

Mercury and Methylmercury Exposure in the New Jersey Pregnant Population

ALAN H. STERN

Division of Science, Research and Technology
New Jersey Department of
Environmental Protection
Trenton, New Jersey

and
Department of Environmental and Community
Medicine

University of Medicine and Dentistry
of N.J.-Robert Wood Johnson Medical School
Piscataway, New Jersey

MICHAEL GOCHFELD

CLIFFORD WEISEL

Environmental and Occupational
Health Sciences Institute

Piscataway, New Jersey

and

Department of Environmental and Community
Medicine

University of Medicine and Dentistry
of N.J.-Robert Wood Johnson Medical School
Piscataway, New Jersey

JOANNA BURGER

Environmental and Occupational
Health Sciences Institute
Piscataway, New Jersey

and

Department of Biology

Rutgers University

Piscataway, New Jersey

ABSTRACT. Methylmercury is a known fetal developmental neurotoxicant. The only significant source of fetal exposure is maternal fish consumption; however, few recent data on exposure of the pregnant population are available. The authors undertook a study of methylmercury exposure in the New Jersey pregnant population to investigate the distribution of exposure and to identify predictors of elevated exposure. Mainly first-trimester pregnant women were recruited through six New Jersey obstetric practices. Hair and blood samples were analyzed for total mercury, and a subset was analyzed for methylmercury. A questionnaire on demographics, life style, and fish-consumption practices was also administered. Although 85–90% of the pregnant population had hair mercury levels that were less than 1.0 µg/gm, 1–2% had levels in a range of possible concern for adverse developmental effects (> 4.0 µg/gm). Regression analysis suggested that blacks and individuals with some college education experienced lower exposures to methylmercury.

<Key words: fish, mercury, methylmercury, pregnant>

METHYLMERCURY (MeHg) is a developmental neurotoxicant that readily crosses the placenta and results in adverse effects in utero. Whereas effects on the adult nervous system have been seen in major poisoning episodes,¹ the developing nervous system appears to be

the most sensitive health endpoint for MeHg exposure.^{2,3} The effects of MeHg on the developing nervous system are also distinct qualitatively from its effects on the adult nervous system.^{2,3} In a recent study in the Faroes Islands, a significant regression relationship between maternal

MeHg exposure and adverse neurological performance in 7-y-old children was observed for a maternal cohort (geometric mean hair Hg level of 4.3 $\mu\text{g}/\text{gm}$).⁴ In an earlier study in New Zealand, Kjellström et al.⁵ found developmental effects associated with maternal MeHg hair levels that were equal to or greater than 6 $\mu\text{g}/\text{gm}$.⁵ Consumption of fish and seafood (hereinafter collectively referred to as "fish") is the primary source of MeHg exposure in the general population.⁶ Therefore, the critical environmental exposure in the assessment of the population-based risk from MeHg is that experienced by the pregnant population. Researchers have conducted numerous studies worldwide to assess MeHg exposure in various populations, but few have specifically addressed the exposure of pregnant populations or of women of childbearing age. Estimates of exposure of these groups in the United States, in whole or in part, are sparse,⁷⁻¹⁰ and they tend to mainly reflect exposures during the 1970s.

We studied mercury exposure in the New Jersey pregnant population to address two important questions relating to the assessment of neurodevelopmental risks from methylmercury: (1) What is the overall distribution of exposure in the New Jersey pregnant population? (2) What are the demographic and life-style factors that we can use to identify subsets of the population with elevated exposures and elevated risk? The latter question is important in the focusing of intervention and communication strategies that are aimed at reducing risk. Although a proportion of the population consumes far greater quantities of fish than the "average" population, we did not design this study to focus on high-end consumers who may consume more than 50 kg of fish/y.¹¹

Method

Overall study design. In this study, we sampled women who used obstetrical services in hospitals, public health clinics, and private physicians' offices. We selected contact locations to provide a generally representative sample of major statewide geographic and population areas and of potentially significant demographic factors in New Jersey. Nonetheless, we did not design the study to yield a statistically random sample of the New Jersey pregnant population. Selection of participants with n practices, however, was essentially random, given the nonregular timing of recruitment visits.

