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Health Risk Assessment of Some Heavy Metals from Canned Tuna and Fish in Tijuana, Mexico

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Abstract

Background: A main route of heavy metal exposure is the consumption of contaminated food or water, resulting in negative health effects.

Objectives: The objective of this study was to assess the health risk related to consumption of canned tuna and fresh fish by evaluating chromium (Cr), cadmium (Cd), mercury (Hg), and lead (Pb) concentrations.

Methods: Forty-eight samples of tuna canned in water and 20 samples of different fish species sold in the city of Tijuana were used. Samples were digested by microwave-assisted digestion. Mercury was measured using the cold vapor atomic absorption spectrometry (CVAAS) method (United States Environmental Protection Agency (USEPA) method 7419b) and Pb, Cd, and Cr were measured using graphite furnace atomic absorption spectroscopy (GFAAS) (USEPA method 7010). Health risk assessment was conducted calculating the total hazard quotients (THQs) using the USEPA region III risk-based concentration table for adults.

Results: The wet weight heavy metal concentrations in the canned tuna for Hg were 0.005 to 1.17 mg/kg, for Pb were 0.07 to 0.32 mg/kg, for Cd were from not detected (ND) to 0.007 mg/kg, and for Cr were 0.02 to 0.65 mg/kg. In the fresh fish samples, concentrations of Hg were 0.14 to 2.14 mg/kg, for Pb were 0.04 to 0.32 mg/kg, for Cd were 0.001 to 0.003 mg/kg, and for Cr were 0.07 to 0.38 mg/kg. The highest Hg concentrations were found in species of mako shark (*Isurus oxyrinchus*) and soupfin shark (*Galeorhinus galeus*). THQ values calculated were below one for all the samples.

Conclusions: The results suggest that the consumption of canned tuna and fish in Tijuana does not represent a health risk for the general population in terms of exposure.

Keywords: Heavy Metal, Health Risk Assessment, Fish, Tuna

1. Background

In recent years, concern about food quality has increased, particularly in those foods at risk of containing toxic elements and compounds that represent a risk to human health, such as persistent organic pollutants (POPs) and heavy metals. Some metals, such as zinc, copper, iron, and manganese, are essential for human health in trace amounts. However, mercury, cadmium, and lead are toxic and not essential (1, 2).

Predator fish such as sharks, swordfish, and tuna may come to contain high amounts of mercury in their tissues. These high concentrations of mercury in fish have stimulated interest in this element because of biomagnification (3). Fish consumption is popular in many countries because it is a good source of protein, minerals, and omega-3 fatty acids, and is relatively low in cholesterol (4). Muscle tissue from tuna is an important part of packaged fish consumption because it is a reliable and convenient source. Ingestion of fish has been identified as the principal source of mercury exposure for humans (5).

The relationship between the concentration of mercury in blood and fish consumption was identified by Bjornberg (5). Fish consumption in Mexico is relatively low, at 11.4 kg per capita-year (6), and is well below the international average of 18 kg per capita-year. Countries such as Japan consume more than 30 kg per capita-year, and in certain sectors of the population, such as coastal regions, consumption is even higher, presenting a greater risk for children and pregnant women. Since adverse health effects are largely dependent on the magnitude of the dose (7), it is important to know the levels of toxic metals in saleable fish to evaluate the health risks associated with its consumption. There have been few studies in Mexico on heavy metal concentration in fish, the majority of which have been concerned with mercury concentration. However, the levels of

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heavy metals in fish consumed in the city of Tijuana are unknown.

2. Objectives

The aim of this work was to evaluate the concentration of Cr, Cd, Hg and Pb in samples of canned tuna and fish sold in Baja California to assess the health risk resulting from consumption of these products.

