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Original Article

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Risk assessment of heavy metals in tuna from Japanese restaurants in the Republic of Korea

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ABSTRACT

Background: Studies on the risk of mercury (Hg) in Korean fishery products focus primarily on total Hg levels as opposed to methylmercury (MeHg) levels. None of the few studies on MeHg in tuna investigated tuna from Japanese restaurants. Few have evaluated lead (Pb), cadmium (Cd) and arsenic (As) in tuna. Thus, this study aimed to conduct a risk assessment by evaluating heavy metal concentrations in tuna from Japanese restaurants.
Methods: Thirty-one tuna samples were collected from Japanese restaurants in the Republic of Korea. They were classified according to region and species. The concentration of heavy metals in the samples was analyzed using the Ministry of Food and Drug Safety Food Code method. The rate of exceedance of maximum residue levels (MRLs) and the risk compared to the provisional tolerable weekly intake (PTWI) set by the Joint Food and Agriculture Organization/World Health Organization Expert Committee on Food Additives (%PTWI) were evaluated for risk assessment.
Results: The mean of MeHg, Pb, Cd and As concentrations were 0.56 ± 1.47 mg/kg, 33.95 ± 3.74 μg/kg, 14.25 ± 2.19 μg/kg and 1.46 ± 1.89 mg/kg, respectively. No sample exceeded the MRLs of Pb and Cd, but 9.7% of the samples exceeded the MRL of MeHg. The %PTWIs of MeHg, Pb, Cd and As were 4.2037, 0.0162, 0.0244 and 1.1627, respectively. The %PTWI of MeHg by age group and sex was highest among men aged 19–29 years (10.6494), followed by men aged 30–49 years (7.2458) and women aged 19–29 years (4.8307).
Conclusions: We found that 3 out of 31 samples exceeded the MRL of MeHg. The %PTWI of MeHg showed significant differences based on age and sex, and the value was likely to exceed a safe level depending on individuals' eating behaviors. Therefore, improved risk management for MeHg is required.

Keywords: Metals, Heavy; Mercury; Risk assessment; Tuna; Republic of Korea

BACKGROUND

Since the 1960s, the Republic of Korea (ROK) has undergone rapid industrialization and urbanization due to economic development and rapid economic growth. With rapid industrialization, our society has been facing environmental problems since the mid-1970s. Serious problems have arisen, such as the pollution of rivers and coastal waters due to factory

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Abbreviations

As: arsenic; BW: body weight; Cd: cadmium; Hg: Mercury; JECFA: Joint Food and Agriculture Organization/World Health Organization Expert Committee on Food Additives; LOD: limit of detection; LOQ: limit of quantification; MeHg: methylmercury; MFDS: Ministry of Food and Drug Safety; MRL: maximum residue level; Pb: lead; PTWI: provisional tolerable weekly intake; ROK: Republic of Korea; %PTWI: the risk compared to the provisional tolerable weekly intake set by the Joint Food and Agriculture Organization/World Health Organization Expert Committee on Food Additives.

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Competing interests

The authors declare that they have no competing interests.

Authors contributions

Conceptualization: Bae SJ, Sakong J; Data curation: Bae SJ, Shin KS; Formal analysis: Bae SJ, Son SY; Funding acquisition: Bae SJ; Investigation: Bae SJ, Park C, Sakong J; Methodology: Bae SJ, Shin KS; Project administration: Bae SJ, Sakong J; Resources: Bae SJ, Shin KS; Supervision: Sakong J; Validation: Sakong J; Visulization: Bae SJ, Baek K, Park C; Writing - original draft: Bae SJ; Writing - review & editing: Baek K, Park C, Sakong J.

wastewater and industrial waste. Heavy metals introduced into rivers and coastal waters by factory wastewater and domestic sewage are primarily accumulated in plankton. They enter the human body through the food chain and introduce toxicity to the human body. Mercury (Hg), lead (Pb), cadmium (Cd) and arsenic (As) are the most common heavy metals that poison humans.[1-4] They have high bioaccumulation potentials and are emerging as a major public health problem.

