

# Mercury in Human Hair Due to Environment and Diet: A Review

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Hair mercury levels increase with the amount of fish in the diet and the amount of mercury in the fish species consumed. If hair mercury levels in people throughout the world were monitored by a standard analytical procedure, the results would indicate locations where people's body burden of mercury is high enough to be subclinically unhealthy and where controls on environmental emissions might be beneficial. The relationship of hair mercury concentration to the method of sampling and analysis of hair, the analysis of the results, the amount of fish consumed, the country and location from which samples were taken and the age, sex and occupation of the donor is discussed.

## Introduction

Mercury and its compounds occur naturally in the environment, but the use of them in industry and their release into the atmosphere by the burning of fossil fuels and the processing of ores has increased environmental levels. The health of some people has been seriously affected, for example in Minamata (1) and Iraq (2).

The world consumption of mercury has been decreasing (3) due to public awareness of its toxicity. However, the amount of mercury already emitted and being recycled in the environment and new emissions from natural and anthropogenic sources is considerable. Also there is a renewed worldwide interest in burning more coal instead of oil for energy: the USA plans to increase its coal production to 1134 million tons by 1985, an increase of 512 million tons (4). Coal contains mercury, which is a volatile metal and easily transported by winds (5), possibly around the world (6, 7). There is an inadequate data base by which health defects caused by these emissions can be determined (8) and consequently environmental mercury levels should be monitored and related to these health defects. A specialized working group (9) identified areas in most urgent need of further investigation as being: sources of atmospheric mercury from fossil fuel combustion

and metal refining; sources and movement of mercury in urban areas; the subclinical effects of mercury poisoning in man, including, in particular, the effects of methylmercury in the diet and the inhalation of mercury vapor in air; the diagnosis of the delayed onset of clinical mercury poisoning.

This increased concern about the health of persons exposed to very low environmental mercury concentrations is because mercury causes subclinical effects at low concentrations (10). The symptoms are difficult to detect and measure. For example, slightly increased levels of mercury in hair have been associated with decreases in academic ability (11). Also, reduced productivity and development of asthenic vegetative syndrome, a subtle behavior change, can occur (12).

Because at present there is no indicator to monitor the total environment to assess changes in man's exposure to mercury, a method for such environmental monitoring is required. It has been reported that mercury accumulates in the following matrices, any one of which could be used as an indicator of environmental mercury levels: lake sediments (13), bird feathers (14), food (15-17), fish (18, 19), surface seawater (6), air (7) and scalp hair (20, 21).

However, the availability of samples for any type of monitoring is important. In this case, of all the matrices mentioned, the easiest to collect, transport and store is human scalp hair.

Mercury has been measured in human hair in forensic studies, for dietary reasons, in toxic and

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health care work and to examine environmental concentrations in polluted and unpolluted regions. This paper reviews some of the literature on these topics in order to determine whether human scalp hair could be used to indicate exposure of people to mercury. Sample preparation and analysis, mercury intake, distribution in the body and toxicological symptoms, and the effects of diet, occupation, habitat, age and sex are considered. Many of those papers which cover the large-scale outbreaks of mercury poisoning have not been included as these have been covered extensively elsewhere (2, 9, 22-24) and are not pertinent to a study of populations with long-term exposure to lower levels of mercury.

## Sample Preparation, Analysis and Data Presentation

Hair can accumulate mercury from blood as the hair grows; from scalp sweat; from sweat and dirt wiped onto the hair from hands; from dust and air and from dyes, shampoos and bleaches. Hair damaged by mechanical curlers could be more susceptible to external mercury uptake. Consideration must be given to these factors and to techniques for sampling, storage, sample preparation and analysis if data sets are to be compared meaningfully.

## Sampling

Hair is easy to collect, transport and store. However, care should be taken that mercury levels in underarm hair, pubic hair, chest hair, and beards (16, 25) are not compared with mercury levels of head hair. Such hairs have different growth rates, are exposed to different amounts of sweat, and are usually covered by clothing and have different concentrations of mercury. For example, in dentists, the ranges of mercury concentrations for head hair, axillary hair and pubic hair were 1.02-10.0 ppm, 0.61-3.1 ppm and 0.85-2.56 ppm, respectively (26). Throughout this paper, unless stated otherwise, "hair" refers to head hair.

Variability has been observed in the mercury concentration of hair from different parts of the head. Hair from the scalp of one donor showed a range of 1.83 ppm on the top of the head to 13.8 ppm at the front (27). However, most people have similar mercury concentrations in hair samples taken from different locations on the head (21, 28). The large range in the first case may have been due to sample contamination or perhaps the

donor habitually pushed hair out of his eyes with mercury-contaminated hands.

Mercury is deposited in hair as it grows, and the amount deposited reflects the body burden of mercury (29). As hair grows an average of 1-1.5 cm per month (30), attempts have been made to examine the history of a donor's exposure to mercury as reflected by segments of hair (29). It has been recommended (31) that, for this type of "history" experiment, bunches of 100 hairs are required and should be bound together by adhesive tape, then cut flush with the scalp. Alternatively, the bunch should be grasped with a hemostat, cut, and fastened into a plastic bag by staples before releasing the hemostat (29). The rate of growth of the bunch should then be measured by dying adjacent hair and measuring the growth later.