3. Methods

Canned tuna and fresh fish samples were collected during 2016 in different commercial establishments in Tijuana, Mexico, using simple random sampling. Forty-eight samples (six samples from eight different brands of canned tuna) were analyzed ensuring that all the samples were from different production batches. We also analyzed 20 samples of fresh fish: five samples from four species: *Isurus oxyrinchus* (mako shark), *Xiphias gladius* (swordfish), *Galeorhinus galeus* (soupfin shark), and *Thunnus albacares* (sellowfin tuna). All the canned tuna and fresh fish samples were analyzed for Cd, Cr, Pb, and Hg. Sample size was determined using a 95% level of confidence, considering that the concentration values are in an amplitude value of 2.5.

The method described by Hight and Cheng (8) was used to determine total Hg in marine products using microwave-assisted digestion for the canned tuna and fish samples. Once the samples had been digested, mercury levels were measured with cold vapor atomic absorption spectrometry (USEPA method 7471b) using a Perkin-Elmer atomic absorption spectrometer, model 372 (Waltham, Massachusetts, US), which was equipped with a hollow mercury cathode lamp.

Sample digestion for the analysis of Cd, Cr and Pb was conducted using the microwave assisted digestion method described by Mindak and Cheng (9). The digested samples were analyzed with the USEPA 7010 method, using a GBC scientific equipment atomic absorption spectrometer, model Xplor AA dual, with a graphite oven, model GF 5000 (Melbourne, Australia).

The Kolmogorov-Smirnov test was performed to determine whether the data set fit a normal distribution. Analysis of variance (ANOVA) was then used to determine any significant differences between the heavy metal concentrations analyzed. The Tukey-Kramer pairwise multiple comparison test was used to determine significant differences between brands or species. The Minitab 16® program was used to perform all the aforementioned statistical analyses.

Table 1 shows the recoveries of quality control and spiked samples. The results obtained for the certified reference samples varied from 95% to 105% recovery. Calibration blanks and method blanks were below the method detection limit, implying that there was no contamination of samples during the analysis process. The relative percentage differences were less than 10% in the duplicated samples and the fortified samples showed between 85% and 102% recovery.

4. Results and Discussion

4.1. Concentration of Metals in Canned Tuna

The average mercury concentration in the different brands analyzed did not exceed the maximum permissible limit (MPL) established in the official Mexican standard (1.0 mg/kg). Only two of the 48 samples analyzed (representing 4.16% of the total) showed a Hg concentration above the MPL (1.170 and 1.040 mg/kg). These results illustrate the importance of regular trace metal controls in canned tuna.

Average Cr and Pb concentrations met the current regulation of 0.5 and 1 mg/kg, respectively; however, compared to European Union (EU) legislation, which for Pb is 0.20 mg/kg, two of the samples (4.16%) showed a concentration above that limit (0.322 and 0.289 mg/kg). The range, mean concentrations, and incidence of occurrence for each of the metals in the analyzed samples are shown in Table 2.

The concentrations of Hg, Pb, Cd, and Cr in canned tuna samples from various published studies around the world are shown in Table 3. Ikem and Egiebor (10) analyzed 29 samples of canned tuna in Alabama, in the United States, and the Cd and Hg mean concentrations were similar to the means obtained in this study. The highest mercury concentrations in individual samples were those reported by Storelli et al. (11) in Italy, and Mol (12) in Turkey, with wet weight values of 1.79 mg/kg and 1.14 mg/kg, respectively. These values are similar to the maximum value reported in this study (1.17 mg/kg), which is higher than the MPL of Mexican regulations (1.0 mg/kg). The lowest mercury concentration was reported in this study (0.005 mg/kg). The maximum concentration was found by Ruelas-Inzunza et al. (13) in canned tuna in the state of Sinaloa (0.51 mg/kg). The mean lead concentration reported in this study was 0.113 mg/kg, which is below the mean reported in Iran by Hosseini et al. (14) of 0.19 mg/kg, thereby meeting the MPL for Pb (1.0 mg/kg) in samples of canned fish. The maximum value reported for lead was 4.13 mg/kg by Mol (12), which is higher than that of the Mexican standards; while, maximum values reported by Olmedo et al. (15), Okyere et al. (16), Hosseini et al. (14) and in this study are higher than the MPL established in the EU (0.2 mg/kg). Their values were