Hg is a heavy metal that presents a significant environmental health burden in terms of human toxicity. It ranks third on the substance priority list published by the Agency for Toxic Substances and Disease Registry after As and Pb.[5] Hg exists in various compounds, and the degree of toxicity can vary greatly depending on its properties.[6] Hg toxicity has been reported in events such as Hg poisoning due to previous occupational exposure, Iraqi grains and Minamata disease in Japan.[7-9] Most cases of Hg exposure in members of the general public, who are not exposed to occupational exposure, are due to the introduction of methylmercury (MeHg) into the human body through food intake. Long-term intake of fishery products, which have accumulated MeHg through the food chain, is suspected to be the main source of exposure.

MeHg that enters the body can be accumulated in the brain and, therefore, MeHg poisoning mainly causes central nervous system disorders.[6,7] Health effects may vary depending on the route of entry, exposure, and individual susceptibility. Studies have reported that MeHg is related to various health issues such as cardiovascular toxicity,[10-12] reproductive and developmental toxicity,[13,14] and immunotoxicity.[15,16] Moreover, concerns have been raised regarding the chronic health effects of low-dose exposure.

The average blood Hg concentration of Korean adults is 4–5 times higher than that of individuals in developed countries,[17] and the need to reduce Hg exposure in the ROK is constantly being emphasized. In the ROK, the Ministry of Environment is preparing Hg management measures that meet international standards. To reduce human exposure and risk caused by Hg, they are laying the social foundation and efficiently implementing the Minamata Convention on Hg. Accordingly, since 2006, a Hg management comprehensive plan has been established and announced every 5 years.

Tuna, a deep-sea fish, is a carnivorous fish with the highest concentration of heavy metals among fish because it belongs to the upper stage of the food chain.[18,19] In developed countries, various studies and warnings have long been conducted on the risk of Hg exposure through excessive tuna intake.[20-22] In a study conducted in Europe, the species that contributed the most to the risk of MeHg were tuna, sea bream and bass; cod, pollack, shrimp and octopus also contributed in some countries.[23]

The annual consumption of per capita fishery product in the ROK shows an increasing trend from 49.5 kg in 2005 to 69.9 kg in 2019, and the per capita tuna supply per day has also increased from 2.76 g in 2005 to 5.32 g in 2019.[24] In the ROK, many people enjoy eating tuna in Japanese restaurants, and in some restaurants and online shopping malls, the number of consumer groups is increasing to the extent that only special parts such as tuna cheeks are handled and sold separately. As consumption and popularity increase, so does the risk of toxicity. There has been a case of Hg poisoning due to sailors' excessive consumption of tuna.[25] Accordingly, the importance of risk assessment of Hg toxicity via tuna intake in the ROK is increasing.

However, studies on Hg in fishery products in the ROK have mainly focused on total Hg or other heavy metal concentrations, as opposed to MeHg.[26-30] MeHg studies on deep-sea fish, tuna and grayfin have been conducted on samples collected in wholesale and retail markets.[31-33] For central and local governments, fishery product safety surveys in the production stage are conducted by the Ministry of Oceans and Fisheries and fishery-related departments of the local government. The safety survey of heavy metals such as Hg, Pb, Cd and As in the distribution stage is conducted by the regional offices of the Ministry of Food and Drug Safety (MFDS) and the food hygiene departments of local governments. The MFDS as a whole promotes safety management from production to distribution, and it is conducted according to the food safety administrative guidelines of the MFDS, which are revised every year. To ensure the safety of fishery products, regular general collection inspections or intensive collection inspections of fishery products selected as special management items are conducted using statistics. The collection sites are generally storage warehouses, agricultural and fishery wholesale markets, as well as large discount stores. Fishery products are collected and inspected regardless of their storage status (i.e., refrigerated or frozen).[34] In the case of tuna, in the production stage, MeHg analysis is carried out after being harvested from the freezing warehouse of the processing plant and collected during frozen storage. In the distribution stage, collection inspections are carried out in special cases, such as when related safety issues are raised. Unlike commonly consumed fishery products that are regularly collected and inspected, collection inspections of tuna are scarcely carried out.

