirex and α-HCH were detected in all samples with geometric means of 27 ng g^{-1} lipids and 3.5 ng g^{-1} lipids.

The concentration of PCB 153 was more than twice as high

Table 2 Limit of detection (LOD) for all compounds studied (μg L^{-1} plasma)

Compound	LOD/μg L^{-1}	Compound	LOD/μg L^{-1}	Compound	LOD/μg L^{-1}
PCB 28	0.007	PCB 156	0.004	α-HCH	0.005
PCB 52	0.004	PCB 169	0.005	β-HCH	0.012
PCB 99	0.009	PCB 170	0.005	γ-HCH	0.008
PCB 101	0.009	PCB 180	0.004	Heptachlor	0.004
PCB 105	0.007	PCB 183	0.005	Oxy Chlordane	0.100
PCB 118	0.007	PCB 187	0.007	Mirex	0.001
PCB 126	0.008	*o,p′*-DDE	0.005	*t*-Chlordane	0.004
PCB 128	0.007	*p,p′*-DDE	0.045	*c*-Chlordane	0.005
PCB 138/163	0.009	*o,p′*-DDT/*p,p′*-DDD	0.007	*c*-Nonachlor	0.003
PCB 149	0.009	*p,p′*-DDT	0.010	*t*-Nonachlor	0.004
PCB 153	0.008	HCB	0.006	Tox 26	0.058
				Tox 50	0.050

Table 3 Wet weight levels of POPs in human plasma from people in Uelen ($n = 50$)

Compound	Average/ μg L^{-1} plasma	Stdev	Median/ μg L^{-1} plasma	Geomean/ μgL^{-1} plasma	Range/ μg L^{-1} plasma	% Below LOD
Lipids	5.3 g L^{-1}	1.3	5.1 g L^{-1}	5.2 g L^{-1}	3.1–7.9 g L^{-1}	
HCB	1.15	0.80	1.08	0.86	0.08–3.42	0
α-HCH	0.02	0.01	0.02	0.02	0.01–0.05	0
β-HCH	2.87	1.98	2.65	2.10	0.216–8.18	0
γ-HCH	0.005	0.006	0.004	0.004	0.004–.048	98
Heptachlor	0.002	0.000	0.002	0.002	0.002–0.002	100
Mirex	0.22	0.24	0.18	0.14	0.02–1.44	0
Oxy Chlordane	1.83	1.85	1.68	1.05	0.05–9.71	4
t-Chlordane	0.004	0.004	0.002	0.003	0.002–0.017	69
c-Nonachlor	0.19	0.15	0.165	0.13	0.013–0.57	0
t-Nonachlor	2.01	1.63	1.68	1.33	0.11–6.97	0
Sum CDs	**4.03**	**3.46**	**3.65**	**2.65**	**0.24–17.27**	
o.p′-DDE	0.006	0.005	0.005	0.005	0.002–0.025	95
p.p′-DDE	3.30	1.97	2.91	2.69	0.46–8.34	0
o.p′-DDT/*p.p′*-DDD	0.03	0.04	0.02	0.01	0.003–0.19	34
p.p′-DDT	0.23	0.17	0.19	0.17	0.01–0.73	3
Sum DDTs	**3.56**	**2.12**	**3.15**	**2.91**	**0.54–9.28**	
PCB 28	0.05	0.03	0.04	0.04	0.003–0.12	2
PCB 52	0.026	0.022	0.018	0.019	0.002–0.108	19
PCB 99	0.57	0.37	0.54	0.44	0.05–1.36	0
PCB 101	0.07	0.10	0.05	0.05	0.004–0.57	2
PCB 105	0.13	0.08	0.12	0.10	0.02–0.29	0
PCB 118	0.76	0.50	0.73	0.57	0.07–1.84	0
PCB 126	0.006	0.017	0.004	0.004	0.004–0.125	98
PCB 128	0.025	0.11	0.004	0.005	0.004–0.73	76
PCB 138/PCB 163	1.51	1.14	1.23	1.09	0.14–5.28	0
PCB 149	0.01	0.01	0.01	0.01	0.004–0.04	45
PCB 153	4.03	3.30	3.30	2.78	0.31–15.75	0
PCB 156	0.13	0.12	0.10	0.08	0.01–0.59	0
PCB 169	0.002	0.001	0.002	0.002	0.002–0.012	98
PCB 170	0.56	0.56	0.41	0.35	0.03–2.42	0
PCB 180	1.20	1.14	0.95	0.76	0.07–5.14	0
PCB 183	0.10	0.07	0.09	0.08	0.012–0.26	0
PCB 187	0.36	0.27	0.28	0.26	0.034–1.24	0
Sum PCBs	**9.54**	**7.39**	**8.00**	**6.79**	**0.853–33.90**	
Tox 26	0.26	0.21	0.21	0.17	0.03–0.83	18
Tox 50	0.22	0.19	0.17	0.15	0.03–0.82	14
Sum tox	**0.48**	**0.39**	**0.39**	**0.32**	**0.05–1.58**	

