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ORIGINAL PAPER

Hair mercury level of coastal communities in Malaysia: a linkage with fish consumption

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Abstract Hair mercury level was assessed in four coastal communities in Malaysia with relation to fish consumption between gender, age, and rural and urban area. Mercury level was found at a range of 0.01–21.00 ($\mu\text{g/g}$ dry wt). The average mercury levels were 13.69, 10.85, 9.94, and 6.78 $\mu\text{g/g}$ dry wt for communities in Kedah, Terengganu, Johor, and Selangor, respectively. The same order was found for the average monthly fish consumption, that is $14,620 \pm 878$, $9,966 \pm 563$, $8,939 \pm 793$, and $8,169 \pm 658$ g/month for communities in the four respective regions. A highly significant positive correlation between hair mercury concentration and fish consumption was observed in all communities. This gives an insight that fish consumption is a significant route of mercury exposure for the coastal communities. Females had higher hair mercury concentration than what males had. Mercury exposure of communities in rural area was higher when compared to that in urban. However, mercury level in all Malaysian communities studied was much lower than no observable adverse effect level (NOAEL) of WHO, that is 50 mg/g dry wt.

Keywords Fish consumption · Mercury exposure · Risk assessment · Hair mercury content · Coastal communities

Introduction

Mercury is ubiquitous in the environment. It can be released and mobilized through both natural processes and anthropogenic activities and concentrates in seawater [1, 2], air [1], fish [3–5], and human or animal tissue [6]. Natural processes of significant Hg emissions include out-gassing of the earth's mantle material, evasion from surface soils, water bodies, vegetation surfaces, wild fires, volcanic activities, and geothermal processes [7, 8]. For over 3,500 years, humans have used mercury for various applications. For example, in the form of cinnabar, HgS, mercury was used as a red pigment in cosmetics and paint. Calomel, Hg₂Cl₂, was one of the ingredients in “teething powder” that prior to 1960 was used to prevent ache in the mouth of children having their first teeth [9]. Metallic mercury has been used in a variety of laboratory equipment such as thermometers, barometers, and diffusion pumps. Elemental mercury forms alloys, called amalgam, with, for example, gold and silver, and this has been used in tooth fillings since the early nineteenth century [10]. In the beginning of the last century, alkyl mercury compounds were introduced as agricultural fungicides [11]. This eventually led to numerous mercury poison disasters, the most serious disaster being in Iraq, in 1971–1972, where maybe as many as 40,000 people were poisoned, of which 500 died [12]. Although more knowledge of its toxicity is now available, mercury in different forms is today still used as constituent in tooth filling material, pesticides, preservatives, catalysts, lamps, and batteries [13].

It is known that human exposure to mercury is mainly through fish consumption. In water or soil, microorganisms can convert inorganic mercury into a more toxic organic form, methylmercury [14–18]. Methylmercury can accumulate in animal tissues and cause biomagnifications in the aquatic food chain. Its concentrations are the highest in top predatory

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species [19]. Therefore, fish-consuming populations are a high-risk group for methylmercury exposure [20, 21].

To assess human exposure to mercury, body fluids such as blood and urine or tissues such as hair and nail have been analyzed [22–25]. Hair is a suitable indicator for biomonitoring of human exposure to mercury that can reflect organ mercury levels as well as dietary intake [26]. It is also reported to be able to reflect the average methylmercury concentrations circulating in the blood [27, 28]. The convenience of hair sampling and its storage give the advantage for monitoring and field studies. However, environmental mercury vapor may bind to the hair [29], while hair permanent treatments and hair coloring may affect the mercury concentration [30–32].

This study aims to assess mercury exposure through mercury measurement in the hair of adult population in four coastal regions, located in northeastern, western, and eastern coastlines of peninsular Malaysia. The influence of fish consumption, with considering the gender, age, rural, or urban factors, to the risk of mercury was evaluated.

Materials and methods

Study areas and population of study

The survey on fish consumption was conducted in four different coastal states of Malaysia; M1, Johor; M2, Terengganu; M3, Kedah; and M4, Selangor (Fig. 1). Sampling locations in each state were divided into two: urban and rural area. The respondents covered were the three main