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Table 1. Quality Control and Sample Spike Results

Element	Recovery, %		Detection Limit (DL), mg/kg
	Quality Control (SRM1[a])	Sample Spike (SRM2[b])	
Pb	95	98	0.01
Cd	105	102	0.001
Cr	101	85	0.01
Hg	97	99	0.000003

Abbreviation: SRM, standard reference materials.
[a]SRM1: ERA 524 (Pb 1.0 μg/mL, Cd 1.0 μg/mL, Cr 1.0 μg/mL), Lot number 330416. SRM1(Hg): ERA 027 (Hg 1000 μg/mL), Lot number 410214.
[b]SRM2: UltraScientific ICP-082 (Pb, 1000 μg/mL), UltraScientific ICP-048(Cd, 1000 μg/mL), UltraScientific ICP-024(Cr, 1000 μg/mL), UltraScientific IAA-280(Hg, 1000 μg/mL), Lot numbers: Pb (CP1239), Cd (CL2608), Cr (R01377), Hg (L00245).

Table 2. Minimum, Maximum, Mean and Standard Deviation (SD) of Hg, Pb, Cd and Cr in Canned Tuna Samples and Fresh Fish Samples (mg/kg ww)

	Sample, N	Hg			Pb			Cd			Cr		
		Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD
Brand							**Canned Tuna**						
M1	6	0.150	0.650	0.304 ± 0.199	0.070	0.110	0.091 ± 0.016	0.0000	0.004	0.0019 ± 0.0014	0.020	0.210	0.123 ± 0.068
M2	6	0.130	0.540	0.292 ± 0.153	0.090	0.130	0.109 ± 0.015	0.0004	0.005	0.0027 ± 0.0018	0.020	0.0450	0.170 ± 0.163
M3	6	0.110	0.670	0.366 ± 0.216	0.090	0.130	0.113 ± 0.014	0.0003	0.005	0.0029 ± 0.0021	0.070	0.300	0.191 ± 0.102
M4	6	0.110	1.170	0.560 ± 0.450	0.080	0.320	0.174 ± 0.105	0.0009	0.006	0.0034 ± 0.0017	0.080	0.650	0.270 ± 0.199
M5	6	0.230	0.840	0.405 ± 0.243	0.110	0.130	0.120 ± 0.007	0.0026	0.007	0.0040 ± 0.0015	0.120	0.260	0.166 ± 0.049
M6	6	0.005	0.320	0.116 ± 0.115	0.090	0.120	0.104 ± 0.009	0.0008	0.006	0.0032 ± 0.0023	0.060	0.180	0.123 ± 0.045
M7	6	0.030	0.210	0.115 ± 0.070	0.080	0.100	0.086 ± 0.008	0.0003	0.007	0.0031 ± 0.0029	0.050	0.400	0.182 ± 0.136
M8	6	0.060	0.280	0.140 ± 0.094	0.080	0.140	0.103 ± 0.020	0.0006	0.003	0.0020 ± 0.0010	0.080	0.170	0.113 ± 0.032
Species							**Fresh Fish**						
Mako shark (*Isurusoxyrinchus*)	5	0.690	2.140	1.286 ± 0.601	0.100	0.320	0.159 ± 0.093	0.001	0.003	0.0023 ± 0.0005	0.160	0.380	0.216 ± 0.093
Yellowfin tuna (*Thunnusalbacares*)	5	0.140	0.570	0.377 ± 0.161	0.090	0.150	0.116 ± 0.026	0.001	0.002	0.0019 ± 0.0001	0.080	0.130	0.102 ± 0.020
Soupfin shark (*Galeorhinusgaleus*)	5	0.460	1.810	1.128 ± 0.522	0.040	0.130	0.096 ± 0.032	0.001	0.002	0.0018 ± 0.0002	0.070	0.180	0.137 ± 0.042
Swordfish (*Xiphias gladius*)	5	0.380	0.720	0.545 ± 0.123	0.080	0.160	0.119 ± 0.030	0.001	0.003	0.0022 ± 0.0004	0.150	0.180	0.168 ± 0.014

Abbreviation: ww, wet weight.

