Available online at www.sciencedirect.com
SCIENCE DIRECT®
Environmental Research 96 (2004) 257–263
Environmental Research
http://www.elsevier.com/locate/envres

Hair mercury levels versus freshwater fish consumption in household members of Swedish angling societies ☆

Cecilia Johnsson,[a] Gerd Sällsten,[a] Andrejs Schütz,[b,✠] Anna Sjörs,[c] and Lars Barregård[a,*]

[a] *Department of Occupational and Environmental Medicine, Sahlgrenska Academy and University Hospital, Goteburg University, P.B. 414, 405 30 Goteburg, Sweden*
[b] *Department of Occupational and Environmental Medicine, Lund University, Lund, Sweden*
[c] *Community of Hagfors, Sweden*

Received 20 August 2003

Abstract

Hair mercury levels were determined in 143 individuals from households of members in angling societies in an area of Sweden with many lakes that have freshwater fish with relatively high mercury levels. Thus, the individuals had a potentially high intake of methyl mercury. The mean mercury concentration of pike and perch was approximately 0.7 μg/g. One-third of the subjects consumed these freshwater fish at least once a week. As could be expected, there was a clear increase in hair Hg with reported freshwater fish consumption ($P<0.001$). The median mercury level in hair was 0.9 μg Hg/g for the whole group, and for those who reported consumption of freshwater fish at least once a week it was 1.8 μg/g. The highest hair mercury level was 18.5 μg/g, in a man who consumed pike and perch several times per week. Men had higher hair Hg than women, also when stratified for fish consumption. This was verified in 32 couples, of which the man and woman consumed the same fish and reported the same consumption. The median hair mercury level in these 32 couples was 1.3 μg/g for men and 0.8 μg/g for women ($P = 0.002$). About half of the subjects had hair mercury exceeding 1 μg/g, corresponding to the reference dose (RfD) of 0.1 μg of mercury per kilogram body weight set by the US Environmental Protection Agency. Although the RfD applies to all populations, the most at-risk group at these levels is pregnant women. There were only 2 women (of 12) of fertile age with hair mercury above 1 μg/g. In Sweden pregnant women are advised not to eat perch and pike at all during pregnancy. Since fish is rich in many important nutrients, it is unsatisfactory that fish consumption must be restricted, and thus there is a need to reduce mercury levels in fish.

Keywords: Methyl mercury; Sport fish; Pike; Perch; Hair

1. Introduction

Methyl mercury is neurotoxic, especially for the developing brain. Seafood is a major source of exposure for humans, and safe intake levels have recently been reviewed (US EPA, 1997, 2001; NRC, 2000). Hair mercury levels increase with the amount of fish in the diet and the amount of mercury in the fish species consumed (WHO, 1990; Clarkson, 2002). The highest mercury levels are found in freshwater predators such as pike and perch, as well as in swordfish and shark (WHO, 1990; US EPA, 1997). Typical mercury levels in pike in the United States, Canada, and Europe are 0.5–1 μg/g (Porvari, 1998; Kosatsky et al., 2000). In a US survey, the mean mercury concentrations in shark and swordfish were about 1 μg/g, while the levels in cod, pollock, or canned tuna were 0.1–0.2 μg/g (Carrington, 2002). Recent estimates for the US general population predicted a median intake of about 7 g of seafood and close to 1 μg of methyl mercury per day in adults. The 95th percentile for methyl mercury was estimated at about 7 μg/day (Carrington, 2002), sportfishers constituting a high-consumption group (Kosatsky et al., 2000). In certain populations fish is a staple food with an intake of more than one meal per day (Shamlaye et al., 1995; Dorea, 2003). The US Food and Drug Administration (FDA) recommends that pregnant women not eat shark,

☆ The Swedish Environmental Protection Agency, Goteborg University, and Sahlgrenska University Hospital, Sweden, funded this work. The study was performed according to the national and institutional guidelines for the protection of human subjects.
*Corresponding author.
E-mail address: lars.barregard@ymk.gu.se (L. Barregård).
✠ Deceased.

