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Hair mercury concentration and fish consumption: Risk and perceptions of risk among women of childbearing age ☆

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ABSTRACT

The purposes of this study were to assess the hair mercury concentration of women of childbearing age in Taiwan, and to calculate a hazard quotient (HQ) to evaluate the risk of fish consumption for these women. We also examined perceptions of risk associated with fish consumption and whether women in our study changed their habits in response to such risks. The average concentration of mercury was 1.73 ± 2.12 μg g^{-1} (range: 0.02–16.34 μg g^{-1}), exceeding the US EPA reference dose of 1 μg g^{-1} in 52.9% of study subjects. The WHO tolerance limit of 10 μg g^{-1} was exceeded in 1.5% of study subjects. Hair mercury concentration in groups who consumed fish was significantly higher than in groups who never consumed fish ($p < 0.05$). The hazard quotient (exposure estimate/oral reference dose) exceeded 1.0 for 29% of subjects, based on the US EPA's reference dose (0.1 μg kg^{-1} d^{-1}), and the average HQ equaled 1.26. When told that some fish contain high levels of mercury that may be harmful for unborn babies, 67.6% of women still indicated that they would not change their amount of fish intake. The high hair mercury concentrations among women of childbearing age in Taiwan are a cause for concern, due to the effect on babies' brain development. The government should provide specific information about risks and benefits of fish consumption for women to make risk-balancing decisions.

1. Introduction

Mercury is distributed throughout the body by the blood stream and accumulates in fat or organs. Toxicity of mercury varies according to its different chemical forms. It can easily enter the human body through the respiratory or digestive tracts to accumulate in the body. Mercury is neurotoxic to humans and can be fatal (WHO, 1990). Methylmercury has lipophilic characteristic which means it penetrates the blood–brain barrier to the central nervous system (CNS) (Aschner et al., 1992). A high proportion of the methylmercury (MeHg) in the human body (98%) accumulates in the brain, posing great hazard to the CNS, especially in developing fetuses. Therefore, it is considered toxic to human beings. The period of gestation in which the CNS develops is most susceptible to MeHg poisoning. Thus exposure to MeHg in this period poses particular hazards for developing infants, as it disturbs the normal development of nerves and organs (Choi et al., 1978). Previous studies have indicated that organic mercury and elemental mercury have similar effects on a fetus' brain (Warfvinge, 1999). Both forms easily penetrate the placenta, whereas inorganic mercury does not (Mansour et al., 1973; Clarkson, 1997; NAP, 2000). Mercury and other toxins enter the fetus' body through the placenta, a fact that has drawn greater attention to women's health issues worldwide.

A fish diet is considered the primary pathway of human exposure to MeHg, resulting in statistically significant differences between high and low fish consumption groups (Foo et al., 1988; Oskarsson et al., 1994). In particular fields, occupational exposure may also contribute to the mercury burden, affecting specific subgroups of a population. Sex is one of the important variables influencing the mercury content of hair; one study found that males had higher hair mercury concentrations than females in a Japanese population (Nakagawa, 1995). But women play a unique role in bearing the next generation. Neurodevelpomental problems during the last two trimesters are evident in children of mothers exposed to high MeHg levels. In the United States, the National Health and Nutrition Examination Survey (NHANES) found that hair mercury levels were increased three-fold for women and two-fold for children among frequent consumers of fish compared with non-consumers (McDowell et al., 2004). In 2004, the US EPA and US FDA warned women who were planning to conceive, pregnant or breast-feeding, as well as their children to avoid consuming tilefish, king mackerel, swordfish and shark. These fishes have mercury concentrations exceeding 1 μg g^{-1}, which may produce adverse health effects (US FDA, 2004).

