# Analysis of the health risk of exposure to breast milk mercury in infants in Taiwan

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## Abstract

The aim of this study was to assess the total concentration and health risk to infants of breast milk mercury in urban mothers and mothers married to fishermen in relation to fish intake in Taiwan. A total of sixty-eight healthy mothers were recruited for the study. The breast milk mercury geometric mean concentration was $2.02 \, \mu g \, l^{-1}$ ($n = 56$, range: $0.24–9.45 \, \mu g \, l^{-1}$) for the city group and $2.04 \, \mu g \, l^{-1}$ ($n = 12$, range: $0.26–8.62 \, \mu g \, l^{-1}$) for the fishermen's group. Of the three sources of mercury exposure (i.e., ingestion (breast milk), inhalation (ambient air), and dermal exposure (shower)), breast-feeding was found to be the largest (96.3–99.6% of the total). From a Monte Carlo simulation, in which methyl mercury accounted for about 50% of total mercury, the hazard quotient (exposure estimate/oral minimal risk level or target organ toxicity dose) exceeded 1.0 for 12.9% of urban babies and 18.8% of fishermen's babies (chronic oral minimal risk level and target organ toxicity dose: $3 \times 10^{-4} \, mg \, kg^{-1} \, d^{-1}$). The calculated mercury exposure was $3.02 \times 10^{-1} \, \mu g \, kg^{-1} \, d^{-1}$ for a 3.49 kg urban baby boy and $3.06 \times 10^{-1} \, \mu g \, kg^{-1} \, d^{-1}$ for a 3.44 kg urban baby girl. These results suggest the life style of mothers (eating raw fish and shellfish such as used in "Sashimi" and "Sushi," and vitamin supplementation) may influence the mercury concentration in breast milk.

## 1. Introduction

Mercury and its compounds are a significant threat to human health, particularly to pregnant women, women of childbearing age, developing fetuses, and breast-fed infants. The US Food and Drug Administration (USFDA) and the US Environmental Protection Agency (USEPA) are advising these women, nursing mothers, and young children to avoid eating fish that contain high levels of mercury such as shark, swordfish, king mackerel, and tilefish, and to eat instead up to three hundred forty grams a week of a variety of fish and shellfish that are lower in mercury (USEPA, 2004). Previous studies have shown that a fish diet is the primary pathway of human exposure to methylmercury (MeHg), and that statistical differences in MeHg intake exist between high and low fish consumption groups (Oskarsson et al., 1995; Foo and Tan, 1998). Moreover, more than 90% of the total mercury in certain fish tissues has been found to be in MeHg form (Bloom, 1992; Kim, 1995; USEPA, 2001). MeHg is neurotoxic, readily absorbed by the gut, and effectively crosses the blood-brain barrier and placenta (JECFA, 2003). The children of pregnant women with MeHg intakes higher than the provisional tolerable weekly dietary intake (PTWI) level

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($1.6\ \mu g\ kg^{-1}\ week^{-1}$) have an increased risk of developmental abnormalities (JECFA, 2003).

The World Health Organization (WHO, 2002) recommends breast-feeding infants exclusively during the first six months of life to achieve optimal growth, development, and health. Breast milk (the first food during this period) may contain toxic chemicals, such as polychlorinated biphenyls, DDT and its metabolites, polychlorinated dibenzo-p-dioxin, polychlorinated dibenzofuran, polybrominated diphenyl ethers, and heavy metals (Senawane, 1995; Hooper and McDonald, 2000). The amount of fish consumed during pregnancy can influence the maternal exposure to MeHg. MeHg can be stored and accumulated over time in body fat and then be mobilized into milk during lactation. Therefore breast-feeding constitutes a major source of exposure to bioaccumulated contaminant for infants.

However, little is known about fish consumption during pregnancy in Taiwan in relation to the mercury concentration of breast milk. The purposes of this study were to assess the total breast milk mercury concentration of urban mothers and mothers married to fishermen in relation to fish intake and to assess the health risks of MeHg exposure in their infants. To assess MeHg exposure in breast-feeding infants, and to assess uncertainty in risk assessment and the impact of these uncertainties on the estimation of expected risk, we used the Monte Carlo technique. Then, we calculated and validated a hazard quotient to evaluate the impact of fish intake on infants in Taiwan.