There has been little research on MeHg in tuna samples just before consumption at the end of the distribution process. A Japanese restaurant is a collection site where no further collection inspection is possible. Therefore, there is a difference from existing studies in that it can finally be confirmed whether proper safety management has been performed. In addition, the safety survey of MeHg in tuna in fishery product safety surveys conducted by the central and local governments has been conducted less frequently under specific storage conditions. Pb, Cd and As in deep-sea fish, tuna and grayfin are less harmful than Hg. However, even considering that only a few studies on Pb, Cd and As have been conducted in the ROK. There are no studies related to the risk in Japanese restaurants. Therefore, this study aimed to conduct a risk assessment of MeHg, Pb, Cd and As in tuna immediately before consumption in Japanese restaurants and confirm whether safety management has been performed properly.

METHODS

Analysis of concentration of heavy metals

The tuna samples for this study were collected from January to April 2021 at Japanese restaurants in various regions in the ROK. A total of 31 cases, 22 bigeye tuna and 9 bluefin tuna samples were collected. They were served as sashimi in a refrigerated state, and only the cheek part was used as a sample. For central and local governments, as a test sample, the head, tail, intestines and scales are removed, and muscle parts including the skin are used. The muscle parts contain the cheek part. For sample preparation, an appropriate amount was put in a 7-mL tube and homogenized 10 times for 1 minute at 6,500 RPM at 4°C to prevent thermal deformation of the sample. More than 100 g was homogenized and frozen at −20°C. For MeHg analysis, MFDS Food Code 8. General test 9.1.7.2 Method 2 was used, which extracts MeHg from the sample with an L-cysteine solution, collects it with the gold amalgam, and measures it with cold vapor atomic absorption spectrophotometry. An automated Hg analyzer (Hydra-C; Teledyne Leeman Labs, Hudson, NH, USA) was used from the combustion of samples to the measurement by cold vapor atomic absorption spectrophotometry. For the preparation of test solutions for Pb, Cd and As, a microwave (Multiwave7000; Anton Paar, Graz, Austria) was used, following the microwave digestion method of MFDS Food Code 8. General test 9.1.2. For concentration measurement, the prepared solution was assessed using a mass spectrometer (7900 ICP-MS; Agilent, Santa Clara, CA, USA) according to inductively coupled plasma mass spectrometry as given by the MFDS Food Code 8. General test 9.1.2.

Validation of analytical procedure

The limit of detection (LOD), limit of quantification (LOQ), recovery rate and linearity were confirmed by the International Council for Harmonization guidelines for heavy metal analysis, and then validation was performed. For the measurement of the calibration curve of the standard solution of MeHg, a 1,000 mg/kg solution of MeHg chloride was used as the standard product. The concentration of the MeHg standard solution showed excellent linearity, as it showed an average correlation coefficient (R^2) of 0.997. The LOD and LOQ were 0.0024 and 0.0071 µg/kg, respectively, and the recovery rate was 95.2%. In the cases of Pb, Cd and As, all showed an R^2 value of 0.999 or more. The LOD values were 0.0026, 0.0006 and 0.0078 µg/kg, respectively, and the LOQ values were 0.0079, 0.0017 and 0.0234 µg/kg, respectively. The average recovery rates were 96.6, 97.2 and 98.0%, respectively (**Supplementary Table 1**).

Risk assessment

The heavy metal concentrations and their descriptive statistics were analyzed by region and species of tuna. The rates of exceedance (%) of maximum residue levels (MRLs) for MeHg, Pd and Cd were estimated; this was not analyzed for As because it does not have an established MRL from the MFDS. For risk assessment, the risk compared to the provisional tolerable weekly intake (PTWI) set by the Joint Food and Agriculture Organization/World Health Organization Expert Committee on Food Additives (JECFA) (%PTWI) was calculated according to the following formulas.

Exposure assessment formula:

$$\text{Weekly Exposure } (\mu\text{g/kg bw/week}) = \frac{\text{C (g/kg)} \times \text{I (g/week)}}{\text{BW(kg bw)}}$$

C indicate the concentration of heavy metals; I indicate weekly intake of tuna; BW indicate body weight.