Participant recruitment. The protocol, including the questionnaire and consent form, was approved by Institutional Review Boards of Robert Wood Johnson Medical School, St. Peter's Hospital, and Cooper Hospital, all of which are located in New Jersey. Pregnant women were contacted between July 1995 and April 1997, prior to their self-initiated appointment for prenatal examinations. Most subjects were sampled during their initial first-trimester work-ups. Physicians' offices and clinics were in six locations in New Jersey: (1) Belford (central-coastal), (2) Springfield (east-central), (3) Hoboken (northeast-coastal), (4) New Brunswick (central), (5) Camden (southwest), and (6) Red Bank (central-coastal).

The less-populated southern areas of the state were not sampled.

Sample collection and questionnaire administration. Hair, which was obtained from the nape of the neck, was taped to a card so that the basal (scalp) end could be identified, and it was stored in Zip-Loc plastic bags. Blood, which was collected into a metal-free tube, was an adjunct to scheduled obstetric blood collection. A trained interviewer used a questionnaire to elicit information on demographics; duration of pregnancy; health status; dental history; life-style factors (e.g., smoking, alcohol consumption); and personal and family fishing frequency. Information on frequency of consumption and portion size was requested by species and was prompted from a list of 17 species with models approximating several serving weights. Given that diet recall is often vague, we used two questions to compare participants' estimates of overall fish consumption by species: (1) How many times a month do you eat a given type of fish? and (2) When was the last time you ate that type of fish? We subsequently standardized responses, relative to units of time and portion size.

Hair and blood sample analysis for total mercury. Mercury was analyzed on a cold-vapor HG-4 instrument. We used 3 ml of whole blood, which was diluted to 100 ml with deionized water with the addition of 2 ml nitric acid, 2.5 ml sulfuric acid, 15 ml potassium permanganate, and 8 ml potassium persulfate (all ultrapure analytical-grade reagents). Samples were microwave-digested at 95 °C for 1 hr. A series of standards that contained 0.2–5.0 ppb Hg was prepared, and a calibration curve with a 0.995 or better correlation was used for calculating Hg absorbances on each run. Any run with recoveries of less than 85% on spiked samples was repeated. The detection limit for blood was 0.5 $\mu\text{g}/\text{l}$. Blood samples that contained Hg concentrations below the detection limit were recorded as one-half the detection limit. The detection limit for hair was 0.02 $\mu\text{g Hg}/\text{gm hair}$. Hair samples with concentrations below the detection limit were recorded as one-half the detection limit. In general, only the 2 cm of hair proximal to the scalp were analyzed. In some cases, however, this amount did not provide sufficient mass for analysis, and longer segments were analyzed. Hair grows at the rate of about 1 cm/mo,¹ and the portion of the hair strand corresponding to the most recent Hg exposure is below the scalp and is inaccessible. A 2-cm sample of hair, therefore, reflects exposure that occurs 2 mo prior to sampling. The half-life of MeHg in blood is approximately 50 d,¹² but the concentration of Hg at the time of sampling can reflect very recent exposures.

Analysis for MeHg. We analyzed hair from 17 of the participants to investigate the ratio between MeHg and total mercury. We used a modified method of Cappon and Smith¹¹ (for biological tissues) to analyze MeHg. Briefly, the washed hair was digested in an alkaline solution, complexed by cysteine, urea, and a cupric ion, then acidified with sulfuric acid. Methylmercury chloride was extracted with toluene, purified, and converted to its bromine derivative. The mercurial bromide

was reextracted and analyzed by capillary gas chromatography/electron capture detector, using an internal standard for quantification.

Data analyses. We used STATISTICA for Windows (release 5.1 [StatSoft Inc. (Tulsa, Oklahoma)]) to conduct statistical analyses. We used the 1995 Residential Birth Data File, maintained by the New Jersey Department of Health and Senior Services,¹⁴ to investigate reweighting of the frequency distribution of hair and blood Hg concentrations on the basis of statewide distributions of demographic data. The total yearly fish meals consumed by each participant (F_T) was calculated as follows:

$$F_T = \sum (F_1 + \dots + F_n),$$

where F_1 = the total yearly fish meals for species 1 (meals/y). We estimated yearly total MeHg intake for each participant for all fish species (E) as follows:

$$E = \sum [(F \cdot M_1 \cdot C_1) + \dots (F_n \cdot M_n \cdot C_n)],$$

where M_1 = participants' estimate of average portion size (gm) for species 1, and C_1 = characteristic MeHg concentration ($\mu\text{g/gm}$) for species 1.¹⁵

We conducted linear multiple-regression analysis by backwards elimination to identify predictors of hair Hg concentration. Independent variables, which were correlated with hair Hg concentration ($r \geq .1$), were entered into the initial regression model, and variables with p values greater than or equal to .1 were eliminated sequentially from the model. Observations with standard residuals greater than 3 were considered as extreme outliers. We used Cook's distance to examine highly influential observations.

