Hair Mercury and Fish Consumption in Residents of O'ahu, Hawai'i

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Abstract

Recent studies have established that men are susceptible to cardiotoxicity from methylmercury exposure, which also poses risks to the pregnant woman. Hair samples were obtained and questionnaires for methylmercury exposure assessment were administered to 110 adults (57 men, 53 women) throughout O'ahu, Hawai'i during December 2010 to January 2011. Hair samples were analyzed for total mercury with a direct mercury analyzer. Men ≥ 46 years had a median of 2.0 µg/g, which was above the reference dose of 1 µg/g, as compared to younger men with a median 1.0 µg/g (P < 0.05). Hair concentrations from older women had a median of 1.2 µg/g of mercury compared to 0.6 µg/g for younger women. Additionally, 38% of women of childbearing age had a Hazard Index > 1.0. This indicates that both men and women were at risk for excessive methylmercury exposure. In the final regression model, male gender, age > 45 years, length of residency > 10 years in Hawai'i, and fish consumption frequency > 1 meal per week were significant factors in increased hair mercury levels. Following safe fish consumption practices allows residents to reap health benefits of fish consumption without excessive toxicant exposure.

Keywords

methylmercury, fish consumption, hazard index, cardiotoxicity, biomarkers, risk, Hawai'i, hair mercury

Introduction

Certain populations in Hawai'i are susceptible to methylmercury exposure due to cultural factors. The types of fish, amount consumed, and how it's prepared are often driven by cultural and lifestyle factors.[1] For instance, certain cultures may consume fish organs, such as fish brains, that accumulate high levels of methylmercury and Asian-Pacific Islanders (APIs) may be at increased risk due to high fish consumption.[1] In addition to cultural susceptibility, recreational anglers and subsistence fishermen who frequently consume locally caught fish, or those who consume predatory oceanic species, such as shark and swordfish, may be more susceptible to mercury exposure.[2] These factors are not accounted for in most assessments and should be taken into consideration so public health solutions are met within cultural contexts.[1]

Background mercury levels in Hawai'i are from magmatic degassing and rock weathering, as well as evaporation from bodies of water.[3] Heightened air mercury levels have been detected during full-scale volcanic eruptions, locally, as well as at considerable distances from Mount Kilauea.[3] Other sources of exposure include anthropogenic sources, such as agricultural pesticides, antifouling paints, and dental amalgam fillings.[4] Mercury is also generated as chemical byproducts from Asian coal-fired power plants that travel long distances through warm ocean currents, and raise mercury levels in the North Pacific Ocean. These findings may explain why mercury levels are increasing in the eastern North Pacific when no local source is apparent, and can cause an increase of mercury levels in fish.[5,6]

Through bioaccumulation and biomagnification, a speciation change from inorganic to methylated forms of mercury occurs; the methylated form accounts for the majority of total mercury in fish tissues.[7] Methylmercury has an affinity for certain tissues.[7] As predatory fishes consume lower trophic level animals, methylmercury accumulates with increased consumption of contaminated organisms.[7] Furthermore, it is suggested that microbes generating methylmercury below the surface mixed layer, which includes an ocean depth between 50 meters to greater than 400 meters, significantly assists in anthropogenic uptake into marine food webs.[8]

Adverse effects to methylmercury exposure were assessed in past studies according to gender-specific endpoints in which both men and women were potentially at risk. Developmental neuropsychological impairment of the fetus was the endpoint measured for women, and an oral reference dose (RfD) was established at 0.1 µg/kg/day.[9]

