

Decline in blood concentrations of mercury and lead in the Inuit population of Nunavik (Québec)

Julie Fontaine¹, Éric Dewailly^{1*}, Daria Pereg¹, Pierre Ayotte¹, Serge Déry²

¹ Unité de recherche en Santé publique, Centre de recherche du CHUL-CHUQ, 2875
boul. Laurier, Bureau 600, Québec (Québec), Canada, G1V 2M2

² Regional Board of Health and Social Services of Nunavik, C.P. 900, Kuujuaq (Québec)
Canada, J0M 1C0

*Corresponding author

Email addresses:

JF: Julie.Fontaine@crchul.ulaval.ca

ED: Eric.Dewailly@crchul.ulaval.ca

PA: Pierre.Ayotte@crchul.ulaval.ca

DP: Daria.Pereg@crchul.ulaval.ca

SD: Serge_Dery@ssss.gouv.qc.ca

Abstract

Background

Arctic populations are exposed to mercury (Hg) and lead (Pb) through their traditional diet. The aim of this study is to examine the trends in Hg and Pb exposure between 1992 and 2004 in the Inuit population of Nunavik (Northern Quebec, Canada) using the data obtained from two broad scale health surveys, and to identify sources of exposure in 2004.

Methods

In 2004, 917 adults aged between 18 and 74 were recruited in the 14 communities of Nunavik to participate to a broad scale health survey. Blood samples were collected and analysed for metals by ICP-MS and dietary and life-style characteristics were documented by questionnaires. Results were compared with data obtained in 1992, where 492 people were recruited for a similar survey in the same population.

Results

Mean blood concentration of Hg was 51.2 nmol/L, which represent a 32 % decrease ($p < 0.001$) between 1992 and 2004. Hg blood concentrations in 2004 were mainly explained by age (r^2 partial = 0.20; $p < 0.0001$), and the most important source of exposure to Hg was marine mammal meat consumption (r^2 partial = 0.04; $p < 0.0001$). In 2004, mean blood concentration of Pb was 0.19 μ mol/L and showed a 55 % decrease since 1992. No strong associations were observed with any dietary source, and Pb concentrations were mainly explained by age (r^2 partial = 0.20.; $p < 0.001$).

Conclusions

Important decreases in mercury and lead exposure were observed. Mercury decrease could be explained by dietary changes and the ban of lead cartridges use likely contributed to the decrease in lead exposure.

Background

Human exposure to environmental contaminants is a well-known phenomenon in the Canadian Arctic. The Inuit of Nunavik are exposed to a plethora of toxic substances that are carried from southern to northern latitudes by oceanic and atmospheric transport and biomagnified in Arctic food webs. As the Inuit traditional diet comprises large amounts of tissues from marine mammals, fish and terrestrial wild game, Inuit are more exposed to metals than populations living in southern regions. Metals of concern include mercury (Hg) and lead (Pb).

Hg is a toxic metal originating from both anthropogenic and natural sources. Despite significant reduction in Hg emissions in Europe and North America, Hg concentrations are still high in the Arctic environment and biota [1]. Although most of the Hg released in the environment is inorganic or elemental, once in the water, it can be transformed into methyl mercury (MeHg) by microbial action [2]. This highly toxic form of Hg is accumulated in animal tissues and is biomagnified in the food chain [3]. In the Arctic, the most significant sources of human exposure to MeHg are fish and marine mammal consumption [4-8].

Contaminant exposure from traditional food consumption among Inuit has been estimate during an extensive dietary survey covering Nunavut and Inuvialuit communities in the late 1990s [9]. Data showed that the mean intake levels of Hg were below the tolerable daily intake levels used by Health Canada. Ringed seal kidney had the highest concentration of mercury (2844 ng/g) but only contributed 2.5% of total intake during late winter, while ringed seal meat had much lower concentration (400 ng/g) but contributed more (15.3%) to Hg intake. Caribou meat had low Hg concentrations (57 ng/g) but due to its frequent consumption, it was the most important contributor (30.1 %) to Hg intake. A recent update in on dietary contaminant exposure done by the same team showed that the contaminants concentrations in 2007 appeared to be similar, with the exception of Hg in ringed seal liver, which was higher, and walrus blubber, which was lower[10].

In adults, MeHg mainly affects the nervous system and is also toxic to the kidney, liver, reproductive organs, and the cardiovascular system [11-13]. Low chronic prenatal exposure similar to that observed in populations exposed through fish consumption may have subtle neurodevelopment consequences [14-16]. In Nunavik, visual information processing [17] and higher tremor amplitude [18] were shown to be related to MeHg exposure in preschool-aged Inuit children. However, these results were not observed in another cohort from the Seychelles Islands [19], and therefore, the effects of prenatal exposure to Hg still raise controversy.

Pb is another toxic metal to which the Inuit may be exposed environmentally. Most of the Pb in the environment comes from anthropogenic sources and is carried to the Arctic by atmospheric transport [1]. It has been clearly shown that environmental levels of Pb have been decreasing in Arctic regions since the ban of leaded gasoline [1,8]. However, high levels of Pb can still be found in Inuit populations in certain Arctic regions due to the past and/or present use of lead shot for hunting wild game [1,5,20]. Hunter can be exposed to Pb by inhalation or ingestion of lead dust released by the friction of the shot against the barrel and by the combustion of high-explosive primers that contain lead styphnate[21]. Moreover, consumer of wild game can be exposed to Pb by ingestion of whole pellets or fragments embedded in meat or by ingestion of game with biologically incorporated lead (mostly exposed through ingestion of spent shot and fishing sinkers)[21] . In a previous dietary survey in Inuit communities of the Canadian Arctic, the major contributors to Pb dietary exposure during late winter were caribou meat (68.4 %; 783 ng/g) and Arctic char (21.4 %; 1009 ng/g) [9].