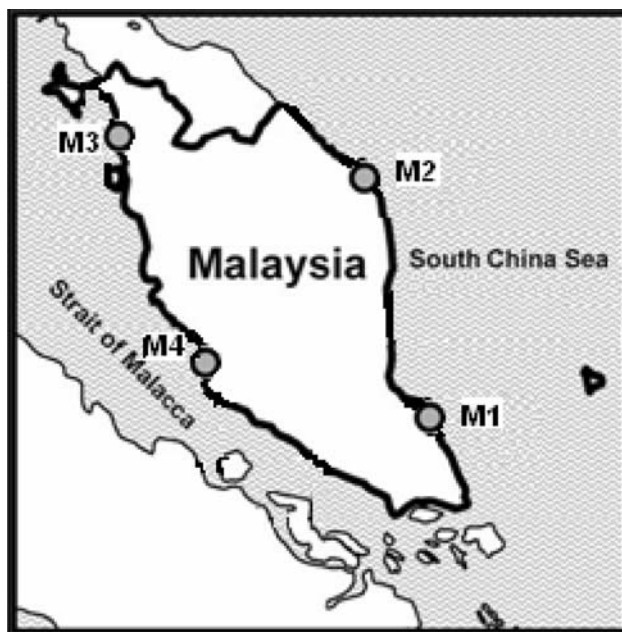


Fig. 1 Map of four coastal communities in Peninsular Malaysia

races (Malay, Chinese, and Indian) living in Malaysia. A total of 800 adults (387 men, 413 women) aged from 18 to 80 years were interviewed to answer the fish consumption questionnaire. However, only 380 respondents (147 men and 233 women) committed to donate their hair sample.

Dietary intake was assessed using a food frequency questionnaire (FFQ) with 1-month recall. The questionnaires were developed based on a review of the literature and other related studies [32, 33]. The questionnaires were pilot-tested on community representatives and were found to be culturally acceptable. The FFQ was divided into the three food categories (canned fish, local fish dishes, and fish snacks). The participants were first asked to identify whether the item was consumed and whether it was cooked at home or eaten outside. To facilitate the recall, a booklet of fish and food picture with serving sizes and local and English names were shown to the respondents.

Hair sample collection and preparation

Hair samples were collected from donors by cutting strands of hair close to the scalp in the occipital region, using a clean stainless steel scissor. The hair samples were then kept in clean polyethylene bags and transported to the laboratory. The samples were cut into pieces (4–6 mm), washed three times with nonionic detergent (1% v/v Triton X-100), and rinsed three times with deionized water. After washing, the hair samples were dried in an electric oven at 60 °C and kept in polyethylene bags until used for mercury analysis [23].

Analytical procedures

Sample preparation and determination of mercury in hair followed the method by Akagi and others [22]. Hair samples (10 mg) were digested through the addition of nitric-perchloric and sulfuric acid solution and heated in a water bath at 90 °C for 30 min. The digested sample was then cooled, diluted with deionized water, and filtered for mercury analysis. Mercury was determined in all the samples, using inductively coupled plasma atomic emission spectroscopy (ICP-AES) (Thermo Elemental, Iris advantage model), according to the manufacturer's instruction. The detection limit was 3 ng/g. Mercury stock standard solution (1,000 mg/l) was prepared by dissolving 0.0677 g of HgCl₂ in the 3% HCl in a 100-ml digestion flask. Analytical accuracy was tested using spiked samples and standard addition method. Ninety-six percent of recovery was obtained using this analytical procedure.

Statistical methods

Statistical analyses were performed with SPSS (version 12.0, SPSS Inc., Chicago, IL, USA) and Minitab (version

14.12.0, © 1972–2004 Minitab Inc.) software. Relationships between mercury, and age and fish consumption were examined by Pearson's correlation coefficient, as well as by simple and multiple regression analyses. Sexual difference in concentrations of mercury in hair was tested by Student's *t* test. ANOVA were used to test the difference between mercury levels in hair of donors residing in different locations. A *P* value of less than 0.05 was considered as statistical significant.

Results and discussion

Regional and race differences in hair mercury levels

Table 1 shows demographic characteristics of hair donors. The hair donors were from urban and rural communities in four Malaysian coastline states. Therefore, there are totally eight communities assessed. Each community covers three major races: Malay, Chinese, and Indian.