## 2. Methods

### 2.1. Collection and digestion of milk samples

A total of sixty-eight healthy mothers were recruited for the study. The subjects were separated into two groups: urban mothers (who lived in Taipei city, $n = 56$) and mothers married to fishermen (who lived in Lykang, Dongshih, and Budai, $n = 12$). Breast milk samples were collected from the subjects during the period from December 2002 to May 2004. All of the mothers provided colostrum samples once early in the postpartum period. Fifty milliliters of breast milk were collected each time using clean polyethylene bottles. Collected samples were shipped back to the laboratory immediately, freeze-dried, and then stored until analysis. Approximately one gram of each sample was microwave-digested (CEM, Model MDS-2000, Matthews, NC, USA) with 4 ml of nitric acid (Suprapur, Merck, Darmstadt, Germany), 2 ml of hydrogen peroxide (Suprapur, Merck) and 2 ml of distilled water in closed polyfluorotetraethylene (PFTE) vessels. After cooling, the residue fluid was diluted to 10 ml with distilled water.

### 2.2. Mercury determinations

Mercury concentration was analyzed by a mercury analyzer (HG-200, Hiranuma, Mito, Japan). Certified reference material (CRM) BCR No. 151 milk powder was used to perform a standard material test to ensure the precision and accuracy of the milk analyses. The precision was 5.14% and the accuracy was 103.9%. The ratio of wet weight to dry weight for breast milk was $6.17 \pm 0.88$ (Chien et al., 2006). We divided the dry weight ($\mu g^{-1}$) by 6.17 to calculate its corresponding wet weight ($\mu g\ l^{-1}$).

### 2.3. Total average daily mercury exposure dose

To better evaluate the total average daily mercury exposure dose of infants, we considered the three sources of mercury bioaccumulation in infants: ingestion (breast milk), inhalation (ambient air), and dermal exposure (shower). The equation used for calculating total average daily exposure dose was

$$E_{total} = E_{ingestion} + E_{inhalation} + E_{dermal} \quad (1)$$

Ingestion exposure (breast milk):

$$E_{ingestion} = \frac{C_{milk} \times IR_{milk}}{BW} \quad (2)$$

where $C_{milk}$: mercury concentration in colostrum ($\mu g\ l^{-1}$); $IR_{milk}$: ingestion rate ($l\ d^{-1}$); and BW: body weight (kg, WHO, 1994).

Inhalation exposure (ambient air):

$$E_{inhalation} = \frac{C_{air} \times IR_{inhalation} \times 10^{-3}}{BW} \quad (3)$$

where $C_{air}$: mercury concentration in air (urban area: 0.42–8.44 ng m$^{-3}$, Tsai et al., 2003; coastal area: 1.82–7.72 ng m$^{-3}$, Kim et al., 2002), $IR_{inhalation}$: inhalation volume (4.5 m$^3$ d$^{-1}$; USEPA, 2002), and BW: body weight (kg, WHO, 1994).

Dermal exposure (shower): Table 1 defines the parameters used in the equation below

$$E_{dermal} = \frac{C_w \times SA \times ABS \times F \times ST \times P}{BW} \quad (4)$$

### 2.4. Infant health risk characterization

Previous studies evaluating the health risk of MeHg in nursing infants demonstrated that about 7–50% of the total mercury was in the MeHg form (Abadin et al., 1997). The non-cancer risk was estimated using the hazard quotient (HQ) approach, which involved calculating a specific endpoint, such as occurrence of a neurological development, immunological, or reproductive effect. HQ is the ratio of the exposure estimate to the appropriate oral minimal risk level (MRL) or target organ toxicity dose (TTD). The chronic oral MRL of $3 \times 10^{-4}$ mg kg$^{-1}$ d$^{-1}$ is recommended for use to assess neurological development effect of MeHg exposure and the TTD for immunological effects is $3 \times 10^{-4}$ mg kg$^{-1}$ d$^{-1}$ (ATSDR, 1999).