In 1999, the use of lead cartridges for hunting migratory birds was banned in Canada, and the public health authorities of Nunavik actively informed the population in order to reduce lead shot use and Pb exposure [20]. Dallaire et al (2003) [22] analyzed 251 cord blood samples between 1994 and 2001, and results showed a strong decrease in blood concentrations of Pb after the ban of lead cartridges (0.20 $\mu\text{mol/L}$ before 1999 compared to 0.12 $\mu\text{mol/L}$ after 1999; $p < 0.0001$).

Environmental exposure to Pb can have detrimental neurological effects in children and adults [23-25]. In Nunavik, blood Pb concentration in Inuit children was associated with deficits in several fine motor tasks [18] and correlated positively with impulsivity and activity [26]. Plusquellec et al (2007) [27] evaluated early behavioural effects of Pb in of 169 11-months old Inuit infants and found that cord blood Pb concentrations were significantly negatively associated to the direct observational measures of infant attention.

In 1992, Santé Québec conducted the first major health survey to assess the general health status of the Inuit population of Nunavik, and mercury and lead concentrations were high compared to the concentrations measured in the general population of Canada [5,28]. Given the known toxic effects of these metals in adults and the developmental effects observed following *in utero* exposure, the objective of this study was therefore to evaluate blood concentration of mercury and lead and its sources among the Inuit of Nunavik in 2004 and evaluate the evolution of these concentrations since the Santé Québec Survey in 1992 [29].

Methods

Population and sampling:

The Nunavik Health Survey [29] was conducted in the 14 communities of Nunavik during fall 2004 on the Canadian Coast Guard icebreaker and scientific research vessel *CCGS Amundsen* (Fig.1), in collaboration with the Institut National de Santé Publique du

Québec, the Nunavik Regional Board of Health and Social Services and the Institut de la Statistique du Québec (ISQ). The ISQ was given the mandate to develop the survey frame. Many sources of information were used by the ISQ to count all private Inuit households in Nunavik. Priority was given to municipal rolls as the most comprehensive source of information. When information was lacking, other lists were used such as those from employers who provide lodging to employees, (Ungava's Tulattavik Health Centre, Inuulitsivik Health Centre, Kativik School Board, etc.), the Quebec electoral roll, the Kativik Housing Bureau and the telephone directory.

A stratified random sample of private Inuit households was selected according to the municipalities. Since home addresses in some municipalities are consecutive, the survey frame was sorted first by home addresses, followed by a systematic draw of a predetermined number of households to avoid selection of two immediate neighbours. Since many Inuit regularly move from one house to another, it was decided to sample households instead of individuals. To obtain a good representation of each community, a proportional allocation of sample units corresponding to the size of each village was chosen. All eligible people of the household were asked to participate according to the survey steps or instruments. A total of 1058 people were recruited for the study and informed consent was obtained from all participants. Blood samples were obtained from 917 participants during the clinical session to evaluate levels of exposure to environmental contaminants. Face-to-face interviews were conducted on board the *Amundsen* to collect information on socio-demographic characteristics and lifestyle habits. A food frequency questionnaire was administered to collect information on food

intakes and eating patterns. The questionnaire used in 2004 measured the consumption of 25 food items of *country foods* which refers to food items derived from fishing, hunting and gathering, recorded for each of the four seasons (of the year prior the interview). Specification of the usual serving size was included in the questions on frequency. Pre-defined serving sizes were included in the questionnaire and a corresponding food model was shown to the respondents.

To assess temporal variation of blood Hg and Pb concentration, we compared our results with data from a survey conducted with a similar protocol by Santé Québec in 1992 [5,28,29]. A systematic sampling was achieved after sorting the survey base by household address to favour a more complete coverage of the territory and to avoid the selection of next-door neighbours. Furthermore, so that each village would be represented, we stratified the sample by village, with quasi-proportional representation of the number of households in each stratum. A total of 400 household were randomly selected and visited by interviewers between September and December 1992, and a total of 493 people were recruited. Protocols for face-to-face interviews and blood sampling were similar to the ones used in 2004. However, the food frequency questionnaire was only administered to 226 women, and the list of country foods was less exhaustive than that used in 2004, hence making comparisons between the surveys difficult.

Biological samples processing

The blood sample for metal analysis was collected from a cubital vein in a 6-mL plastic vacutainer containing potassium EDTA as the anticoagulant (BD Medical). Once collected, blood samples were kept at 4°C until stored at –20°C on the ship. During their transfer from the ship to Québec City, the samples were kept frozen in insulated containers with ice packs. Laboratory analysis for contaminants was performed at the *Centre de Toxicologie of the Institut National de Santé Publique du Québec*. This facility is accredited ISO 17025 and participates in the QA/QC program of the Canadian Northern Contaminants Program and the Arctic Monitoring Assessment Program.

In 2004, Pb and Hg were determined in whole blood samples from individual participants by inductively coupled plasma mass spectrometry (ICP-MS), which allows the simultaneous determinations of several metals in elementary form in various matrices. Blood samples are diluted in ammonium hydroxide and metals are brought to their elementary form by passing through argon plasma before being identified by mass spectrometry. All samples were analysed on Perkin Elmer Sciex ICP-MS instruments: lead was quantified on the Elan 6000 and mercury on the DRC II. Detection limits were 0.001 µmol/L for Pb and 0.5 nmol/L for Hg. Accuracy and precision were measured using reference material from the Interlaboratory Comparison Program of the Centre de Toxicologie (INSPQ). The coefficient of variation was 2.8%, and the relative bias was +3.1 % for the Pb reference specimen analysed on 10 different days (consensus median value from participating laboratories = 0.6 µmol/L). The coefficient of variation was 2.1 %, and the relative bias was +1.6 % for the total Hg reference specimen analysed on 10 different days (consensus median value from participating laboratories = 66 nmol/L).