Although the developing brain is the critical target organ for children, the cardiovascular system may be the most sensitive for adults.[10] Methylmercury induced cardiotoxicity is thought to be a consequence of the promotion of lipid peroxidation.[11,12,13] Precursors to methylmercury toxicity include increased oxidative stress and inflammation, reduced defense from oxidative injury, thrombosis, vascular smooth muscle and endothelial dysfunction, dyslipidemia, and immune and mitochondrial dysfunction.[14] Cardiovascular symptoms of methylmercury toxicity include hypertension, increased carotid intima-media thickness and carotid artery obstruction, cerebrovascular accident, generalized atherosclerosis, and renal dysfunction.[14] In a prospective study in Finland, men with the highest hair mercury levels (≥2.0 µg/g) had an adjusted 1.60-fold risk of an acute coronary event, 1.68-fold risk of cardiovascular disease (CVD), 1.56-fold risk of coronary heart disease (CHD), and 1.38-fold risk of any death compared to men in the lower two-thirds of exposure levels.[13,15] In addition, for each additional microgram of mercury in the hair, the risk of an acute coronary event increased by 11%, the risk of CVD death increased by 10%, the risk of CHD death increased by 13%, and the risk of any death increased by 5%.[13] Another study in Japan divided healthy volunteers into a control group and a treatment group.[16] The treatment group consumed tuna and swordfish for 14 weeks at levels deemed tolerable by the Japanese government. Average methylmercury levels in the hair samples started at 2.3 µg/g and peaked at 8 µg/g. Levels declined nearly back to baseline, 4.9 µg/g, during the next 15 weeks once the treatment was removed. Despite the treatment group consuming fish at levels deemed safe, subtle changes to their heart rhythm were observed that may affect long term health.[16] A long term methylmercury exposure study conducted among residents of Minamata supported a causality between methylmercury exposure and hypertension.[17] When compared to a control group from the Ariake area, residents of Minamata manifested more frequent episodes of hypertension; dose-response trends from hair samples were concurrent with hypertension episodes.[17]

Despite some molecular and epidemiological data indicating cardiotoxicity, some well-designed studies found no effect on cardiotoxicity. After controlling for docosahexaenoic acid and eicosapentaenoic acid in the US Health Professionals Study, there was no association between an increased risk of cardiovascular disease and toenail mercury concentrations.[18] Other studies showed no adverse effects of mercury exposure on coronary heart disease, stroke or total cardiovascular disease.[19] In a Swedish nested case-control study, there was no association between the risk of myocardial infarction and mercury concentrations in erythrocytes after adjusting for docosahexaenoic and eicosapentaenoic acid.[20]

Although the risk of exposure to mercury has been assessed in women of childbearing age in Hawai'i,[21] few studies have assessed risks to men and older individuals. The goal of this study was to assess the levels of methylmercury exposure related to fish consumption levels and practices among sampled residents of O'ahu, Hawai'i using hair as a biomarker of exposure.

Methods

This was a cross sectional study; a total of 110 adults (57 men, 53 women) at public areas from the central, west, southeast, windward and north regions of O'ahu were approached from December 2010 – January 2011, and screened prior to survey and hair collection. Participation was anonymous and voluntary and was based upon the following criteria: spoke English, older than 18 years of age, non-pregnant women, and current resident of O'ahu. The study was conducted after participant signed the consent form. The protocol was approved by San Diego State University's Institutional Review Board, reference number 588056.

The survey included demographic information about the participant, their fish consumption habits, and their general knowledge of methylmercury. Demographic questions included gender, ethnicity, age, education, income, city of residency, length of residency in Hawai'i, and presence of amalgam fillings. Fish consumption questions included whether fish was caught or purchased, how many times a week fish was consumed, what parts of fish was consumed, and approximate portion size eaten. Participants were surveyed on their general knowledge of methylmercury and included any awareness of fish consumption advisories, if they were concerned about methylmercury toxicity, if their consumption would decrease if they knew fish was contaminated with methylmercury, and if they felt fully informed about the risks and benefits of fish consumption and methylmercury exposure through fish consumption.

In order to assess the absorbed dose, levels of total mercury in scalp hair were selected as biomarkers. Untreated hair samples were cut with unused razor blades from the occipital region and placed in a polyethylene bag with their appropriate identifiers. Hair samples and double distilled water were placed into plastic weigh boats, then high-performance liquid chromatography (HPLC) grade acetone was added to remove impurities.[22,23] After the acetone was decanted, samples were placed on a hotblock and dried until constant weight was achieved using an analytical balance. Methylmercury was analyzed through a direct mercury analyzer (DMA) (Milestone, Shelton, CT). A calibration curve was created from a 100 parts per billion (ppb) mercury working standard using volumes of 5, 10, 50, 100, and 200 μL. Certified Reference Material (CRM) for trace metals of dogfish liver (DOLT-4) was analyzed to ensure acceptable mercury recovery. Quality assurance and quality control included percent recovery of CRM and a low level laboratory control standard (LCS), coefficient of variation, and relative percent difference (RPD). CRM and LCS percent recoveries ranged from 93-108%, coefficient of variation ranged between 1.0%-9.4%, and RPD ranged from 1.0%-5.2%.