0013-9351/$ - see front matter © 2004 Elsevier Inc. All rights reserved.
doi:10.1016/j.envres.2004.01.005

swordfish, king mackerel, or tilefish. For freshwater fish, consumers are advised to seek further advice from national or local authorities (CFSAN/FDA, 2001). In Sweden mercury concentrations in fish offered for sale must not exceed 1 mg/kg. The Swedish National Food Administration (SNFA) has recommended restrictions on the consumption of certain species of freshwater fish: northern pike (*Esox lucius*), perch (*Perca fluviatilis*), pike-perch (*Lucioperca lucioperca*), burbot (*Lota lota*), and halibut (*Hippoglossus hippoglossus*). Women are advised to avoid these fish species completely during pregnancy (SNFA, 2003).

Members of sport-fishing societies could be assumed to have the highest consumption of freshwater fish in Sweden. The aim of the study was to investigate fish consumption among families with a member in these societies, the influence of freshwater fish consumption on mercury levels in hair, and the prevalence of hair mercury above the limits discussed in recent reviews. The results could be used in risk assessment of mercury exposure among anglers.

2. Subjects and methods

The participants were recruited from a study of fish consumption performed in 1996 in Hagfors, Sweden, an inland community with approximately 14,000 inhabitants. Questionnaires were mailed to all households ($n = 482$, 824 household members) with a member in a sport-fishing society. Six hundred thirty individuals (76%) from 389 households responded, 401 men and 229 women. Of these, 150, including all individuals reporting consumption of pike or perch at least once a week, and a random sample of the other respondents were asked to participate in the present study. Therefore, while freshwater fish was consumed at least once a week by about 10% in the total group of 630 household members, this figure was higher among the 150 individuals targeted for the present study.

Of the 150 individuals, 2 had died since the screening questionnaire was answered, 1 could not participate because of disease, and 4 declined. The study group thus included 143 subjects, 92 men and 51 women. About half of the subjects were couples of different sex (37 pairs). The average age was 61 (19–97) years, and 57% had amalgam fillings. The Ethics Committee of the Orebro Hospital approved the study.

2.1. Fish consumption

Fish consumption was estimated for each subject using a questionnaire. In the questionnaire the consumption of freshwater fish with high mercury content (pike, perch, burbot, and pike-perch) during the past year was evaluated, as well as the consumption of species of saltwater fish, which were known to have a low mercury contamination. There were four alternatives for each species of fish: consumption once a week or more, once a month or more (but less than once a week), more seldom, and never. Since the subjects reported consumption separately for several fish species consumed (Table 1), the total consumption was also categorized (Table 2). Category 1 ($N = 39$) included subjects who ate freshwater fish *less than once a month*, and category 2 ($N = 104$) included subjects who ate freshwater fish *at least once a month*. In category 2a ($N = 45$), they ate freshwater fish *at least once a week* and in category 2aa ($N = 13$) *at least twice a week*. For example, if an individual reported eating pike, as well as perch, at least once a week for each species, the consumption category was 2aa. Only categories 1 and 2 are mutually exclusive. For example, in addition to the 45 subjects in category 2a, some of the other subjects in category 2 may in fact have eaten freshwater fish at least once a week. This may be the case, e.g., for those reporting consumption once a month or more for each of the species of pike, perch, and pike-perch.

2.2. Mercury in fish

Before the study of hair Hg levels, we compiled all fish mercury analyses performed in the county of Varmland, 1974–1997 (Sjors, 1998). These samples had been analyzed mainly by the SNFA. In most cases total Hg was analyzed (Skare, 1972), and in some cases MeHg (Westoo, 1968). In 1953 pike samples, standardized to pikes of 1 kg (Lindestrom, 2001), the mean mercury concentration was 0.84 (SD, 0.48) μg/g. The mercury levels were similar in pikes from the community of

Table 1
Consumption of pike, perch, burbot, pike-perch, and saltwater fish in 143 individuals from angling societies in the community of Hagfors, Sweden

Fish consumption	Pike		Perch		Burbot		Pike-perch		Saltwater fish	
	N	%	*N*	%	*N*	%	*N*	%	*N*	%
Once a week or more	16	11	41	29	2	1	1	1	52	36
Once a month or more	60	42	53	37	12	8	5	3	53	37
Less than once a month	44	31	43	30	34	24	32	22	12	8
Never	23	16	6	4	95	66	105	73	26	18

Table 2
Mercury levels in hair in 143 individuals from angling societies in the community of Hagfors, Sweden, stratified by consumption of pike (irrespective of other fish), perch (irrespective of other fish), and all freshwater fish