Mercury concentrations in blood and hair have been widely used as biomarkers for human mercury exposure. The normal

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ratio of mercury in hair ($\mu g\ g^{-1}$) and blood ($ng\ l^{-1}$) is 190:1. In the absence of acute exposure, mercury levels in hair are much higher than in the blood, the ratio rising to 370:1 (Phelps et al., 1980; Shrestha and Fornerino, 1982). Hair is a good indicator for evaluating the mercury accumulation in the body. The growth rate of hair (1 cm per month) and the tendency of toxins such as mercury to accumulate in hair make it possible to estimate long-term exposure (Díez et al., 2008). Around 85% of the total mercury in hair is organic mercury, which may have adverse health effects when the level is higher than 10–20 $\mu g\ g^{-1}$ (WHO, 1990). Studies focused on people who like consuming tuna revealed the median mercury level in their hair to be 9.6 $\mu g\ g^{-1}$ (range: 1.4–34.5 $\mu g\ g^{-1}$) (Carta, 2002). Davidson et al. (1998) investigated pregnant women in the Seychelles and found the average concentration of MeHg in hair was 6.8 $\mu g\ g^{-1}$ in the year 2000. Pregnant British women have been found to have total mercury concentration in hair of 0.39 $\mu g\ g^{-1}$ in 2001 (Razagui and Haswell, 2001).

In our previous study, we investigated mercury levels of blood in pregnant women and found that in 89% of cases (n=65), the mean levels ($9.1 \pm 0.4\ \mu g\ l^{-1}$) exceeded the US National Research Council (US NRC) recommended limit of 5.8 $\mu g\ l^{-1}$ (Schober et al., 2003; Hsu et al., 2007). In 2005, a study in Taiwan revealed that the average hair mercury concentration of 46 dentists (3.94 $\mu g\ g^{-1}$) was 1.6 times higher than in the public (2.40 $\mu g\ g^{-1}$) (Taiwan EPA, 2005). Dentists are most likely being exposed to mercury vapor from amalgams used for dental fillings.

To our knowledge, few studies have examined the mercury of body burden fish consumption and perceptions of risk among women of childbearing age in Taiwan. The purposes of this study were to assess the total hair mercury concentration of women of childbearing age in relation to fish intake. In order to assess mercury exposure, we calculated and validated a hazard quotient (HQ) to evaluate the risk from fish consumption. We also examined the perceptions of risk associated with fish consumption and whether women in our study have changed their habits in response to that risk.

2. Materials and methods

2.1. Hair samples collection and questionnaires

This study collected 263 hair samples from four different groups (college students n=75, the general public n=63, dental workers n=83, and medical workers n=42) from 1 January 2007 to 28 February 2008 in Northern Taiwan, and investigated their lifestyles, dietary habits, living environments and basic demographic information by questionnaire. The volunteers were recruited through written announcements that were distributed through the Taipei Medical University website, dental association, and county health bureau. Written informed consent was obtained from all study participants. Approximately 2-cm hair samples were collected from the occipital area of scalp using stainless steel surgical scissors by a trained interviewer. Samples were stored in polythene bags for mercury analysis in the next 3 weeks. The Institutional Review Board of Taipei Medical University approved the study (P950045).

2.2. Determination of total mercury concentration in hair

Hair samples were rinsed three times with distilled deionized water after washing with a neutral detergent. After drying it in the shade under a hood, hair samples of 0.1 g were weighed out. The weighed hair was digested for 3 h with 5 mL of 65% strong nitric acid and 0.1 g $K_2S_2O_8$ in 90 °C. After digestion, we diluted samples with 2% nitric acid to 50 mL and preserved it in 4 °C for analysis. Mercury concentrations were determined with a mercury analyzer (HG-200; Hiranuma, Mito, Japan). Each sample was analyzed in triplicate. Certified reference material from the Shanghai Institute of Nuclear Research, China (GBW09101) was used to perform a standard material test to ensure the precision and accuracy of the hair analyses. The precision values for the material was 96.3% and the accuracy value was 5.3%. The detection limit for mercury analysis was 5 $ng\ g^{-1}$.