The Hazard Index is exposure expressed as a noncarcinogenic risk and establishes whether methylmercury contaminated fish has the potential to endanger human health. As exposure increases above the reference dose, probability of adverse health effects also increases. The National Research Council and Environmental Protection Agency (EPA) have established the reference dose of an equivalent hair mercury concentration of 1 μg/g.[24,25,26] Risk indices were calculated using a one-compartmental model assuming that biological parameters were at steady state. A ratio of 250:1 converted hair mercury concentrations (mg of Hg/kg of hair) to blood mercury concentrations (mg of Hg/L of blood) prior to calculating the daily dietary intake.[27] The Hazard Index should be 1 or less to minimize risks for participants of childbearing age.

Statistical analyses were performed using IBM SPSS Statistics software, version 20 (IBM Corp., Armonk, NY). Data were not normally distributed; therefore, the Mann-Whitney nonparametric test and the Kruskal-Wallis k-sample test assessed significance between mercury hair levels and demographic or fish consumption variables. To study the joint effects of various risk factors, a multiple linear regression analysis was conducted. First, the distribution of the hair mercury level was examined and log transformed to convert the raw hair mercury level to a dependent variable that has a distribution close to the normal distribution. A multiple linear regression model was fitted for the log transformed mercury level against the significant independent variables which were significant in the bivariate analysis including age, gender, length of residency in Hawai'i, frequency of eating seafood per week, fish parts consumed, target organ consumed, and living in north or west regions of O'ahu compared to other regions. From this initial model, only the significant predictors ($P < .05$) were retained in the final model. Regression diagnostics were used to assess the goodness of fit and assumptions of regression before drawing statistical inferences from the final model. Cross-tabulation and chi-square analysis were applied to assess general information responses with demographic and consumption variables.

Results

Median hair levels were reported in this study since hair mercury concentrations were not normally distributed. Demographic and other variables along with unadjusted hair mercury concentrations for each variable are given in Table 1. Significant demographic variables in univariate analysis, unadjusted for fish consumption, included age, gender, current O'ahu region of residency, as well as years of residency in Hawai'i (Table 1). Men exhibited increased hair mercury concentrations compared to women ($P < .05$); median hair mercury concentrations were 1.2 micrograms of mercury per gram of hair (µg/g) for men and 0.7 µg/g for women (Table 1). Median mercury hair levels among men and women were further subcategorized to 45 years old and younger, and 46 years old and older. Men (≥46 years) had higher hair mercury concentrations than younger men (median of 2.0 µg/g vs. 1.0 µg/g) ($P < .05$) (Table 1). Older women ≥45 years also had higher hair mercury levels than younger women, 1.2 µg/g vs 0.6 µg/g. (Table 1).

Residents who lived along the North/West regions of O'ahu had significantly higher median hair mercury levels of 1.1 µg/g, in comparison to median hair mercury concentrations of 0.7 µg/g from residents who resided in other regions (south, windward, east, and central) (Table 1). Those living in Hawai'i for less than ten years had significantly lower mercury levels of 0.4 µg/g, compared to 1.1 µg/g from those residing for more than ten years (Table 1). Other demographic variables measured in univariate analysis were ethnicity, education, income, and presence of amalgam fillings but none were significant.

In univariate analysis, fish consumption significantly contributed to increased hair mercury concentrations (Table 2). Significant variables unadjusted for demographic variables included frequency of fish consumption ($P < .01$), portion size of fish meal ($P < .001$), frequency of fish consumption in conjunction with portion size ($P < .001$), amount of fish parts consumed ($P < .001$), and whether or not target organs were consumed ($P < .001$) (Table 2). Residents who consumed fish at a frequency of <1 day/week had lower hair mercury levels (0.7 µg/g) compared to residents consuming fish at a higher frequency of 1 to >6 days/week (1.2 µg/g) (Table 2). Residents who consumed 1 pound, and >1 pound of fish/meal each week had the highest hair mercury concentrations, 1.7 µg/g and 1.1 µg/g, respectively, compared to residents consuming 1/2 pound of fish per meal or less, each week (0.9 µg/g and 0.6 µg/g) (Table 2).