Results

Characteristics of the study sample. Selected summary data for the sample of pregnant women are presented in Table 1. Hair samples were obtained from all participants, and blood samples were obtained from 76% of participants. Some participants were not willing to disclose income data, and the maximum level of educational attainment was, therefore, taken as a surrogate for income. The study sample was reasonably well matched to the 1995 statewide maternal birth cohort for race (χ^2 goodness-of-fit = 6.83, degrees of freedom [df] = 3, $p > .05$), but the sample was significantly younger than the birth cohort (mean age = 25.7 y vs. 29.5 y, respectively; χ^2 goodness-of-fit = 59.8, $df = 4$, $p < .05$). With respect to education, the study sample overestimated the proportion of individuals who did not complete high school and underestimated the proportion who had postcollege education (χ^2 goodness-of-fit = 61.3, $df = 3$, $p < .05$). These results suggest that the study population was somewhat biased toward lower-socioeconomic-status participants. Absence of dental fillings was reported by 24% of participants; 30% reported 1–5 fillings, 30% reported 5–10 fillings, and 16% reported 10–20 fillings.

Fish consumption. At least some fish consumption

was reported by 92% of participants. Participants reported, on average, 83 fish meals/y (standard deviation [SD] = 103, maximum = 757). Canned tuna was the most commonly consumed fish (mean = 30 meals/y), followed by shrimp, fish sticks (assumed pollack), and flounder. Collectively, these fish accounted for 72% of all estimated yearly fish meals. Estimation of MeHg intake, which was based on typical MeHg concentration by species, gave a mean of 1,721 $\mu\text{g/y}$ ($SD = 2,779 \mu\text{g/y}$, maximum = 22,107 $\mu\text{g/y}$). Each of 2 participants reported eating 1 meal per year of large-mouth bass, a New Jersey freshwater fish with known elevated levels of Hg. Fishing by someone in the household was reported by 23% of the sample (i.e., 10% freshwater, 13% saltwater, and 2% freshwater and saltwater). Therefore, self-caught fish-consumption frequency appeared to account for at least some fraction of total consumption.

Blood Hg concentrations. The range of total Hg concentration in blood ($n = 149$) was from less than 0.5 to 32.0 $\mu\text{g/g}$. Only 15% of samples had Hg concentrations above the detection limit. When we set the concentration for the remaining samples to half the detection limit, we obtained a mean concentration of 0.99 $\mu\text{g/l}$ (standard error [SE] = 0.28 $\mu\text{g/l}$). For both raw distributions and distributions reweighted according to

Table 1.—Selected Characteristics of the Study Sample

Characteristic	<i>n</i>	Percentage
Sample size	189	
Hair samples analyzed for total Hg	189	
Hair samples analyzed for methylmercury	17	
Blood samples analyzed for total Hg	143	
Age (y)		
\bar{x}	25.7	
SD	7.5	
Minimum	13.0	
Maximum	53.0	
Race		
White	96	50.8
Black	43	22.8
Hispanic	37	19.6
Asian	12	6.3
Native American	1	0.5
Education (highest education level achieved)		
Did not complete high school	43	22.8
Completed high school	63	34.2
Some college	57	31.0
Postcollege	13	7.1
Days pregnant at sampling		
\bar{x}	75.0	
SD	32.8	
Minimum	20.0	
Maximum	158.0	
Sampled within first trimester		
Yes	133	70.3
No	56	29.6

Notes: \bar{x} = mean, and SD = standard deviation

the 1995 New Jersey Birth Registry, the vast majority of participants had blood Hg concentrations less than 1.0 µg/l. However, 3–6% of participants had blood Hg concentrations between 5.0 µg/l and 10 µg/l, and 1–3% of participants had values that exceeded 10 µg/l (Table 2).