2.3. Estimating the hazard quotient

Information on dietary intake of fish was obtained by questionnaire. The method of estimating the HQ from the US EPA (1989) was used to analyze the health risk to women of childbearing age. The individual HQ was the ratio between the exposure and the reference dose. The following equation was used:

$$HQ = \frac{C_{mi} \times IR_i}{RfD \times BW_i}$$

where C_{mi} is the geometric mean of the mercury concentration in fish ($\mu g\ g^{-1}$), IR_i the ingestion rate of fish ($g\ d^{-1}$), RfD the US EPA's reference dose (0.1 μg Hg $kg\ bw^{-1}\ d^{-1}$) or acceptable daily intake determined by WHO (0.23 μg Hg $kg\ bw^{-1}\ d^{-1}$); BW_i the individual's body weight (kg).

Individual calculations were based on fish species consumed, mercury concentration, and fish consumption rate, divided into five categories: never, <1, 1–2, 3–5, >5 meals/week. The quantity of fish was established according to the form of consumption: a fish cutlet up to 120 g constituted one serving. Mercury concentrations of various species of fish have been published in our previous study (Chien et al., 2007). For example, one woman had a body weight of 50 kg and ate milkfish, hairtail, and salmon, with a fish consumption rate of <1 meals/week. The calculation based on the data for the ingestion rate of fish is 8.7 $g\ d^{-1}$. The geometric mean of the mercury concentration of the edible portions of three fish is 0.052 $\mu g\ g^{-1}$. Thus

$$HQ = \frac{0.052 \times 8.7}{0.1 \times 50} = 0.09$$

For non-carcinogenic effects, an HQ exceeding 1.0 indicated a potential health risk.

2.4. Statistical analysis

Our data was not normally distribution, therefore we used non-parametric statistical methods, Wilcoxon Rank sum test and the Kruskal–Wallis test to test the differences in mercury concentration in hair caused by variation in age, lifestyles and diet. Spearman correlation coefficients were used to compare the relationship of height, weight, BMI, age, tooth-fillings, fish consumption and mercury levels in hair. All statistical analyses were conducted using SAS 9.0 for Windows. Results were considered significant in a two-tailed test if $p < 0.05$.

3. Results

3.1. Demographic characteristics of participants

Demographic characteristics of the 263 study subjects and their frequency of fish and sashimi consumption are summarized in Table 1. The average age was 31.3 ± 10.7 years old. Fish consumption was 1–2 meals per week in 34% of the study sample, ≥ 3 meals per week in 30%, and 74% reported less than 1 meal per week of sashimi per week. Occupational exposure to mercury was found among 64% of the women and only 9% had >5 tooth-fillings with amalgam.

3.2. Hair mercury concentrations and fish consumption

The distribution of mercury concentration in hair is shown in Fig. 1; the average concentration was $1.73 \pm 2.12\ \mu g\ g^{-1}$ (range: 0.02–16.34 $\mu g\ g^{-1}$). Hair mercury concentrations exceeded the US EPA reference dose of 1 $\mu g\ g^{-1}$ in 52.9% of study subjects, and 1.5% of study subjects had levels higher than the tolerance limit of 10 $\mu g\ g^{-1}$ declared by WHO (WHO, 1990). Of our 263 subjects, 125 were employed in medical-related careers (83 dental workers and 42 medical workers). They had two times the geometric mean hair mercury concentration of the general public, with medical workers showing the most severe exposure (Fig. 2; dental workers: 1.16 $\mu g\ g^{-1}$; medical workers: 1.79 $\mu g\ g^{-1}$; general public: 0.82 $\mu g\ g^{-1}$). Compared to observations from the same age group, the dental workers had higher hair mercury concentrations than the general public, in common with other research results (Taiwan EPA, 2005; Zolfaghari et al., 2007). We explore the association between age, rate of fish consumption, and the mercury concentration of hair in the study population. According to our results, there was a statistically significant association between age and hair mercury

concentrations (r_s=0.26, $p<0.0001$) (data not shown). People who consumed greater quantities of fish presented higher hair mercury concentrations (r_s=0.32, $p<0.0001$) (data not shown). Based on their fish consumption rate, we separated subjects into different groups (never, <1 meal/week, 1–2 meals/week, 3–5 meals/week, >5 meals/week) to identify differences in hair mercury concentration. Hair mercury concentration in groups who consumed fish was significantly higher than in the group who never consumed fish ($p<0.05$). Those who ate fish more than five times a week had significantly higher hair mercury concentrations than those who ate fish less than three times a week ($p<0.05$) (Fig. 3).

