

# Human accumulation of mercury in Greenland

Poul Johansen <sup>a,\*</sup>, Gert Mulvad <sup>b,c</sup>, Henning Sloth Pedersen <sup>b,c</sup>,  
Jens C. Hansen <sup>c</sup>, Frank Riget <sup>a</sup>

<sup>a</sup> National Environmental Research Institute, University of Aarhus, Frederiksborgvej 399, DK-4000 Roskilde, Denmark

<sup>b</sup> Primary Health Care Center, DK-3900 Nuuk, Greenland

<sup>c</sup> Centre for Arctic Environmental Medicine, University of Aarhus, Universitetsparken, DK-8000 Aarhus C, Denmark

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## Abstract

In the Arctic, the traditional diet exposes its people to a high intake of mercury especially from marine mammals. To determine whether the mercury is accumulated in humans, we analyzed autopsy samples of liver, kidney and spleen from adult ethnic Greenlanders who died between 1990 and 1994 from a wide range of causes, natural and violent. Liver, kidney and spleen samples from between 33 and 71 case subjects were analyzed for total mercury and methylmercury, and liver samples also for selenium. Metal levels in men and women did not differ and were not related to age except in one case, i.e. for total mercury in liver, where a significant declining concentration with age was observed. The highest total mercury levels were found in kidney followed by liver and spleen. Methylmercury followed the same pattern, but levels were much lower, constituting only 19% of the total mercury concentration in liver and spleen and as little as 3% in kidney. In liver selenium was found in surplus to mercury on a molar basis. Mercury concentrations in the liver and kidneys of Greenlanders were elevated compared to levels in the general population in Japan, Korea and several European countries, except in the Faroe Islands where mercury levels were 2–3 times higher. This is in accordance with the expected exposure of mercury in the diet.

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## 1. Introduction

The traditional Arctic diet exposes people to a high intake of mercury. Johansen et al. (2004) calculated a mean mercury intake of 42 µg/day/person in the fall and 66 in the spring based on a dietary study conducted in a region of Greenland, where traditional diet (fish, seabirds, seals and whales) is important (Pars et al., 2001). This intake is about 10 times higher than calculated mercury intake in Denmark (5 µg/day, Larsen

et al., 2002). It also exceeds or is very close to the “Acceptable Daily Intake” (ADI), which may be calculated to 43 µg/day of total mercury for a person weighing 60 kg (FAO/WHO, 1989). A significant part of the mercury in the Greenland diet is present as methylmercury, and as the PTWI for methylmercury recently has been lowered to 1.6 µg/kg-bw (WHO, 2003), the exceedance for methylmercury is even higher in Greenland, up to about a factor of 4 in the study mentioned above.

In most countries fish is the most important mercury source to the general population. Of other sources the most important appears to be amalgam used as filling in

\* Corresponding author. Tel.: +45 46301936; fax: +45 46301914.  
E-mail address: [poj@dmu.dk](mailto:poj@dmu.dk) (P. Johansen).

teeth, causing leakage of small quantities of mercury, but in spite of intensive research, deleterious health effects of this mercury source have not been identified (Yip, 2003).

In the Greenland study (Johansen et al., 2004) the main mercury sources in the traditional diet were muscle and liver from seals. Very high mercury concentrations are found in seal liver as a result of bioaccumulation, and they are also seen in whales, seabirds, and polar bears (Dietz et al., 1996). The high dietary mercury intake is reflected in the blood of people. Lately blood mercury levels in Greenland and other Arctic countries have been systematically monitored as part of the Arctic Monitoring and Assessment Programme (AMAP) and within the Arctic the highest levels were found in Greenland (AMAP, 2003).

Because of the high mercury exposure in Greenland it would be expected that these people accumulate mercury to concentrations above what is seen in regions with lower exposure. In this study we compare mercury levels in autopsies of liver, kidney and spleen from Greenland Inuit with those of other non-occupationally exposed populations.

## 2. Materials and methods

The population of Greenland totals approximately 57,000, of which 12% are non-natives, primarily Danes. The population is spread along the coast in 16 towns and 60 settlements. Autopsies are uncommon in Greenland, except for forensic cases in which a pathologist is brought in from Denmark. As part of a cooperative study of atherosclerosis in Alaska and Greenland, three physicians in Greenland were trained in autopsies and collections of specimens. Specimen collection began in the autumn of 1990 and continued through the autumn of 1994; specimens from 105 autopsy cases were collected. This autopsy rate represents approximately 10% of the total number of deaths that occurred in Greenland during this period. The cases are proportionally representative of the age, sex, and mode of death (natural/violent) of all deaths during this period. All were ethnic Greenlanders and all were more than 18 years old. Case subjects were death in Nuuk and Ilulissat. The hospital in Nuuk is the central hospital for Greenland, and the cases here therefore came from all parts of Greenland.