Hair grows and stops growing, or rests, for periods of time, and the use of rested hairs might confuse the history of the donor's mercury burden. However, in one study this factor had little effect on the hair mercury concentrations (28). The same study also showed that the variability in mercury concentrations along the hair of each donor was less than that observed between donors. I examined the variability in hair mercury levels of four people sampled several times for over a year, the mercury concentrations being  $2.4 \pm 0.3$  ppm,  $1.7 \pm 0.8$  ppm,  $6.1 \pm 0.3$  ppm and  $22.5 \pm 4.4$  ppm. Hair mercury concentrations of one person studied showed a range of only 7.88-8.14 ppm over a 14-month period (27, 32). The authors found that the differences between mercury content of hair from donors sampled repetitively for up to a year became less, compared to the first sample, as the time increased. The reason for this is that repetitive seasonal changes in diet and metabolism cause a yearly pattern in the amount of mercury excreted into the hair so long as the life-style of the donor does not change radically. Such a cycle has been found in a 5-year series of hair samples with the maximum values occurring each midsummer (29). However, in one forensic investigation, increased time caused increased variability in the mercury levels (33). These donors perhaps had lifestyles that varied from year to year.

When lifestyles do change radically, for example if people change their place of residence, the hair mercury levels also change, reflecting those of the communities in which they live. This has been seen for donors who moved from: (1) Japan to Burma and East Pakistan (34) where the mercury levels dropped from about 10 ppm to 2 ppm and 6 ppm, respectively; (2) Canada to Iraq (30) where levels fell from 5 ppm to 1.5 ppm; (3) Japan

to New York (31) where levels dropped from 8-10 ppm to 1.5 ppm; (4) Japan to North and South America and Europe, then back to Japan (35), where levels fell from about 6 ppm to 2 ppm and rose again when the people returned, or (5) many different areas of the U.S. into an academy where they were all subject to similar food and environment (11). Initially, the scatter in the hair mercury concentrations was large, but after one year it had become much smaller.

When sampling, it is necessary to be aware of the donor's treatment of his hair. For example, was the hair treated with thiol-containing colutions (36); was the hair washed with mercurial soap which can raise the hair levels to 100 ppm (37) or was the hair damaged by the use of curling devices (11)? The donor's occupation and details of his use of contraceptive spermicides and cosmetics containing mercurials, such as skin lightening creams, are valuable information. The last has been shown to produce hair mercury levels as high as 9220 ppm in Kenyan women (38). Such individually contaminated samples must be eliminated from general population data for large-scale environmental surveys.

## Hair Storage and Washing Procedures

Inorganic mercury and methylmercury in hair samples are stable for long periods (29). Such stability may not be apparent if samples were contaminated with grease, skin, paper packaging or mercury vapor not removed before analysis. Prior to washing, the root and skin must be removed (27).

There are conflicting opinions about whether and how hair should be washed before mercury analysis. Some mercury in sweat attaches to sulfhydryl groups of hair (39). One author (40) soaked hair in an artificial sweat (Hg concentration 200 µg/g) for 16 hr and then either washed it in detergent, rinsed and analyzed or analyzed it without washing. The concentration of mercury used was very high and more than 1000 ppm was initially absorbed of which 50% was removed by washing. Normally only a minute fraction of mercury in hair would be from sweat. Another author believes that neither mercury accumulated on hair externally nor that derived from blood during the hair's formation is removed by washing (41). To confirm this, hair was used which had mercury concentrations that increased from the head to the ends of the hair. This increase could have been due to old hair ends becoming externally contaminated, or have been the result of the

donor being exposed to less mercury from food or environment. These hair samples were washed for 2 min in organic solvent, rinsed, then washed in nonionic detergent to remove suspected external contaminants, but there was not much difference before and after washing (40).

Several authors have observed little difference in mercury levels before and after hair samples were cleaned and concluded that it was not necessary to wash their samples or that washing and re-analysis was required only for samples which gave high values (28, 31, 42, 43). However, one of these authors (31) found that hair samples exposed to mercury vapor accumulated 0.13 µg/g after 25 min, of which 93% could be removed by a detergent wash.

More detailed studies of the absorption and removal of mercury in human hair have been made (21, 44-46). The last report showed that mercury levels decrease in hair washed before analysis. When hair cleansing agents including water, alcohol, detergent, 1 N NaOH, and 1 N HCl were compared, the NaOH was too powerful, as it removed significant amounts of the structurally bound mercury, reducing levels from 6.4 ppm to 1.3 ppm (30). Acetone-methanol and water have been used to remove external particles and grease (29).

To resolve some of these problems, I did experiments to determine whether mercury vapor could increase hair mercury levels, and whether this mercury could be removed by washing. It was found that unless an ultrasonic bath was used to remove some types of detergents, the mercury levels in some hair samples could be increased by a factor of 10. I found that a 0.1% solution of Triton X-100 (a nonionic detergent) made up in mercury-free water gave the most reproducible results. The hair and detergent were placed in polypropylene sieves in an ultrasonic bath and then rinsed several times with mercury-free water (21). This is the preferred way of removing external contaminants without affecting structural mercury. This detergent has also been used successfully by others (11, 45).