3.3. Hazard quotient and perceptions of risk

We used the US EPA reference dose (0.1 μg Hg kg bw^{-1} d^{-1}) to calculate HQ_a and found the average HQ_a equal to 1.26. Of our study group, 29% exceeded the fish mercury exposure amount recommended by the US EPA, and subjects over 40 years old had twice the HQ of those less than 30 years old. Using the acceptable daily intake announced by WHO (0.23 μg Hg kg bw^{-1} d^{-1}) to calculate HQ_b, the average HQ_b was equal to 0.55. Of the 97 subjects, 14 (14%) exceeded the fish mercury exposure amount determined by WHO; of these, 11 subjects were over 40 years old. In Fig. 4, the relationship between hair mercury concentration and HQ indicated that hair concentrations of $HQ_a>1$ subjects were significantly higher than those of $HQ_a\leq 1$ subjects (median 1.37 vs. 1.08 μg g^{-1}, p=0.03). The same results were found comparing $HQ_b>1$and $HQ_b\leq 1$ subjects (median 1.14 vs. 1.50 μg g^{-1}, p=0.12). Because of insufficient sample size, this pattern did not achieve statistical significance.

In this study, we not only analyzed study subjects' hair mercury concentration, but also investigated risk perception about mercury exposure. The US Food and Drug Administration (US FDA) and Environmental Protection Agency (US EPA) advises pregnant women, women of childbearing age, nursing mothers, and young children not to eat fish that contain high levels of mercury such as shark, swordfish, king mackerel, and tilefish. We found that approximately 44.8 % women did not know about the

Table 1
Demographic characteristics of study population (n=263).

	Characteristic
Age (years)	31.3 ± 10.7
Occupational exposure	
Yes	48%
No	52%
Amalgam fillings	
Yes	64%
No	36%
Amalgam fillings	
0	36%
≤5	55%
>5	9%
Consume traditional Chinese herbs	
Yes	84%
No	16%
Fresh fish consumption	
Never	7%
<1 meal/week	29%
1–2 meals/week	34%
3–5 meals/week	24%
≥5 meals/week	6%
Sashimi consumption	
Never	41%
<1 meal/week	33%
1–2 meals/week	24%
≥3 meals/week	2%

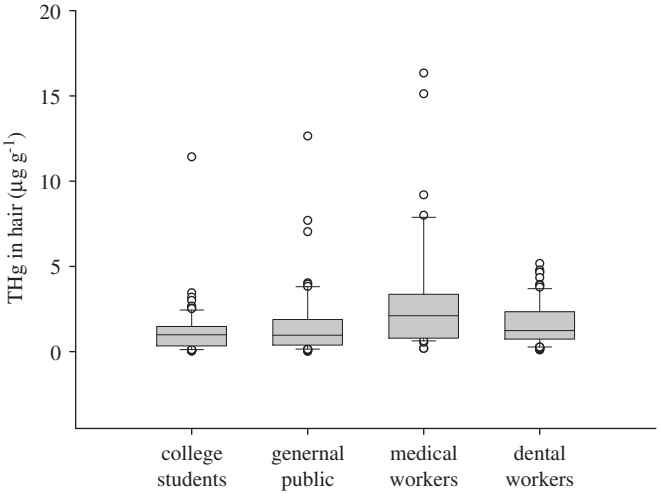

Fig. 2. Box and whisker plots display the distributions of the mercury concentration of hair in the four study groups. The box includes 50% of the values and is limited by the 25% and 75% percentiles.