Tissue samples for mercury analysis were collected during a series of 80 consecutive autopsies performed between November 1992 and mid-October 1994, during the course of an atherosclerosis study. These samples were frozen immediately after collection and stored

at  $-80^{\circ}\text{C}$  until time of analysis. Samples were cut by ordinary stainless steel blades and placed in polyethylene containers previously controlled to be metal free. Kidney samples were taken as 0.5-cm thick slices containing cortex and medulla. Liver and spleen samples were taken as a  $2 \times 2 \times 2$ -cm block. Immediately after sampling, the material was frozen and sent to Department of Environmental and Occupational Medicine, University of Aarhus, Denmark for analysis. Here a subset of the samples was analyzed, from 32 to 71 case subjects, selected randomly among the 105 cases. Not all tissues from the same individual were analyzed. Therefore the number of analyses reported differs (see Table 1).

The analytical principle used for total mercury and selenium was atomic absorption spectrometry with a mercury hydride system. The procedures and description of analytical quality measures are previously described in Hansen et al. (1983) and Hansen et al. (1984). Methylmercury was determined by gaschromatography with a method modified from Westöo (1968) as described in details by Hansen et al. (1990).

Metal concentrations were logarithmic transformed after which data did not differ significantly from being normally distributed (Shapiro–Wilk test,  $p > 0.05$ ). Linear regression analyses were performed to test the age dependency on metal concentrations. Prior to test of difference between sexes, Barlett test for homogeneity of variance was applied and in no cases did the variance differ between sexes (Barlett test,  $p > 0.05$ ). Analyses of variance were performed to test the difference in mean log-transformed metal concentrations between men and women. Pearson's correlation analysis was applied to test the correlation between log-transformed metal concentrations among tissues.

## 3. Results and discussion

Data from 102 people were available for this assessment with almost equal number of men and

Table 1  
Hg, MeHg and Se concentrations ( $\mu\text{g/g}$  wet wt) in autopsy samples from Greenlanders

	Mean	Standard deviation	Min	Max	N
Hg liver	0.538	0.307	0.087	1.523	71
MeHg liver	0.103	0.053	0.022	0.210	34
Se liver	0.500	0.171	0.216	1.094	36
Hg kidney	1.403	1.208	0.024	4.920	37
MeHg kidney	0.046	0.028	0.008	0.105	33
Hg spleen	0.098	0.064	0.031	0.313	35
MeHg spleen	0.019	0.013	0.003	0.058	32

women (57 men, 45 women). Mean age and standard deviation were  $57.9 \pm 18.7$  for men and  $61.2 \pm 16.7$  for women. No significant differences between sexes of log-transformed totalHg, MeHg and Se concentrations in any tissues were found (analysis of variance,  $p > 0.05$ ). Data were also tested for age dependency. Age was significantly associated with metal concentrations only for total mercury in liver, where a declining concentration with age was observed ( $p = 0.034$ ).

Table 1 summarizes the results. The highest mercury levels were found in kidney followed by liver and spleen. Methylmercury followed the same pattern, but levels were much lower, constituting only 19% of the total mercury concentration in liver and spleen and 3% in kidney.

We have tested for possible correlation of metal levels between tissues, using Pearson's product-moment correlation procedure (Table 2). In all combinations there was a positive correlation and in six out of eight combinations this correlation was significant.

We did not have specific information of diet or lifestyle factors that could affect mercury exposure in each individual. However, as all were ethnic Greenlanders and as subject cases analyzed were selected randomly, it is reasonable to assume that they will be representative of the general population's exposure to mercury. The average age of the case subjects was about 60 years. Thus we may suspect that a traditional Greenland diet has been common to many of these people and therefore that they have had a high mercury exposure for many years. The amount of traditional food has been declining during the past century. In surveys carried out in the 1990s in Greenland traditional food constituted 25–30% of the total diet (Pars, 1997; Deutch, 2003). The amount of traditional food consumed varies with season (availability of animal species), the age (younger consumes less traditional food than older) and place of residence (in rural areas people generally eat more traditional food than in urban) (Pars et al., 2001).