I also showed that increasing concentrations (unnaturally high levels) of moist mercury vapor, released by reduction of mercuric chloride solution by stannous chloride, caused proportional increases in hair mercury levels, and that different hair types absorbed different amounts of mercury. Mercury vapor from liquid mercury had no effect on hair mercury levels. Exposure of hair to air containing 1 µg/m<sup>3</sup> mercury, a factor of about 100 more than normal levels, caused insignificant mercury uptake whether the hair was washed

after exposure or not. This indicated that samples stored under normal conditions should not accumulate mercury from the atmosphere. However, a rinse with Triton X-100 and water should still be done to remove large particles and grease.

It is essential that techniques for sampling and pretreatment of hair samples for mercury analysis must be standardized in order that differences in concentration caused by environmental factors are not swamped by analytical variability (47).

## Methods of Analysis

A compilation of methods used to determine mercury in hair has been made (43). Dry vapor atomic absorption and neutron activation analysis have been used to compare values in replicate samples of hair with good correlation (48).

A syringe injection method has been developed and gives excellent reproducibility on replicate samples and commercial standards (49, 50). Also, the range of hair mercury concentrations found by using the method is the same as that found by most other workers (21). The literature contains accounts (51, 52) which describe what appears to be a well-tested, externally standardized analytical method, but which gives hair mercury concentrations in normal populations ten times higher than in most other surveys. The authors were aware of the discrepancy and suggested that other workers were losing mercury. They believe (personal communication) that the data are correct although the analyses were not validated by another laboratory. These data were not used in the correlations discussed later. Incorrect preparation of standards is often the cause for such disagreements (53).

## Statistical Presentation of Data

Most authors report hair mercury concentrations as arithmetic means; some use geometric means or medians. Some authors do not filter out anomalous results and others arbitrarily eliminate high levels. I recently discussed in detail the problem of comparing results presented in different ways (21), and showed that filtered arithmetic means or geometric means could be used.

## Mercury Intake, Distribution in the Body and Symptoms

### Relationships between Mercury in Hair and Other Body Samples

Tracer experiments showed that 1% of a dose of methylmercury appeared in the blood once the

distribution of the dose in the body became stable (54). It is important to understand the relationship between mercury in hair and that in blood in order to justify the use of hair as an indicator of the exposure of the body to mercury. A correlation of 0.935 ( $p < 0.001$ ) between total mercury concentrations in hair and blood has been found (29). The ratio of inorganic mercury to methylmercury in red blood cells is 0.04-0.05 (29, 54, 55), about one quarter of that in hair.

Usually about 95% of ingested methylmercury is absorbed into the body but only 15% of inorganic mercury. When a meal which contains methylmercury is consumed, peak blood mercury levels are reported to occur 4-14 hr later (54). It then takes several hours for the mercury to be distributed in the body, and months for it to be eliminated. The mercury remaining in the blood appeared to be in equilibrium with that in the rest of the body, and its concentration was reflected in the amount of mercury deposited in the hair.

It has also been shown that if inorganic mercury levels increase in the blood, so do methylmercury levels (56, 57), and that intake of methylmercury alone causes higher levels of both organic and inorganic mercury in the hair (2).

One study (55) gave a formula derived for the relationship between total mercury intake of a 70 kg person and blood total mercury levels:

$$\text{Daily mercury intake (mg/day)} \times 0.9 = \text{Blood mercury concentration } (\mu\text{g/mL}) \quad (1)$$

A mean ratio of concentrations of total mercury in hair to total mercury in blood was 292 (55). Other comparisons between concentrations of total mercury in hair and blood have shown a ratio of about 300 (16,58-62). In another study, the ratio of inorganic mercury in hair to that in blood was 420, for organic mercury the ratio was 278 and for total mercury the ratio was 296 (29). These experiments showed that blood levels may have changed during the time taken for hair to grow from the scalp after its formation, making the determined ratio slightly different from the true ratio at the moment of formation.

Between 61% and 82% of inhaled inorganic mercury vapor is retained (63). Mercury ore processors who inhaled about 1 mg of mercury vapor per day had  $25.0 \pm 6.1$  ppm in their hair and a hair to blood ratio of  $441 \pm 110$  (range 105-940) (64). Other workers who breathed only the mercury ore dust but very little vapor had hair levels of  $4.0 \pm 0.8$  ppm, while the local population had only  $1.8 \pm 0.4$  ppm.

The mechanisms by which the two forms of

mercury enter the hair are still unknown. However, inorganic mercury is more concentrated in hair than in blood. As discussed previously, we can discount external uptake even at air mercury concentrations 100 times natural levels. Therefore, the mechanism could be a selective removal of mercury species from the blood in the hair follicle during the hair's formation. An unlikely alternative is that excretion of sweat containing inorganic mercury may change the ratio by absorption as the hair emerges. However, once the hair is cut there is no further change in this ratio. Because the relationship between methylmercury and inorganic mercury in hair is constant in any one person, measurements of total mercury can be used as an indicator of the person's body burden of mercury (29).

The mercury levels in urine compared to those in hair are difficult to interpret because the concentrations depend on how much the donor has been drinking, the number of days since exposure [after exposure, excretion of mercury increases exponentially with time for several days (54)], and the history of the donor's previous exposure to mercury (56,65). The biochemistry of accumulation and excretion is complex. For example, after the mercury concentration in the liver reaches a critical level, there is a steep increase in the level in the brain (9,66). Presumably there is also more mercury in the blood and a greater excretion rate into the hair and urine.