Hair Hg concentrations. The range of total Hg concentration in hair ($n = 189$) was from less than 0.2 to 9.1 µg Hg/gm hair. Setting the concentration for samples below the detection limit (21%) at half the detection limit yielded a mean hair concentration of 0.53 µg/gm hair ($SE = 0.07$ µg/gm). With respect to raw and reweighted distributions, the great majority of participants had hair Hg concentrations that were less than 1.0 µg/gm. However, 2–3% had concentrations that exceeded 2.0 µg/gm, and 1–2% had concentrations greater than 4.0 µg/gm (Table 3).

Hair-blood relationship. The mean hair-to-blood ratio ($n = 149$) was 1.48 (µg Hg/gm hair)/(µg Hg/l blood) ($r = .28$, $p = .001$); when we considered only detectable values for hair and blood ($n = 22$), the ratio was 0.90 ($r = .14$, $p > .05$). These values, which are inconsistent with those generally reported from populations with high fish consumption (i.e., ~ 0.25 [µg/g]/[µg/l]),¹² may reflect temporal differences between hair and blood Hg levels that resulted from sporadic fish consumption.

Hair MeHg concentrations. We were unable to conduct measurements of MeHg in blood because insufficient sample volumes were available. MeHg was measured in hair samples from 17 participants. The regression relationship between total Hg and MeHg for all 17 participants indicated that a mean of 67% of total Hg in hair is present as MeHg. This level was somewhat lower than expected. At very low concentrations of total Hg, however, there was considerable scatter; this likely reflected the influence of various sources of inorganic

Hg exposure. When we considered only those samples with total Hg concentrations in excess of 0.3 µg/gm, the mean MeHg fraction of total Hg was 81%—in agreement with values reported elsewhere for fish consumers.^{15,17} Nonetheless, even for this subset, individual MeHg/total Hg ratios in this sample varied considerably (minimum = 0.03, maximum = 0.91). Interestingly, the regression line for samples that contained Hg concentrations in excess of 0.3 µg/gm closely predicted the measured values of Hg and MeHg from the hair of one of the authors, who consumed fish fairly frequently, and his hair contained high levels of Hg (total Hg = 3.1 µg/gm) (Fig. 1).

Relationships between fish consumption and hair Hg. Hair Hg was weakly—but significantly—correlated with the \log_{10} of estimated total fish Hg intake/y ($r = .18$, $p = .02$ [Fig. 2]). Estimates of total fish meals consumed per year, as well as number of meals of canned tuna per year, however, were not correlated significantly with hair Hg. Consumption of canned tuna during the preceding 30 d or consumption of at least one meal of high-Hg fish (i.e., tuna steak, shark, swordfish, or bluefish) in the past year was not associated with higher hair Hg concentrations (t test).

Reduced sample based on fish-Hg-specific exposure. We investigated possible misclassification of elevated Hg exposure as MeHg exposure by identifying those individuals with elevated Hg in hair, but who had few characteristics of MeHg exposure. We assumed that an individual's elevated hair Hg level was potentially misclassified with respect to elevated MeHg exposure if all of the following conditions were met: (1) hair Hg concentration was greater than 2.0 µg/gm, (2) blood Hg concentration was below the detection limit (0.1 µg/l), (3) less than 1 meal/y of high-Hg fish was reported, (4)

Table 2.—Distribution of Blood Mercury Concentrations

Concentration (µg/l)	Unweighted n (total = 149)	Unweighted percentage of total	Age-weighted percentage of total	Race-weighted percentage of total	Education-weighted percentage of total
≥ 0.25 to < 1.0	127	85.2	76.9	84.4	83.6
≥ 1.0 to < 5.0	15	10.1	14.8	10.9	10.1
≥ 5.0 to < 10	5	3.4	5.6	3.2	5.0
≥ 10	2	1.3	2.6	1.6	1.3

Table 3.—Distribution of Hair Mercury Concentrations (Full Sample)

Concentration (µg/gm)	Unweighted n (total = 189)	Unweighted percentage of total	Age-weighted percentage of total	Race-weighted percentage of total	Education-weighted percentage of total
≥ 0.1 to < 1.0	165	87.3	84.5	86.9	89.2
≥ 1.0 to < 2.0	18	9.5	12.3	9.9	8.1
≥ 2.0 to < 4.0	3	1.6	2.0	1.5	1.7
≥ 4.0 to < 6.0	1	0.5	1.0	0.6	0.3
≥ 6.0 to < 8.0	1	0.5	0.1	0.6	0.3
≥ 8.0 to < 10.0	1	0.5	0.1	0.5	0.0

the number of fish meals/y was less than the population median of 58 meals/y, and (3) the estimated MeHg intake was less than the population median of 859 µg/y. We, therefore, created a reduced sample by eliminating two observations (i.e., 9.1 µg/g and 2.7 µg/g) from the total sample. Frequency distributions of hair Hg for this reduced sample were similar to those for the total sample.