In Table 3 we have compared the total mercury and selenium levels in Greenlanders with levels found in

Table 2  
Correlation coefficients of Hg, MeHg and Se levels in tissues

	Hg liver	Hg kidney	Hg spleen
Hg liver		0.50**	0.25
Hg kidney			0.08
MeHg liver	0.47**	0.68***	0.44*
MeHg kidney			0.41*
Se liver	0.40*		

Significance levels: \* $0.01 < p < 0.05$ , \*\* $0.001 < p < 0.01$ , \*\*\* $p < 0.01$ .

Table 3  
Mean mercury and selenium concentrations ( $\mu\text{g/g}$  wet wt) in human tissue

Country	Hg liver	Hg kidney	Hg spleen	Se liver	Reference
Greenland	0.54	1.40	0.10	0.50	This study
Faroe Islands	0.81	3.8	0.05	0.48	Julshamn et al. (1989)
Norway	0.11	0.17	0.01	0.44	Julshamn et al. (1989)
Sweden		0.50			Barregard et al. (1999)
Sweden	0.10	0.22			Muramatzu and Parr (1988)
Denmark	0.1	0.2		0.3	Hansen pers. comm. (2000, 2003)
Poland	0.03	0.07		0.29	Hać et al. (2004)
Poland	0.02	0.04	0.004		Lech and Sadlik (2004)
Spain	0.14	0.25			García et al. (2001)
Korea	0.20	0.28	0.16		Yoo et al. (2002)
Japan	0.35	0.60			Suzuki et al. (1993)
Japan	0.48	0.55			Matsuo et al. (1989)

other autopsy studies, where the individuals died of accidental or natural causes. None was suspected to have been occupationally exposed to mercury. In most studies more than 30 and up to 150 individuals were analyzed and included both males and females of a range of ages, but with mean ages more than 30 years and often older. Fewer individuals were included in the study from Norway (13 individuals) and the Faroe Islands (10 individuals) (Julshamn et al., 1989).

Compared to other studies in Denmark, Norway and Sweden total mercury levels in the liver and kidneys from Greenlanders were elevated, mostly by a factor of 7–8 and they were also higher than found in Spain, Poland, Korea and Japan. However, they were lower than found in the study in the Faroe Islands (Julshamn et al., 1989).

In spleen total mercury levels differed in an unsystematic way among populations, whereas selenium concentrations in the livers of Greenlanders were similar to what was found in the Faroe Islands and Norway and somewhat higher than in Denmark and Poland.

Significantly elevated mercury concentrations have also been found in the brain of Greenlanders. In an autopsy study of 17 Greenlanders and 12 Danes, the median total mercury concentration was 174 ng/g wet wt in Greenlanders and 4 ng/g in Danes (Pedersen et al., 1999).

Methylmercury was also determined by Pedersen et al. (1999). The mean MeHg concentration in the brain of

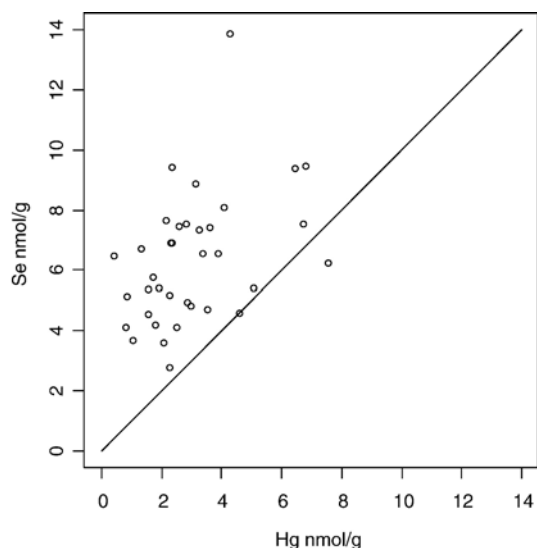


Fig. 1. Molar concentration of Se (nmol/g) depicted against molar concentration of Hg (nmol/g) in liver.

Greenlanders was 30 ng/g and since there was a negative correlation between age and MeHg, while total mercury showed an increase with age, the authors suggest that a slow transformation of MeHg to inorganic Hg (demethylation) takes place in the brain. However, demethylation in the body is considered to take place mainly in the liver (Berlin, 1986), resulting in relatively low MeHg levels in liver, kidney and spleen (Table 1).

