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SCIENCE DIRECT
Environmental Research 96 (2004) 239–249
Environmental Research
http://www.elsevier.com/locate/envres

Mercury in canned tuna: white versus light and temporal variation

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Received 17 August 2003; received in revised form 26 November 2003; accepted 3 December 2003

Abstract

There are abundant data and advisories for mercury levels in wild fish, but far fewer for commercial fish that compose a large majority of the fish most people eat. Until recently, relatively little attention has been devoted to examining mercury in canned tuna, despite its great importance in human diets. There is substantial media coverage of the benefits and risk from fish consumption, but few peer-reviewed data on canned tuna, the most commonly consumed fish in the United States. In this paper, we examine the levels of total mercury in canned tuna obtained from a New Jersey grocery store from 1998 to 2003, looking for temporal consistency within this data set and particularly for comparison with the Food and Drug Administration's 1991 study. We analyzed 168 cans individually for total mercury. All values are reported as parts per million (= μg/g) on a wet weight basis. In a subset of samples analyzed for total and inorganic mercury, the inorganic mercury was below detection levels; hence at least 89% of the mercury can be considered methylmercury. We found that white-style tuna had significantly more total mercury (mean 0.407 ppm) than light-style tuna (mean 0.118 ppm), presumably reflecting that "white" tuna is albacore, a species relatively larger than the skipjack tuna, which is commonly available as "light" or "chunk light." The maximum mercury in a can was 0.997 ppm, but 25% of white tuna samples exceeded 0.5 ppm. Data suggest a slight increase in levels since 1991, and mercury levels were significantly higher in 2001 than in other years. The mean level of mercury in white tuna (mean 0.407 ppm) was significantly higher than the mean value of 0.17 ppm currently used by the U.S. Food and Drug Administration (FDA) in its risk assessment and public information. There were no significant differences in mercury levels in tuna packed in oil compared to water. Draining contents had no effect on mercury levels, and the fluid, both oil and water, contained little mercury. These data indicate that people who eat canned tuna frequently can choose light tuna and reduce their mercury intake. Canned mackerel had much lower levels of mercury than tuna. Since cans of white tuna frequently exceed the FDA's original action level of 0.5 ppm, it would be prudent to continue some systematic monitoring of the nation's canned fish supply, particularly as the targets of commercial fisheries inevitably change as certain stocks become depleted.

Keywords: Methylmercury; Mercury; Canned tuna; Exposure; Risk; Food and drug administration; Consumption advisories; Albacore

1. Introduction

Fish provide a healthful source of dietary protein, and are relatively low in cholesterol and high in omega-3 (n-3) fatty acids (National Research Council, 2000). Several studies have documented the long-term cardio-protective benefits for adults as well as the reproductive benefits of eating fish. However, benefits may be offset by the presence of contaminants, particularly methylmercury (MeHg) and polychlorinated biphenyls (PCBs), which have been reported in many fish species from many localities (Environmental Protection Agency [EPA], 1998). Over more than three decades studies have shown positive correlations between mercury levels in humans and fish consumption (Bjornberg et al., 2003). A recent review of data from the National Health and Nutrition Examination Survey (NHANES) found that women who ate three or more servings of fish a month had a mercury level four-fold higher than that in the reference population (Schober et al., 2003).

Contaminants in fish are particularly detrimental for developing fetuses and young children (Jacobson et al., 1989, 1990; Institute of Medicine [IOM], 1991; Sparks

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doi:10.1016/j.envres.2003.12.001

and Shepherd, 1994; Jacobson and Jacobson, 1996; Schantz, 1996; National Research Council, 2000). Methylmercury interferes with the architecture of the developing brain, disrupting microtubule assembly (Graff et al., 1993) and interfering with the temporal sequencing of cell adhesion molecules that guide neuronal migration and connections (Dey et al., 1999). Some studies have shown an association between contaminant levels in fish, fish consumption by pregnant women, and deficits in neurobehavioral development in children (Weihe et al., 1996; Jacobson and Jacobson, 1996; Grandjean et al., 1998).