In 1992 blood Pb concentrations were determined by graphite furnace atomic absorption spectrometry (GFAAS) (Perkin Elmer, model ZL 4100). Samples were diluted and injected directly into the instrument. Blood Hg concentrations were determined by cold-vapor atomic absorption spectrometry (CVAAS) (Pharmacia Mercury monitor). Samples were microwave-digested with nitric acid, and an aliquot was used for the analysis. In order to compare the different laboratory procedures used in 1992 and 2004, the INSPQ performed a quality control study within the framework of the Quebec Interlaboratory Comparison Program. The INSPQ used both methods to determine the Hg and Pb concentrations and obtained strong correlations. The bias observed was 8% for Hg ($y = 0.92x + 2.83$; $R^2=0.99$) and 6% for Pb ($y = 0.94x - 0.0025$; $R^2=0.93$). We can therefore assume that both methods (ICP-MS and furnace atomic absorption spectrometry) give comparable results.

Statistical analysis

Descriptive statistics were performed in order to present consumption of country food items and metal concentrations in whole blood. Blood Hg and Pb concentrations as well as the most consumed food items (marine mammal meat, fish, terrestrial mammal meat and game birds meat) satisfied log-normality criteria and geometric mean were therefore used. Student's t-tests or analyses of variance were used to compare variables according to gender, age category and region of residence. For the purpose of this study, the Nunavik territory was divided in two regions (Hudson Bay and Ungava Bay regions) in relation to the different dietary habits of the residents. Other country food items were

consumed by less than 50% of the sample, therefore these variables were treated dichotomously (consumer, non-consumer). Chi-square test was used to compare proportions and Mantel-Haenszel Chi-square test was used to evaluate trend. Comparisons have also been made with data obtained from the 1992 Santé Québec Survey. The variation in metal concentrations between 1992 and 2004, stratified according to gender, age category, region of residence and tobacco consumption was compared using Student's t-tests. Given the sampling procedures used in both surveys, these comparisons include an adjustment in proportions or rates to take into account the change in the population's age structure. This adjustment is made on the basis of 5-yr age categories using Nunavik 2001 census of Statistics Canada as reference population. However, only raw data is reported in the text, tables and figures to avoid any possible confusion with adjusted proportions. All analyses of variance used a Satterthwaite correction to account for the sampling strategy used in both surveys and the results are presented as Satterthwaite chi-squared. We performed analyses of variance to assess multivariate associations between metal blood concentrations and various variables. All personal characteristics (gender, age, region of residency) and consumption habits that were associated ($p \leq 0.10$) with metal concentrations in blood were considered in the predictive model. To be retained in the final model, a variable had to show significant association (i.e., $p \leq 0.05$) with metal concentrations in blood. Statistical analyses were conducted using the SAS statistical Package v. 9.1 (SAS Version 9.1, SAS Institute, Cary, NC) with an α threshold of 0.05.

+Results

Table 1 shows that the 917 participants of the 2004 survey and the 493 participants of the 1992 survey had similar characteristics and then, results obtained from those two studies were comparable. Men and women were equally represented in 2004 and had the same age structure (results not shown). The mean age for men in 2004 was 36.4-yr old (95% confidence interval (CI) = 35.9-37.0) and 36.9-yr old for women (95%CI = 36.2-37.2). In 2004, smokers represent 77.5% of the sample.

The mean daily consumption of the country food items of consumed by most of the participants is presented in table 2. Only consumption of fish significantly increased with age ($p = 0.0001$). Consumption of marine mammal meat ($p < 0.0001$), fish ($p = 0.01$) and game birds meat ($p = 0.01$) was significantly higher in men than women. In Hudson's bay region, mean consumption of marine mammal meat ($p < 0.0001$), fish ($p = 0.04$), and game birds meat ($p = 0.01$) was significantly higher than in Ungava's bay. Other country food items were consumed by less than 50% of the sample, therefore these variables were treated dichotomously, and proportions of consumers are presented in table 3. Proportion of consumers of marine mammal's kidneys and liver (p -trend = 0.003), salmon and trout (p -trend < 0.0001) and duck meat (p -trend < 0.0001) increased significantly with age. Proportion of consumers did not vary according to gender, except for consumption of salmon and trout ($\chi^2 = 12.6$; $p < 0.001$). In Hudson's bay region, the proportion of consumer of marine mammal's kidneys and liver ($\chi^2 = 107.7$; $p < 0.0001$) and duck meat ($\chi^2 = 40.7$; $p < 0.0001$) were higher than in Ungava's bay, while it was lower for consumption of salmon and trout ($\chi^2 = 41.7$; $p < 0.0001$) (results not shown).

Figure 2 and 3 present the distribution of the Hg and Pb concentrations measured in blood of Inuit adults in 2004. Hg and Pb were detected in all 917 samples. Table 4 presents descriptive statistics for the blood concentrations of Hg and Pb detected among the Inuit adult population aged 18 to 74 during the 1992 Santé Québec Survey and the 2004 Nunavik Inuit Health Survey, stratified for gender, age and region of residence, respectively. In 2004, mean blood Hg concentrations were significantly higher in women than in men, whereas mean Pb concentrations were higher in men. Adults aged 45 to 74 had significantly higher concentrations ($p < 0.001$) of Hg and Pb than younger adults. Mean Hg concentrations were significantly higher in communities along Hudson Bay ($p < 0.001$), but no difference was observed between the two regions for blood Pb concentrations ($p = 0.19$). Analyses of variance (results not shown) also showed that Hg concentrations were significantly different according smoking habits ($p < 0.001$), and that Pb concentrations were associated with hunting frequency, but not with alcohol consumption ($p = 0.12$) and tobacco consumption ($p = 0.36$).