Multiple-regression model of MeHg exposure. The independent variables that met the criteria for initial entry into the multiple-regression analysis appear in Table 4. Multiple-regression analyses with raw hair Hg concentration (reduced sample) as the dependent variable gave a highly nonnormal distribution of residuals. We, therefore, used log₁₀-transformed concentrations to carry out the analyses. The final regression model explained 30% of the variance. Post-hoc analysis of variance (ANOVA) suggested that blacks have significantly lower hair Hg levels than whites, Hispanics, or Asians. No extreme outliers were present. Elimination of one highly influential observation reduced the total yearly fish-Hg intake to borderline significance, and it caused "having completed some college" to become significant. If education was taken as a surrogate of income, this model suggested that elevated MeHg exposure in the fish-consuming New Jersey pregnant population was most likely to be found among lower- and upper-class nonblacks (vs. middle-class nonblacks).

Discussion

The great majority of pregnant women in our sample had MeHg exposures that were below those associated with fetal neurodevelopmental toxicity.^{4,5} However, in 3 cases we observed hair Hg levels that exceeded 4.0 µg/gm, and in 2 cases (1%) levels exceeded 6 µg/gm. Based on the still-developing scientific literature, such exposures may present an elevated risk of such toxicity.

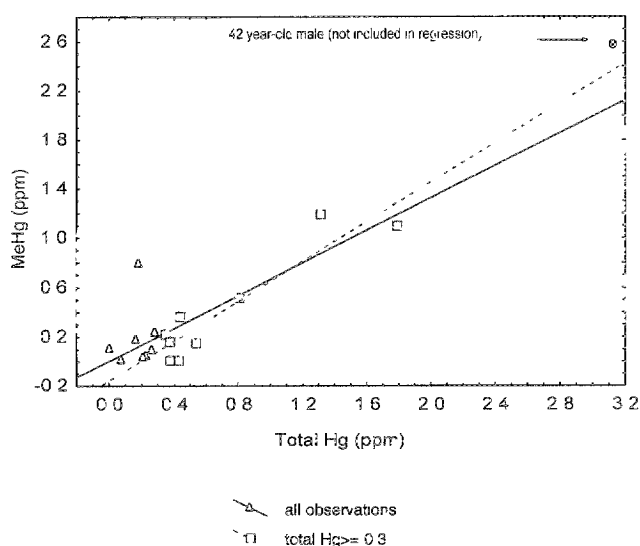


Fig. 1. Relationship of methylmercury (MeHg) to total mercury. All observations: $\text{MeHg} = 0.003 + 0.662 \cdot x + \text{eps}$. Total Hg ≥ 0.3 ppm: $\text{MeHg} = -0.159 + 0.807 \cdot x + \text{eps}$.

The analysis of demographic factors revealed that individuals with at least some college education had lower Hg levels than those with no college or those with postgraduate education. In addition, blacks had lower Hg levels than the other groups. Whereas data by region on fish-consumption frequency and preferences are lacking, we believe that the patterns found in New Jersey are likely typical of those found in other areas of the United

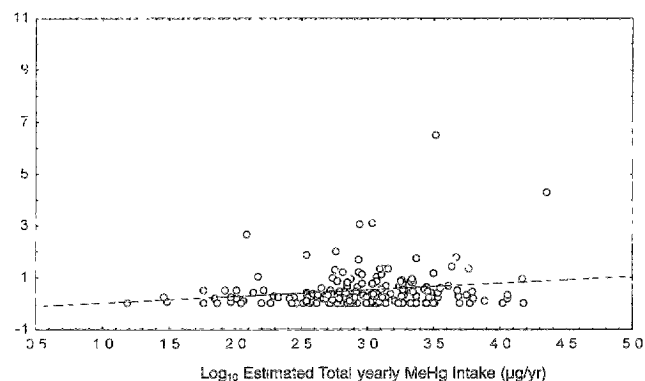


Fig. 2. Relationship of log₁₀ estimated yearly methylmercury (MeHg) intake and hair Hg concentration: $y = -0.243 + 0.256 \cdot x$.