0.385 mg/kg, 0.30 mg/kg, 0.93 mg/kg, and 0.32 mg/kg, respectively.

The mean Cd concentration in this study was 0.003 mg/kg, which is lower than the mean concentrations reported in Table 3, with the exception of the mean value reported by Ikem and Egiebor (10) (0.002 mg/kg). The maximum concentration value for Cd was 0.45 mg/kg, which was reported by Okyere et al. (16) in Ghana. However, all the results shown in Table 3 are below the MPL established in Mexican standards for Cd (0.5 mg/kg). The maximum values for Cd reported by Okyere et al. (16) (0.45 mg/kg), Hosseini et al. (14) (0.27 mg/kg), Olmedo et al. (15) (0.17 mg/kg), and Storelli et al. (11) (0.14 mg/kg) are all above the MPL of the EU (0.1 mg/kg). In most of the studies shown in Table 3, Cr concentrations were not quantified. The only value reported was 0.006 mg/kg by Ikem and Egiebor (10), which was approximately 28 times lower than those in this study (0.167 mg/kg).

4.2. Metal Concentrations in Fish

The heavy metal concentrations in samples of fresh fish of the different species analyzed in this study are shown in Table 2. None of the average Pb and Cd concentrations in the different fish species analyzed were higher than the MLP established by the official Mexican standard of 1.0 mg/kg and 0.5 mg/kg, respectively. Similarly, these average concentrations were lower than the MPL established in the EU regulations (0.2 mg/kg for Pb and 0.1 mg/kg for Cd). The mean concentrations of Hg in mako shark and soupfin shark samples exceeded the MPL (1.0 mg/kg), with average concentrations of 1.286 and 1.128 mg/kg, respectively. The highest individual concentrations of Hg were observed in these two species, with values for mako shark of 2.14 mg/kg and 1.81 mg/kg for soupfin shark. Sixty percent of the fresh fish samples analyzed had Hg concentrations that were higher than the MPL established by the official Mexican standard.

Based on the Tukey-Kramer test on fresh fish samples,

Table 3. Mercury, Lead, Cadmium, Chromium and Tin Concentration Found in Other Published Studies for Canned Tuna in mg/kg (ww), Mean in Brackets

Region	Species	Number of Samples	Concentration, mg/kg				Reference
			Hg	Pb	Cd	Cr	
Alabama, USA	NE	29	0.053 - 0.739 (0.284)	0.000 - 0.031 (0.001)	0.000 - 0.053 (0.002)	0.000 - 0.067 (0.006)	Ikem and Egiebor (10)
Slovenia	NE	15	(0.02 - 0.8)	-	-	-	Miklavcic et al. (17)
Spain	Yellowfin tuna	12	0.035 - 0.894 (0.22)	0.004 - 0.385 (0.004)	0.020 - 0.170 (0.046)	-	Olmedo et al. (15)
Ghana	NE	15	0.12 - 0.2	0.01 - 0.30	0.01 - 0.45	-	Okyere et al. (16)
Iran	NE	21	0.043 - 0.253 (0.117)	0.013 - 0.073 (0.037)	0.005 - 0.072 (0.022)	-	Emami Khansari et al. (18)
Iran	Yellowfin tuna	120	-	0.02 - 0.93 (0.19)	0.02 - 0.27 (0.15)	-	Hosseini et al. (14)
Italy	NE	135	0.04 - 1.79 (0.41)	0.02 - 0.16 (0.06)	0.01 - 0.14 (0.04)	-	Storelli et al. (11)
Lebanon	NE	5	0.07 - 0.12	-	-	-	Obeid et al. (19)
Mexico	Yellowfin tuna	42	0.25 - 0.51	-	-	-	Ruelas-Inzunza (13)
New Jersey	Yellowfin tuna	220	0.09 - 0.43	-	-	-	Burger and Gochfeld (20)
Turkey	NE	15	0.026 - 0.041	0.167 - 0.188	0.001 - 0.019	-	Mol (12)
	Tuna (NE)	60	0.01 - 1.14	ND - 4.13	ND - 0.09	-	
Tijuana, Mexico	Yellowfin tuna	48	0.005 - 1.170 (0.278)	0.07 - 0.32 (0.113)	0.000 - 0.007 (0.0029)	0.02 - 0.65 (0.167)	This study
MPL Mexican standard (NOM-028-SSA1-1993)			1.0	1.0	0.5	NE	
Commission regulation (EC) No. 1881/2006 of December 19, 2006			0.5	0.2	0.1	NE	