as that of PCB 138/163, followed in sequence by PCB 180 > 118 > 99 > 170 > 187; PCB 187 levels were considerably higher than the remaining congeners. Reanalyses of 20 samples showed no co-elution for PCB 153, but high amounts of PCB 163 were found to co-elute partly with PCB 138. PCB 163 had a geometric mean of 0.22 μg L^{-1} plasma. It must be noted that the separation of PCB 138 and 163 was only partial, adding uncertainty to their relative amounts. PCB 146 was also identified in all 20 plasma samples with a geometric mean of 0.15 μg L^{-1} (Table 5). The PCB congeners were all highly inter-correlated. These correlations were all significant, except for some of the lower chlorinated congeners like PCB 28, 52 and 101. The correlation between PCB 170 and 180 had an r coefficient of 0.994, while that of PCB 138/163 and PCB 153 was 0.984.

Diet, lipids and POPs

No food item except blubber was found to significantly affect the plasma concentrations of POPs in the statistical models. Of the different combinations of blubber intake, the sum of all three types of blubber was the best predictor of intake of POPs. Attempts were also made to use the frequency of intake instead of intake in g per day in the statistical models, and it was found not to be a good predictor of intake of POPs. The diet is highly seasonal and the whole year needs to be considered for the complete input. The results from the ANOVA are shown in Table 6 where the concentrations of POPs in the low and high blubber intake groups are listed. Here the levels of POPs in both intake groups are adjusted for the other significant predictors, age and gender. Age and gender were significant factors for all the studied compounds and their respective p-values are listed. The intake of blubber was a significant predictor of sum PCBs ($p = 0.01$) and borderline for sum CDs ($p = 0.02$) and sum DDTs ($p = 0.04$). It was not a significant factor for sum tox and β-HCH, even though there seems to be an increase in levels with consumption. For the sum tox and β-HCH there was a significant interaction between age and gender. The interaction factor was however not included in the model because of the low number of participants. BMI and the self-reported domestic use of pesticides were not significant predictor variables for any of the compounds.

Clearly, the amount of lipids in plasma was found to increase significantly with age independent of gender (Table 6). The same significant increase with age was observed for free cholesterol, total cholesterol and phospholipds. The amount of triglycerides did not increase with age nor blubber intake (results not shown). There was a slight increase in the amounts of lipids with the consumption of blubber, but it was not of significance (Table 6).

For men, none of the plasma concentrations of POPs increased significantly with age, not even when age was treated as a continuous variable. The intake of blubber was borderline significant ($p = 0.04$) for the plasma sum CDs, otherwise not. BMI was only borderline significant for the sum tox and sum CDs (results not shown).

For the women, the level of POPs increased significantly with age. The levels of POPs did however not increase consistently but seemed to increase slowly at low age with a greater increase

Table 4 Lipid-weight levels of POPs in human plasma from Uelen ($n = 50$)