Table 2 shows mercury concentration in human hair from the eight communities in the Peninsular Malaysia. Mercury concentration in hair of Malaysian ranged from

Table 1 Demographic characteristics of hair donors

Characteristics	Men (<i>N</i> = 147)	Women (<i>N</i> = 233)	Overall (<i>N</i> = 380)
Age	37.72 ± 1.17	38.90 ± 0.89	38.44 ± 0.71
State			
Johor (M1)	13.61	11.16	12.11
Terengganu (M2)	27.89	39.05	34.73
Kedah (M3)	36.05	42.91	40.26
Selangor (M4)	22.44	6.86	13.16
Geographical location			
Rural	36.05	36.90	36.57
Urban	63.94	63.09	63.42
Race			
Malay	85.03	92.27	89.47
Chinese	10.20	5.15	6.57
Indian	4.76	2.57	2.63
Education			
None	2.04	6.86	5
Primary school	23.80	16.30	19.21
Secondary school	52.38	51.93	52.10
Vocational school	6.12	2.14	3.68
College/university	15.64	22.47	20
Income			
<500	78.23	82.40	80.78
500–1,000	10.88	16.73	14.47
>1,000	10.88	0.85	4.73

All values (except the age) are expressed in percentage

Table 2 Hair mercury concentration in populations from four states in Peninsular Malaysia

Population group	Mercury concentration (µg/g dry wt)		
	Mean	SE	Range
Johor (M1)	9.94	0.78	0.60–19.76
Urban	9.84	0.88	0.60–19.76
Rural	10.31	1.66	3.80–17.40
Terengganu (M2)	10.85	0.49	0.10–19.90
Urban	9.82	0.54	0.98–19.90
Rural	12.47	0.91	0.10–19.75
M3 Kedah (M3)	13.69	0.48	0.05–21.00
Urban	11.41	0.74	0.05–20.50
Rural	15.99	0.52	3.36–21.00
Selangor (M4)	6.78	0.94	0.02–19.74
Urban	5.34	0.28	0.02–17.29
Rural	8.22	0.87	0.38–19.74

0.02 to 21.00 µg/g dry wt. There was a significant difference between mercury concentration of communities in rural and urban area ($P < 0.001$). The mercury levels were higher in rural communities. Hair mercury concentrations between communities in the four states were significantly different ($P < 0.001$). The value was highest in communities of Kedah and lowest in communities of Selangor, while those between donors from Johor and Terengganu were not significantly different ($P > 0.001$). However, there was no significant difference between hair mercury contents of the three studied races ($P > 0.001$).

Age- and gender-dependent accumulation of mercury in humans

In communities of Selangor, Kedah, and Terengganu, female donors showed significantly higher mercury concentration in hair than what the male donors showed ($P < 0.05$). Table 3 shows the correlation between mercury concentrations and age of donors. The significant correlation was only found slightly between hair mercury content and age of males from Terengganu ($R^2 = 0.283$).

Effect of fish consumption on hair mercury level in hair

Fish consumption is one of the main sources of mercury intake in humans [31, 34–38]. Fish consumption (g/month) has been calculated in hair donors to determine the mercury exposure through fish consumption. Questionnaire results showed that Malaysian people, on average, consumed 11,442 g fish/month (Table 4). In the three studied states, communities in rural area consumed significantly higher amounts of fish when compared to those in urban area.

Table 3 Pearson correlation coefficient between hair mercury concentrations and age of respondents in four coastal states in Malaysia

Group	<i>N</i>	<i>R</i> ²	<i>P</i>
All	380	0.103	0.045
Male	234	0.004	0.949
Female	146	0.203	0.014
Selangor	44	−0.257	0.093
Male	37	−0.134	0.428
Female	7	−0.711	0.073
Kedah	158	0.135	0.092
Male	79	0.113	0.321
Female	79	0.063	0.580
Terengganu	132	−0.018	0.834
Male	81	0.283	0.043
Female	51	−0.161	0.150
Johor	46	0.132	0.382
Male	37	0.108	0.525
Female	9	0.233	0.546

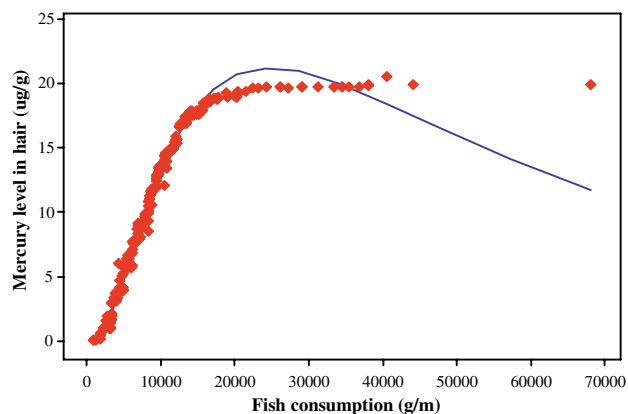
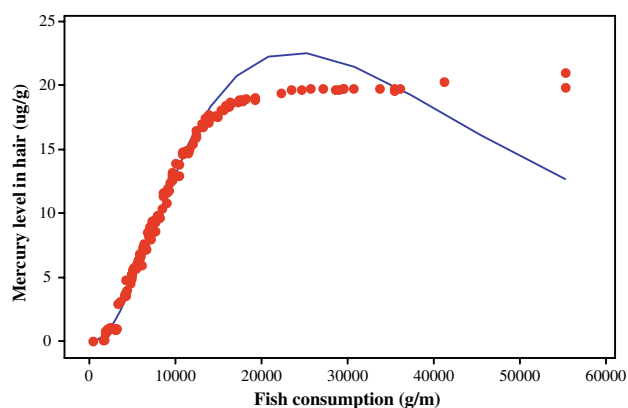
Table 4 Pearson correlation coefficient between hair mercury concentrations and fish consumption of population in four coastal states in Malaysia