As shown in Table 4, statistically significant declines ($p < 0.001$) in Hg (32%) and Pb (55%) exposures were observed between 1992 and 2004, and this was observed in both genders. Metals concentrations also decreased for all age categories, and for both regions of residence, between 1992 and 2004.

A positive association (Table 5) was observed between blood Hg concentrations and consumption of marine mammal meat, marine mammal kidney and liver and salmon and trout. A model including consumption of marine mammals' meat, kidney and liver, age, gender and region of residence as independent variables explained 27% of the variation of Hg concentration ($p < 0.0001$). Of all these variables, age was the most highly associated to Hg blood concentrations (partial R^2 of 0.20), followed by marine mammal meat consumption (partial R^2 of 0.04)

As shown in Table 5, all the traditional food consumption variables selected were correlated with Pb concentrations. A model including consumption of game birds and marine mammal kidneys and liver, age, gender and tobacco consumption as independent variables explained 25% of the variation of Pb concentration ($p < 0.0001$). However, associations with dietary variables were very low (partial R^2 of 0.01) and as for Hg, age was the most highly associated variable (partial R^2 of 0.20).

Discussion

This study aimed at describing current exposure to Pb and Hg in the Inuit population of Nunavik, identify current dietary sources of exposure and compare these levels to those prevailing 12 years ago. The results showed a general decrease in exposure to both metals during the 12 year time span.

Mercury

In 2004, average blood Hg concentrations were statistically higher in women than in men. The associations between Hg and gender reported in other studies vary according to different populations [30,31]. Hg blood concentrations were statistically higher in adults aged 45 to 74 compared to younger adults, as observed in other studies [4,30,32,33]. Hg is not known to bioaccumulate in human tissues and this association could be explained by the tendency of young adults to eat less traditional food than previous generations. Indeed, in our population sample, we observed a significant lower intake of certain traditional food items (marine mammal kidneys and liver, fish, duck meat) in younger people. Moreover, the concentration of omega-3 fatty acid in plasma phospholipids, a biological marker of seafood consumption, was nearly two times lower ($p < 0.0001$) in the 18-24 yr age group (5.0 % ; 95% CI = 4.8-5.3) than in the 45-75 yr age group (9.9 ; 95% CI = 4.8-5.3). As in 1992 [5], blood concentrations of Hg were higher in Hudson's Bay residents compared to Ungava's Bay residents. A possible explanation for this difference is that Hudson's Bay residents consume significantly more marine mammal meat, kidney and liver, which are known sources of Hg intake [34-36]. Indeed, in the present study, blood concentrations of Hg were mainly explained by age (partial R^2 : 0.20) and consumption of marine mammal meat (partial R^2 : 0.04), liver and kidney (partial R^2 : 0.01). These observations match the results obtained in 1992, where Hg concentrations were correlated with age and consumption of beluga and seal meat and liver (R^2 : 0,30) [5].

Between the 1992 and 2004 health surveys, an important decrease (32 %) in blood concentrations of Hg was observed in the Inuit population of Nunavik. However, levels of Hg in the environment do not seem to have shown a consistent decrease over the last decade [37,38]; on the contrary, evidence for increasing levels of Hg in the Canadian Arctic is observed in a number of marine birds and mammals [39-42]. It is therefore more likely that the decrease observed in blood concentrations of Hg in Nunavik Inuit could be attributed to changes in dietary habits. Indeed, the mean intake of marine mammal meat decreased from 28.7 g/day in 1992 to 17.5 g/day in 2004, which represents an approximate 40% decrease [43]. These changes in dietary habits could result from the promotion of less contaminated traditional food (such as Arctic Char) in the Arctic, the decrease in traditional food consumption associated to a shift to a globally more westernized life-style. Despite the observed decrease, Hg body burden in this population nevertheless remains a concern, based on the proportion of the population showing blood concentrations above the maximum recommended level.

Mean blood Hg concentrations (51.2 nmol/L) was still much higher in Nunavik than in the general population of Québec City (3.7 nmol/L;n=470) [44]. This mean concentration was were also higher than those observed in the Cree populations of Oujé-Bougoumou (21.3 nmol/L; n=169) and Nemaska (14.4 nmol/L; n=71) (province of Québec, Canada) [45]. However, mean blood Hg concentration in Nunavik was much lower than those recently measured in specific groups such as high-end fish consumers from San Francisco [46], fish consumers from Brazilian Amazon [47] and Inuit population from Greenland [48].

Mean blood Hg concentration (51.2 nmol/L) was lower than the acceptable blood concentration of 99.7 nmol/L established by Health Canada for the general adult population [49], but the maximum concentration reached 1200 nmol/L, which is 12 times higher than the maximum recommended concentration. Furthermore, 28% of individuals from the general population of Nunavik and 72% of women of reproductive age were above their respective recommended blood level (99.7 nmol/L for the general population; 28.9 nmol/L women of childbearing age).

Lead

Mean blood concentrations of Pb were higher in men and in adults aged 45 to 74, a finding that is consistent with data from other studies [4,5,50-52]. Milman *et al* (1994) suggest that the gender difference observed in Pb body burdens could be explained by the higher content of hemoglobin in men's blood [32]. Reinforcing this possible explanation for gender difference, 40% of women in Nunavik were anemic in 2004 [53].

Blood Pb concentrations increased slightly with increasing annual game bird consumption, a finding which is again consistent other studies [5,21,50,54]. A significant association could be observed with smoking, as reported in other studies [5,6,20,33].