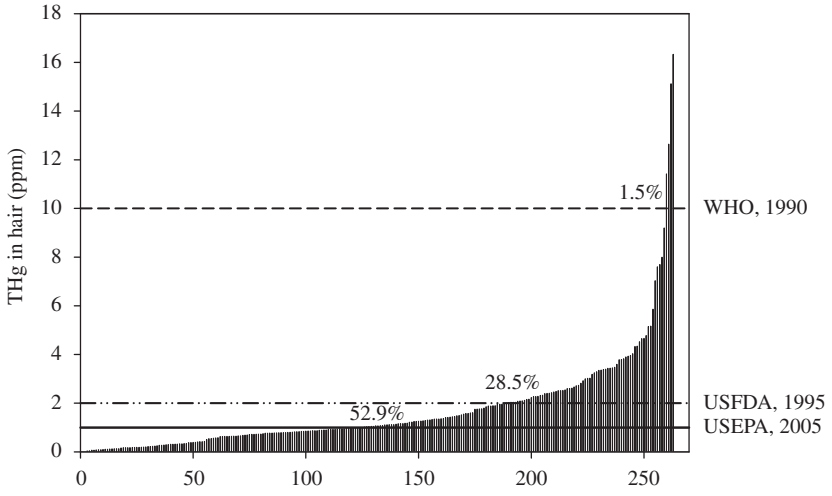

Fig. 1. Distribution of mercury concentration in hair in the total study population. —: 1 μg g^{-1} US EPA, 2005; ··—··: 2 μg g^{-1} US EPA, 1995; — — : 10 μg g^{-1} (WHO, 1990).

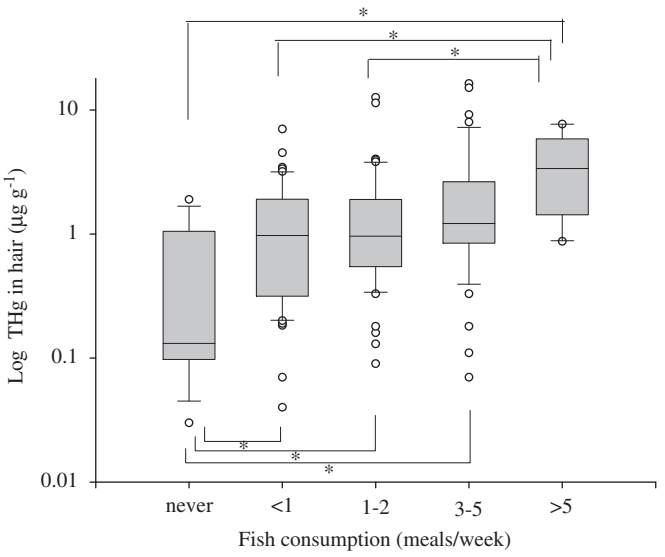

Fig. 3. The mercury concentration of hair in relation to fish consumption rate (meals/week).

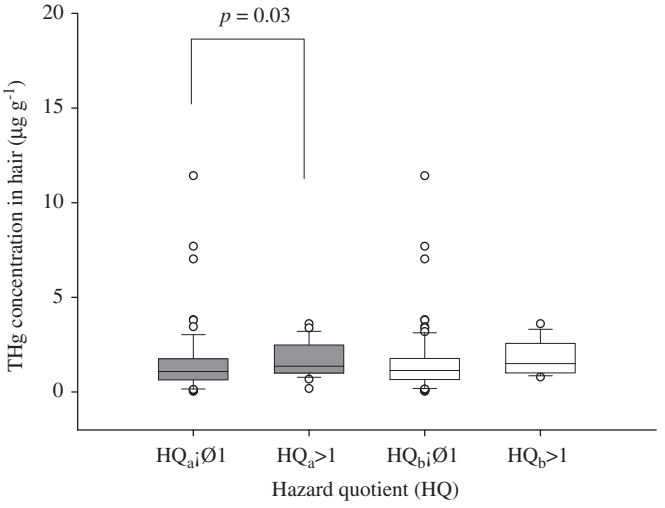

Fig. 4. Box and whisker plots display the distributions of the mercury concentration of hair for different hazard quotients. HQ_a: reference dose=0.1 μg Hg kg bw^{-1} d^{-1}, US EPA, 2005; HQ_b: reference dose=0.23 μg Hg kg bw^{-1} d^{-1}, WHO, 1990.