For example, an HQ for neurological development effect is calculated as follows:

Table 1
Physiological parameters for estimating infants body burden

| Parameter | Symbol | Values | Reference |
|---|---|---|---|
| Hg concentration in water | $C_w$ (mg l$^{-1}$) | 0.002 | Taipei Water Department (2005) |
| Surface area | SA (m$^2$) | $SA = 0.02350 H^{0.42246} W^{0.51456}$ baby boy: 0.243 m$^2$ baby girl: 0.239 m$^2$ | USEPA (2002) |
| Dermal contact fraction | $F$ | 80% | USEPA (2002) |
| Showering time | ST (min d$^{-1}$) | 10 | USEPA (2002) |
| Dermal absorption fraction | ABS (mg mg$^{-1}$) | 0.01 | USEPA (1997) |
| Dermal penetration constant | $P$ (cm h$^{-1}$) | $1.67 \times 10^{-3}$ | USEPA (1997) |
| Body weight | BW (kg) | Baby boy: 3.49 kg baby girl: 3.44 kg | WHO (1994) |

$$HQ_{neurodevelop} = \frac{C_m^* \times IR}{MRL_{neurodevelop} \times BW \times 10^3}$$

where IR: ingestion rate (l d$^{-1}$); $C_m^*$: MeHg concentration in colostrum (µg l$^{-1}$, 7–50% of total mercury); MRL: minimal risk level ($3 \times 10^{-4}$ mg kg$^{-1}$ d$^{-1}$); and BW: body weight (kg, WHO, 1994).

## 2.5. Uncertainty and Monte Carlo analysis

The chi-square and Kolmogorov–Smirnov (K–S) statistics were used to optimize the goodness of fit of the distributions of mercury concentrations in the breast milk of urban mothers and mothers married to fishermen. Distribution of the body weight was fitted to data obtained from the WHO (WHO, 1994). Chien et al.'s (2006) estimate of 400–500 ml of breast milk intake was used in our calculations. The implemented parameter probability distributions are summarized in Table 2. To assess uncertainty in risk assessment and its impact on the estimation of expected risk, we used the Monte Carlo technique. This involved inputting individual distributions of exposure variables to generate output probability distributions of the health risk estimates (USEPA, 1997). The Monte Carlo simulation and estimation of sensitivity were performed using Crystal Ball software (version 2000.2, Decisioneering, Denver, CO, USA). The health risk was calculated from 10,000 iterations of the risk model using randomly selected

Table 2
Input variables/parameter values used to define distributions for Monte Carlo simulation

| Input variable | Symbol | Distribution | Mean | SD |
|---|---|---|---|---|
| Hg concentration in breast milk[a] | $C_m$ (µg l$^{-1}$) | | | |
| City group | | Lognormal | 2.03 | 2.48 |
| Fishermen's group | | Lognormal | 2.04 | 3.10 |
| Body weight | BW (kg) | | | |
| Baby boy | | Normal | 3.49 | 0.40 |
| Baby girl | | Normal | 3.44 | 0.37 |
| Breast milk ingestion rate for baby | IR (l d$^{-1}$) | Normal | 0.45 | 0.03 |

[a] MeHg forms accounted for about 7–50% of total mercury (Abadin et al., 1997).

values derived from each probability distribution of the model parameters.

## 2.6. Statistics

The distributions of continuous variables were expressed as mean ± standard deviation (SD). Between-group differences in age, height, weight, and body mass index were evaluated by the Mann–Whitney $U$ test. The chi-square test was used to assess the independence of two categorical variables. All statistical analyses were conducted using STATISTICA version for Windows. Results were considered significant in a two-sided test if $p < 0.05$.

## 3. Results and discussion

Demographic characteristics of the sixty-eight mothers and their frequency of fish and shellfish consumption during pregnancy are summarized in Table 3. The age was significantly higher in the city group ($31.1 \pm 4.0$ years) than the fishermen's group ($24.8 \pm 2.7$ years) ($p < 0.001$). Fish consumption was 1–2 meals per week in 44.6% of the city group and more than seven meals per week in 75% of the fishermen's group. The frequency of fish consumption ($p < 0.001$) but not the consumption of shellfish was significantly different between the two groups. None of the mothers had occupational exposure to mercury and in the city group only one mother smoked cigarettes and six mothers drank alcohol (10.7%) during pregnancy.