Table 4.—Final Multiple Regression Model of Log₁₀ Hair Mercury Concentration (Reduced Sample [n = 167])

Independent variable	β (slope)	Standardized β	p
RACEB	-0.887	-0.505	< .001
EDUCAT3	-0.127	-0.249	.055
LOG ₁₀ TOTALHG	0.226	0.159	.017
Intercept	-1.145		< .001
Overall p < .001			
Overall R ² = 0.30			

Notes. The following independent variables met criteria for initial entry into multiple-regression analysis:

- DAYSPREG = number of days pregnant calculated from last menstruation,
- AGE = maternal age in years,
- SALTWATERFISH = do you or someone in your family salt-water fish at least once per year? (Y/N),
- NUMFILLING = number of self-reported dental amalgam surfaces (0, 1–5, 6–10, 11–20, > 20),
- RACEB = dummy variable for Black, with White as referent category,
- RACEA = dummy variable for Asian, with White as referent category,
- HIGRADE = highest grade achieved in school;
- EDUCAT3 = dummy variable for some college education (did not graduate), with completion of < 12th grade as referent category,
- EDUCAT4 = dummy variable for completed college (no postgraduate), with completion of < 12th grade as referent category,
- LOG₁₀TOTALHG = base 10 logarithm of estimated total fish mercury intake per year (µg), and
- HIFISH = ate at least one meal of high-mercury concentration fish in the past year (e.g., tuna, steak, shark, swordfish, bluefish)

States, particularly the northeast and mid-Atlantic states. The exclusion of the comparatively small fraction of the New Jersey population in the southern portion of the state, however, should be viewed with some caution. This area supports active residential and commercial marine fisheries and may, therefore, contain a greater proportion of frequent fish consumers. In addition, this study did not target high-end fish consumers, and it cannot, therefore, provide information on the patterns or range of exposure of the fraction of the population with the greatest exposures.

A dietary recall study in New Jersey¹⁵ estimated that approximately 20% of women 18–40 y of age had MeHg intakes that exceeded the U.S. Environmental Protection Agency's reference dose (i.e., corresponding to a hair Hg level of ~1 µg/gm). In the current study, we found that 10–15% of pregnant women in New Jersey had levels that exceeded this concentration. These estimates, based on different approaches, are in reasonable agreement. In an earlier study, in which fish-consuming women of childbearing age were represented in the United States,⁷ Smith et al. found that approximately 20% had hair Hg levels that exceeded 1 µg/gm, and approximately 5% had hair levels in excess of 2 µg/gm. In two studies of women at delivery in Iowa,^{8,9} investigators found mean total blood Hg concentrations of 1.01 µg/l (maximum = 8 µg/l) and 0.79 µg/l (maximum = 5.0 µg/l); in addition, there was less variability than was observed in our data. A small sample in Cleveland¹⁰ had a total mean blood Hg concentration of 3.4 ng/g (= 3.6 µg/l) at delivery. Although such a value seems large, compared with our observations, the small sample size makes comparisons problematic.

It is somewhat surprising that our estimates of fish-Hg intake were not better predictors of hair Hg levels. Perhaps the following factors accounted for this finding among our study population: participants' inaccuracy with respect to long-term recall of consumption, inaccuracy and variability in the assignment of average concentrations of MeHg by fish species, and sporadic fish consumption. Recall is more accurate when fish consumption constitutes a larger proportion of the diet and when recall is requested over a short and definite period. In the current study, the recall period was open ended. Studies of Hg exposure are seriously hampered by the lack of recent systematic data on Hg concentration in commercial fish. The most comprehensive data date from the 1970s.¹⁸ Furthermore, intraspecies variability in Hg concentration is generally not known and can lead to errors in estimation of intake, especially when infrequent consumption is involved. Many participants in this study consumed fish only sporadically. For such consumers, the analysis of 2 cm of hair for most of our samples may not have represented a sufficiently long period, and long-term average consumption may not have been captured. Sporadic consumption can also account for the poor correlation between blood and hair Hg inasmuch as the exposure represented by the proximal 1 cm of hair is offset from the exposure represented by blood concentration by approximately 1 mo.⁷

Finally, we wish to emphasize that, in this study, we

did not intend to specifically characterize the fraction of the population with the highest levels of dietary exposure to MeHg. It is quite likely that the range of exposure to MeHg extends considerably beyond that seen in our sample. The sample was neither sufficiently large nor sufficiently focused on high-end fish consumers; therefore, we could not provide a clear picture of the extent of exposure or the consumption characteristics of such consumers.