Risk assessment formula:

$$\%\text{PTWI} = \frac{\text{Weekly Exposure } (\mu\text{g/kg bw/week})}{\text{PTWI } (\mu\text{g/kg bw/week})} \times 10^2$$

For the calculation, the weekly intake of tuna and BWs of Korean individuals were obtained using data from the Korea National Health and Nutrition Examination Survey in 2019 and the National Health Screening Statistics in 2020, respectively.

Statistical analysis

The Korean National Environmental Health Survey on Third Stage (2015–2017) was used to calculate the frequency of tuna intake. Statistical analysis was performed using a statistical software package (IBM SPSS Statistics Version 26.0; IBM Corp., Chicago, IL, USA).

RESULTS

The concentration of heavy metals in tuna

MeHg, Pb, Cd and As concentrations in the 31 samples ranged from 0.26–1.08 mg/kg, 2.70–262.03 μg/kg, 2.43–41.86 μg/kg and 0.43–3.61 mg/kg, respectively. The geometric means of those were 0.56 ± 1.47 mg/kg, 33.95 ± 3.74 μg/kg, 14.25 ± 2.19 μg/kg and 1.46 ± 1.89 mg/kg, respectively. The arithmetic means of those were 0.61 ± 0.23 mg/kg, 67.29 ± 70.43 μg/kg, 18.14 ± 10.93 μg/kg and 1.75 ± 1.01 mg/kg, respectively (**Table 1**).

In 22 samples of bigeye tuna, MeHg, Pb, Cd and As concentrations ranged from 0.26–1.08 mg/kg, 2.70–262.03 μg/kg, 4.52–41.86 μg/kg and 0.88–3.61 mg/kg, respectively. The geometric means of those were 0.56 ± 1.54 mg/kg, 31.05 ± 3.97 μg/kg, 19.12 ± 1.81 μg/kg and 1.99 ± 1.55 mg/kg, respectively. The arithmetic means of those were 0.59 ± 0.26 mg/kg, 83.05 ± 70.07 μg/kg, 18.83 ± 10.00 μg/kg and 2.15 ± 0.89 mg/kg, respectively (**Table 1**).

In 9 samples of bluefin tuna, MeHg, Pb, Cd and As concentrations ranged from 0.38–0.80 mg/kg, 7.56–217.46 μg/kg, 2.43–23.31 μg/kg and 0.43–1.16 mg/kg, respectively. The geometric means of those were 0.58 ± 1.28 mg/kg, 42.22 ± 3.33 μg/kg, 6.94 ± 2.12 μg/kg and 0.69 ± 1.42 mg/kg, respectively. The arithmetic means of those were 0.60 ± 0.14 mg/kg, 74.64 ± 75.03 μg/kg, 8.99 ± 7.26 μg/kg and 0.73 ± 0.25 mg/kg, respectively (**Table 1**).

The MFDS set the MRLs for MeHg, Pb and Cd in fishery products as 1.0, 0.5 and 0.2 mg/kg, respectively. No MRL has been established for As in fishery products. No sample exceeded the MRLs for Pb and Cd, but 9.67% of the samples exceeded the MRL for MeHg (**Table 2**).

Table 1. Concentration of heavy metals in tuna by region

Variables	Sample number	MeHg (mg/kg)		Pb (μg/kg)		Cd (μg/kg)		As (mg/kg)	
		GM ± GSD (Minimum–Maximum)	AM	GM ± GSD (Minimum–Maximum)	AM	GM ± GSD (Minimum–Maximum)	AM	GM ± GSD (Minimum–Maximum)	AM
Total	31	0.56 ± 1.47 (0.26–1.08)	0.61	33.95 ± 3.74 (2.70–262.03)	67.29	14.25 ± 2.19 (2.43–41.86)	18.14	1.46 ± 1.89 (0.43–3.61)	1.75
Bigeye tuna	22								
Total		0.56 ± 1.54 (0.26–1.08)	0.59	31.05 ± 3.97 (2.70–262.03)	83.05	19.12 ± 1.81 (4.52–41.86)	18.83	1.99 ± 1.55 (0.88–3.61)	2.15
Bluefin tuna	9								
Total		0.58 ± 1.28 (0.38–0.80)	0.60	42.22 ± 3.33 (7.56–217.46)	74.64	6.94 ± 2.12 (2.43–23.21)	8.99	0.69 ± 1.42 (0.43–1.16)	0.73

MeHg: methylmercury; Pb: lead; Cd: cadmium; As: arsenic; GM: geometric mean; GSD: geometric standard deviation; AM: arithmetic mean.