Category	N	Hair mercury (μg/g)			
		Mean	Median	Min	Max
All	143	1.7	0.9	0.1	18.5
Pike					
Less than once a month	67	1.0	0.5	0.1	7.1
Once a month or more	60	1.9	1.5	0.1	8.7
Once a week or more	16	3.9	3.3	0.5	18.5
Perch					
Less than once a month	49	0.7	0.5	0.1	2.9
Once a month or more	53	1.8	1.2	0.1	7.0
Once a week or more	41	2.6	1.5	0.1	18.5
All freshwater fish					
(1) <once per month	39	0.5	0.4	0.1	2.0
(2) ⩾once per month	104	2.1	1.5	0.1	18.5
(2a) ⩾once per week	45	2.7	1.8	0.1	18.5
(2aa) ⩾twice per week	13	3.9	3.3	0.5	18.5

In the case of those who ate all freshwater fish, fish consumptions of the various species (see Table 1) were added; therefore, there is some overlap between fish consumption categories. Category 2a is included in category 2, and category 2aa is included in category 2a.

Hagfors, located in the middle of the county of Varmland, mean 0.83 μg/g, in 191 samples collected in the same period. In the most popular lake for fishing, the level was slightly lower, however, at about 0.55 μg/g in pike in the 1990s. There was a slight tendency toward decreased levels over time. In the 1990s the mean mercury in pikes in Varmland was 0.72 μg/g ($N = 919$). While the mean weight of the pikes caught for analysis was 1 kg, the mean weight for perch ($N = 518$) was 230 g. The mean mercury level in perch was 0.68 μg/g. Also for perch, there seems to be a decrease in the 1990s, but the number of recent fish samples was low. For pike-perch and burbot the mean mercury levels were 0.69 ($N = 210$) and 0.82 ($N = 105$) μg/g, respectively. Typical weights for pike-perch and burbot were about 1 kg.

2.3. Mercury in hair

A bundle of hair was cut from the neck close to the scalp and stored in a polyethylene bag. The hair samples were collected about 7 months after the questionnaires were answered. The samples were stored at room temperature until analysis. The total mercury content in hair (10–30 mg) was determined using a cold-vapor atomic-fluorescence technique. The samples were digested for 16 h in 70°C using a mixture of concentrated perchloric and nitric acids (5:1), and mercury was preconcentrated on gold before detection (Bergdahl et al., 1995). For quality assurance we used the certified reference material Human Hair GBW 09101 from the Shanghai Institute of Nuclear Research. For 38 reference samples inserted among the hair samples of the present study, the mean result was 1.79 μg/g (SD, 0.15 μg/g) compared with the target value of 2.16 μg/g (uncertainty, ±0.21 μg/g). The precision for duplicate analyses was good with a relative standard deviation below 5%.

2.4. Statistics

In the comparisons between the groups with different fish consumption, the Kruskal–Wallis test and Wilcoxon's rank sum test were used. For comparisons between couples with the same consumption category we used the paired t test. A P value less than 0.05 denoted statistical significance.

3. Results

3.1. Fish consumption

In Table 1 the consumption of different fish species is presented, according to the questionnaire given 7 months before the hair samples were collected. Pike and perch were the most frequently consumed species of freshwater fish. Nearly all subjects (96%) had eaten perch during the past year. Saltwater fish was consumed at least once a week by 36%, and the corresponding figures for pike and perch were 11% and 29%, respectively. Men ate pike and perch slightly more frequently than women, whereas women consumed saltwater fish somewhat more often than men (Fig. 1). The consumption of burbot and pike-perch was similar for men and women. When the consumption of various freshwater species were combined, 45/143 (31%) consumed such fish at least once a week (Table 2). There was a positive association between the consumptions of freshwater and saltwater fish. In category 1, 10% consumed saltwater fish at least once a week, while this figure was 21% in category 2 and 29% in category 2a.