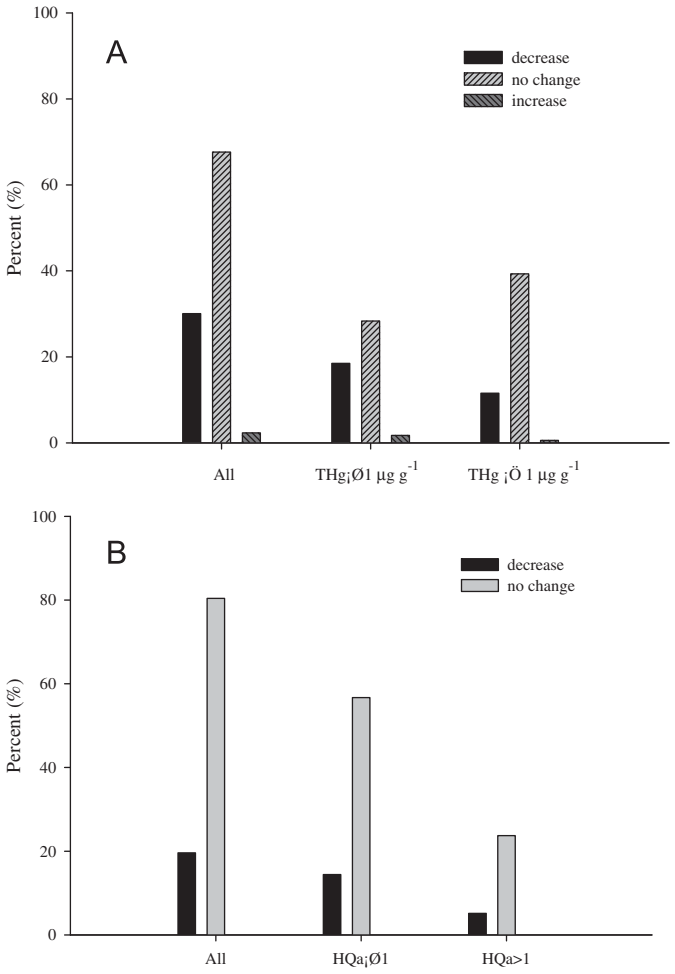

Fig. 5. Percent of women of childbearing age providing answers for perceptions on risks of fish consumption. (A) Some fish contain high levels of mercury that may be harmful for unborn babies; would you change your fish intake?. (B) When informed that fish may be contaminated with PCBs, dioxins, and heavy metals, which can all have adverse effects on developing infants, would you change your fish intake?.

advisory. Even when told that some fish contain high levels of mercury that may be harmful to unborn babies, 67.6% of women still indicated that they would not change the amount of fish they consume. In Fig. 5A, we found that the mercury concentration $\leq 1\ \mu g\ g^{-1}$ ($THg \leq 1\ \mu g\ g^{-1}$) group, 18.5% of women indicated that they would decrease their fish intake amount, compared to 11.6% in the mercury concentration $< 1\ \mu g\ g^{-1}$ ($THg > 1\ \mu g\ g^{-1}$) group. A similar pattern is also found in the $HQ_a > 1$ subjects and the $HQ_a \leq 1$ subjects, who stated that they would not change their behavior (56.7%, and 23.7%, respectively) (Fig. 5B).

4. Discussion

In this study, we calculated HQ to evaluate the potential health risk from mercury to women of childbearing age. We found hair mercury concentrations exceeded the US EPA reference dose of $1\ \mu g\ g^{-1}$ in 52.9% of our study subjects, and 1.5% had concentrations higher than the tolerance limit of $10\ \mu g\ g^{-1}$ declared by the WHO. Our results provide essential information regarding perceptions of risk associated with fish consumption; 67.6% of women would not change their behavior and would continue eating fish, even when told that some fish contain high levels of mercury that may be harmful for unborn babies. In addition, we also found that hair mercury concentrations increased with increasing frequency of consuming fish.