Table 2. Rate of exceedance (%) of the MRLs of heavy metals in tuna

Heavy metals	MRLs[a] (mg/kg)	Rate of exceedance (%)
MeHg	1.0 (in deep-sea fish, tuna, and billfish)	9.67
Pb	0.5 (in fish)	0.00
Cd	0.2 (in marine fish)	0.00
As	-[b]	-

MRL: maximum residue limit; MeHg: methylmercury; Pb: lead; Cd: cadmium; As: arsenic; MFDS: Ministry of Food and Drug Safety.
[a]Values were established by the MFDS; [b]The MRL of As for fishery products has not been established by the MFDS.

Table 3. Risk assessment of heavy metals in tuna among the Korean population

Heavy metals	C[a] (mg/kg)	Weekly exposure[b] (μg/kg bw/week)	PTWI[c] (μg/kg bw/week)	%PTWI	I[d] (for %PTWI as 100; g/week)
MeHg	0.5637	0.0673	1.6	4.2037	174.84
Pb	0.0339	0.0040	25.0	0.0162	45,427.73
Cd	0.0143	0.0017	7.0	0.0244	30,153.85
As	1.4617	0.1744	15.0	1.1627	632.14

C: concentration of heavy metals; PTWI: provisional tolerable weekly intake; %PTWI: the risk compared to the provisional tolerable weekly intake set by the Joint Food and Agriculture Organization/World Health Organization Expert Committee on Food Additives; I: weekly intake of tuna; MeHg: methylmercury; Pb: lead; Cd: cadmium; As: arsenic; JECFA: Joint Food and Agriculture Organization/World Health Organization Expert Committee on Food Additives.
[a]Geometric mean is used; [b]Weekly intake of tuna and body weight were calculated as 7.35 g/week and 61.6 kg, respectively. The values came from the Korean National Health and Nutrition Examination Survey in 2019; [c]Values were established by the JECFA. Since the JECFA withdrew the PTWIs of Pb and As in 2010, previous JECFA values were used for these metals; [d]Values at which the %PTWI becomes 100 by tuna consumption alone were calculated.

Table 4. The %PTWI of MeHg in tuna by age group and sex[a] according to the Korean National Health and Nutrition Examination Survey

Sex	Age groups (years)			
	19–29	30–49	50–64	≥ 65
Total	8.2820	5.5770	2.6180	0.9816
Male	10.6494	7.2458	1.3528	1.7963
Female	4.8307	3.2992	4.1452	0.2638

%PTWI: the risk compared to the provisional tolerable weekly intake set by the Joint Food and Agriculture Organization/World Health Organization Expert Committee on Food Additives; MeHg: methylmercury.
[a]Values of the weekly intake of tuna and the body weights of each individual come from the Korea National Health and Nutrition Examination Survey in 2019. Each value is based on age, group, and sex.

Risk assessment of heavy metals through tuna intake

The average weekly intake of tuna and BW obtained from the Korea National Health and Nutrition Examination Survey in 2019 were 7.35 g/week and 61.6 kg, respectively. The weekly exposure of MeHg, Cd, Pd and As via tuna intake calculated by applying the geometric mean of the samples, weekly intake of tuna, as well as BW were 0.0626, 0.0038, 0.0016 and 0.1624 μg/kg bw/week, respectively (**Table 3**).