3.2. Mercury levels in hair

In Fig. 2, the distribution of the mercury levels in hair is shown, and in Table 2 the levels are presented for the different categories of freshwater fish consumption. As could be expected, there was a clear increase in hair Hg with reported fish consumption, whether stratified for pike, perch, or total freshwater fish consumption ($P < 0.0001$ for any stratification). The median mercury level in hair was 0.9 μg Hg/g hair for the whole group, and for those who reported consumption of freshwater fish at least once a week it was 1.8 μg/g. Forty-seven

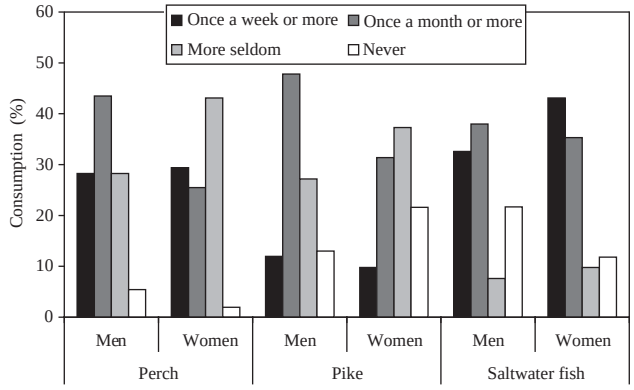

Fig. 1. Consumption of perch, pike, and saltwater fish in 91 men and 51 women from angling societies in Hagfors, Sweden.

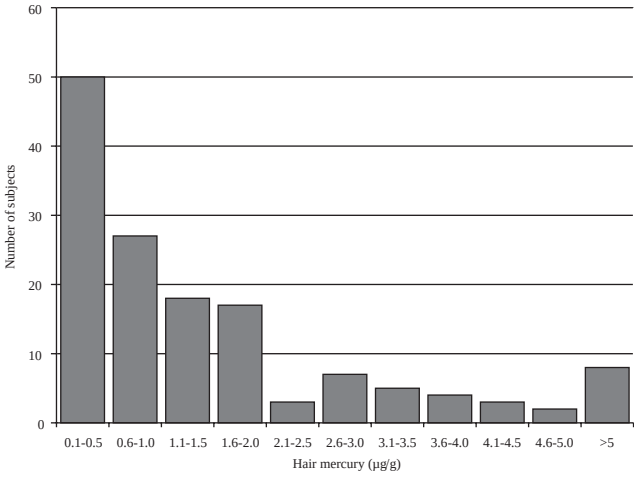

Fig. 2. Distribution of hair mercury levels in 143 individuals from angling societies in Hagfors, Sweden.

Table 3
Mercury levels in hair in men and women stratified for reported fish consumption

Category	Men			Women		
	N	Hair mercury (µg/g)		*N*	Hair mercury (µg/g)	
		Mean	Median		Mean	Median
All	92	2.0	1.1	51	1.1	0.7
(1) <once per month	20	0.5	0.5	19	0.5	0.4
(2) ⩾once per month	72	2.4	1.6	32	1.4	1.3
(2a) ⩾once per week	29	3.1	1.8	16	1.8	1.7
(2aa) ⩾twice per week	9	4.6	3.3	4	2.3	2.6

percent of the 143 subjects had hair mercury exceeding 1 µg/g. The median mercury level in category 2aa, subjects who ate freshwater fish more than twice a week, was about eight times higher than the group who rarely or never ate freshwater fish (category 1). The highest hair mercury level, 18.5 µg/g, was found in a 75-year-old man in category 2aa.

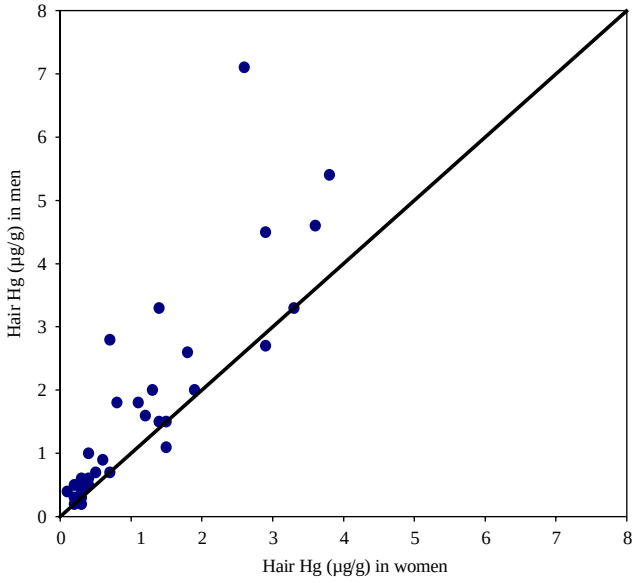

Fig. 3. Mercury in hair in men and women from 32 household couples in the same fish consumption category as reported in questionnaires. The line of identity is shown.