In multivariate analysis, the following variables retained significance: men, older age, longer residency, and frequency of fish consumption (Table 3). The final regression model outputs indicated that age greater than 45 years was associated with an increase in geometric mean hair mercury levels by 1.5 times (Table 3). Women's geometric mean hair mercury levels decreased 0.5 times relative to men's hair mercury levels (Table 3). The geometric mean mercury hair levels for residents who lived in Hawai'i for 11-40 years increased 1.9 times compared to the mercury levels of residents who lived there for 1-10 years (Table 3). People who ate fish >1 day/week had a 1.7 times increase in their geometric mean hair mercury levels compared to people who ate fish at a frequency of <1 day/week (Table 3).

The questionnaire also asked about methylmercury awareness (Table 4). When asked if participants saw fish advisories around O'ahu, the majority of men (61%) and women (54%) reported not seeing advisories around O'ahu. More than half of the residents living in south, west, central, and windward O'ahu reported to not seeing fish advisories. The majority (70%) of those who consumed fish at a frequency of <1 day/week had not seen fish advisories around O'ahu, while slightly more than half (52%) of those who consumed fish at a greater frequency of 1 to >6 days/week reportedly saw fish advisories ($P < .05$). The majority of those who consumed <1/4 lb (68%) and >1/2 lb (83%) had not seen fish advisories; however, slightly more than half of those who consumed 1/4 to 1/2 lb of fish per meal (58%) reportedly saw fish advisories ($P < .05$).

The majority of men (59%) and women (66%) reported being concerned about methylmercury exposure, as were residents of most areas. The concern was also high among all levels of fish consumption. Participants were asked if they would cease fish consumption if methylmercury was present in fish. The majority of men (56%) and women (73%) reported they would stop eating fish (Table 4).

Participants were asked if they felt fully informed about fish consumption issues and methylmercury exposure from fish consumption. The majority of men (60%) and women (62%) reportedly felt uninformed about fish consumption; 84% of men and 76% of women felt uninformed about methylmercury exposure.

Discussion

This study ascertained that being male, older age, residing in Hawai'i for a longer time and eating fish >1 day per week were factors associated with higher hair mercury levels. Among the men assessed in this study, 37% had hair mercury levels >2.0 µg/g, associated with cardiotoxic risk in some studies.[11,13] Although women of childbearing age had the lowest levels assessed in this study, it should be noted that 38% had an HI >1.0. Women appeared to have lower body burdens of methylmercury which may be due to other routes of elimination, such as transfer of methylmercury to breast milk as well as the fetus; however, the number of offspring for women of childbearing age was not assessed in this study.

An investigation by Taiwan's EPA reported that people older than 40 years of age had higher mercury hair concentrations than people younger than 20 years old.[28] Studies from other countries also found that increasing age correlated with higher hair mercury concentrations.[28] Since mercury is not easily excreted, the body burden increases with age.[28] Yorifuji, et al, (2009) also found that high exposures were associated with older fishermen.[29]