### **Absorption, Excretion and General Effects**

Organic and inorganic mercury compounds have high affinity for sulfhydryl groups, can inhibit a large number of enzymes, can precipitate protein, and can kill every kind of living cell (67). The different mercury species can act synergistically and increase or reduce the damage being caused by other toxic agents that have entered the body (9). Mercury species have different biological half-lives in the body. Methylmercury disappears biphasically with half-lives of 7.6 and 52 days. Other estimates of half-lives include: for total mercury, 33 days (34); for mercury vapor tracer, up to 64 days in various parts of the body (63). For methylmercury the following half-lives have been reported, 72 days over a range 35-189 (68), 70 days (69) and a range of 33-120 days (58). Some specialists (70) have reviewed the absorption of mercury into, and its excretion from, most organs of the body. Organic mercury is effectively absorbed through the digestive tract and mercury vapor is taken in through the lungs and skin.

The toxicity of each mercury species depends on its resistance to metabolic breakdown, the ease with which it can pass across body membranes and whether the cells it destroys can be replaced. Methylmercury damages and destroys nerve and brain cells that cannot be replaced. With mild exposure, other nerve cells will take over the functions of dead ones, but once major symptoms occur, they are irreversible. Inorganic mercury attacks areas with replaceable cells such as the cardiovascular, urogenital and endocrine systems so most symptoms may disappear if exposure to mercury vapor ceases (71).

### **Exposure and Symptoms due to Intake of Inorganic Mercury Vapor**

Long exposure to low levels of mercury vapor by dental personnel gave hair mercury levels of up to 286 ppm with associated irritability (72). Mercury vapor can also induce sore eyes, skin rashes and gingivitis, lead to abnormal electroencephalograms, make copying simple diagrams difficult (73), cause daytime tremors and insomnia, psychological and personality disturbances called erethism (41,65,74). Asthenic vegetive syndrome is the first stage of this classical inorganic mercury poisoning (9,12,24,71). Symptoms include irritability, large decreases in productivity, losses of memory, appetite, weight and self-confidence, increased emotional liability and excitability, apathy, enlarged thyroids, muscular weakness, vivid dreams and depression.

In most outdoor areas, air mercury concentrations are low so there is little risk of subclinical symptoms. However, in some homes, teaching or research laboratories where thermometers have been dropped, dental surgeries, industrial and mercury mining areas that are known to have higher air mercury levels (10,75), some of these subtle symptoms have occurred. Of an experimental control group who worked in an environment with about 10  $\mu\text{g}/\text{m}^3$ , 40% suffered from asthenic vegetive syndrome (76). These mercury levels were very high compared to most indoor exposure areas.

### **Exposure and Symptoms Due to Intake of Organic Mercury**

Clinical symptoms were observed to be mild, moderate and severe in people who had 120-600, 200-800 and 400-1600 ppm of mercury, respectively, in their hair (30). These clinical symptoms have been reviewed extensively (9,10,24,67). However, hair mercury levels higher than those

reported in crippled Minamata patients have been found in people not showing clinical signs of intoxication (9,58). Classical clinical symptoms include loss of coordination (cerebellar ataxia), constriction of the visual field; hearing losses and speech difficulties (dysarthria), numbness and loss of sensation (paresthesia). Infants born to exposed mothers have cerebral palsy. Lesions in the brain and other tissues in affected people have been described (41,58,77).

In Sweden subclinical effects were observed in a survey of people who had eaten large quantities of fish. These people had a changed number of chromosomes in each lymphocyte cell, and some chromosomes were damaged (9). Other studies have shown that: 7.4% of persons examined who ate saltwater fish three times each week had hair mercury levels of  $11.9 \pm 8.0$  ppm (range 0.6-21.8 ppm) and had neurological symptoms (60); and 30% of all households on the Pribilof Islands had one or more persons suffering from neurological disease suspected, but not proven, to be due to mercury ingested with seal and seal lion products. In this case, the mean hair mercury levels found were only 2.4-6.5 ppm (78). At low hair mercury concentrations (mean 2.2 ppm, range 0.5-15 ppm), a correlation has been made which shows that the first effects of environmental mercury can be very subtle. Academic ability of seamen in a college was greatest in those with lowest mercury levels in their hair. A similar correlation occurred for iodine, supporting the suggestion that the thyroid functions differently when mercury is present (76). The affinity of mercury for, and subsequent blocking of, the sulfhydryl groups that are involved in transmission of information in the brain is suggested as a cause (11).

## Factors Affecting Hair Mercury Levels

Fish consumption, country and place of residence, occupation, age and sex all have some effect on hair mercury levels. Analytical techniques and sample handling can sometimes cause differences as discussed above.