Men had higher hair Hg than women ($P = 0.02$), and this difference could be seen also when stratified for fish consumption (Table 3). There were 37 couples in the group, and among them 32 couples were in the same consumption category. The median hair mercury level in these 32 couples was 1.3 µg/g for men and 0.8 µg/g for women ($P = 0.002$; see Fig. 3). There were 12 women aged <50 years, and 2 of these had hair Hg above 1 µg/g.

4. Discussion

The present study examined a relatively large group of people with a potentially high intake of methyl mercury, namely households of members of angling societies in a region with many lakes containing freshwater fish with relatively high mercury levels. The median mercury level in hair was 0.9 µg/g, and as could be expected there was a clear increase in hair mercury with increasing freshwater fish consumption. The data may be used for a risk assessment of anglers in the region. Men had higher hair mercury than women, and the possible differences between men and women will be discussed below.

4.1. Mercury in fish and fish consumption

As described above, typical pike and perch mercury levels in the 1990s were about 0.6–0.8 µg/g. This is similar to pike mercury levels reported from Finnish reservoirs (Porvari, 1998) and the St. Lawrence River in Montreal (Kosatsky et al., 2000), but much lower than in some contaminated Spanish rivers (Raldua and Pedrocchi, 1996; 1.7–2.8 µg/g). The mean mercury levels

in perch in our study area (0.6–0.7 μg/g) are higher than those reported for yellow perch (*Perca flavescens*) in the St. Lawrence River (Kosatsky et al., 2000; 0.2–0.4 μg/g), in lakes of the state of Maryland, USA (Castro et al., 2002; 0.1–0.2 μg/g), or in the Savannah River in the state of South Carolina, USA (Burger et al., 2001; 0.3 μg/g).

About 10% of the 630 household members in the angling societies reported consumption of freshwater fish at least once a week. According to a questionnaire survey of the general Swedish population (age 17–79 years) in 1997, less than 1% consumed freshwater fish once a week or more, and about 6% reported such consumption at least once a month but less than once a week (Becker and Pearson, 2002). In a study of 197 Swedish pregnant women in 1990, about 3% reported eating freshwater fish at least once a week (Oskarsson et al., 1994). In a more recent Swedish study, however, all 123 pregnant women consumed freshwater fish less often than once a week (Bjornberg et al., 2003), and this was also the case in our own studies of 280 randomly selected pregnant women recruited 1996–2000 (unpublished data). Thus, as could be expected, anglers' households consume freshwater fish much more often than the general population.

4.2. Mercury in hair

It is well known that consumption of freshwater fish increases mercury concentrations in hair (WHO, 1990; Clarkson, 2002). This was also shown in the present study (Table 2). The hair Hg level in the group that consumed freshwater fish at least once a week (category 2a) was about the same as that of a previous Swedish study of 50 subjects with a similar consumption (Oskarsson et al., 1990). The group with low consumption had hair mercury levels similar to those found in other Swedish studies of subjects with a low consumption of freshwater fish (Bratel et al., 1997; Bjornberg et al., 2003). In Canada, Kosatsky et al. (2000) found lower hair Hg levels (median, 0.9 μg/g) in citizens of Montreal, who consumed sport fish at least once a week, compared to participants in category 2a in the present study. The reason may be that the Montrealers consumed mainly perch with relatively low mercury levels.

In a large study of US women ($n = 2820$) aged 15–45, considered representative of the US population, the geometric mean hair methyl mercury was 0.3 μg/g, and about 10% had hair Hg above 1 μg/g (Smith et al., 1997). In higher income subgroups, exposure levels may be higher, however, as shown by a study of blood mercury levels in California (Hightower and Moore, 2003). In pregnant New Jersey women, Stern et al. (2001) found a mean hair Hg of 0.5 μg/g, and 13% had hair Hg above 1 μg/g.

Men had significantly higher mercury levels in hair than women, also stratified for reported fish consumption. This was also the case in the couples consuming the same fish. The reason for this may be that men consumed larger servings of fish, even when body weight was taken into account. The same result has been found in a previous study (Oskarsson et al., 1990). It is less likely that the higher hair mercury levels in men are caused by a sex-related difference in metabolism. The findings in adult mice point rather in the opposite direction, with a slower elimination and a higher body burden in female mice after methyl mercury exposure (Nielsen and Andersen, 1996).

4.3. Validity aspects

The mercury analyses were performed with modern techniques yielding low detection limits and good precision. External reference samples were used. These showed good accordance with the expected values. We therefore consider the mercury levels to be valid.