Table 1. Demographic Variables as Reported by Residents in Relation to Median, Minimum, and Maximum Hair Mercury Levels and Hazard Index Greater than the RfD of 1 µg/g			
Variable	**n (%)**	**Median Hair Hg (µg/g) (min – max)**	**Hazard Index > RfD n (% participants)**
Age, years			
18-25	34 (31)	0.7 (0.02 – 7.0)	8 (26)
26-35	24 (22)	1.0 (0.06 – 5.7)	9 (38)
36-45	16 (15)	0.8 (0.1 – 3.3)	6 (40)
46-55	26 (23)	1.8 (0.05 – 23.3)	18 (69)
> 56	10 (9)	1.4 (0.3 – 6.7)	7 (78)
Gender			
Men*	57 (52)	1.2 (0.2 – 7.0)	29 (53)
< 45 Years	35 (32)	1.0 (0.2 – 7.0)	13 (37)
> 46 Years*	22 (20)	2.0 (0.5 – 6.7)	16 (73)
Women	53 (47)	0.7 (0.02 – 23.3)	20 (38)
< 45 Years	39 (35)	0.6 (0.02 – 2.4)	10 (26)
> 46 Years	14 (12)	1.2 (0.05 – 23.3)	9 (64)
North/West vs Other Regions			
North/West*	33 (30)	1.1 (0.02 – 7.0)	18 (58)
All Others	74 (66)	0.7 (0.05 – 23.3)	31 (40)
Non-respondents	3 (4)	NA	NA
Residency, years (< 1 – 10 vs 11 – 40)			
< 1 – 10	15 (14)	0.4 (0.06 – 1.8)	1 (7)
11 – 40***	89 (81)	1.1 (0.02 – 23.3)	47 (53)
Non-respondents	6 (6)	NA	NA
Ethnicity			
Asian	39 (35)	1.1 (0.05 – 23.3)	19 (49)
Hispanic/Latino	5 (4)	0.5 (0.1 – 1.0)	0 (0)
Native Hawaiian/Pacific Islander	29 (26)	1.0 (0.02 – 7.0)	14 (48)
White/Caucasian	17 (15)	1.0 (0.06 – 5.7)	7 (41)
Mixed Race	18 (16)	1.0 (0.2 – 2.6)	8 (44)
Non-respondents	2 (2)	NA	NA
Education			
Grade School	2 (2)	2.1 (1.0 – 3.2)	1 (50)
High School	34 (31)	1.0 (0.05 – 23.3)	16 (47)
Associates/Trade Degree	15 (14)	0.7 (0.02 – 2.1)	7 (47)
Current College	20 (18)	0.8 (0.1 – 2.6)	7 (35)
College Degree	28 (25)	1.0 (0.1 – 5.4)	12 (43)
Graduate Degree	11 (10)	1.1 (0.06 – 6.7)	5 (45)
Income			
< 25,000 USD	23 (21)	0.8 (0.06 – 23.3)	6 (26)
25,000 USD – 39,999 USD	13 (12)	1.1 (0.1 – 7.0)	6 (46)
40,000 USD – 49,999 USD	11 (10)	1.0 (0.02 – 3.3)	5 (45)
50,000 USD – 75,000 USD	20 (18)	1.6 (0.1 – 5.4)	13 (65)
> 75,000 USD	23 (21)	1.6 (0.05 – 6.7)	13 (57)
No Response	19 (17)	0.7 (0.3 – 4.5)	5 (26)
Non-respondents	1 (1)	NA	NA
Fillings			
Yes	82 (75)	1.0 (0.02 – 23.3)	38 (47)
No	28 (25)	0.7 (0.06 – 5.4)	12 (43)

* significantly higher, $P < .05$; ***significantly higher, $P < .001$; NA = Not applicable

Table 2. Fish Consumption Factors as Reported by Residents in Relation to Median, Minimum, and Maximum Hair Mercury Levels and Hazard Index Greater than the RfD of 1 µg/g			
Variable	**n (%)**	**Median Hair Hg (µg/g) (min – max)**	**Hazard Index > RfD n (% participants)**
Source			
Store	70 (64)	1.0 (0.05 – 23.3)	32 (46)
Fishing	14 (13)	1.1 (0.1 – 5.4)	7 (50)
Store and Fish	20 (18)	0.9 (0.02 – 5.7)	8 (40)
Other	5 (4)	0.2 (0.06 – 1.4)	1 (20)
Non-respondents	1 (1)	NA	NA
Frequency			
< 1 day/week	51 (46)	0.7 (0.02 – 23.3)	15 (30)
1 - > 6 days/week**	59 (54)	1.2 (0.1 – 7.0)	34 (59)
Portion			
< 1/4 lb.	47 (43)	0.6 (0.02 – 23.3)	11 (24)
1/4 - 1/2 lb.***[a]	51 (46)	1.5 (0.1 – 6.7)	31 (62)
> 1/2 lb.	12 (11)	1.5 (0.1 – 5.7)	7 (58)
Frequency and Portion			
1/4 lb/week	34 (31)	0.6 (0.02 – 23.3)	6 (18)
1/2 lb/week	24 (22)	0.9 (0.1 – 5.5)	10 (42)
1 lb/week***[b]	30 (27)	1.7 (0.2 – 6.7)	21 (70)
> 1 lb/week*[c]	22 (20)	1.1 (0.1 – 7.0)	10 (45)
Amount of Fish Parts Consumed-Grouped Together			
< 1 – 2	70 (64)	0.7 (0.02 – 7.0)	23 (33)
3 – > 6***	39 (35)	1.6 (0.1 – 23.3)	25 (64)
Non-respondents	1 (1)	NA	NA
If Target Organs (Brain, Head, Heart) Are Consumed			
Yes***	36 (33)	1.9 (0.1 – 23.3)	25 (71)
No	73 (66)	0.7 (0.02 – 7.0)	24 (33)
Non-respondents	1 (1)	NA	NA