Compound	Average/ ng g^{-1} lipids	Stdev	Median/ ng g^{-1} lipids	Geomean/ ng g^{-1} lipids	Range/ ng g^{-1} lipids
HCB	211.4	130.4	204.0	167.7	19.7–531.4
α-HCH	4.0	2.1	3.5	3.5	1.0–10.6
β-HCH	524.3	319.5	519.7	409.6	51.1–1281.5
γ-HCH	1.0	1.2	0.8	0.8	0.5–9.2
Heptachlor	0.4	0.1	0.4	0.4	0.3–0.7
Mirex	41.1	41.0	28.6	27.0	3.1–228.7
Oxy Chlordane	339.2	327.3	281.2	204.5	7.0–1537.9
t-Chlordane	0.7	0.6	0.5	0.6	0.3–2.7
c-Nonachlor	34.2	23.9	32.8	25.1	2.6–106.1
t-Nonachlor	362.2	264.2	315.8	260.6	25.9–1123.0
Sum CDs	**736.4**	**592.1**	**683.0**	**518.1**	**56.2–2734.6**
o.p'-DDE	1.1	0.8	1.0	0.9	0.3–3.5
p.p'-DDE	608.9	322.9	563.2	520.4	90.7–1633.3
o.p'-DDT/*p.p'*-DDD	4.7	5.6	2.9	2.6	0.4–24.4
p.p'-DDT	42.7	30.6	36.2	33.7	1.0–167.2
Sum DDTs	**657.5**	**344.7**	**607.7**	**563.3**	**106.8–1726.0**
PCB 28	8.6	4.4	8.1	7.3	0.4–19.7
PCB 52	4.9	4.2	3.5	3.6	0.3–24.5
PCB 99	105.3	61.4	100.4	85.4	10.8–311.9
PCB 101	14.0	20.4	10.4	9.5	0.8–123.3
PCB 105	24.2	13.1	23.8	20.1	3.5–52.4
PCB 118	139.9	85.0	142.5	109.6	16.5–336.8
PCB 126	1.2	2.8	0.8	0.8	0.5–20.3
PCB 128	4.8	19.7	0.8	1.1	0.5–122.2
PCB 138/PCB 163	275.0	187.9	253.9	210.5	27.6–836.6
PCB 149	2.0	1.2	1.7	1.7	0.5–6.1
PCB 153	744.0	579.0	645.1	537.8	65.9–2645.3
PCB 156	24.0	21.1	20.1	16.4	1.9–93.6
PCB 169	0.5	0.3	0.5	0.5	0.3–2.3
PCB 170	103.3	98.3	68.4	66.9	6.6–431.2
PCB 180	220.1	196.8	164.0	147.2	16.9–813.6
PCB 183	18.4	10.5	18.8	15.0	2.7–43.4
PCB 187	64.9	43.4	60.2	49.5	7.5–196.4
Sum PCBs	**1755.3**	**1262.7**	**1606.2**	**1316.4**	**175.2–5614.1**
Tox 26	45.9	32.7	41.4	32.7	4.1–144.2
Tox 50	40.0	29.7	33.3	28.9	4.8–134.8
Sum tox	**85.9**	**61.6**	**75.5**	**62.7**	**10.3–279.0**

Table 5 Additional PCB congeners and PCB 138 and PCB 163, based on repeat analyses of 20 of the plasma samples (μg L^{-1})

Compound	Average/μg L^{-1}	Stdev	Median/μg L^{-1}	Geomean/μg L^{-1}	Range/μg L^{-1}
PCB 138	0.820	0.657	0.825	0.562	0.080–2.206
PCB 146	0.217	0.199	0.171	0.137	0.017–0.660
PCB 157	0.056	0.055	0.042	0.031	0.002–0.170
PCB 163	0.376	0.372	0.308	0.220	0.020–1.216
PCB 167	0.034	0.030	0.028	0.022	0.004–0.117
Sum additional congeners[a]	0.683	0.650	0.578	0.414	0.043–2.136
% of total sum PCBs	7.2	1.4	7.3	7.1	5.1–11.1
% of 163 relative to 138	40.9	13.2	37.9	39.1	24.4–76.4

[a]Sum of PCB 146, 157, 163 and 167.

Table 6 Lipid weight levels of POPs in two blubber intake groups,[a] adjusted for age and gender. The *p*-values for the significant predictors used in the ANOVA are listed. Logarithmic values were used in the model

	Low blubber intake ($n = 25$)		High blubber intake ($n = 25$)		*p*-value		
Compound	GM/ ng g^{-1} lipids[b]	Range/ ng g^{-1} lipids	GM/ ng g^{-1} lipids[b]	Range/ ng g^{-1} lipids	Age group[c]	Gender	Blubber intake[a]
Sum PCBs	1127.4	175.2–3378.6	1791.0	363.5–5614.1	0.04	<0.001	0.01
Sum DDTs	507.7	106.8–1379.0	686.3	223.8–1726.0	0.02	<0.001	0.05
Sum CDs	463.7	56.2–1595.4	742.9	112.0–2734.6	0.01	<0.001	0.02
Sum tox	59.9	10.3–175.2	78.5	13.3–279.0	0.04	0.002	>0.05
β-HCH	390.2	51.1–1281.5	533.0	91.6–1160.7	0.01	0.006	>0.05
Lipids[d]/g L^{-1}	5.07	3.36–7.84	5.52	3.06–7.85	<0.001	>0.05	>0.05

[a]Blubber intake in two equal size groups, low and high intake. [b]GM-Geometric mean. [c]Two age groups, 0–40 years and 41+ years. [d]The level of lipids is only adjusted for age.