## Mercury in Hair and Consumption of Fish

Because the first disaster due to mercury in the environment was associated with fish contaminated with methylmercury (the main form in most fish) (22,79), reports from all over the world have been made on hair mercury levels in rela-

tion to fish consumption. The mercury concentration in the fish consumed, the amount in each meal and the frequency at which fish meals are taken are important factors. Most countries have regulations disallowing the sale of fish containing more than 0.5 ppm (this level varies in different countries, sometimes being lower to protect people or higher to protect the fishing industry) (24). However, such a regulation is difficult to impose on people who catch fish for subsistence. Also, several meals a week of large fish with just less than 0.5 ppm would be more damaging than one of slightly more than 0.5 ppm. People at risk, such as pregnant women, should be educated so that they can determine how much fish to eat.

A review of mercury levels in hair of people who had been poisoned by contaminated fish has been made (9). Such studies indicate positive correlations between hair mercury levels and fish consumption. However, at lower levels no significant difference was found in hair mercury levels between a fish-eating group and a control group (80), and others found no correlation between hair mercury levels and the amount of fish in the diet (43). Several areas near lakes with different degrees of mercury pollution were examined and a positive correlation between the number of fish meals per week and hair mercury levels was found in some, but not all, of 462 residents (81).

There was no difference in the range of hair mercury levels (3.5-4.3 ppm) of Eskimo mothers and their babies who lived on the coastline where they ate more fish and seal products compared to those living inland and those in urban groups. This was thought to be due to use of mercury-containing seal oil in food preparation by both groups (82). Only marginal differences were found between two groups who ate 20-125 g/day of fish in the UK, one which lived by an industrially polluted sea and another which did not (62). Hair levels were  $2.0 \pm 0.17$  (range 0.1-11.3) ppm and  $1.35 \pm 0.14$  (range 0.4-5.8) ppm, respectively, for the two groups. Correlations of fish eating habits, the number of mercury amalgam dental fillings, residence in urban or rural areas and mercury levels in blood and nails were reported by some investigators, but they found no correlation with hair levels (47). They concluded that hair mercury levels reflect an individual's exposure due to personal habits rather than the effects of community habits and the environment.

Positive correlations between the amount of uncontaminated fish in the diet and hair mercury levels have also been found (42,53,83-85). In one study for all age groups, people who ate fish every meal had hair mercury concentrations that dif-

ferred from groups that ate it less than once a day (86). The concentrations were 5.78 ppm and 3.71 ppm for total mercury and 3.17 ppm and 2.15 ppm for methylmercury. Similarly, in Cadiz, those who ate fish up to four times per week had a mean level of 4.1 (range 0.7-8.0) ppm compared to fishermen, who probably ate more fish and probably selected the largest fish (which have the highest mercury concentrations) and who had a mean level of 19.8 (range 10.3-45.4) ppm. A baby had a hair mercury level of 17.5 ppm, and this dropped to 3.5 ppm once the child stopped eating swordfish (87). Overweight people have been advised to eat tuna meals to lose weight. Some tuna contain more than 0.5 ppm, so people who consume large amounts of tuna should be wary, as a mean of 14 ppm has been reported in hair from such dieters compared to less than 5 ppm in a control group (41). In Japan, tuna fishermen had 19.9 ppm in their hair compared to city workers and inland farmers who had 3.9-7.2 ppm (88). In China, fishermen had  $6.0 \pm 1.2$  ppm compared to farmers who had  $0.9 \pm 0.7$  ppm (21).

Consumption of freshwater fish by local fishermen causes many of the high hair mercury concentrations found in some populations. For example, hair mercury levels can be three to eight times higher in these groups than in groups who eat only saltwater fish. It is suggested that the difference can be accounted for by atmospheric movement of mercury vapor and its washout into the drainage areas by rain and snow (15).

In Papua, New Guinea, a group of people who ate barramundi from the Lake Murray area had  $16.7 \pm 5.2$  ppm hair mercury levels compared with a group from Bougainville who had only  $2.0 \pm 1.5$  ppm (21). The mercury in Lake Murray is released by natural erosion from mercury-containing rocks.

A similar effect has been observed in Canada in people living on an Indian reservation. There was a positive correlation between the amount of fish eaten and hair levels if the fish were caught locally. Of this group of 71 people, 23 had neurological symptoms caused by methylmercury, 44% of the group had more than 20 ppm and 23% had more than 30 ppm mercury in their hair (89).

Inorganic mercury levels of islanders ranged from 6 to 22% of total hair mercury levels on different Pacific islands between Japan and Hawaii, the largest percentages being found in Hawaii (90). The total levels indicate combinative exposure to methylmercury and inorganic mercury. In Hawaii the inorganic content is believed to be due to the consumption of Pacific blue marlin, which is one of the few fish known to contain

about 50% of its total mercury in the inorganic form (91).

A nonfishing group of Oriomo Papuans who live on meat and sago had hair mercury levels of 1.4 (range 0.2-1.5 ppm), whereas a Japanese population who ate between 103 and 111 g/day fish had levels of  $27.1 \pm 11.9$  ppm in men and  $11.6 \pm 4.5$  ppm in women (92). Another study of different cultural groups (institutionalized Japanese and Americans living in Japan and not consuming as much fish as the locals, Nepalese who do not eat fish, Americans in America, and two groups of Indians in Bombay—one of which was vegetarian) showed conclusively that fish in the diet increases hair mercury levels (86,93). In another study, which compared vegetarians with members of a fishermen's union, the two groups showed mean methylmercury levels of 1.7 and 6.2 ppm, respectively, with corresponding mean total mercury concentrations of 5 and 18.9 ppm (94). In another study, 559 hair samples collected from 32 locations in 13 countries were analyzed for mercury to determine whether industrial mercury release had an effect on hair mercury concentrations. The amount of fish the donors had individually eaten was ignored, and an overall mean mercury concentration was calculated for each location. The multivariate regression of these means against national average fish consumption of each country (95) and the countries gross national product is given by Eq. (2).