Fig. 1 shows box-and-whisker plots of colostrum mercury concentrations. The geometric mean of mercury concentration in all colostrum samples ($n = 68$) was 2.03 µg l$^{-1}$ (range: 0.24–9.45 µg l$^{-1}$). The breast milk mercury concentration was 2.02 µg l$^{-1}$ (range: 0.24–9.45 µg l$^{-1}$) for the city group and 2.04 µg l$^{-1}$ (range: 0.26–8.62 µg l$^{-1}$) for the fishermen's group. These were not significantly different between the two groups. The three most popular fish (in descending order of intake) were cod, salmon, and anchovy for the city group and milkfish, tilapia, and hairtail for the fishermen's group. In our previous study, the mercury concentrations in fish increased in the following order: milkfish ($0.04 \pm 0.04$ mg kg$^{-1}$ wet wt.) < hairtail ($0.05 \pm 0.01$ mg kg$^{-1}$ wet wt.) < salmon ($0.06 \pm 0.07$ mg kg$^{-1}$ wet

Table 3
Demographic characteristics and frequency of fish and shellfish consumption during the pregnancy of urban mothers and mothers married to fishermen

| Characteristic | City group ($n = 56$) | Fishermen's group ($n = 12$) | $p$-Value |
|---|---|---|---|
| Age (years) | $31.1 \pm 4.0$ | $24.8 \pm 2.7$ | <0.001 |
| Height (cm) | $160 \pm 4.0$ | $158 \pm 4.2$ | 0.434 |
| Weight (kg) | | | |
| Before pregnancy | $53.4 \pm 8.0$ | $50.3 \pm 7.3$ | 0.178 |
| After pregnancy | $66.4 \pm 9.6$ | $63.0 \pm 8.4$ | 0.253 |
| Body mass index (kg m$^{-2}$) | | | |
| Before pregnancy | $21.0 \pm 2.9$ | $20.1 \pm 2.6$ | 0.190 |
| After pregnancy | $26.0 \pm 3.4$ | $25.2 \pm 3.4$ | 0.389 |
| Drinking during pregnancy | | | 0.235 |
| Yes | 6 (10.7%) | 0 (0%) | |
| No | 50 (89.3%) | 12 (100%) | |
| Smoking during pregnancy | | | 0.641 |
| Yes | 1 (1.8%) | 0 (0%) | |
| No | 55 (98.2%) | 12 (100%) | |
| Fish consumption | | | <0.001 |
| <3 meals/month | 12 (21.4%) | 0 (0%) | |
| 1–2 meals/week | 25 (44.6%) | 1 (8.3%) | |
| 3–6 meals/week | 16 (28.6%) | 2 (16.7%) | |
| >7 meals/week | 3 (5.4%) | 9 (75.0%) | |
| Shellfish consumption | | | 0.256 |
| <3 meals/month | 40 (71.4%) | 7 (58.3%) | |
| 4–8 meals/month | 12 (21.4%) | 5 (41.7%) | |
| >12 meals/month | 4 (7.2%) | 0 (0%) | |

Values are given as mean ± standard deviation or $n$ (%).
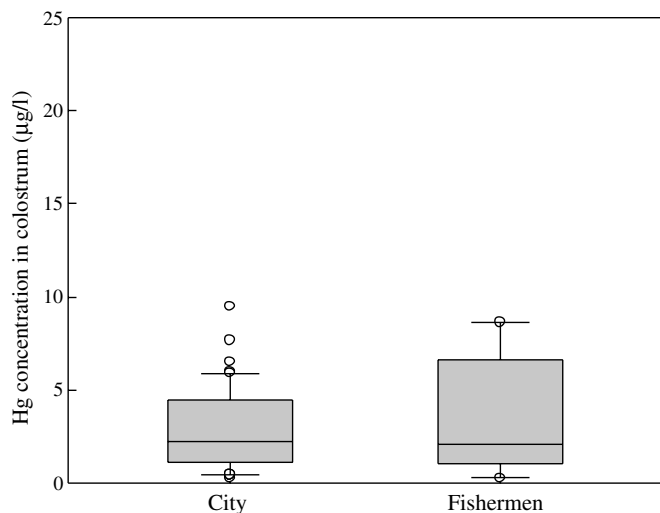