Blood Pb concentrations showed a 55% decrease over the 12-year period. This decreasing trend has also been observed in cord blood obtained from Nunavik newborns, with markedly lower concentrations in 1999 [22]. This suggest that the strong decrease in

Pb concentrations in adults and newborns could be not only attributed to the decreasing environmental levels (since the ban of leaded gasoline), but could also be a beneficial consequence of the ban on lead shot use for hunting wild game and birds, a policy implemented by the Public Health Directorate in 1998 [20]. In an effort to reduce exposure the public health authorities of Nunavik also actively informed the population about the toxic effects of lead from ammunition on children's health [20]. However, mean blood concentration of Pb observed in 2004 (0.19 $\mu\text{mol/l}$) was still higher than the concentrations observed in the general population of southern Québec (0.10 $\mu\text{mol/L}$; n=441) [44], as well as levels measured in the native Cree populations of Oujé-Bougoumou (0.10 $\mu\text{mol/L}$; n=169) and Nemaska (0.10 $\mu\text{mol/L}$; n=71)[55].

Mean blood Pb concentrations was lower than the maximum concentration recommended by Health Canada (0.48 $\mu\text{mol/L}$) [56], but still, almost 10% of the population sample and 2% of women of childbearing age showed levels above the maximum recommended level, with a maximum observed of 2.4 $\mu\text{mol/L}$.

Conclusions

These encouraging results clearly demonstrate that implementation of public health campaigns, such as the ban of lead cartridges, may reduce Inuit exposure to toxic metals. For Hg, important decreases in blood concentrations were observed and could be explained by dietary changes. Nevertheless, a significant proportion of the population still show blood concentrations above the maximum recommended levels. Promoting the

consumption of less contaminated fish species should therefore continue, especially for more sensitive populations such as pregnant women and women of childbearing age.

Competing interests

The author(s) declare that they have no competing interests.

Authors' contributions

JF performed the statistical analyses, interpretation of data and wrote the manuscript.

ED conceived of the study, participated in its design and coordination and helped writing the manuscript.

PA, DP and SD participated in the design of the study, provided support in the interpretation of data, and manuscript writing.

Acknowledgements

We are grateful to the *Ministère de la Santé et des Services sociaux du Québec*, the *Régie régionale de la Santé et des Services sociaux du Nunavik*, ArcticNet and the Northern Contaminant Program (NCP). We also want to thank Danièle St-Laurent and Louis Rochette, as well as the *Institut de la Statistique du Québec* for the development of the statistical design. Finally, we want to thank the Nunavik population for their participation in this research.

Reference

1. Arctic Monitoring and Assessment Programme: *AMAP Assessment Report: Arctic pollution issues*. Oslo, 1998.
2. Jensen S, Jernelov A: **Biological methylation of mercury in aquatic organisms**. *Nature* 1969, **223**:753-754.
3. Boening DW: **Ecological effects, transport, and fate of mercury: a general review**. *Chemosphere* 2000, **40**:1335-1351.
4. Bjerregaard P, Hansen JC: **Organochlorines and heavy metals in pregnant women from the Disko Bay area in Greenland**. *Sci Total Environ* 2000, **245**:195-202.
5. Dewailly E, Ayotte P, Bruneau S, Lebel G, Levallois P, Weber JP: **Exposure of the Inuit population of Nunavik (Arctic Quebec) to lead and mercury**. *Arch Environ Health* 2001, **56**:350-7.
6. Grandjean P, Weihe P, Jorgensen PJ, Clarkson T, Cernichiari E, Videro T: **Impact of maternal seafood diet on fetal exposure to mercury, selenium, and lead**. *Arch Environ Health* 1992, **47**:185-95.
7. Hansen JC, Gilman AP: **Exposure of Arctic populations to methylmercury from consumption of marine food: an updated risk-benefit assessment**. *Int J Circumpolar Health* 2005, **64**:121-36.
8. Van Oostdam J, Donaldson SG, Feeley M, Arnold D, Ayotte P, Bondy G, Chan L, Dewailly E, Furgal CM, Kuhnlein H, Loring E, Muckle G, Myles E, Receveur O, Tracy B, Gill U, Kalhok S.: **Human health implications of environmental contaminants in Arctic Canada: A review**. *Sci Total Environ* 2005, **351-352**:165-246.
9. Kuhnlein H, Receveur O, Chan HM, Loring E: *Assessment of dietary benefit / risk in Inuit communities*. Ottawa; 2000.
10. Chan HM, Receveur O, Muir D, Stern G, Evans M: *Estimation of the dietary contaminant exposure in Nunavut and Inuvialuit: an update. Synopsis of research conducted under the 2006 Northern Contaminant Program*. 2007.
11. ATSDR: *Toxicological profile for mercury*. Atlanta; 1999.
12. Clarkson TW, Magos L: **The toxicology of mercury and its chemical compounds**. *Crit Rev Toxicol* 2006, **36**:609-62.