Hair Hg concn =  
(ppm)

$$0.94 + 0.08 \text{ Fish consumption} + 0.47 \text{ GNP} \\ (\text{kg/person/year}) \quad (\text{\$U.S.} \times 10^{12}) \quad (2)$$

Of the variability in the mean hair mercury concentrations 69.4% was accounted for, 65.4% being due to national fish consumption. The correlations for the two variants are significant at the 0.5% and 5% level, respectively (96).

Further studies should be done that are designed to eliminate people who eat fish to determine whether GNP really has significant effect or whether it is a statistical anomaly of this dataset. Vegetarians throughout the world would be a good group to monitor. Examination of changes in hair mercury levels of vegetarians over several decades might help explain some results that have been found which suggest increased environmental mercury pollution, e.g., between 1962 and 1970 one community had hair mercury levels that increased from 1.5 ppm to 3-6 ppm. Factors such as increased fish consumption, or consumption of larger fish could be eliminated.

To assess the effect of sex (sex was converted into a dummy variable with males = 1 and females = 0), age (in years) and the frequency of fish consumption on the variability in hair mercury levels, Eqs. (3) and (4) using multivariate analysis have been derived (97).

$$\begin{aligned} \text{Organic mercury levels in hair (ppm)} = \\ 1.64 (\text{average number of fish meals/week}) + \\ 0.17 (\text{age}) - 0.48 (\text{sex}) + 1.27 \quad (3) \end{aligned}$$

$$\begin{aligned} \text{Inorganic mercury levels in hair} = \\ 0.075 (\text{average number of fish meals/week}) + \\ 0.006 (\text{age}) - 0.23 (\text{sex}) + 0.31 \quad (4) \end{aligned}$$

The correlations with fish consumption had the most effect. Sex was insignificant for both organic and inorganic mercury. Age was significant only for the organic values.

A list of hair mercury levels reported in the literature has been compiled (98). A correlation between these mean hair mercury concentrations, excluding those of people occupationally exposed, and those of people who had eaten contaminated fish or ate fish several times a day, and the amount of fish consumed per head of population per year (96) in each country sampled, gave a positive linear correlation as described in Eq. (5):

$$\begin{aligned} \text{Hair Hg concn} = 1.67 + 0.13 \text{ Fish consumption} \quad (5) \\ (\text{ppm}) \quad (\text{kg/person/year}) \end{aligned}$$

The correlation coefficient was 0.54 and 29% of the variability in the mercury concentrations was accounted for (significant at 0.5% level).

Hair mercury levels in groups of people from 13 countries who ate fish once or less a month (group A), once or twice a month (group B), once a week (group C) and every day (group C+) were analyzed (21). The mean levels for the four groups for combined data from all countries were  $1.4 \pm 1.3$  ppm,  $1.9 \pm 1.5$  ppm,  $2.5 \pm 2.2$  ppm and  $11.6 \pm 6.6$  ppm, respectively, the differences between consecutive groups being significant at 0.5% level. The differences between consecutive groups A, B, C and C+ were also significantly different for each of the following locations: Canada, Hong Kong, Monaco, New Zealand, Papua, New Guinea, and United Kingdom.

When the mean hair mercury levels were plotted against a scale of increasing number of fish meals, the plots for the individual countries tended to run parallel. Explanations are: (1) each donor may be exposed to a mercury burden determined by the background mercury concentration of the environment plus an amount of mercury related to the amount of fish consumed individu-

ally; (2) the amount of mercury in the different species of fish eaten in different countries could be different; (3) the size or age of a particular species caught by one country may differ from another country; (4) the degree of contamination of coastal waters from which fish are taken and distributed for consumption may vary (18). I believe a combination of these explanations is most probable. The data from which Eq. (2) was derived, were re-analyzed. The mean mercury concentrations of groups A, B and C, i.e.,  $(\bar{A} + \bar{B} + \bar{C})/3$ , in each country was calculated; in other words, the number of fish meals eaten by each group was fixed, and it was assumed that on average the same amounts of large and small fish would be eaten. These means were then regressed against the national fish consumption and GNP.

$$\begin{aligned} \text{Hair Hg concn} = 1.05 + 0.095 \text{ Fish consumption} \quad (6) \\ (\text{ppm}) \quad (\text{kg/person/year}) \end{aligned}$$

In this case the effect of GNP was not significant, but at the 0.5% level, 74.1% of the variability in the mean hair mercury concentrations was accounted for by the national fish consumption (96). This unexpected result (because everyone had eaten equivalent number of fish meals) indicates that it is possibly variability in the mercury content of different species or sizes of fish consumed that explains the differences in mean hair mercury levels between countries.

For instance, highly populated industrialized countries which also have a great demand for fish—such as Japan—have large, wide-ranging deep sea fishing fleets. They catch many large fish and marine mammals, such as black marlin, bluefin tuna and whales for their domestic market. These species are known to have high concentrations of mercury (91).