Fig. 1. Box and whisker plots display the distributions of the mercury concentrations of colostrum in the city ($n = 56$) and fishermen's groups ($n = 12$); median (horizontal line in the box), minimum, and maximum are shown. The box includes 50% of the values and is limited by the 25% and 75% percentiles.

wt.) < cod (0.11 ± 0.08 mg kg$^{-1}$ wet wt.) < tilapia (0.12 ± 0.06 mg kg$^{-1}$ wet wt.) (Chien, 2005). Interestingly, some mothers in the city group ate raw fish and shellfish as used in "Sashimi" and "Sushi." The three fish species most frequently used in "Sashimi" in Taiwan are swordfish, tuna, and salmon. Approximately 34.7% of the swordfish mer-

cury concentrations exceeded the Codex guideline level of 1 mg kg$^{-1}$ (FAO/WHO, 1991; Chien, 2005).

Mercury concentrations in breast milk in our study are comparable to those found in other studies. Mercury concentrations in breast milk in Brazil are 5.8 µg l$^{-1}$ in high-fish eaters (Barbosa et al., 1998) and 3.3 µg l$^{-1}$ in non-fish eaters living near gold fields (Nunes-Junior and Sotério, 2000). A study in Saudi Arabia reported that mercury concentrations in breast milk were 4.15 µg l$^{-1}$ and 2.19 µg l$^{-1}$ for Riyadh and Al-Ehssa residents, respectively (Al-Saleh et al., 2003). In Taiwan, the geometric mean in our study is slightly higher than the value (1.0 µg l$^{-1}$) published by Ding et al. (1993).

Table 4 shows the average daily mercury exposure dose in infants. There was not significantly different between the city group infants and fishermen's group infants. According to our findings, inhalation and dermal contact with mercury are not the major source of exposure. Breast-feeding was estimated to represent 96.3–99.6% of the total mercury exposure in infants. Thus, breast milk is the major source of mercury exposure for infants. In our study, the calculated mercury exposure was $3.02 \times 10^{-1}$ µg kg$^{-1}$ d$^{-1}$ and $3.06 \times 10^{-1}$ µg kg$^{-1}$ d$^{-1}$ for an urban baby boy and baby girl (based on assumed weights of 3.49 kg and 3.44 kg and exposures of 1.04 µg d$^{-1}$ and 1.04 µg d$^{-1}$, respectively). The total estimated mercury exposure for Canadians consuming various types of foods is 3.3 µg d$^{-1}$ for toddlers, 5.6 µg d$^{-1}$ for children, 6.7 µg d$^{-1}$ for teens, 9.4 µg d$^{-1}$ for adults, and 6.8 µg d$^{-1}$ for seniors (Richardson et al., 1995).

Fig. 2 shows the probability density distribution of the predicted hazard quotient in the city and fishermen's groups for a baby boy exposed to different amounts of MeHg. The Monte Carlo simulation showed that if MeHg is about 50% of total mercury, then 12.9% and 18.8% of the hazard quotient estimates exceed 1.0 for the city and the fisherman's babies, respectively, whereas if it is about 7% of total mercury, none of the hazard quotient exceeds 1.0. Note that a hazard quotient exceeding 1.0 indicates that breast milk consumption by infants is a potential health risk, such as risk of neurological development and immunological problems.

A multiple regression model for breast milk mercury concentration as function of age, supplementation with vitamins, mercury intake from fish, and selenium intake from fish is shown in Table 5. Breast milk mercury concentration increased with age and with mercury intake from fish, though the increases did not reach statistical significance. Breast milk mercury concentration was significantly lower in those who took vitamins than those who did not during pregnancy ($p = 0.06$). Interestingly, breast milk mercury concentration decreased with selenium intake from fish. Oskarsson et al. (1995, 1996) observed a positive association between breast milk mercury concentration and fish consumption in mature milk. Barbosa et al. (1998) demonstrated that infant MeHg exposure during the fetal and breast-feeding periods is strongly related to maternal