In our study, 1.5% of subjects had hair mercury concentrations exceeding the WHO tolerance limit of $10\ \mu g\ g^{-1}$. According to the WHO's assessment, adverse health effects result if total hair mercury exceeded $10\ \mu g\ g^{-1}$ or blood mercury exceeded $40\ \mu g\ l^{-1}$ (WHO, 1990). Taiwan's EPA administered research in 2005 to investigate the concentration of mercury in the hair of Taiwan's citizens. Results showed that the average concentration of mercury in hair was $2.4\ \mu g\ g^{-1}$ (N=1066), which is higher than the level recommended as permissible by the US EPA ($1\ \mu g\ g^{-1}$) (Taiwan EPA, 2005). Table 2 shows comparisons of average hair mercury levels among women in different countries. The average mercury level in mothers' hair was 6.8 and $10.3\ \mu g\ g^{-1}$ in the Seychelles islands and Amazonia, respectively (Myers et al., 2000; Chevrier et al., 2009). Research from French Guiana indicated that mothers (whose children were less than 12 years old) had higher levels of hair mercury (upper Maroni: 12.7; Camopi: $6.7\ \mu g\ g^{-1}$,

Table 2
Comparison of women's hair mercury levels in different populations.

Country/location	*N*	Hair Hg mean (SD [a]) ($\mu g\,g^{-1}$)	Subjects	References
French Guiana			Mothers (children < 12 years)	Cordier et al. (2002)
Upper Maroni		12.7 (10.2)		
Camopi		6.7 (6.5)		
Awala		2.8 (1.4)		
France, Amazonia	269	10.3	Mothers	Chevrier et al. (2009)
France, Paris	81	1.37 (0.94)	Mothers	Huel et al. (2008)
Seychelles Islands		6.8	Mothers	Myers et al. (2000)
Germany	43	6.15	Mercury-exposed mothers	Bose-O'Reilly et al. (2008)
Japan, Shiranui Bay		2.1	Women	Harada et al. (1998)
Japan, Tokyo and surrounding areas		2.02	Women	Nakagawa (1995)
Japan, Akita	154	1.73	Mothers	Iwasaki et al. (2003)
Japan		1.51	Women	Ohno et al. (2007)
China, Zhoushan island)	59	2.3	Piscatorial household's mother	Cheng et al. (2009)
China (such as Shanghai, Ningbo, Dalian, Xiamen, and Zhoushan)	321	0.72[b]	Healthy female inhabitants in the areas along the coast and the rivers	Liu et al. (2008)
Japan, Korean	214			Tsuchiya et al. (2008)
Japanese	106	1.23	Women of childbearing age	
Korean	108	0.61	Women of childbearing age	
Korea, Seoul		1.1	Women	Lee et al. (2000)
Korea	111	0.91	Mothers	Kim et al. (2008)
Italy	115	0.563	Women ages 35–45 in Naples, Italy	Díez et al. (2008)
Canada	87	0.37[c]	Women from two communities who consumed freshwater fish	Abdelouahab et al. (2008)

[a] Standard deviation.
[b] Geometric mean.
[c] Median.

and Awala: 2.8 $\mu g\,g^{-1}$) (Cordier et al., 2002). In 2008, Reilly et al. found that the average total mercury in hair of mercury-exposed mothers in Germany was 6.15 $\mu g\,g^{-1}$ (Bose-O'Reilly et al., 2008).