Assessing fish consumption by questionnaires is not optimal. The average mercury levels in the different fish species are known, but this is not the case for the fish servings eaten by our subjects. Moreover, we have no information about the size of fish portions. This will blur the association between reported fish consumption and actual methyl mercury intake. This is, however, also the case for most previous studies in this field. A flaw in the questionnaire design was that the wording of the questions on fish consumption caused an uncertainty about the total number of freshwater fish meals for some of the subjects, resulting in consumption categories that were not mutually exclusive.

The questionnaires on fish consumption were answered in winter, 7 months before the summer period when the hair samples were collected. According to the questionnaires, the number of anglers fishing pike and perch in winter was about 75% of the corresponding number for the summer period. Therefore, the fish consumption reported here might be somewhat lower than it is in summer. However, many of the subjects kept frozen pike and perch from the summer and ate it in the winter. Moreover, since the hair samples taken reflect the MeHg intake 3–12 months previously, depending on the length of the hair, we think that this is not a serious problem in the present study. In the study of Montrealers (Kosatsky et al., 2000), about 25% lower concentrations of mercury in blood were found in winter compared to summer, but no comparisons were reported for hair mercury.

4.4. Risk assessment

Methyl mercury is neurotoxic, and the developing brain is much more sensitive to methyl mercury than the

mature brain. Two large studies have recently been performed to assess the impact of exposure to methyl mercury on the fetal brain. In the Faroe Islands the population was exposed to methyl mercury mainly from pilot whale meat with a high concentration of methyl mercury, around 2 μg/g. The study showed that high prenatal exposure to methyl mercury resulted in neuropsychological deficits at 7 years of age in the children studied (Grandjean et al., 1997, 1998, 2003).

In a study in the Seychelles the fish consumption of pregnant women was high, typically 10–15 meals per week (Shamlaye et al., 1995), while the mercury level in the ocean fish consumed was relatively low, about 0.2–0.3 μg/g (Cernichiari et al., 1995). No negative effects on developmental tests up to 5.5 and 9 years of age were found to be associated with methyl mercury exposure, as measured by hair Hg in the pregnant mothers (Davidson et al., 1998, 2001; Myers et al., 2003).

The US Environmental Protection Agency decided to rely on the Faroe Islands study (US EPA, 2001; NRC, 2000). A benchmark dose analysis was performed and converted into a maternal intake of 1.1 μg/kg body weight (bw) a day. Applying a safety factor of 10, a reference dose (RfD) of 0.1 μg/kg bw was recommended. If maternal hair Hg at parturition was used as a benchmark, with a safety factor of 10, the corresponding hair Hg level would be 1 μg/g (US EPA, 2001). Risk assessment in the European Union has followed a similar path (European Commission, 2002), recommending an RfD of 0.1 μg/bw a day. The RfD would not be exceeded by eating 3 meals of 100 g each per week of fish with a mercury level of 0.1 μg/g. It would, however, be exceeded in a 60-kg pregnant woman with 1 meal per week of perch containing 0.5 μg/g of mercury.

The RfD corresponds to a level of about 1 μg/g hair. In the present study most of the anglers consuming freshwater fish at least once a week exceeded this level. Although the RfD applies to all populations, the only group at risk at these levels is pregnant women and their fetuses. Among the subjects we studied, only 10% were women of fertile age, and only two of them had mercury levels above 1 μg. These two women consumed pike less than once per week. In Sweden pregnant women are advised not to eat perch and pike at all during pregnancy, and results from studies of randomly selected Swedish pregnant women have shown that this advice is followed (Bjornberg et al., 2003). However, about 5% them have hair mercury levels of 1 μg/g or higher caused by the consumption of seafood other than freshwater fish several times per week (Oskarsson et al., 1994; Bjornberg et al., 2003).

Since fish is rich in many important nutrients (Connor, 2000; Olsen and Secher, 2002), it is unsatisfactory that fish consumption must be restricted. As long as the mercury levels in freshwater fish are high, the advice to pregnant women to avoid these species is necessary, but in the long run there is a need to reduce the mercury levels in fish so that they can be consumed without restrictions.

Acknowledgments

We thank Dr. Edvard Lidén for assistance with designing the hair mercury sampling campaign.