Table 4
Average daily mercury exposure dose in infants

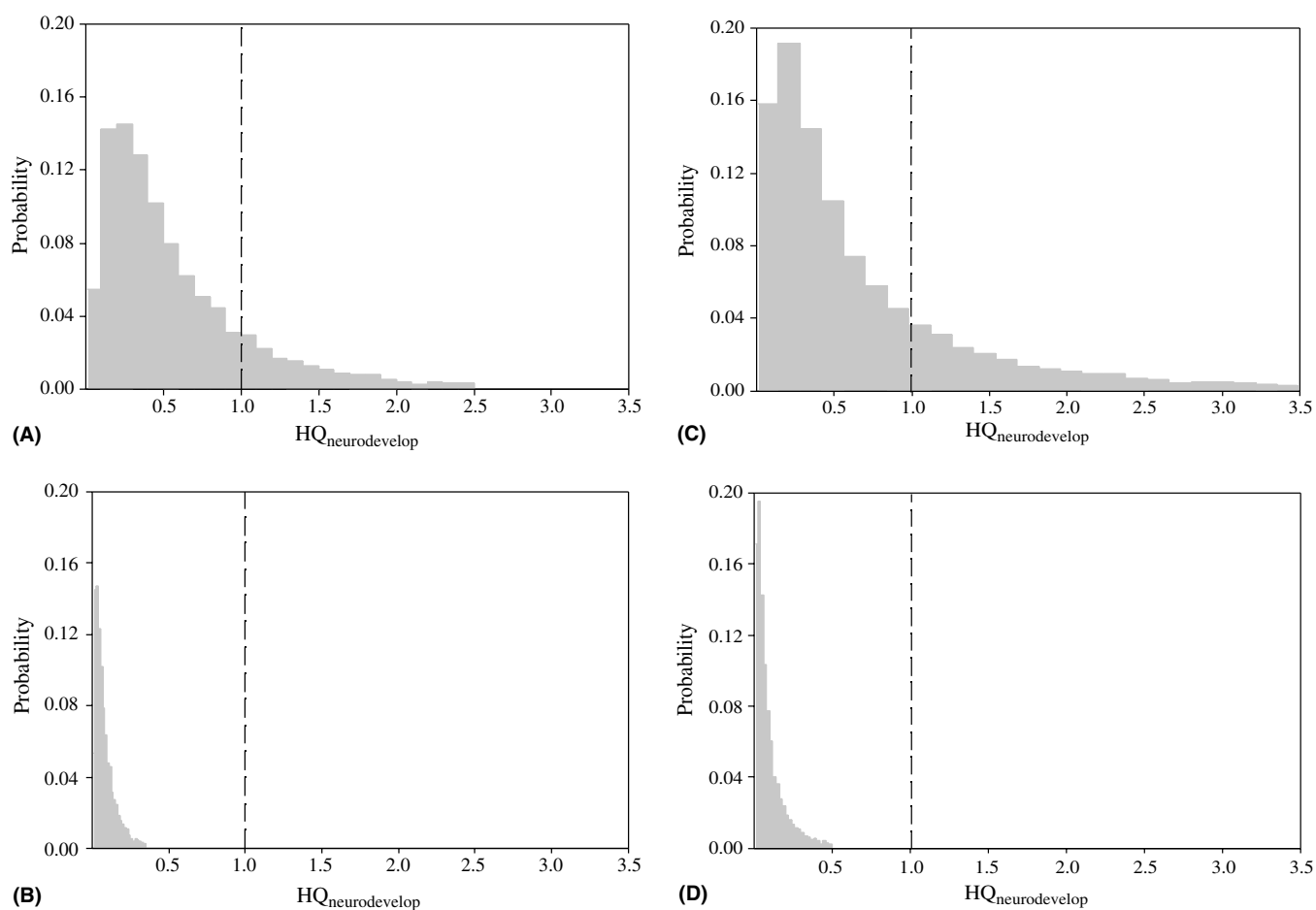| Exposure | Daily mercury exposure dose ($\mu g\ kg^{-1}\ d^{-1}$) | | | |
| --- | --- | --- | --- | --- |
| | City group | | Fishermen's group | |
| | Baby boy | Baby girl | Baby boy | Baby girl |
| Breast milk | $2.91 \times 10^{-1}$ | $2.95 \times 10^{-1}$ | $2.92 \times 10^{-1}$ | $2.97 \times 10^{-1}$ |
| Air | $1.09 \times 10^{-2}$ ($5.41 \times 10^{-4}$) | $1.10 \times 10^{-2}$ ($5.49 \times 10^{-4}$) | $9.95 \times 10^{-3}$ ($2.34 \times 10^{-3}$) | $1.01 \times 10^{-2}$ ($2.38 \times 10^{-3}$) |
| Shower | $3.10 \times 10^{-6}$ | $3.15 \times 10^{-6}$ | $3.10 \times 10^{-6}$ | $3.15 \times 10^{-6}$ |
| Total | $3.02 \times 10^{-1}$ ($2.92 \times 10^{-1}$) | $3.06 \times 10^{-1}$ ($2.96 \times 10^{-1}$) | $2.93 \times 10^{-1}$ ($2.92 \times 10^{-1}$) | $3.07 \times 10^{-1}$ ($2.99 \times 10^{-1}$) |