Table 7 The lipid weight levels (geometric mean, GM) of POPs for men and women in the two age groups adjusted for blubber intake and the results from the independent sample *t*-test for the gender differences in the two age groups

	40 years and below			Above 40 years		
Compound	Men GM $n = 15$/ ng g^{-1} lipids	Women GM $n = 15$/ ng g^{-1} lipids	*t*-test (*p*-value)	Men GM $n = 9$/ ng g^{-1} lipids	Women GM $n = 11$/ ng g^{-1} lipids	*t*-test (*p*-value)
Sum PCBs[a]	2046.8	679.1	<0.001	2272.2	1280.3	>0.05
Sum DDTs[a]	699.4	357.6	0.002	792.5	651.6	>0.05
Sum CDs[a]	822.1	245.9	<0.001	1204.2	480.7	0.001
Sumtox[a]	99.1	30.5	<0.01	88.8	90.4	>0.05
β-HCH[a]	510.6	241.0	0.03	662.9	505.0	>0.05
Lipids/g L^{-1}	4.69	4.51	>0.05	5.94	6.02	>0.05

[a]The logarithmic values where used for the *t*-test.

at higher age. Below the age of 40 there was no significant correlation between age and the sum PCBs and sum DDTs (lipid weight). Above the age of 40 this association was borderline significant ($p = 0.04$) for both compound groups. Intake of blubber was only significant for the concentration of sum PCBs. Duration of breastfeeding was not a significant factor in predicting plasma levels of POPs, but the time spent breastfeeding was highly correlated to age.

In Table 7, the results from an independent sample *t*-test of the gender differences in two age groups are shown. Below the age of 40, the levels of POPs are significantly ($p < 0.01$) lower among the women. The only exception was for β-HCH where the difference was borderline significant ($p = 0.03$). Above 40 years of age, there is no longer a significant gender difference ($p > 0.05$) in the levels except for the chlordanes ($p < 0.01$). As for the lipids, there was no gender difference in any age group. The same results were obtained using ANOVA adjusting for the blubber intake.

Discussion

Methodological issues

Through the food frequency questionnaire we were able to identify the intake of blubber as a significant contributor to increased levels of PCBs and borderline for sum DDTs and sum chlordanes. The dietary issue is, however, extremely complex with great seasonal variations in both intake and physical activity, especially for the hunters. Comparing calculated energy intake (median) to expected energy needs for high physical activity, it seems that the self-estimated food intake was high for some of the participants. Especially among women aged from 30 to 60 years, the estimated intake was 18024 kJ per day compared to a calculated need of 10228 kJ per day. Among men from the age of 18 to 30 years, the estimated energy intake was 20360 kJ per day compared to a calculated need of 14825 kJ per day.[19] It must, however, be noted that most hunters were in this age group and they eat considerable amounts when hunting, indicating that this discrepancy might be expected. In addition the people live under extreme conditions with high energy needs. The reported energy intake in Greenland in the year 1926, was also reported to be 1.5 times their expected needs.[17] Among men (30–60) and women (18–30), the energy intake was comparable to their calculated energy need. These calculations constitute a crude comparison to assess that the self-estimated intake could be used as an approximate measure of intake of the different food items. It should be emphasised that the calculation of energy intake was based only on 11 food items (approximately 95% of the energy intake) and not total food intake. It must also be noted that the numbers in each group was low, adding additional uncertainty to the values.

Levels of POPs

In a comparison of the concentrations of POPs in this study with previous studies, we discuss the different compound groups separately. The geometric mean level of the sum PCBs (17 congeners) found in men and women were 2027 ng g^{-1} lipids and 884 ng g^{-1} lipids respectively. This is considerably lower than what was found in men from Scoresbysund (6750 ng g^{-1} lipids) on the Eastern Coast of Greenland, but in the same range as from the other settlements of that region. As for the women, the levels were in the same range as found in the Disko Bay area of Greenland.[13] The mean sum PCB level of 1755 ng g^{-1} lipids found in this study also appears to be lower than what was found in Nunavik (northern Quebec), where the mean sum PCBs (20 congeners) was 4080 ng g^{-1} lipids.[25]