13. Myers GJ, Davidson PW, Cox C, Shamlaye C, Cernichiari E, Clarkson TW: **Twenty-seven years studying the human neurotoxicity of methylmercury exposure.** *Environ Res* 2000, **83**:275-85.
14. Debes F, Budtz-Jorgensen E, Weihe P, White RF, Grandjean P: **Impact of prenatal methylmercury exposure on neurobehavioral function at age 14 years.** *Neurotoxicol Teratol* 2006, **28**:363-75.
15. Counter SA, Buchanan LH: **Mercury exposure in children: a review.** *Toxicol Appl Pharmacol* 2004, **198**:209-30.
16. Grandjean P, Weihe P, White RF, Debes F, Araki S, Yokoyama K, Murata K, Sorensen N, Dahl R, Jorgensen PJ: **Cognitive deficit in 7-year-old children with prenatal exposure to methylmercury.** *Neurotoxicol Teratol* 1997, **19**:417-428.
17. Saint-Amour D, Roy MS, Bastien C, Ayotte P, Dewailly E, Despres C, Gingras S, Muckle G: **Alterations of visual evoked potentials in preschool Inuit children exposed to methylmercury and polychlorinated biphenyls from a marine diet.** *Neurotoxicology* 2006, **27**:567-78.
18. Despres C, Beuter A, Richer F, Poitras K, Veilleux A, Ayotte P, Dewailly E, Saint-Amour D, Muckle G: **Neuromotor functions in Inuit preschool children exposed to Pb, PCBs, and Hg.** *Neurotoxicol Teratol* 2005, **27**:245-57.
19. Davidson PW, Myers GJ, Cox C, Wilding GE, Shamlaye CF, Huang LS, Cernichiari E, Sloane-Reeves J, Palumbo D, Clarkson TW: **Methylmercury and neurodevelopment: Longitudinal analysis of the Seychelles child development cohort.** *Neurotoxicol Teratol* 2006, **28**:529-535.
20. Levesque B, Duchesne JF, Gariépy C, Rhainds M, Dumas P, Scheuhammer AM, Proulx JF, Dery S, Muckle G, Dallaire F, Dewailly E.: **Monitoring of umbilical cord blood lead levels and sources assessment among the Inuit.** *Occup Environ Med* 2003, **60**:693-5.
21. Kosatsky T, Przybysz R, Weber JP, Kearney J: **Puzzling elevation of blood lead levels among consumers of freshwater sportfish.** *Arch Environ Health* 2001, **56**:111-6.
22. Dallaire F, Dewailly E, Muckle G, Ayotte P: **Time trends of persistent organic pollutants and heavy metals in umbilical cord blood of Inuit infants born in Nunavik (Quebec, Canada) between 1994 and 2001.** *Environ Health Perspect* 2003, **111**:1660-4.
23. **Toxicological profile for lead.** [<http://www.atsdr.cdc.gov/toxprofiles/phs13.html>]
24. Grandjean P: **International perspectives of lead exposure and lead toxicity.** *Neurotoxicology* 1993, **14**:9-14.

25. Loghman-Adham M: **Renal effects of environmental and occupational lead exposure.** *Environ Health Perspect* 1997, **105**:928-39.
26. Fraser S, Muckle G, Despres C: **The relationship between lead exposure, motor function and behaviour in Inuit preschool children.** *Neurotoxicol Teratol* 2006, **28**:18-27.
27. Plusquellec P, Muckle G, Dewailly E, Ayotte P, Jacobson SW, Jacobson JL: **The relation of low-level prenatal lead exposure to behavioral indicators of attention in Inuit infants in Arctic Quebec.** *Neurotoxicol Teratol* 2007, **29**:527-537.
28. Rey M, Turcotte F, Lapointe C, Dewailly E: **High blood cadmium levels are not associated with consumption of traditional food among the Inuit of Nunavik.** *J Toxicol Environ Health* 1997, **51**:5-14.
29. Santé Québec: *A health profile of the Inuit: Report of the Santé Québec Health Survey among the Inuit of Nunavik, 1992.* Montréal, Québec; 1994.
30. Dumont C, Girard M, Bellavance F, Noel F: **Mercury levels in the Cree population of James Bay, Quebec, from 1988 to 1993/94.** *Canadian Medical Association Journal* 1998, **158**:1439-45.
31. Kosatsky T, Przybysz R, Armstrong B: **Mercury exposure in Montrealers who eat St. Lawrence River sportfish.** *Environ Res* 2000, **84**:36-43.
32. Milman N, Mathiassen B, Hansen JC, Bohm J: **Blood levels of lead, cadmium and mercury in a Greenlandic Inuit hunter population from Thule district.** *Trace Elements and Electrolytes* 1994, **11**:3-8.
33. Rhainds M, Levallois P, Dewailly E, Ayotte P: **Lead, mercury, and organochlorine compound levels in cord blood in Quebec, Canada.** *Arch Environ Health* 1999, **54**:40-7.
34. Berti PR, Receveur O, Chan HM, Kuhnlein HV: **Dietary exposure to chemical contaminants from traditional food among adult Dene/Metis in the western Northwest Territories, Canada.** *Environ Res* 1998, **76**:131-42.
35. Chan HM, Kim C, Khoday K, Receveur O, Kuhnlein HV: **Assessment of dietary exposure to trace metals in Baffin Inuit food.** *Environ Health Perspect* 1995, **103**:740-6.
36. Lockhart WL, Stern GA, Wagemann R, Hunt RV, Metner DA, DeLaronde J, Dunn B, Stewart RE, Hyatt CK, Harwood L et al.: **Concentrations of mercury in tissues of beluga whales (*Delphinapterus leucas*) from several communities in the Canadian Arctic from 1981 to 2002.** *Sci Total Environ* 2005, **351-352**:391-412.