The average hair mercury concentration among the 125 subjects employed in medical-related careers (83 dental workers and 42 medical workers) was twice that of the general public in our study. Previous research indicated that dentists had two times more hair mercury concentration than the general population in Iran (Zolfaghari et al., 2007). Mercury makes up fifty percent of the composition of amalgam. When filling a tooth or removing a filling, dentists have higher risk of exposure to mercury vapor. One study in the West of Scotland showed that mercury vapor exposure among dentists exceeded the OES (Occupational Exposure Standard: 25 $\mu g\,m^{-3}$, The Health and Safety Executive) in 25% of study subjects (Ritchie et al., 2004). The International Academy of Oral Medicine and Toxicology (IAOMT) has been promoting mercury removal. Sweden prohibited the use of mercury in 2004. In Canada, Germany, France, Britain, Norway and Australia, they restrict the use of mercury and recommend not using amalgam in fillings for children under 6 years old, pregnant and breast-feeding women and patients with kidney dysfunction. The US FDA is planning to recommend the discontinuation of amalgam for dental fillings starting in 2009.

Investigation by Taiwan's EPA also found that subjects over 40 years old had 1 $\mu g\,g^{-1}$ higher mercury concentration than those less than 20 years old (Taiwan, 2005). Study results from other countries also indicated that increasing age correlates with higher hair mercury concentrations (Yasutake et al., 2003; Zolfaghari et al., 2007; Kim et al., 2008). Boischio and Henshel (2000) similarly indicated that the burden of mercury in the body increase with age, because mercury is not easily excreted from human bodies. We likewise found a strong positive correlation between hair mercury levels and age, showing that mercury levels accumulate with age. Study subjects under age twenty had the lowest levels of hair mercury. We also found that hair mercury concentrations increased with increasingly frequent fish consumption. One study in Italy reported that those who consumed more fish (5–6 meals/week) had twice the level of hair mercury than those who consumed less fish (none or less) (Díez et al., 2008). Knobeloch et al. (2007) also found the level of hair mercury was positively correlated with monthly fish meals in Wisconsin.

Over 50% women said they know that fish may be contaminated with PCBs, dioxins, and heavy metals which can all have adverse effects (data not shown). Nonetheless, 67.6% of women would not change their amount of fish intake, even when told that some fish contain high levels of mercury that may be harmful for unborn babies. The data (48%) presented in our paper clearly indicates that women of childbearing age have very limited knowledge from media about "which fish are safe to eat?" and "what are the effects of contaminants?". Similarly, an investigation of people fishing, walking, and engaging in other recreation in three coastal regions of the New York Bight showed that respondents did not have accurate information about contaminants in fish (such as mercury and polychlorinated biphenyls, PCBs) to make informed decisions about balancing risk (Burger and Gochfeld, 2009). Similarly, many spouses and family members in Taiwan offer fish to pregnant women, as a way of maintaining optimal health. Fish contains high-quality protein and essential nutrients, such as long-chain omega-3 polyunsaturated fatty acids, which can reduce the incidence of pre-term delivery. Axelrad et al. (2007) used a Bayesian hierarchical model

to estimate the dose-response relationship of prenatal mercury and intelligence quotients (IQ). They also found that as maternal hair mercury increased 1 $\mu g\ g^{-1}$ it corresponded to approximately −0.18 IQ points (95% confidence interval, −0.378 to −0.009).

5. Conclusion

The high hair mercury concentrations in women of childbearing age in Taiwan are a cause for concern due to the effect on the fetal brain development. To ensure the seafood to be safely consumed many practices to prevent and reduce microbial or chemical contamination in Taiwan. Health officials regularly check on the sanitation standards of food vendors and food-processing factories and release timely information to the public. Fishing has been an integral part of life in Taiwan. The industry expanded from small-scale coastal fisheries to cover commercial aquaculture and deep-sea fishing. The Council of Agriculture, Executive Yuan (COA) began promoting food traceability with the launching of the Taiwan Good Agricultural Practice (TGAP) certification for seafood. The implementation of food traceability systems has not only helps farmers make details of their products' histories available online, but also enhanced consumer confidence. The consumers are able to access details of a product's history. The government should provide more specific information about risks and benefits of fish consumption in the future so women can make better risk-balancing decisions.

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