Population group	Fish consumption (g/month)			
	Mean	SE	<i>R</i> ²	<i>P</i>
Johor (M1)	8,939	793	0.902	0.000
Urban	9,084	956	0.909	0.000
Rural	8,343	1,051	0.994	0.000
Terengganu (M2)	9,966	563	0.867	0.000
Urban	8,653	618	0.810	0.000
Rural	12,051	1,019	0.906	0.000
Kedah (M3)	14,620	878	0.723	0.000
Urban	12,181	1,236	0.750	0.000
Rural	17,060	1,194	0.665	0.000
Selangor (M4)	8,169	1,031	0.875	0.000
Urban	7,076	1,076	0.904	0.002
Rural	9,263	1,151	0.885	0.002

Donors living in Kedah state showed the highest fish consumption of 14,620 g fish/month. There was no gender difference in terms of consumption ($P > 0.005$). A highly significant positive correlation was found between hair mercury concentration and with consumption in all the studied populations (Figs. 2, 3).

Comparison of hair mercury levels to other Asian countries

To understand the mercury contamination status in Malaysia, concentrations of hair mercury in this study were compared

**Fig. 2** Correlation between hair mercury level ($\mu\text{g/g}$ dry wt) and fish consumption (g/month) in Malaysian women ($S = 0.07358$; $R^2 = 97.6\%$)**Fig. 3** Correlation between hair mercury level ($\mu\text{g/g}$ dry wt) and fish consumption (g/month) in Malaysian men ($S = 0.1173$; $R^2 = 94.6\%$)

with those in recent studies from other Asian countries (Table 5). Concentration of hair mercury in Malaysian communities studied was higher than that in previous research done by Sarmani and Alakili [39]. It can be explained by the different geographical and environmental conditions. The highest mercury levels in the present study, which were found in rural area or fishery villages, were comparable to those from Japan (Wakayama, Kumamoto) and Indonesia (Medan) [31, 40]. However, the highest mercury level in the Malaysian communities was far below that reported for Cambodia, Japan (Tokushima, Minamata, Chiba), and China (Harbin) [24, 31, 40, 41].

World Health Organization (WHO) reported that no health effect was observed in donors with the hair mercury level below 50 mg/g dry wt, based on the neurotoxicity data in Japan and Iraq [42, 43]. According to the report, mercury in all hair donors either from rural or from urban area in four states in Peninsular Malaysia was well below NOAEL of WHO. It was known that the estimation level of mercury in maternal hair that reflects no appreciable adverse effects

Table 5 Comparison of hair mercury level ($\mu\text{g/g}$ dry wt) of Malaysian communities with those in other Asian countries