1.1. Advisories

In many states contaminant levels in some recreationally caught freshwater fish are sufficiently high to cause adverse health effects (IOM, 1991), which has led to managing risk by issuing consumption advisories for many water bodies and fish species. Fish advisories stimulated our studies of anglers to determine consumption patterns, perceptions of risk by anglers, and their compliance with advisories (Burger et al., 1993, 1999a, b). Despite the abundance of advisories aimed at fishermen, there is a paucity of advice for consumers of commercial fish, although this makes up about 95% of all consumption in the United States (Stern et al., 1996).

In 2001, the U.S. Food and Drug Administration (FDA) issued a consumption advisory, based on mercury, that pregnant women and women of child-bearing age who may become pregnant should avoid eating four species (or species groups) of saltwater fish: shark, swordfish, king mackerel, and tilefish (FDA, 2001a). In 2002 the FDA's advisory committee recommended expanding the advice to specifically mention tuna, but that has not been done to date. The FDA is currently (November and December 2003) reviewing its advisory.

Methylmercury is among the best known of environmental contaminants, engendering an extensive literature (Mahaffey, 1999; National Research Council, 2000). The risks from mercury in fish gained widespread media coverage in 2003 (e.g., Raines, 2003; Gorman, 2003), calling attention to canned tuna as a source of excessive mercury.

The present study was begun to assist New Jersey's Mercury Task Force in developing recommendations about advisories and monitoring (NJ Task Force, 2002). It also complemented our studies of wild-caught fish in New York (Burger et al., 1993), New Jersey (Burger et al., 1999a), Puerto Rico (Burger and Gochfeld, 1991), and South Carolina (Burger et al., 1999b). In this paper, we examine the levels of mercury in national brands of canned tuna purchased from a New Jersey grocery store chain from 1998 to 2003. This paper addresses the levels of mercury in different styles (solid white, chunk white, and chunk light tuna) and examines interyear variation, including comparison with the FDA's 1991 study (Yess, 1993). We also tested differences between oil- and water-packed tuna and between drained and undrained contents.

1.2. Benefits of fish consumption

The question of risk from eating fish is complicated, however, by the positive health and social benefits of consuming fish (Toth and Brown, 1997). Fish provide omega-3 (n-3) fatty acids, which reduce cholesterol levels (Hunter et al., 1988; Kimbrough, 1991; Horn, 1992; Anderson and Wiener, 1995). For some people fish may be their main source of protein, while for others, it may be the healthiest source. Fish consumption has been associated with improved pregnancy outcomes, including fewer preterm and low-birth-weight deliveries (Olsen and Secher, 2002), attributable in part, at least, to n-3 fatty acids (Allen and Harris, 2001). On the other hand Guallar et al. (2002) indicated that mercury might offset the cardioprotective benefits for adults. Thus, assessing the levels of mercury in commercial fish is important from a public health perspective.

2. Methods

2.1. Source and types of canned tuna samples

Canned tuna was purchased from one central New Jersey chain grocery store. Our sampling regime varied over time, and involved purchasing three to five cans each of several different national brands of tuna (in water) each year from 1998 to 2003. After initial analyses revealed higher mercury levels in white than in light tuna, in later years we oversampled chunk white and solid white. Sample sizes and styles are given in Table 1. Mercury was analyzed in the Environmental and Occupational Health Sciences Institute Elemental Analysis Laboratory. In several years we examined mercury levels in tuna packed in oil and compared levels in drained and undrained samples. In 2001 we also compared mercury levels in drained and undrained canned mackerel ($n = 9$).