Abbreviations: MPL, maximum permissible level; NE, not specified; ND, not detected.

significant differences only exist for Hg between shark-tuna, shark-swordfish, tuna-soupfin shark, and soupfin shark-swordfish.

The concentrations of Pb, Cd, and Cr were low. For example, all the samples had Cd concentrations < 0.10 mg/kg and 95% of the samples had Cr and Pb concentrations lower than 0.20 mg/kg.

Table 4 shows some of the studies published around the world. The highest mean mercury concentrations in the fresh fish samples were found in the mako shark (1.286 mg/kg) and soupfin shark (1.128 mg/kg). These values are comparable to those reported in Spain by Olmedo et al. (15), whose maximum value for a shark species was 1.406 mg/kg and 1.227 mg/kg for swordfish. Falco et al. (21) reported maximum Hg values found in swordfish between 1.59 and 2.22 mg/kg. All these results exceed the MPL of current legislation in Mexico of 1.0 mg/kg.

The average Hg values obtained in this study (0.545 mg/kg) are similar to the average concentrations reported by Olmedo et al. (15) for the swordfish species (0.540 mg/kg). However, unlike this study, the range of Hg concentrations reported by Olmedo et al. (15) show a maximum value of 1.227 mg/kg, which is higher than the MPL. In the different species of tuna analyzed, only two maximum concentration values exceed the MLP of Mexican standards: those reported in Italy by Storelli et al. (11) (1.76 mg/kg) and in Slovenia by Miklavcic et al. (17) (1.11 mg/kg). The highest range of lead concentration was reported in studies conducted in Egypt by Hussein and Khaled (22), with values from 0.67 to 0.99 mg/kg for bluefin tuna, followed by the concentrations found in this study for yellowfin tuna, ranging from 0.09 to 0.15 mg/kg and with an average value of 0.116 mg/kg. The concentrations of Pb in shark, soupfin shark, and swordfish in this study were the highest compared to the studies presented in Table 4. The average concentration for shark was 0.159 mg/kg, soupfin shark was 0.096 mg/kg, and swordfish was 0.119 mg/kg, while the average Pb concentrations in the other studies ranged between 0.004 and 0.1 mg/kg. However, none of the results exceeded the maximum permissible limit for Pb established in the Mexican standard NMX-AA-027-SSA1-1993 of 1.0 mg/kg and the EU standard of 0.2 mg/kg. Cadmium concentrations did not exceed the MPL of 0.5 mg/kg. These values were the lowest compared to the studies reported in Table 4. The maximum reported value for Cd of 0.127 mg/kg was in yellowfin tuna in the study conducted by Olmedo et al. (15). Generally, the average concentrations in the other studies were three to four times higher than those obtained from the samples in this study (0.001 to 0.002 mg/kg).