References

Becker, W., Pearson, M., 2002. Dietary Habits and Nutrient Intake in Sweden 1997–98: The Second National Food Consumption Survey. Riksmaten 1997–98 (in Swedish). Swedish National Food Administration, Uppsala, Sweden, pp. 1–199.

Bergdahl, I.A., Schütz, A., Hansson, G.-Å., 1995. Automated determination of inorganic mercury in blood after sulphuric acid treatment using cold vapour atomic absorption spectrometry and an inductively heated gold trap. Analyst 120, 1205–1209.

Bjornberg, K.A., Vahter, M., Petterson-Grawé, K., Glynn, A., Cnattingius, S., Darnerud, P.O., Atuma, S., Aune, M., Becker, W., Berglund, M., 2003. Methyl mercury and inorganic mercury in Swedish pregnant women and in cord blood: influence of fish consumption. Environ. Health Perspect. 111, 637–641.

Bratel, J., Haraldsson, T., Meding, B., Yontchev, E., Öhman, S.-C., Ottosson, J.-O., 1997. Potential side effects of dental amalgam restorations. I. An oral and medical investigation. Eur. J. Oral Sci. 105, 234–243.

Burger, J., Gaines, K.F., Boring, C.S., Stephens Jr., W.L., Snodgrass, J., Gochfeld, M., 2001. Mercury and selenium in fish from the Savannah River: species, trophic level, and locational differences. Environ. Res. 87, 108–118.

Carrington, C.D., Bolger, M.P., 2002. An exposure assesment for methylmercury from seafood for consumers in the United States. Risk Anal. 22, 689–699.

Castro, M.S., McLaughlin, E.N., Davis, R.P., Morgan II, R.P., 2002. Total mercury concentrations in lakes and fish of western Maryland, USA. Arch. Environ. Contam. Toxicol. 42, 454–462.

Cernichiari, E., Toribara, T.Y., Liang, L., Marsh, D.O., Berlin, M.W., Myers, G.J., Cox, C., Shamlaye, C.F., Choisy, O., Davidson, P., Clarkson, T.W., 1995. The biological monitoring of mercury in the Seychelles study. Neurotoxicology 16, 613–628.

CFSAN/FDA (Center for Food Safety and Applied Nutrition, US Food and Drug Administration), 2001. Consumer Advisory: Mercury in Fish, March 2001. URL: www.cfsan.fda.gov

Clarkson, T.W., 2002. The three modern faces of mercury. Environ. Health Perspect. 110, 11–23.

Connor, W.E., 2000. Importance of *n*-3 fatty acids in health and disease. Am. J. Clin. Nutr. 71 (suppl.), 171S–175S.

Davidson, P.W., Myers, G.J., Cox, C., Axtell, C., Shamlaye, C., Solane-Reeves, J., Cernichiari, E., Needham, L., Choi, A., Wang, Y., Berlin, M., Clarkson, T.W., 1998. Effects of prenatal and postnatal methylmercury exposure from fish consumption on neurodevelopment: outcomes at 66 months of age in the Seychelles Child Development Study. J. Am. Med. Assoc. 280, 701–707.

Davidson, P.W., Kost, J., Myers, G.J., Cox, C., Clarkson, T.W., Shamlaye, C., 2001. Methylmercury and neurodevelopment: reanalysis of the Seychelles Child Development Study outcomes at 66 months of age. J. Am. Med. Assoc. 285, 1291–1293.

Dorea, J.G., 2003. Fish are central in the diet of Amazonian riparians: should we worry about their mercury concentrations? Environ. Res. 92, 232–244.

European Commission, 2002. Health effects and risk assessment. In: Working Group on Mercury, Ambient Air Pollution by Mercury (Hg), Position Paper on Mercury. Air Quality, Daughter Directives, European Commission (Chapter 6), URL: www.europa.eu.int/comm/environment/air/background.htm#mercury

Grandjean, P., Weihe, P., White, R.F., Debes, F., Araki, S., Murata, K., Sørensen, N., Dahl, D., Yokoyama, K., Jørgensen, P.J., 1997. Cognitive deficit in 7-year-old children with prenatal exposure to methylmercury. Neurotoxicol. Teratol. 19, 417–428.

Grandjean, P., Weihe, P., White, R.F., Debes, F., 1998. Cognitive performance of children prenatally exposed to "safe" levels of methylmercury. Environ. Res. 77, 165–172.