37. Steffen A, Schroeder W, Macdonald R, Poissant L, Konoplev A: **Mercury in the Arctic atmosphere: an analysis of eight years of measurements of GEM at Alert (Canada) and a comparison with observations at Amderma (Russia) and Kuujjuarapik (Canada).** *Sci Total Environ* 2005, **342**:185-98.
38. Steffen A, Banic C, Scherts T, Lawson G, Muir D: *Mercury measurements at Alert.* Ottawa; 2006.
39. Arctic Monitoring and Assessment Programme: *Arctic Pollution 2002.* Oslo; 2002.
40. Braune BM, Outridge PM, Fisk AT, Muir DC, Helm PA, Hobbs K, Hoekstra PF, Kuzyk ZA, Kwan M, Letcher RJ, Lockhart NC, Norstrom RJ, Stern GA, Stirling I.: **Persistent organic pollutants and mercury in marine biota of the Canadian Arctic: an overview of spatial and temporal trends.** *Sci Total Environ* 2005, **351-352**:4-56.
41. INAC: *Canadian Arctic Contaminants Assessment Report II.* Ottawa; 2003.
42. Muir D, Braune B, DeMarch B, Norstrom R, Wagemann R, Lockhart L, Hargrave B, Bright D, Addison R, Payne J, REimer, K.: **Spatial and temporal trends and effects of contaminants in the Canadian Arctic marine ecosystem: a review.** *Sci Total Environ* 1999, **230**:83-144.
43. Blanchet C: **Nutrition and Food Consumption among the Inuit of Nunavik. Qanuippitaa? How are we? Nunavik Inuit Health Survey 2004.** *Institut national de santé publique du Québec & Nunavik Regional Board of Health and Social Services*, in press.
44. Leblanc A, Lapointe S, Beaudet A, Côté I, Dumas P, Labrecque F, Lamy C, Larochelle J, Lepage L, Pelletier F et al: *Étude sur l'établissement de valeurs de référence d'éléments traces et de métaux dans le sang, le sérum et l'urine de la population de la grande région de Québec.* Québec; 2004.
45. Dewailly E, Nieboer E: *Exposure and preliminary health assessments of the Oujé-Bougoumou Cree population to mine tailings residues.* Québec; 2005.
46. Hightower JM, Moore D: **Mercury levels in high-end consumers of fish.** *Environ Health Perspect* 2003, **111**:604-8.
47. Passos CJ, Mergler D, Lemire M, Fillion M, Guimaraes JR: **Fish consumption and bioindicators of inorganic mercury exposure.** *Sci Total Environ* 2007, **373**:68-76.
48. Deutch B, Dyerberg J, Pedersen HS, Asmund G, Moller P, Hansen JC: **Dietary composition and contaminants in north Greenland, in the 1970s and 2004.** *Sci Total Environ* 2006, **370**:372-81.
49. Health Canada Mercury Issues Task Force.: *Mercury. Your health and the environment. A resource tool.* Ottawa; 2004.

50. Bjerregaard P, Johansen P, Mulvad G, Pedersen HS, Hansen JC: **Lead sources in human diet in Greenland.** *Environ Health Perspect* 2004, **112**:1496-8.
51. Chu NF, Liou SH, Wu TN, Chang PY: **Reappraisal of the relation between blood lead concentration and blood pressure among the general population in Taiwan.** *Occup Environ Med* 1999, **56**:30-3.
52. Ducoffre G, Claeys F, Bruaux P: **Lowering time trend of blood lead levels in Belgium since 1978.** *Environ Res* 1990, **51**:25-34.
53. Plante C, Blanchet C, Rochette L, Turgeon-O'Brien H: **Iron deficiency and anemia among Nunavik women.** *Institut national de santé publique du Québec & Nunavik Regional Board of Health and Social Services*, in press.
54. Hanning RM, Sandhu R, MacMillan A, Moss L, Tsuji LJ, Nieboer E: **Impact on blood Pb levels of maternal and early infant feeding practices of First Nation Cree in the Mushkegowuk Territory of northern Ontario, Canada.** *J Environ Monit* 2003, **5**:241-5.
55. Bussieres D, Ayotte P, Levallois P, Dewailly E, Nieboer E, Gingras S, Cote S: **Exposure of a Cree population living near mine tailings in northern Quebec (Canada) to metals and metalloids.** *Arch Environ Health* 2004, **59**:732-741.
56. Health Canada: *Update of Evidence for Low-Level Effects of Lead and Blood Lead Intervention Levels and Strategies-Final Report of the Working Group.* Ottawa; 1994.

Figures

Figure 1 - The Amundsen's route around Nunavik

Figure 2 - Frequency distribution of mercury concentrations (nmol/l) in blood samples of 917 Inuits from Nunavik

Figure 3 - Frequency distribution of lead concentrations ($\mu\text{mol/l}$) in blood samples of 917 Inuits from Nunavik

Tables

Table 1: Distribution of participants by gender, age, current smoking status, region of residence and municipality in 1992 and 2004

	1992 (n=493)		2004 (n = 917)	
	N ¹	% ²	N ¹	% ²

Gender					
	Men	209	51.2	414	51.5
	Women	284	48.9	503	48.5
Age groups					
	18-24	107	27.8	206	23.9
	25-44	233	47.7	471	50.4
	45-74	153	24.5	240	25.7
Smoking habits					
	Non smokers	42	10.0	76	8.9
	Ex-smokers	79	16.3	119	13.6
	Smokers	312	73.8	663	77.5
Region of residence					
	Hudson Bay	274	59.1	497	56.7
	Ungava Bay	219	40.9	420	43.3

¹ Crude sample size

² Weighted values

Table 2: Mean daily consumption (Grams per day, annual basis) of various country food items by gender and age, 2004

		Men			Women		
		n	Geometric Mean	CI 95%	n	Geometric Mean	CI 95%
Marine mammal meat							
Age group	18-24	76	3.1	2.2-4.5	92	2.4	1.9-3.1
	25-44	184	3.8	3.0-4.7	212	2.1	1.7-2.5
	45-74	79	4.4	3.2-5.8	105	2.7	2.1-3.6
	All	339	3.8	3.2-4.4	409	2.3	2.0-2.6
Fish							
Age group	18-24	78	17.3	12.1-24.7	94	13.0	9.2-18.4
	25-44	189	29.3	24.0-36.0	218	22.0	18.2-26.6
	45-74	87	37.7	28.8-49.4	110	28.1	21.6-36.5
	All	354	27.5	23.6-32.1	422	20.9	18.2-24.0
Terrestrial mammal meat							
Age group	18-24	78	17.1	12.0-24.2	94	19.6	14.2-26.9
	25-44	189	23.9	19.5-29.4	215	20.4	17.2-24.2
	45-74	85	26.4	20.4-34.2	108	19.1	14.2-25.5
	All	352	22.6	19.4-26.3	417	19.8	17.4-22.6
Game birds meat							
Age group	18-24	78	12.8	9.2-17.9	94	6.1	4.3-8.8
	25-44	189	10.3	8.1-13.1	218	8.1	6.6-10.0
	45-74	87	13.5	9.8-18.6	111	10.0	7.4-13.5
	All	354	11.6	9.8-13.8	422	8.1	6.9-9.4