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Requests for reprints should be sent to Alan H. Stern, Dr. P.H., State of New Jersey Department of Environmental Protection, Division of Science, Research and Technology, P.O. Box 409, Trenton, NJ 08625-0409.

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References

1. World Health Organization (WHO). Environmental Health Criteria, 107. Methylmercury. Geneva, Switzerland: WHO, 1990.
2. United States Environmental Protection Agency (USEPA). Mercury Study Report to Congress V. Health Effects of Mercury and Mercury Compounds. Research Triangle Park, NC: USEPA, December 1997, EPA-452/R-97-007.
3. Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for Mercury, Draft for Public Comment. Atlanta, GA: ATSDR, August 1997.
4. Grandjean P, Weihe P, White RF, et al. Cognitive deficit in 7-year-old children with prenatal exposure to methylmercury. *Neurotoxicol Teratol* 1997, 19:17–28.
5. Kjellstrom T, Kennedy P, Wallis S, et al. Physical and Mental Development of Children with Prenatal Exposure to Mercury from Fish. Solon, Sweden. National Swedish Environmental Protection Board, August 1989; Report 3642.
6. United States Environmental Protection Agency (USEPA). Mercury Study Report to Congress VII. Characterization of Human Health and Wildlife Risks from Mercury Exposure in the United States. Research Triangle Park, NC: USEPA, December 1997, EPA-45/R-97-009.
7. Smith JC, Allen PV, Von Burg R. Hair methylmercury levels in U.S. Women. *Arch Environ Health* 1997, 52:476–80.
8. Kuntz WD, Pitkin RM, Bostrom AW, et al. Maternal and cord blood background mercury levels: a longitudinal surveillance. *Am J Obstet Gynecol* 1982, 143:440–43.
9. Pitkin RM, Bahns JA, Filler LJ, et al. Mercury in human maternal and cord blood, placenta and milk. *Proc Soc Exp Biol Med* 1976, 151:565–67.
10. Kuhnert PM, Kuhnert BR, Erhard P. Comparison of mercury levels in maternal blood, fetal cord blood, and placental tissues. *Am J Obstet Gynecol* 1981, 139:208–11.
11. Burger J, Stephens W, Borng CS, et al. Factors in exposure assessment: ethnic and social differences in fishing and consumption of fish caught along the Savannah River. *Risk Analysis* 1999, 19(3):427–38.
12. Stern AH. Estimation of the interindividual variability in the one-compartment, pharmacokinetic model for methylmercury.

- implications for the derivation of a reference dose. *Reg Toxicol Pharmacol* 1997, 25:277-88.
13. Cappon C, Smith JC. A simple and rapid procedure for the gas-chromatographic determination of methylmercury in biologic samples. *Bull Environ Contam Toxicol* 1978, 19:600-07.
 14. New Jersey Department of Health and Senior Services. Residential Birth Data (unpublished). Trenton, NJ. Center for Health Statistics, 1995.
 15. Stern AH, Korn LR, Ruppel BE. Estimation of fish consumption and methylmercury intake in the New Jersey population. *J Expos Anal Environ Epidemiol* 1996, 6:503-24.
 16. Phelps RW, Clarkson TW, Kershaw TG, et al. Interrelationships of blood and hair mercury concentrations in a North American population exposed to methylmercury. *Arch Environ Health* 1980, 35:161-68.
 17. Cernichari E, Toribara TY, Liang L, et al. Biological monitoring of mercury in the Seychelles Study. *Neuro Toxicol* 1995, 16:613-28.
 18. Hall RA, Zook EG, Meaburn GM. National Marine Fisheries Service Survey of Trace Elements in the Fishery Resource. Silver Spring, MD. National Oceanic and Atmospheric Administration, 1978, Technical Report NMFS SSRF-721.
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