The average results obtained for Cr for all the species analyzed in this study varied between 0.102 and 0.216 mg/kg (Table 4). The maximum Cr value in this study was similar to the value reported by Guerin et al. (24) in France for tuna, with a mean of 0.294 mg/kg. As with the canned tuna samples, there is no MPL for Cr in Mexican regulations or international standards, and therefore no conclusion can be drawn regarding compliance.

4.3. Characterization of Health Risk

Estimation of both contaminant intake and exposure is an important part of total diet studies because they con-

Table 4. Concentration of Hg, Pb, Cd and Cr Found in Other Published Studies for Fresh Fish in mg/kg (ww), Mean in Brackets

Region	Species	Number of Samples	Concentration, mg/kg				References
			Hg	Pb	Cd	Cr	
South Korea	NE	NE	0.24 ± 0.007	-	-	-	Islam et al. (23)
Egypt	Bluefin tuna[a]	NE	-	0.67 - 0.99	0.05 - 0.06	0.74 - 0.86	Hussein and Khaled (22)
Slovenia	Bluefin tuna[a]	3	0.16 - 1.11	-	-	-	Miklavcic et al. (17)
Spain	Bluefin tuna[a]	11	0.298 - 0.779 (0.47)	0.004 - 0.004 (0.004)	0.000 - 0.127 (0.008)	-	Olmedo et al. (15)
	Swordfish[b]	11	0.177 - 1.227 (0.540)	0.004 - 0.064 (0.004)	0.002 - 0.060 (0.009)	-	
	Shark (NE)	22	0.153 - 1.406 (0.698)	0.004 - 0.316 (0.004)	0.000 - 0.008 (0.003)	-	
Spain	Tuna (NE)	NE	0.38 - 0.58	0.01 - 0.02	0.01 - 0.02	-	Falco et al (21)
	Swordfish[b]	NE	1.59 - 2.22	0.01 - 0.02	0.01 - 0.02	-	
France	Tuna (NE)	8	-	(0.007)	-	(0.294)	Guerin et al. (24)
Italy	Bluefin tuna[a]	20	0.07 - 1.76 (0.61)	ND - 0.33 (0.07)	ND - 0.03 (0.01)	-	Storelli et al. (11)
New Jersey	Yellowfin tuna[c]	NE	0.65 ± 0.1	0.04 ± 0.01	0.03 ± 0.005	-	Burger and Gochfeld (25)
Turkey	Tuna (NE)	4	-	0.10 ± 0.01	0.08 ± 0.006	1.08 ± 0.10	Tuzen and Soylak (26)
Tijuana, Mexico.	Mako shark[d]	5	0.69 - 2.14 (1.286)	0.10 - 0.32 (0.159)	0.001 - 0.003 (0.0023)	0.16 - 0.38 (0.216)	This study
	Yellowfin tuna[c]	5	0.14 - 0.57 (0.377)	0.09 - 0.15 (0.116)	0.001 - 0.002 (0.0019)	0.08 - 0.13 (0.102)	
	Soupfin shark	5	0.46 - 1.81 (1.128)	0.04 - 0.13 (0.096)	0.001 - 0.00 (0.0018)	0.07 - 0.18 (0.137)	
	Swordfish[b]	5	0.38 - 0.72 (0.545)	0.08 - 0.16 (0.119)	0.001 - 0.003 (0.0022)	0.15 - 0.18 (0.168)	
MPL official Mexican standard (NOM-027-SSA1-1993)			1.0	1.0	0.5	NE	
Commission regulation (EC) No. 1881/2006 of December 19, 2006			1.0	0.2	0.1	NE	

Abbreviations: MPL, maximum permissible level; NE, not specified; ND, not detected; ww, wet weight.
[a] Bluefin tuna (*Thunnus thynnus*)
[b] Swordfish (*Xiphias gladius*)
[c] Yellowfin tuna (*Thunnus albacares*)
[d] *Isurus oxyrinchus*

vert the analytical results of contaminants in food into dietary exposure data that can be compared to reference values or established health standards (27).