Table 3: Proportion of consumers (at least once a year) of various country food items by gender and age, 2004

	Men	Women	All
--	-----	-------	-----

		N ¹	% ²	N ¹	% ²	N ¹	% ²
Marine mammal kidneys and liver							
Age group	18-24	25	30.0	22	21.7	47	26.2
	25-44	58	33.6	70	35.7	128	34.6
	45-74	35	47.8	94	34.4	67	41.4
	All	118	36.1	124	32.0	242	34.2
Salmon and trout							
Age group	18-24	31	39.0	21	19.6	52	30.1
	25-44	11	59.6	94	43.7	205	52.2
	45-74	54	64.1	73	66.7	127	65.4
	All	196	55.9	188	44.6	384	50.5
Duck meat							
Age group	18-24	7	10.9	9	8.8	16	9.9
	25-44	38	20.7	27	13.1	65	17.1
	45-74	31	35.5	40	36.6	71	36.0
	All	76	22.1	76	18.6	152	20.4

¹ Crude sample size

² Weighted values

Table 4: Blood mercury (nmol/L) and lead (µmol/L) by year of survey, gender, age and residence

	1992			2004				P-value ²
	N ¹	Geometric Mean	CI 95%	N ¹	Geometric Mean	CI 95%	Range	
Mercury (nmol/L)								
All	492	74.8	(69.2-80.9)	917	51.2	(47.9-54.6)**	0.4-1200	
Gender								
Men	209	70.3	(62.1-79.6)	414	45.8	(41.5-50.5)**	0.4-1200	< 0,001
Women	283	79.9	(74.4-85.8)	503	57.6	(53.7-61.8)**	1.0-820	
Age groups								
18 to 24 years	107	50.6	(43.0-59.7)	206	31.5	(27.7-35.8)**	2.2-820	< 0.001
25 to 44 years	233	69.2	(62.3-76.7)	471	44.3	(40.1-48.9)**	0.4-420	
45 to 74 years	152	135.9	(120.2-153.6)	240	106.6	(96.1-118.2)*	4.6-1200	
Women childbearing age (18 to 39 years)	175	64.5	(59.2-70.3)	308	41.7	(38.2-45.6)**	1.0-820	
Region of residence								
Hudson	274	93.1	(84.2-102.8)	497	58.7	(53.1-64.8)**	0.4-1200	< 0.001
Ungava	218	54.6	(48.4-61.6)	420	42.8	(38.9-47.1)**	1.0-520	
Lead(µmol/L)								
All	493	0.42	(0.40-0.44)	917	0.19	(0.18-0.20)**	0.028-2.4	
Gender								
Men	209	0.46	(0.43-0.49)	414	0.22	(0.21-0.24)**	0.044-2.4	< 0,001

Women	284	0.38	(0.35-0.40)	503	0.17	(0.16-0.17)** *	0.028-1.5	
Age groups								
18-24	107	0.31	(0.28-0.34)	206	0.14	(0.13-0.15)*	0.033-0.8	< 0.001
25-44	233	0.43	(0.40-0.46)	471	0.19	(0.17-0.20)*	0.028-2.4	
45-74	153	0.56	(0.52-0.60)	240	0.29	(0.27-0.31)*	0.039-1.5	
Women of childbearing age (18 to 39 years)	175	0.33	(0.31-0.36)	308	0.13	(0.12-0.14)*	0.028-1.0	
Region of residence								
Hudson	274	0.48	(0.44-0.51)	497	0.20	(0.19-0.21)*	0.036-2.4	0.19
Ungava	219	0.35	(0.33-0.37)	420	0.19	(0.18-0.20)**	0.028-1.4	

¹ Crude sample size

² P-value for comparison between categories in 2004; based on the Satterthwaite χ^2 test

* Significant difference between health surveys $p < 0.01$

** Significant difference between health surveys $p < 0.001$

Table 5 : Pearson's correlation coefficients between blood mercury and lead concentrations (log values), and various independent variables, 2004

Independent variables	Pearson's coefficient	P value
Mercury		
Consumption of marine mammal meat ¹	0.15	< 0.0001
Consumption of marine mammal kidneys and liver ²	0.16	< 0.0001
Consumption of salmon and trout ²	0.07	0.04
Consumption of ducks ²	0.06	0.12
Consumption of caribou meat ¹	0.04	0.30
Lead		
Consumption of marine mammal meat ¹	0.09	0.02
Consumption of marine mammal kidneys and liver ²	0.09	0.01
Consumption of fish ¹	0.08	0.02
Consumption of terrestrial mammal meat ¹	0.06	0.11
Consumption of game birds ¹	0.10	0.01

¹ Grams per day, annual basis

² Dichotomous: consumers/non-consumers

Table 6 : Partial coefficient and R² of predictive models for mercury and lead blood concentrations (log values) , 2004

Total Model	Partial R²	P value	R²	p value
Mercury				
Consumption of marine mammal meat ¹	0.04	< 0.0001	0.27	< 0.0001
Consumption of marine mammal kidneys and liver ²	0.01	0.003		
Age (years)	0.20	< 0.0001		
Gender	0.02	0.001		
Region of residence (Hudson Bay , Ungava Bay)	0.02	0.001		
Lead				
Consumption of game birds ¹	0.01	0.002	0.25	< 0.0001
Consumption of marine mammal kidneys and liver ²	0.01	0.05		
Age (years)	0.20	< 0.0001		
Gender	0.04	< 0.0001		
Tobacco consumption (smoker, non-smoker)	0.04	< 0.0001		

¹ Grams per day, annual basis

² Dichotomous: consumers/non-consumers



Figure 1