Of the PCB congeners PCB 153 is by far the most dominant congener with levels twice that of PCB 138/163. This has also been observed in other populations depending heavily on marine mammals.[25] The reanalyses of 20 samples revealed that PCB 163 constituted about 40% of the PCB 138 content (Table 5) in all the reanalysed samples, thus increasing the difference in ratio of 153 to 138 further. The high levels of PCB 163 have to our knowledge not been reported in human samples before. The partial separation of PCB 138 and PCB 163, as well as the high levels of PCB 163, questions the conversion of PCB 138 and PCB 153 levels to Arochlor 1260 by using the following summation formula: Arochlor 1260 = 5.2(153 + 138). This formula was deducted from the congener composition in Arochlor 1260[26] and employed, among other places, in the AMAP report 1998.[5] Our data suggest that it should perhaps be 5.2 (138 + 153 + 163), if the PCB 138 and PCB 163 are separated. This has, however, not been validated further. The few reports of PCB 163 in the environment might be the consequence of its poor separation from PCB 138 in most previous studies.

It was further found that PCB 146, 157, 163 and 167 constituted about 7% of the sum PCBs (Table 5). This adds up to a considerable part of the total burden and needs to be considered when analysing individual congeners, especially since PCB 146 and 163 were present in all the analysed samples. As observed in previous studies, most PCB congeners were highly correlated.[27–29] On a lipid weight basis the sum PCBs and PCB 153 had a Pearson correlation coefficient of 0.99 ($p < 0.001$).

The β-HCH level in women (1.7 μg L^{-1} plasma) was lower, but not significantly (*t*-test; $p > 0.05$), than what has been found in delivering women from Arkhangelsk (3.1 μg L^{-1}).[30] On the other hand, it was higher than in any of the native populations from Greenland, Canada and the Faeroe Islands both for men and women.[5,13,25,31] The β-HCH levels in men (331 ng g^{-1} lipids) was 4 times higher than the highest levels reported previously (93 ng g^{-1} lipids) from Eastern Greenland.[13] Elevated β-HCH levels compared to the PCBs have also been observed in Polar Bears from the Chukotka Peninsula.[17]

These findings are also consistent with oceanic transport data, which indicates that β-HCH enters the Arctic Ocean through the Bering Strait.[32]

As for the DDTs, chlordanes and toxaphenes, the observed concentrations are comparable to what has been found in other native populations.[5,13] Mirex was also present in 96% of the samples when analysing Inuit breast milk samples.[31] The ratio of DDE to DDT was found to be 15.4 (range 5–45). This value seems lower than what has been reported in Greenland, Sweden, Norway and Iceland (26.0–35.0), but comparable to Inuit women from Canada (16.8). The observed ratio is also higher than what has been found in Nikel and Arkhangelsk (8 and 7, respectively);[17] it is thus not low enough to conclude that fresh local sources are present. It might, however, indicate a difference in metabolite pattern in the diet, or a combination of exposure from marine mammals and another source of DDT.

As noted the amount of lipids in plasma increased significantly with age. That is an important consideration when using wet weight levels in plasma.

POPs and diet

First of all, we emphasise the fact that the traditional diet is rich in essential nutrients and of great cultural importance for the native people.[5] However, as found elsewhere, the consumption of marine mammals had a significant effect on the levels of some POPs.[5,31,33] Despite the uncertainties in estimated intake, there is no doubt that the blubber intake is also higher than what has been published from other populations. The intake of traditional food has declined in most other parts of the Arctic with 60–90% of the diet in northern Canada and Greenland now being from a commercial source.[17] In Ittoqqortoormiit and Tassilaq (Greenland), the median blubber intake was estimated to be 6 g per day in both places (personal communication B. Deutch), compared to a median intake of 49 g per day in Uelen.

In the Faeroe Islands, the estimated daily intake of whale blubber between 1974 and 1980 was estimated to be 11.8 g.[34] By comparison the people from Uelen reported a median daily consumption of 5 g whale blubber, in addition to 26 g of walrus blubber and 18 g of seal blubber. The total daily intake of blubber and marine mammal meat adds up to 253 g per day. This is comparable to a reported daily intake of 300 g of ringed seal, bearded seal, beluga skin and walrus among the Canadian Inuits.[31] Despite the high intake of blubber, the PCB and DDE concentrations in plasma are lower than found in some communities on the East Coast of Greenland by B. Deutch and J. C. Hansen,[13] and slightly lower than among Inuits in northern Quebec.[25] This might indicate that the levels of these compounds are lower in the marine mammals from the Russian eastern Arctic. Lower levels of PCBs and DDTs in marine mammals of the Arctic have been reported in *Arctic Pollution 2002*.[17]

Even though the plasma levels of POPs seem to increase with intake of blubber, it was only for the sum PCBs ($p = 0.01$) that blubber was a significant predictor. For sum CDs and for sum DDTs the intake of blubber was of borderline significance ($p = 0.02$ and 0.04, respectively). These findings suggest that even though there are apparent uncertainties associated with the questionnaire used, we were still able to predict the levels of some POPs using the dietary information.