The chronic daily intake (CDI) in mg/kg/day is calculated using the Equation 1. This equation has been used in other studies (28-30).

$$CDI = \frac{C \times RF \times IR \times CF \times ABS \times EF \times ED}{BW \times AT} \quad (1)$$

Where:

C is the contaminant concentration (mg/kg, wet weight);

RF is the reduction factor;

IR is intake rate (g/day);

CF is the conversion factor of 10-3 kg/g;

ABS is the absorption fraction (as assumed to be 100%);

EF is the exposure frequency (days/year);

ED is exposure duration;

BW is body weight;

AT is the average exposure.

The reduction factor is a number between 0 and 1, which describes the fraction once the fish has been cooked (assumed to be 1). The potential effects of the non-carcinogenic health risk were assessed using the hazard quotient (HQ).

$$HQ = \frac{CDI}{RfD} \quad (2)$$

Where CDI is chronic daily intake and RfD is the reference dose.

The HQ was calculated using an EF of 365 days/year, this number represents the worst case scenario or less optimistic case, considering the total annual canned tuna consumption of 1.23 kg/year per capita and 1.34 kg/year per capita of fresh tuna (we assume this consumption figure for each of the analyzed fish species), with an ED of 75 years, an IR of 3.4 g/day for canned tuna and 3.7 g/day for the rest of the analyzed fish species, a BW of 70 kg, and an AT of 27375 days (365 day/year per 75 years). The RfD values (mg/kg day) used for the calculation of HQs were: for Hg: 3×10^{-4}; Cd: 1.2×10^{-2}; Pb: 5.9×10^{-2}; Cr: 1.2×10^{-4} (31).

Table 5 shows the HQs for Hg, Cd, Pb, and Cr and the total hazard quotients (THQ) for canned tuna and fish species (mako shark, yellow fin tuna, soupfin shark and swordfish) marketed in the city of Tijuana, Mexico as well as the HQs and THQs reported by other published research.

It is important to assess the risk to human health of the consumption of food containing potentially harmful chemicals. Chronic exposure to heavy metals at relative low concentrations produce neurotoxicity, hepatotoxicity, poor reproductive capacity, chronic toxicity to kidneys, im-

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Table 5. Hazard Quotients (HQs) and Total Hazard Quotients (THQ) for the Analyzed Metal in Canned Tuna and Fish Species (Mean in Brackets, Where Indicated)

	HQ				THQ	References
	Hg	Cd	Pb	Cr		
Canned tuna	0.0345 -0.1889 (0.0946)	0.00001 - 0.00003 (0.00002)	0.00008 - 0.00027 (0.00012)	0.0696 - 0.2615 (0.1327)	0.227	This study
Mako shark	0.3763	0.00001	0.00029	0.1682	0.545	
Yellowfin tuna	0.0997	0.00001	0.00013	0.0562	0.156	
Soupfin shark	0.3186	0.00001	0.00012	0.0783	0.397	
Swordfish	0.1274	0.00001	0.00014	0.0809	0.209	
Fish (Swordfish, bluefin and tuna)	0.04 - 0.80	0.01 - 0.05	-	-	-	Barone et al. (32)
Tuna fish (Thunnus thynnus)	-	0.00986 - 0.01341 (0.0072)	0.04125 - 0.06080 (0.0308)	0.00011 - 0.00013 (0.00012)	0.038	Hussein et al. (22)
Fish (8 species)	0.026	0.005	0.025	-	0.056	Lopez-Barrera et al. (33)
Canned tuna (olive oil and brine)	0.021 - 1.441 (0.310)	0.001 - 0.102 (0.0173)	0.0001 - 0.0043 (0.00067)	-	0.328	Pappalardo et al. (34)
Fish (5 species)	0.10 - 5.09 (2.392)	0.01 - 0.03 (0.024)	0.002 - 0.020 (0.01)	-	2.426	Storelli and Barone (35)
Silver carp	-	0.01246	0.00928	0.00452	0.026	Miri et al. (36)
Fish	0.03 - 0.40 (0.058)	0.001- 0.02 (0.0032)	0.002- 0.05 (0.0152)	0.0001 - 0.0010 (0.00016)	0.076	Wang et al. (37)
Fish (17 species)	0.08 - 1.50 (0.548)	0.01 - 0.04 (0.016)	0.002 - 0.02 (0.0083)	-	0.574	Storelli (38)
Tuna (Albacore)	1.87	0.03	0.18	-	2.08	