Selenium is an essential trace mineral and has experimentally been shown to reduce the toxic response in the nervous system associated with exposure to mercury (WHO, 1990), but the efficacy of selenium as an antidote against mercury toxicity in humans is controversial (Magos, 1991). It is however notable that selenium is present in substantial surplus to mercury on a molar basis (Fig. 1). According to Drasch et al. (2000) a detoxifying effect of Se against Hg is caused by a formation of largely inert Hg–Se-enzyme complexes.

### 3.1. Dietary exposure of mercury

Johansen et al. (2004) calculated a mean total mercury intake of 43  $\mu\text{g}/\text{day}/\text{person}$  in the fall and 66 in the spring based on a dietary study conducted in Disko Bay, a region of Greenland, where traditional diet (fish, seabirds, seals and whales) is important. Two sources, seal muscle and seal liver, dominated, constituting about 60% of the total intake, with about half coming from muscle and the other half from liver. Other sources were scattered among fish, birds and whales, whereas the terrestrial species were insignificant.

In Denmark the intake of total mercury from food is more than 10 times lower than the calculated intake in Greenland. Larsen et al. (2002) have estimated a mean intake of 5  $\mu\text{g}/\text{day}/\text{person}$  with fish as the most important source in Denmark in the period 1988–92. In the Faroe Islands the mean intake of total Hg from pilot whale may be calculated to 214  $\mu\text{g}/\text{day}/\text{person}$  (Andersen et al., 1987). However, this intake figure most likely is overestimated as it is based on calculations from the total Faroese catch of pilot whales and includes a very high total mercury contribution (154  $\mu\text{g}/\text{day}/\text{person}$ ) from liver, which is not normally eaten (Weihe pers. comm.). On the other hand whale kidney and fish, which will be mercury sources in the diet, are not included in the exposure. Whale kidney was eaten in the 1980s (Weihe pers. comm.) and fish intake was high. Vestergaard and Zachariassen (1987) report a mean intake of 72 g fish/day in the Faroe Islands and compare this with an intake of 18 g in Denmark. We cannot quantify these other mercury sources from the diet, but taking the discussion above into account, it seems likely that the exposure in the 1980s was higher in the Faroe Islands than in Greenland for some groups of the population. The individuals included in the 1989 autopsy study from the Faroe Islands seem to have been exposed to a particular high mercury intake, as they were selected among people, who had eaten much pilot whale (Julshamn et al., 1989).

In conclusion there appears to be an agreement between mercury exposure and levels found in the liver and kidney of humans in Denmark, Greenland and the Faroe Islands: The higher mercury intake, the higher resulting mercury concentration in liver and kidney (Table 4).

In the diet the fraction of organic mercury (which is mainly methylmercury) has to be considered, since methylmercury is more toxic than inorganic mercury and at the same time is more easily absorbed in the gastrointestinal tract (Berlin, 1986). There are few direct measurements of methylmercury in the Greenland diet.

Table 4  
Human mercury exposure and concentration in liver and kidney

	Exposure ( $\mu\text{g}/\text{day}/\text{person}$ )	Liver concentration ( $\mu\text{g}/\text{g}$ )	Kidney concentration ( $\mu\text{g}/\text{g}$ )
Denmark	5	0.1	0.2
Greenland	55	0.5	1.4
Faroe Islands	214	0.8	3.8

The exposure figure from the Faroe Islands most likely are overestimated, see text.

However, based on studies by Dietz et al. (1990), we may estimate a mean methylmercury intake of 38 µg/day/person in the fall and 54 µg/day/person in the spring in the diet study in the Disko Bay (Johansen et al., 2004). This intake constitutes 86–89% of the total mercury intake and therefore most of the mercury intake in the traditional Greenland diet is as methylmercury. Our calculation is based on the assumption that all mercury in muscle tissue is MeHg and that the MeHg concentration in liver and kidney is 1 µg/g (data from Dietz et al., 1990). This is a high intake, significantly exceeding the European Food Safety Authority's TDI of 0.23 µg/kg-bw/day and the US-EPA Reference dose of 0.1 µg/kg-bw/day (Hansen and Gilman, 2005). Depending on which of these to compare with, the intake is exceeded by a factor of about 3 to 9 in the Disko Bay study for a person weighing 60 kg. The actual intake is at a level where neuro-physiological effects might appear (Hansen and Gilman, 2005). Subtle neurobehavioral deficits have been observed in children at age 7–12 years in the Thule district, North Greenland (Weihe et al., 2002).

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