Fig. 2. Probability density distribution of predicted hazard quotient in the city and fishermen's groups for a baby boy exposed to different amounts of MeHg. (A) city group, MeHg: 50%; (B) city group, MeHg: 7%; (C) fishermen's group, MeHg: 50% and (D) fishermen's group, MeHg: 7%.

mercury body burden. In Austria, a significant positive relation was found between breast milk mercury concentration and vitamin supplementation ($p < 0.05$) (Gundacker et al., 2002). The exogenous application of the vitamin E ($\alpha$-tocopherol) decreased mercury toxicity in rats (Welsh, 1979), and B-complex and E vitamins were found to mobilize a significant amount of mercury from brain, spinal cord, liver, and kidneys in rats (Bapu et al., 1994). Similarly, a study in rats found that selenium may protect against the acute neurotoxicity of MeHg (Ohi et al., 1980). The possible mechanisms of protection include redistribution of mercury (Mengel and Karlog, 1980), competition for binding sites (Lucu and Skreblin, 1981; Leonzio et al., 1982), formation of a mercury-selenium complex (Naganuma and Imura, 1981; Magos et al., 1987), and prevention of oxidative damage (Cuvin-Aralar and Furness, 1991; Imura and Naganuma, 1991; Nylander and Weiner, 1991). In addition to vitamin supplementation and fish selenium consumption, the life style of mothers may influence mercury concentration in breast milk.

Table 5
Multivariate regression analysis of breast milk mercury concentration

|  | Coefficient | *p*-Value |
|---|---|---|
| Intercept | 0.47 | 0.81 |
| Age | 0.13 | 0.12 |
| Supplementation with vitamins | −1.37 | 0.06 |
| Fish mercury consumption[a] | 1.23 | 0.52 |
| Fish selenium consumption[b] | −1.94 | 0.35 |

($n = 68$).

[a] Calculation based on individual consumed fish species, mercury concentration, and fish consumption rate divided into four categories (<3 meals/month, 1–2 meals/week, 3–6 meals/week, and >7 meals/week). For example, one mother ate milkfish, hairtail, and salmon <3 meals/month $\frac{0.04+0.05+0.06}{3}$ Hg mg kg$^{-1} \times 1 = 0.05$ Hg mg kg$^{-1}$.

[b] Calculation based on individual consumed fish species, selenium concentration (Chien, 2005), and fish consumption rate.

## 4. Conclusion

Our study explored the association between mothers' consumption of fish and shellfish and mercury body burden in infants in Taiwan. According to our findings, breast milk mercury concentrations are not significantly different between urban mothers and mothers married to fishermen. The mercury concentration of breast milk may be affected by the life style of mothers, such as supplementation with vitamins, fish mercury consumption, and fish selenium consumption. In conclusion, fish have certain nutrients good for health; however, women of childbearing age, to reduce the body burden of mercury in their infants, should be concerned about mercury accumulated in fish.

## Acknowledgement

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