The PTWIs of MeHg, Pb Cd and As set by the JFCFA were 1.6, 25.0, 7.0 and 15.0 μg/kg bw/week, respectively. By applying weekly exposure via tuna, the %PTWI of those were 4.2037, 0.0162, 0.0244 and 1.1627, respectively. Assuming the extreme scenario in which the %PTWI of each heavy metal is 100 by tuna consumption alone, their weekly intake would be 174.84, 45427.73, 30153.85 and 632.14 g/week, respectively (**Table 3**).

The %PTWI of MeHg in tuna by age group and sex was calculated by applying data from the Korea National Health and Nutrition Examination Survey in 2019. The %PTWI was highest in men aged 19–29 years, followed by men aged 30–49 years and women aged 19–29 years, with values of 10.6494, 7.2458 and 4.8307, respectively (**Table 4**).

DISCUSSION

The ROK is a country that consumes a large amount of tuna, especially in the form of sashimi. Sashimi consumption is estimated to be 360,000–496,000 mt worldwide, including 300,000–400,000 mt in Japan, 30,000–50,000 mt in the United States of America, and 15,000–20,000 mt in the ROK.[35] Bluefin tuna is the most expensive kind of tuna, but it is frequently consumed as it is a delicacy. After hatching, the body length grows to 52–78 cm at 1 year, 102–124 cm at 3 years, 143–160 cm at 5 years, and 225–234 cm at 11 years. It is estimated that it has a total length of about 460 cm.[36] Bigeye tuna is another popular high-quality tuna served with bluefin tuna. After hatching, the body length grows to 55 cm at 1 year, 100 cm at 3 years, 140 cm at 5 years, and 160 cm at 6 years. Its total length is about 250 cm.[37] These 2 species are the top predators of the marine ecosystem besides whales and sharks, and they have a long lifespan, so the accumulation of heavy metals in the body is quite high.

In the ROK, studies have been conducted on the concentration of heavy metals in tuna, but not from Japanese restaurants. In a study on Korean fishery products distributed wholesale conducted by the National Institute of Fisheries Science in 2017, the MeHg concentration of bluefin tuna was 0.183 mg/kg.[38] In a study on Korean fishery products distributed wholesale conducted by the Gyeonggi-do Institute of Health and Environment in 2017, the MeHg concentration of bigeye tuna was 0.230 mg/kg and that of bluefin tuna was 0.192 mg/kg.[33] A report on Korean food safety conducted by the MFDS in 2017 found that the MeHg concentration of bigeye tuna was 0.291 mg/kg and that of bluefin tuna was 0.178 mg/kg. In addition, the concentrations of Pb, Cd and As in bluefin tuna were 0.0240, 0.0167 and 1.747 mg/kg, respectively.[39] The concentrations of Pb, Cd and As in the present study were below or slightly above the values identified in previous studies and were considered safe, but that of MeHg showed a difference of more than twice the previously reported value.

The MRLs for Hg in food in the ROK are divided into total Hg and MeHg. The MFDS has been monitoring food since the 2000s and has evaluated the safety of heavy metals based on this. Through this safety evaluation of food, the MRLs for heavy metal concentrations have been established and are being revised. The MRLs were set so that the total Hg could not exceed 0.5 mg/kg in fishery products (except for deep-sea fish, tuna and billfish). The MRLs of deep-sea fish, tuna and billfish were set at 1.0 mg/kg for MeHg, but not for total Hg.[40] Overseas, the MRL of MeHg is set at 0.5 (carnivorous, 1.0) by the Codex Alimentarius Commission, 1.0 by the United States and 0.5 (carnivorous, 1.0) by China.[41] In this study, 9.7% of the samples exceeded both Korean and foreign MRLs.

For Korean and foreign Hg safety surveys, fishery products are generally measured in refrigerated or frozen conditions.[42,43] Tuna is generally stored in a frozen state and then used in various dishes. The water content of tuna may decrease during cooking processes such as grilling, frying and boiling. Therefore, the MeHg concentration of tuna after cooking may be higher than when it is refrigerated, frozen, or raw.[44,45] Since the samples analyzed in this study were raw portions of tuna, the concentration of MeHg in tuna may be higher when consumed after cooking. Therefore, consumers must pay attention to the different preparations of tuna.