## Hair Mercury Levels in Different Countries and Places of Residence

Table 1 shows the weighted mean hair mercury levels in 35 countries, calculated from means listed in a literature survey (98). When hair mercury levels are plotted against latitude, there is a significant peak in the midlatitude northern hemisphere countries. At latitudes  $>22^\circ\text{N}$ , weighted mean hair mercury levels are  $3.81 \pm 2.47$  ppm compared to  $2.32 \pm 1.31$  ppm and  $1.69 \pm 0.40$  ppm at latitudes  $0-22^\circ\text{N}$  and in the southern hemisphere, respectively. The differences are significant at 0.5% level. It has been suggested that this probably results from the loss of mercury from industry and from burning fossil fuels



Table 1. Weighted mean hair mercury concentrations from a list compiled from the literature for 35 countries.<sup>a,b</sup>

Country	Weighted mean hair mercury concentrations $\bar{X}_w$ , ppm	Statistical analysis <sup>c</sup>		
		Total number of sample, $\Sigma N_i$	Weighted standard error <sup>d</sup> $\sqrt{V_m}$	Number of means $A$
America South	1.3	4.0	1.5	1.0
Australia	1.7	1518.0	0.4	11.0
Bolivia	1.3	1.0	0.7	1.0
Brazil	5.7	1.0	6.2	1.0
Burma	3.5	30.0	N/A	1.0
Canada	1.8	827.0	0.1	6.0
China	2.8	99.0	1.5	3.0
Finland	1.4	200.0	0.2	4.0
France	1.3	226.0	1.1	9.0
W. Germany	0.5	30.0	0.1	2.0
Hong Kong	3.0	26.0	1.8	1.0
India	1.6	46.0	1.0	3.0
Iraq	1.0	100.0	N/A	1.0
Italy	1.6	361.0	1.3	13.0
Japan	5.0	1916.0	1.5	64.0
Kenya	7.9	71.0	N/A	1.0
S. Korea	2.3	420.0	0.2	3.0
Mexico	1.5	10.0	N/A	1.0
Monaco	1.7	33.0	2.1	1.0
Nepal	0.3	45.0	0.2	2.0
New Zealand	1.8	100.0	0.5	4.0
Norway	2.7	1.0	N/A	1.0
Pakistan	3.5	25.0	1.5	3.0
Papua, New Guinea	2.8	133.0	4.8	4.0
Poland	0.3	1.0	0.03	1.0
Pribilof Is.	4.6	49.0	0.5	2.0
South Africa	1.9	32.0	1.2	1.0
Spain	2.7	3.0	1.4	2.0
Sweden	7.9	1.0	N/A	1.0
Switzerland	0.8	2.0	0.4	1.0
Thailand	2.1	2.0	0.5	2.0
U.K.	5.0	1223.0	2.1	11.0
U.S.A.	2.9	444.0	1.5	17.0
Venezuela	1.0	24.0	0.3	1.0
Yugoslavia	0.2	N/A	N/A	1.0

<sup>a</sup>Data of Airey (98).

<sup>b</sup>Results from people who ate fish every day, who ate contaminated fish or who were occupationally exposed are omitted.

<sup>c</sup> $N_i$  = number of samples in mean  $X_i$ ,  $A$  = number of means in each country,  $X_w = \Sigma X_i N_i / \Sigma N_i$ ;  $V_m = [A/(A-1)] [(\Sigma X_i^2 N_i / \Sigma N_i) - X_w^2]$ ; N/A = not reported in literature.

<sup>d</sup>Standard deviation for  $A = 1$ .

(99). However, in another analysis (21), people living in both northern and southern hemispheres at latitudes  $>40^\circ\text{N}$  had hair mercury concentrations which were significantly lower than at other latitudes even in industrial countries. The author suggests that lower soil temperatures could retard mercury volatilization and inhibit its movement into pathways which get back to man.

## Comparisons of Polluted Versus Unpolluted Areas

In Iraq, a survey was made of people who lived in areas known to be contaminated with mercury

and those from an area believed to be free from contamination. The hair mercury levels were significantly different, being 1-12 ppm and 0.1-4 ppm, respectively (30). Similarly, around a new caustic soda plant in Thailand, hair mercury levels were 2.9 ppm compared to 2.3 ppm in unpolluted areas (significant at 2% level) (100). When a polluted area and control area were investigated and populations in each area put into groups according to fish consumption, the differences between polluted and unpolluted areas were large for all groups (1). For Japanese living in France and Japanese in Japan, mercury levels were 2.3 ppm and 3.7 ppm, respectively (101). The inorganic mercury content of Japanese on a Hawaiian

Island was many times that of Japanese on other islands (48). Differences in the type of fish consumed was probably the cause. Generally, mercury levels in Japanese living in Japan are higher than those living in other countries because of pollution and diet (35, 102). One report (35) showed that Japanese had an average of  $6.02 \pm 2.88$  ppm compared to workers from many different countries who had  $1.89 \pm 1.47$  ppm. Hair mercury levels of students living overseas for 1.5 years were the same as the natives and took about the same time to return to their original levels on their return.