We analyzed tuna from 168 cans including 86 solid white, 37 chunk white, and 45 chunk light. These designations are standardized by the Food and Drug Administration (FDA, 1977) with reference to a Munsell gradient of darkness. White "is limited to the species *Thunnus germo* (albacore), and is not darker than Munsell value 6.3". Light tuna ranges from Munsell 6.3 to not darker than 5.3. Solid consists of "loins cut in transverse segments to which no free fragments are

Table 1
Total mercury in canned tuna (1998–2003)

	N	Median	Mean	SD	SE	CV	Max
Entire sample	168	0.311	0.330	0.199	0.015	60.3	0.997
All white tuna	123	0.368	0.407	0.167	0.015	41.0	0.997
Chunk white	37	0.315	0.355	0.166	0.027	46.8	0.997
Solid white	86	0.4	0.429	0.164	0.018	38.2	0.783
All light tuna[a]	45	0.087	0.118	0.099	0.015	83.9	0.447
	Comparing all white with all light				$\chi^2 = 78.9$[b]	$P<0.0001$	
	Comparing all chunk with all solid white				$\chi^2 = 6.39$	$P = 0.010$	
All tuna in water	136		0.346	0.196	0.017	56.7	0.997
All tuna in oil	32		0.259	0.197	0.035	76.0	0.719
	Comparing all water with all oil				$\chi^2 = 5.54$	$P = 0.019$	
All light in water[a]	26	0.072	0.096	0.062	0.012	64.7	0.244
All white in water	110	0.368	0.405	0.168	0.016	41.5	0.997
Chunk white in water	37	0.315	0.355	0.166	0.027	46.6	0.997
Solid white in water	73	0.401	0.431	0.165	0.019	38.3	0.783
	Comparing light with white in water				$\chi^2 = 58.5$	$P<0.0001$	
	Comparing chunk versus solid white in water				$\chi^2 = 6.3$	$P = 0.012$	
Oil							
Chunk light[a]	19	0.112	0.149	0.130	0.030	87.5	0.447
Solid white	13	0.369	0.419	0.166	0.046	39.6	0.719
	Comparing light with white in oil				$\chi^2 = 15.2$	$P<0.0001$	

All values are in ppm (μg/g) on wet weight basis.
[a] All of the light tuna was designated "chunk light."
[b] Kruskal–Wallis non parametric one-way analysis of variance computed using the Wilcoxon Option in Proc NPAR1WAY of SAS, yielding a χ^2 value.

Table 2
Interlaboratory comparisons on split samples of canned tuna (New Jersey)

Year	N	EOHSI laboratory	Lancaster laboratory[a]	Quebec laboratory[b]	Correlations with		Percent difference of means[c]	
		Mean ± SE	Mean ± SE	Mean ± SE	Lancaster	Quebec	Lancaster	Quebec
2001	8[d]	0.701 ± 0.03	0.691 ± 0.06	0.663 ± 0.05	0.95	0.72	4.1%	5.4%
2002	20	0.239 ± 0.03	No longer providing service	0.265 ± 0.03		0.93		9.8%
2003	18	0.301 ± 0.06	No longer providing service	0.286 ± 0.05		0.93		6.6%

The samples sent out in 2001 were all high in mercury (>0.5 ppm). The 2002 and 2003 were randomly chosen split samples.
[a] Lancaster's Food Service Laboratory ceased providing this service after 2001.
[b] Institut national de santé publique du Québec.
[c] Percent difference between the mean values in the outside reference laboratory and the EOHSI mean value.
[d] Eight samples all over 0.50 ppm were submitted for confirmation in 2001.

added" while chunk consists of "a mixture of pieces in which the original muscle structure is retained" (FDA, 1977). Light tuna comprises mainly skipjack (*Katsuwonus pelamis*), which is generally a smaller species than albacore (which is now generally considered *Thunnus alalunga*).