Along with the MRLs for MeHg in fishery products, many countries and international organizations investigate a safe level of human intake of MeHg. Regarding PTWI, which indicates a level that is safe to accumulate in the human body due to dietary intake over a lifetime, the MFDS stipulated 2.0 μg/kg bw/week as the acceptable intake level for MeHg. In addition, for pregnant and lactating women and 1–2-, 3–6-, and 7–10-year-old children, which are sensitive groups with concentrated health effects from Hg, it was recommended that less than 100 g, 25 g, 40 g, and 65 g was consumed per week, respectively.[43] The JECFA and European Food Safety Authority set the PTWI value in their areas at 1.6 μg/kg bw/week and 1.3 μg/kg bw/week, respectively.[46,47]

When the %PTWI of heavy metals in food exceeds 100, it is judged to exceed safe levels.[48] Most of the exposure to Hg in members of the general population who are not occupationally exposed is due to food intake. The %PTWI of MeHg by food intake in the Korean population is 15.0%, and the extreme (top 95%) is 55.0%.[49] This suggests that exposure to MeHg via tuna intake in the Korean population is still within a safe level. However, assuming the extreme scenario in this study in which the %PTWI becomes 100 by tuna consumption alone, the tuna intake per week would be 174.84 g. Since adults consume 150–300 g of tuna in a single meal, this extreme %PTWI is possible for those who eat tuna more than once a week. In the Korean National Environmental Health Survey on Third Stage (2015–2017), it was calculated as 13.9% answered that they eat large fish at least once a week. However, it should be considered that this ratio includes large fish other than tuna and canned fish. Furthermore, when the value of the %PTWI was divided by age group and sex, the group with the highest value was 2.53 times the total value and 40.37 times the value of the group with the lowest value. This shows the need for risk management according to age and sex.

Unlike Pb, Cd and As, it has been confirmed that MeHg was present in tuna just before being served as sashimi after fishery product safety surveys were conducted by the central and local governments. The central and local governments need to monitor MeHg concentrations more carefully than just before consumption at Japanese restaurants. Since it is difficult to conduct a full investigation of tuna, consumers must pay attention to their tuna intake. Therefore, additional awareness programs, such as mandatory warning posters on the toxicity of MeHg, are required to help consumers exercise caution.

Further studies are warranted on the dose-response relationship between the intake of tuna and the concentration of MeHg in the blood to establish the causal association. In addition, to accurately evaluate exposure and risk through tuna consumption, the proportion of tuna in the total food group and the food group that mainly contributes to MeHg intake should be considered. Larger samples are also required to validate the statistical conclusions of this study.

This study has another limitation. Tuna has a variety of habitats with different Hg accumulation rates. Therefore, the concentration of Hg in tuna differs depending on the habitat.[50,51] Moreover, Hg is taken up at a faster rate than it is excreted. The concentration of Hg typically increases with their size and age.[52,53] However, in restaurants, they are sold in a mixed state of various habitats, sizes and ages, so it was not possible to identify these in this study. Therefore, it is possible that the concentration of MeHg was overestimated. Furthermore, Hg concentration differs depending on the part of the muscle of the product.[54] So, it is necessary to distinguish it into various edible parts in addition to the edible part used in this study. Considering these points, it is possible to more accurately evaluate the risk of MeHg due to tuna intake. Additional research is needed wherein samples are collected by classifying the tuna based on habitat, size, age and edible parts.

CONCLUSIONS

This study revealed that tuna served in Japanese restaurants have high concentrations of MeHg. Although the %PTWIs of MeHg, Pb, Cd and As were at safe levels in the Korean population, there were samples of MeHg that exceeded the established MRL. The %PTWI of MeHg has the potential to exceed a safe level depending on eating behaviors, and the value showed a large difference according to age and sex. Therefore, local and central governments should improve monitoring and promote awareness programs of MeHg. Further studies are required to establish the causal association between the concentration of MeHg in the blood and tuna intake.

SUPPLEMENTARY MATERIAL

Supplementary Table 1

LOD, LOQ, recovery rate, and linearity of heavy metals in tuna

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