mune system dysfunction, as well as teratogenic manifestations (39-41). The HQ values for Hg, Cd, Pb and Cr were below 1 indicating that the health risk from consuming the investigated fish species is insignificant. The highest HQ values were found in Hg, the highest HQ being for mako shark (0.3763) with an average HQ value of 0.2305 from all the analyzed samples. The HQ values for the rest of the investigated metals were two to five orders of magnitude lower.

The highest HQ value in Table 5 was from Italy reported by Storelli and Barone (35) with a value of 2.392 for mercury in five species of fish. This value can be compared with the HQ value of 1.87 for two samples of tuna albacore reported by Storelli (38). These values are 10-fold the average values reported in this study (0.23). This difference of HQ values is due to a large difference in fish consumption between Mexico and Italy. The average HQ value for Hg in canned tuna in this study was 0.0946 which is approximately three-fold lower than the HQ value reported by Pappalardo et al. (34) (0.310). Generally, the HQ values for Cd, Pb and Cr were very low. The highest HQ values for Cd and Pb were reported by Storelli (38) for tuna albacore (0.03 and 0.18, respectively), these values being 250 times higher than the values obtained in this study (0.00012 for canned tuna and 0.00017 for fresh fish). For Cr, the highest values were 0.1327 for canned tuna and 0.096 for the other fish analyzed in this study, approximately 600 times higher than the values reported by Hussein et al. (22) (0.00012) and 20 times higher than the value reported by Miri et al. (36) (0.00452). Analogously, the THQ values for canned tuna were 0.227 and for fresh fish between 0.156 and 0.545. These values are higher than all the other studies in Table 5, except the studies by Storelli and Barone (35) and Storelli (38) with reported values of 2.43 and 2.08, respectively. In summary, all the values obtained in this study were below one, indicating no health risk for consuming canned tuna or the fish analyzed in this study.

5. Conclusions

This study analyzed the concentrations of cadmium, mercury, lead, and chromium in samples of canned tuna and fresh fish, providing information about contamination by trace metals. According to the results, no HQ value exceeded a value of one, indicating no risk to health from the consumption of the products analyzed in this study (canned tuna, mako shark, yellowfin tuna, soupfin shark, and swordfish). The risk may be higher in populations that consume a greater quantity of fish (for example, coastal populations).

Uncorrected Proof

Although the concentrations are below the limit values, there is a potential future risk because of the increase in wastewater discharge and industrial activities. It is, therefore, of great importance to constantly monitor these products, to minimize the health risks associated with their consumption.

Footnotes

Authors' Contribution: Study concept and design: Diana Dolores Rodriguez-Mendivil, Enrique Garcia-Flores and Fernando Toyohiko Wakida. Analysis and interpretation of data: Diana Dolores Rodriguez-Mendivil, Enrique Garcia-Flores, Fernando Toyohiko Wakida, and Juan Temores-Pena. Critical revision of the manuscript for important intellectual content: Diana Dolores Rodriguez-Mendivil, Enrique Garcia-Flores, and Fernando Toyohiko Wakida. And Juan Temores-Pena. Statistical analysis: Diana Dolores Rodriguez-Mendivil and Enrique Garcia-Flores.

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