[a]=Mann-Whitney comparison between < 1/4 lb and 1/4 - 1/2 lb., [b]=Mann-Whitney comparison between 1/4 lb./week and 1 lb./week; [c]=Mann-Whitney comparison between 1/4 lb./week and > 1 lb./week; *significantly higher, $P < .05$; **significantly higher, $P < .01$, ***significantly higher, $P < .001$; NA = Not applicable

Table 3. Final Model for Log Transformed Mercury Levels				
Independent Variable	**Exp (Regression Coefficient)**	**Regression Coefficient**	**Standard Error**	***P*-Value**
Age (> 45 years)	1.54	0.43	0.20	.03
Gender (Female)	0.50	-0.69	0.19	.0004
Length of Residence (> 10 years)	1.92	0.66	0.27	.02
Frequency of Eating Fish (> 1 Day/Week)	1.72	0.54	0.19	.004

Table 4. Percentage of Total Participants Reporting Sentiments on Public Health Information About Methylmercury Exposure Through Fish Consumption

Response	n	% Participants	n (%) Men	n (%) Women
If fish advisories seen around Oahu (n = 109)				
No	63	58	35 (61)	28 (54)
Yes	46	42	22 (39)	24 (46)
If concerned about methylmercury exposure (n = 109)				
No	41	38	23 (41)	18 (34)
Yes	68	62	33 (59)	35 (66)
Cease fish consumption if methylmercury present in fish (n = 105)				
No	38	36	25 (44)	13 (27)
Yes	67	64	32 (56)	35 (73)
Fully informed about fish consumption (n = 108)				
No	66	61	33 (60)	33 (62)
Yes	42	39	22 (40)	20 (38)
Fully informed about methylmercury exposure from fish consumption (n = 107)				
No	86	80	46 (84)	40 (76)
Yes	21	20	9 (16)	12 (23)

Converting hair mercury concentrations from study participants to blood mercury concentrations, and comparing values to a 2013 national report from the US Department of Health and Human Services (UHDHHS) showed that levels in the participants were greater than the national average.[30] The UHDHHS reported geometric mean blood concentration for 2009-2010 as 0.883 µg/L for men and 0.845 µg/L for women.[30] In this current study, the estimated median blood mercury concentration from Hawai'i residents was 4.8 µg/L for men, and 2.8 µg/L for women.

It was hypothesized that ethnicity and cultural fish consumption practices may play a role in methylmercury toxicity. Ethnicity was not a significant factor for increased hair mercury levels in this data. Nevertheless, cultural and lifestyle factors, such as consumption of different fish parts, especially target organs (brain, head, and/or heart), resulted in high hair mercury levels in the univariate analysis, but was insignificant in multivariate analysis. This could be due to low power to detect such an effect. Some communities might be more susceptible than the general US population to contaminant exposure by consuming different fish parts with higher concentration of contaminants [1]

Most residents were concerned about methylmercury exposure through fish. They are likely to be receptive to education regarding safe consumption, since many lack knowledge about methylmercury exposure as a potential risk of consuming fish. Despite the health benefits, many reported they were willing to remove fish from their diet due to methylmercury concerns. However, fish is an essential food source for coastal populations, and is a source of nutrients, such as long chain omega-3 fatty acids, eicosapentanoic acid, docosahexanoic acid, selenium, and vitamin E, which can help prevent chronic diseases like cardiovascular disease, and have positive effects on systems that are adversely affected by methylmercury.[13,31]

Limitations of this study included a non-random sample of the population, a lack of information on whether fish consumed was local or imported, the use of a questionnaire that assessed only current fish consumption habits requiring the extrapolation of current fish consumption to the full time frame captured by the hair sample (1 – 2 months), and a lack of information regarding length of residency in their current area of O'ahu.

In conclusion, this study assessed the level of methylmercury exposure in relation to fish consumption among residents of O'ahu, Hawai'i using hair as a biomarker of exposure. Older men, longer residency in Hawai'i, and increased fish consumption habits were significant factors in higher hair methylmercury concentrations. In this group, older men had the highest hair mercury concentrations in comparison to younger men and women of any age; therefore, future studies are needed to establish safe levels for this group. The benefits of fish consumption should be highlighted along with the potential risks from methylmercury exposure.

Conflict of Interest/Disclosure Statement

None of the authors identify any conflict of interest or have any financial disclosures.

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