As found in other studies, age and gender are significant predicting factors for all POPs in plasma;[23,35] but for sum tox and β-HCH there was also a significant interaction (results not shown). The likely reason for the interaction was that there was no significant age increase in POP plasma levels among men as opposed to the women. Even though this interaction was not significant for the other compounds it adds uncertainty to the statistical analyses of men and women together.

Even after adjusting for differences in blubber intake, which was higher among the young men compared to the young women, the concentrations of POPs were still significantly lower among premenopausal women. The observed difference can possibly be explained by extensive breastfeeding keeping the plasma levels low in that period. Breastfeeding has been found to reduce the levels of POPs in women considerably.[35–37] In the present study, however, breastfeeding was not found to significantly reduce the levels of POPs when it was included in the ANOVA. The reason for this we believe is the fact that age and period of breastfeeding was highly correlated, implying that duration of breastfeeding was also correlated to the time elapsed since the last period of lactation. Thus the broad age distribution likely masked the effects of lactation thereby reducing the importance of this factor in the model. We had no information on time elapsed since the last period of breastfeeding making it impossible to adjust for this. This is the reason for the age division by considering that women below 40 are normally fertile and closer to the last lactation period. The two age groups could thus be considered as recent breast feeders and old breast feeders, explaining the difference in levels of POPs.

Above the age of 40, the plasma concentrations of POPs among women had increased considerably, and the gender difference was no longer significant. The reason for the lack of significance might be the small numbers in each group and the broad concentration range. The increase in plasma concentrations with age among women could likely be explained by accumulation with time since the last period of breastfeeding (Table 7). The older women also reported eating more blubber than the younger women (comparable to the amount older men consumed (results not shown)). It was only for the chlordanes that the levels were still significantly ($p < 0.01$) different in the above-40 group.

The reason for the non-significant age increase among men is not clear, but might indicate that the intake rate is not much above elimination rate. It seems like they are approaching a steady state for these compounds but there appears not to be enough statistical power to discern this in the present study. It has also been shown that for a given contamination level in the diet, the net absorption of hexachlorobenzene (HCB), PCBs and PCDD/Fs in human volunteers diminishes as the blood level of the compounds increases.[38] The amount of lipids also increased significantly with age and the lipid weight data were employed in the analyses. Another explanation for the slow increase in levels might be the observation that men's consumption of wildlife may be inversely correlated with age (Personal Communication E. Nieboer). The interviewers also had that impression of the people in Uelen, but the energy intake was only slightly higher among the younger men, and not of significance.

High β-HCH levels might be of special health concern considering the fact that this compound is found in higher levels in the liver compared to adipose tissue.[39] Further, the most crucial time window of sensitivity for adverse effects by PCBs appears to be the prenatal and the early postnatal period.[40] As a Dutch PCB/dioxin study has illustrated subtle clinical, endocrine and mental/psychomotor development effects can occur in breastfed infants.[41,42] It has also been reported that nursing babies absorb more than 90% of these compounds when present in breast milk.[43,44] In a study by Ayotte and colleagues of dioxin-like compounds, it was found that breastfeeding strongly influenced body burden during childhood, but not after the age of 20.[45] The women in this study breastfed their children for a long time period. It is reasonable to assume that the first children breastfeeding likely will receive the highest amounts of POPs from their mothers. Nevertheless, the health benefits of breastfeeding do appear to outweigh the negative aspects from POP exposure; only extreme levels should result in advice against breastfeeding.[5,46]

Conclusions

Self-reported intake of the sum of seal, walrus and whale blubber was found to be a significant predictor of the plasma concentrations of sum PCBs and borderline for sum CDs and sum DDTs, for males and females combined.

The increase in levels of POPs with age is not significant among the men in this study, whereas age is a highly significant factor for women.

Below the age of 40, the levels of POPs are significantly lower among women compared to men. Above the age of 40 the levels are still different but no longer at significance, except for the chlordanes.

High amounts of PCB 163 were found partly to co-elute with PCB 138.

The levels of β-HCH were elevated compared to the PCBs confirming previous findings that ocean currents through the Bering Strait are the main transporters of β-HCH to the Arctic Ocean or indicating the presence of fresh sources.

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