2.2. Analysis

Sample preparation, digestion, and analysis were done in three separate rooms to minimize cross contamination. All analyses were performed in the Elemental Analysis Laboratory of the Environmental and Occupational Health Sciences Institute, which is a partnership of Rutgers University and Robert Wood Johnson Medical School. A subset of samples were analyzed at outside reference laboratories for quality assurance (see Table 2). All analyses were done on individual cans; compositing was not performed. Contents were drained and samples were weighed to 0.1 mg. All analyses and calculations were carried out to four significant figures. All laboratory equipment and containers were washed in 10% HNO_3 solution prior to each use and rinsed with dionized water. Fish was digested in Ultrex ultrapure nitric acid in a microwave (MD 2000 CEM), using a digestion protocol of three stages of 10 min each under 50, 100, and 150 pounds per square inch (3.5, 7, and 10.6 kg/cm^2) at 70 × power. Digested samples were subsequently diluted in 100 ml deionized water. Mercury was analyzed by cold vapor atomic absorption spectrometry using the HGS-4 analyzer. In 2002 and 2003 analyses were also performed using a Lumex atomic absorption spectrometer with Zeeman background correction, which provided better precision near the detection level. Correlations between the HGA-4 and Lumex exceeded 0.92 and mean values of replicates were within 3%.

The method detection limit (MDL) ranged from 0.05 ppm with the HGA-4 to 0.03 with the Lumex and the few nondetectable values were set at half the MDL. For water drained from cans, the MDL was 0.001 ppm. We used Kruskal–Wallis nonparametric one-way analysis of variance (SAS-NPAR1WAY with Wilcoxon option) to examine for differences among independent variables (Statistical Analysis System [SAS], 1995) and nonparametric Kendall tau procedure for testing correlations. The level for significance was designated as <0.05. All results are reported as parts per million (ppm), equivalent to micrograms per gram on a wet weight basis, rounded to three significant figures.

2.3. Quality control analyses

All specimens were run in batches that included blanks, a standard calibration curve, and spiked specimens. The accepted recoveries for spikes ranged from 85% to 115%; batches outside these limits were rerun. The coefficient of variation (C.V.) on replicate samples ranged from 2% to 12%. Further quality control included periodic blind analysis of an aliquot from a large sample of known concentrations and blind runs of replicate samples. Analyses from earlier years were rerun and confirmed with batches in later years. Replicates were run for half of the cans, and all digests were analyzed in duplicate with mean values used. We also measured the moisture content.

We used two external laboratories to analyze split samples. In 2001 samples were submitted to the Lancaster Laboratories, Inc., Food Service Division (which closed in 2002) and to the Institut National de Santé Publique du Québec (Quebec) for quality control (Table 2). In 2002 and 2003 samples were also sent to the Quebec laboratory, which runs the international proficiency testing program for mercury. High results (>0.50 ppm) from early years were confirmed in the outside laboratories.

3. Results

3.1. Quality control

Quality control is an essential part of any laboratory quality assurance program. The quality control samples (blanks, standards) were within specifications, and the replicate data used were all within 15%. However, we were surprised by the number of replicates that exceeded 10%. This prompted us to test several cans repeatedly, demonstrating that the ratio of maximum to minimum in different parts of a single can vary by more than 10%. The average difference between duplicates (on the same extract) was 0.2%. The average difference between replicates (separate digests of same sample) was 0.78%.

The comparison between the EOHSI and the outside laboratories shows generally very close agreement across laboratories, despite differences in method (Table 2). The Lancaster results were obtained on dried specimens corrected for moisture content. The Quebec results were reported to the nearest 0.05 ppm with an MDL of 0.05. Correlations were generally high and means were in close agreement.

3.2. Total mercury

The main findings of our study were the consistently higher levels in white tuna (overall mean 0.407 ppm; median 0.368 ppm) than in light tuna (mean 0.118 ppm; median 0.087 ppm; Table 1). We found a somewhat higher mean (0.429 ppm) for solid white than for chunk white (0.355 ppm), but this varied across years. The level of 0.3 ppm was exceeded by 67% of the white and 7% of the light tuna samples; 25% of the white, but none of the light exceeded 0.5 ppm. The maximum value for total mercury in our sample was 0.997 ppm. We found significant variation among years; samples purchased in 2001 were higher than in earlier or later years of the study (Table 3). There were no differences in the concentrations of mercury for tuna packed in oil or in