Location	Mean	Median	Range	Remark	References
Malaysia	11.45	12.00	0.01–21.00	Rural and urban area	Current research
Kuala Lumpur, Malaysia	–	3.38	0.59–18.37	Urban area	Sarmani and Alakili 2004 [39]
Libya	–	0.81	0–3.6	–	Sarmani and Alakili 2004 [39]
Jordan	–	0.69	0.32–4.0	–	Sarmani and Alakili 2004 [39]
Cambodia	3.1	–	0.54–190	–	Agusa et al. 2005 [41]
Phnom Penh, Cambodia	–	–	5.2–58	–	Agusa et al. 2007 [24]
Japan	1.51	–	–	Female	Ohno et al. 2007 [25]
Minamata, Japan	–	–	2.46–705	Patients of Minamata disease	Harada 1995 [45]
Shiranui Bay, Japan	5.0	–	–	Male	Harada et al. 1998 [36]
Shiranui Bay, Japan	2.1	–	–	Female	Harada et al. 1998 [36]
Minamata, Japan	1.76	–	0.09–10.56	–	Yasutake et al. 2003 [31]
Kumamoto, Japan	1.57	–	0.14–19.18	–	Yasutake et al. 2003 [31]
Tottori, Japan	2.04	–	0.00–12.52	–	Yasutake et al. 2003 [31]
Wakayama, Japan	2.04	–	0.00–20.66	–	Yasutake et al. 2003 [31]
Chiba, Japan	3.37	–	0.14–26.76	–	Yasutake et al. 2003 [31]
Tokyo and surrounding areas, Japan	2.98	–	–	Male	Nakagawa 1995 [44]
Tokyo and surrounding areas, Japan	2.02	–	–	Female	Nakagawa 1995 [44]
Tokushima, Japan	4.62	–	0.626–24.6	–	Feng et al. 1998 [40]
Harbin, China	1.69	–	0.112–36.4	–	Feng et al. 1998 [40]
Medan, Indonesia	3.13	–	0.203–19.9	–	Feng et al. 1998 [40]
Hong Kong, China	3.33	–	–	Fertile male	Dickman et al. 1998 [46]
Hong Kong, China	4.23	–	–	Sub-fertile male	Dickman et al. 1998 [46]
Seoul, Korea	1.7	–	–	Male	Lee et al. 2000 [52]
Seoul, Korea	1.1	–	–	Female	Lee et al. 2000 [52]
Diwalwal, Philippines	–	2.77	–	Downstream of gold mine	Drasch et al. 2001 [53]
Diwalwal, Philippines	–	1.71	–	Gold mine, nonoccupation	Drasch et al. 2001 [53]
Diwalwal, Philippines	–	3.62	–	Gold mine, occupation	Drasch et al. 2001 [53]
Diwalwal, Philippines	–	2.65	–	Control	Drasch et al. 2001 [53]
Doha, Kuwait	4.181	–	–	Fisherman	Al-Majed and Preston 2000 [37]
Bangladesh	0.44	–	0.02–0.95	Fish consumption	Holsbeek et al. 1996 [35]
Mansoura, Egypt	0.23	–	0.11–0.41 0.23	Urban area	Mortada et al. 2002 [23]

in the offspring is $14 \mu\text{g/g}$ dry wt of hair mercury [43]. Moreover, Harada et al. [36] reported that the upper limit of a normal hair mercury level is $10 \mu\text{g/g}$ dry wt. However, Grandjean et al. [26] showed that mercury-related neuro-psychological dysfunctions were present in children even with mercury levels below $10 \mu\text{g/g}$ dry wt in maternal head hair in the Tapajos River basin, Brazil, and in the Faroe Islands, Denmark. In this study, 44% of respondents had more than $14 \mu\text{g/g}$ dry wt of hair mercury, and 61% had more than $10 \mu\text{g/g}$ dry wt of hair mercury. If the high hair mercury levels are associated with the body burden and are not due to external deposition onto the surface of hair, certain populations in Malaysia may have risk of neurotoxic effects due to the elevated mercury exposure.

This study also showed the significant difference between hair mercury levels of different gender, as reported

above. This is in accordance with other researchers results. Batista et al. [34] reported that women exhibited higher mercury level in their hair than what men exhibited, whereas mercury concentration in the hair of males was higher than that of females in other studies [31, 44–46]. However, some studies showed that gender is unlikely to be an important factor determining mercury accumulation in hair [23, 31, 38, 41, 47].

Fish consumption was the most significant predictor of mercury in the population studied. Our results support the findings of earlier studies, indicating that the concentration of mercury found in hair of adult respondents with no occupational exposure is mainly dependent on dietary intake [35, 48–53]. Mercury exposure was higher in rural area compared to that in urban area. These could be explained by the difference between diet, community life style, and

environmental factors. In the urban communities, the typical monthly fish consumption consisted of canned tuna, sardine, anchovies and salmon, fish ball and nuggets, and fresh fishes found in the local markets; while in rural or fishing villages, peoples consumed locally caught fresh fish. The number of fish consumption in rural area was generally higher than that in urban area.

The fact that the concentration of hair mercury in Malaysian communities studied here was higher than that of previous research done by Sarmani and Alakili (2004) [39] is due to the different geographical and environmental conditions. The relatively high mercury level found in hair of Malaysian communities suggests an existence of mercury risk in Malaysia.

Discussion

Fish consumption was the most significant predictor of mercury in the coastal communities studied. Mercury exposure was higher in rural area when compared to that in urban area. This could be explained by higher fish consumption of communities in rural area or fishery villages. In all the four coastal states, female donors showed higher mercury concentration in hair than that showed by males. Mercury level in all Malaysian communities studied did not exceed NOAEL of WHO. However, the level remains relatively high and gives a risk alert of the mercury exposure.

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