## Occupation

Since the days of the "mad hatters" (people in the felt hat industry who were intoxicated by mercury), there has been awareness of mercury intake during the working day. Other examples of people exposed occupationally include fingerprint police in the 1940s (103), molybdenum refinery workers in Japan (86), fishermen, mercury miners and processors, chemical industrialists, pesticide preparers (64,94,101,104), dentists (57,58,72,104-106), hospital employees (107), thermometer workers (108), chlorine manufacturers (65) and polarography students (109). In most of these workplaces, inorganic mercury vapor is released, and although in some countries there are recommended maximum levels for working areas, many people are exposed because of ignorance of the dangers or because of the inability of the companies to reduce the levels in old plants. Fisherman and fish marketers, however, select and eat at their own risk a lot of large fish with their high methylmercury load. Most people are ignorant or skeptical of the dangers and people who fish to survive have no choice but to eat their catches (110).

Hair mercury concentrations in some of these workers are interesting. For example when people are exposed to mercury vapor, e.g., dentists (57,58), although the inorganic levels in blood are high as expected, the ratio of methylmercury to total mercury is the same as in control groups. Explanations given include methylation of mercury in the body. However, it has been shown that although hair inorganic mercury levels increased while hair organic mercury levels did not change, organic mercury levels increased significantly in the red blood cells, and levels of both inorganic and organic mercury increased in the plasma (56). One explanation given is that increased concentrations of inorganic mercury releases organic mercury from other sites in the body; the affinity

of mercury for renal metallothionein is discussed (56).

## Age

We have seen from the formulae derived by Suzuki's group (97) that age is a significant factor for methylmercury concentrations but not for inorganic mercury concentration. This factor may be related to the total mass and dietary composition, in particular, the fish content, of food consumed and hence the absolute weight of mercury ingested. Young children eat less than other age groups and would therefore excrete less mercury into their hair. In elderly people when mercury input rate is equal or less than mercury excretion rate, no further accumulation occurs. For example, slight increases in mercury hair levels only up to the age of 40 years were found by one worker (105) whereas another (60) found that fish-eating islanders of Cagliari had increases up to the age of 50 years. However, another worker (110) found that hair mercury levels of fishing communities in Malaysia increased with age for the whole sample. Both total and methylmercury in hair have also been found to increase with age (93). People aged more than 55 years exposed to large doses of methylmercury developed only mild or even no classical symptoms even when hair mercury levels reached more than 1000 ppm (30). However, in infants, even small doses caused severe symptoms. Babies born with Minamata disease had 25-33% less mercury in their hair than their mothers, who showed no classical symptoms. Infants affected by the disease had more mercury in their hair than unaffected babies (22,79).

## Sex

When radiotracer doses of methylmercury and inorganic mercury were administered, they were excreted with a mean biological half life of 71 days in women and 79 days in men for methylmercury and 37 days in women and 48 days in men for inorganic mercury (54). These differences should be reflected in the levels measured in hair, with women having slightly lower levels than men, probably due to their eating proportionally less, or to loss of blood monthly or hormonal and biochemical mechanisms.

In Japan, males had higher hair mercury levels than females, and the author suggests that mercury is absorbed from the hair cream used by men (93). Male Pakistanis had up to 6 ppm compared to females who had less than 1 ppm (34). Male

Yanamamo Indians in Venezuela (111), male Japanese (112) and male Seoul citizens (105) all had more mercury in their hair than females from the same countries.

However, Suzuki's group (90) and others (30,43) have shown that sex is an insignificant factor for any form of mercury accumulation in hair. A few workers found that the females had higher levels than the males of a population. For example, in Idaho residents it was shown that males had mean levels of 2.5 ppm and females 5.9 ppm (42). Also a few female Japanese were reported to have more total mercury than the males but the same amount of methylmercury (102), and Polish females had slightly higher levels than men, both having mean levels below 0.6 ppm (113).

Care must be taken in this type of comparison as seen in the Thailand study. Males with short hair were compared with females with long hair shortly after the opening of a new chloro-alkali plant. At the time of sampling, local fish had 5-51 times more mercury than fish from an unpolluted control area. The short-haired males had elevated levels but the females did not appear to be affected because the ends of the long female hair were sampled. This hair had been formed prior to the plant opening (100).

## Conclusions

Head hair can be used to indicate a person's or a community's exposure to mercury providing that the sampling, washing and analysis is consistent. Changes over time in mean hair mercury levels in any community and differences between different communities are valid only if there is consistency also in the type of statistical mean used.

Generally, mean hair mercury levels increase in people up to the age of 50 years, are slightly higher in men than in women and are much higher in people occupationally exposed to mercury than in the rest of the population.

When the conditions above are obeyed, it is shown that hair mercury levels increase with an increasing frequency of fish consumption; the national average fish consumption per head in any country accounts for 74.1% of the variability in mean hair mercury levels, and may be due to the size of fish species eaten. Higher hair mercury concentrations have been found in midlatitude northern hemisphere countries than in other countries but lower concentrations in countries at latitudes  $>40^\circ$  north or south.

A small percentage of people in some communities that have hair mercury levels not normally associated with mercury intoxication, but who

eat a lot of fish or marine mammals have mild neurological symptoms. Reduced academic ability has been correlated with increased hair mercury concentration over a range of values not uncommon in most populations.

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