Grandjean, P., White, R.F., Weihe, P., Jorgensen, P.J., 2003. Neurotoxic risk caused by stable and variable exposure to methylmercury from seafood. Ambul. Pediatr. 3, 18–23.

Hightower, J.M., Moore, D., 2003. Mercury levels in high-end consumers of fish. Environ. Health Perspect. 111, 604–608.

Kosatsky, T., Przybysz, R., Armstrong, B., 2000. Mercury exposure in Montrealers who eat St. Lawrence River sportfish. Environ. Res. 84, 36–43.

Lindestrom, L., 2001. Mercury in sediment and fish communities of lake Vanern, Sweden: recovery from contamination. Ambio 30, 538–544.

Myers, G.J., Davidson, P.W., Cox, C., Shamlye, C.F., Palumbo, D., Cernichiari, E., Sloane-Reeves, J., Wildning, G.E., Kost, J., Huang, L.S., Clarkson, T.W., 2003. Prenatal methylmercury exposure from ocean fish consumption in the Seychelles child development study. Lancet 361, 1686–1692.

Nielsen, J.B., Andersen, O., 1996. Elimination of recently absorbed methyl mercury depends on age and gender. Pharmacol. Toxicol. 79, 60–64.

NRC (National Research Council), Committee on the Toxicological Effects of Methylmercury 2000. Toxicological Effects of Methylmercury. National Academy Press, Washington, DC.

Olsen, S.F., Secher, N.J., 2002. Low consumption of seafood in early pregnancy as a risk factor for preterm delivery: Prospective cohort study. Br. Med. J. 324, 1–5.

Oskarsson, A., Ohlin, B., Ohlander, E.-M., Albanus, L., 1990. Mercury levels in hair from people eating large quantities of Swedish freshwater fish. Food Addit. Contam. 7, 555–563.

Oskarsson, A., Lagerkvist, B., Ohlin, B., Lundberg, K., 1994. Mercury levels in the hair of pregnant women in a polluted area in Sweden. Sci. Total Environ. 151, 29–35.

Porvari, P., 1998. Development of fish mercury concentrations in Finnish reservoirs from 1979 to 1994. Sci. Total Environ. 213, 279–290.

Raldua, D., Pedrocchi, C., 1996. Mercury concentrations in three species of freshwater fishes from the lower Gallego and Cinca Rivers, Spain. Bull. Environ. Contam. Toxicol. 57, 597–602.

Shamlaye, C.F., Marsh, D.O., Myers, G.J., Cox, C., Davidson, P., Choisy, O., Cernichiari, E., Choi, A., Tanner, M.A., Clarkson, T.W., 1995. The Seychelles Child Development Study on neurodevelopmental outcomes in children following in utero exposure to methylmercury from a maternal fish diet: background and demographics. Neurotoxicology 16, 97–612.

Sjors, A., 1998. Fish mercury in lakes of Värmland county: report from the community of Hagfors (in Swedish). Hagfors, Sweden.

Skare, I., 1972. Microdetermination of mercury in biological samples. 3. Automated determination of mercury in urine, fish, and blood samples. Analyst 97, 148–155.

Smith, J.C., Allen, P., Burg, R., 1997. Hair methyl mercury levels in U.S. women. Arch. Environ. Health 52, 476–480.

SNFA (Swedish National Food Administration), 2003. Dietary recommendations for pregnant women (in Swedish). URL: www.slv.se

Stern, A.H., Burger, J., Gochfeld, M., Weisel, C., 2001. Mercury and methyl mercury exposure in the New Jersey pregnant population. Arch. Environ. Health 56, 4–9.

US EPA (US Environmental Protection Agency), 1997. Mercury Report to Congress, Vol. VI: Characterization of Human Health and Wildlife Risks from Anthropogenic Mercury Emissions in the United States. EPA-452/R-97-001f, US EPA, Washington, DC, URL: www.epa.gov/ttnatw01/112nmerc/

US EPA (US Environmental Protection Agency), 2001. Water Quality Criterion for the Protection of Human Health: Methylmercury. US EPA, Washington, DC, URL: www.epa.gov/waterscience/criteria/methylmercury

Westoo, G., 1968. Determination of methylmercury salts in various kinds of biological material. Acta Chem. Scand. 22, 2277–2280.

WHO (World Health Organization), 1990. IPCS Environmental Health Criteria, Vol. 101, Methylmercury. WHO, Geneva.