Table 3
Mercury in canned tuna: comparison among years for white tuna in water

Year	N	Mean
1998	6	0.319
1999	21	0.314
2000	18	0.212
2001	27	0.517
2002	12	0.332
2003	26	0.475
Total *N*	110	Grand mean = 0.361
Among years (1998–2003)		
Kruskal–Wallis χ^2	33.6	
Probability	$P<0.0001$	

All values are for total mercury in ppm (μg/g) on wet weight basis.

water, and no differences for whether it was drained or undrained (Table 4). Similarly, there were no differences in the mercury concentrations of drained versus undrained mackerel, another readily available canned fish (Table 4), which had levels almost an order of magnitude lower than in white tuna.

Because we oversampled white tuna (both solid and chunk) in water, we do not emphasize a single mean value for all canned tuna. Multiple regression analysis for total mercury in water-packed tuna was tested with the general linear models procedure (PROC GLM) of SAS, using brand, style (white versus light), and year as independent class variables. The overall model was significant ($F = 13.2$, $P < 0.001$; Table 5). Both style ($F = 84$, $P < 0.0001$) and year ($F = 7.02$, $P < 0.0001$) were significant contributors to the overall r^2 of 0.6, while brand did not enter significantly ($F = 1.7$, $P > 0.20$). The sample size for oil-packed was too small for this analysis.

3.3. *Yearly variation*

No attempt was made to achieve a balanced design of style over years. Data broken down by years is presented in Table 3. The highest single category for any year was the mean value of 0.540 for chunk white in water in 2003. The lowest was for chunk light in oil of 0.074 in 2000. Our mean values for light and chunk white were similar to the 1991 data, but our mean for solid white was significantly higher ($P < 0.05$). We also compared our methylmercury results, both calculated and analyzed, with the FDA's 1991 data (Table 5), finding that our results for solid white tuna (1998–2003) were significantly higher than the 1991 results (Yess, 1993). Our results for chunk light and chunk white were slightly, but not significantly higher.

3.4. *Oil versus water*

Many brands of tuna are packed in both oil and water. Oil is usually vegetable oil (sometimes olive oil). We compared each of the three styles packed in oil versus water (Table 1). None of the comparisons were significant ($P > 0.10$), although oil-packed tuna averaged slightly lower levels for white and higher levels for light ($P > 0.10$).

3.5. *Drained versus undrained*

We drained all cans prior to removing tissue for analysis. In a subset of cans we compared drained and undrained results. Draining had no consistent effect on mercury content (Table 4). Likewise, the liquid component, when analyzed, had very low levels of mercury, usually below the MDL for liquid of 0.001 ppm with a maximum of 0.07 ppm.

3.6. *Methylmercury content*

Forty samples were analyzed by the Quebec laboratory for total and inorganic mercury, calculating

Table 4
Comparison of mercury levels in canned tuna and mackerel before and after draining

	Number	Mean ± SE	Kruskal–Wallis χ^2	(*P* value)
Canned tuna				
Undrained	11	0.43 ± 0.03	0.8	NS
Drained	11	0.46 ± 0.15		
Canned mackerel				
Undrained	9	0.033 ± 0.003	1.1	NS
Drained	9	0.026 ± 0.004		

All values are for total mercury in ppm (μg/g) on wet weight basis.

Table 5
Comparison of current results with the FDA's 1991 study (Yess, 1993)

		Chunk light	Chunk white	Solid white	All white	Water[a]	Oil[a]
1991 FDA study (Yess, 1993)							
Methylmercury (analyzed)	Mean	0.100	0.310	0.260	0.271	0.191	0.079
	SD	0.110	0.170	0.160	0.160	0.160	0.100
Current study							
Methylmercury (calculated based on 89%)[b]	Mean	0.132	0.353	0.480[c]	0.412	0.354	0.245
Methylmercury (calculated) excluding year 2001	Mean	0.132	0.375	0.442[c]	0.418	0.352	0.242
Analyzed methylmercury for 2003 only[d]	Mean	0.040	0.450	0.329	0.355	0.243	0.233

All values are in ppm (μg/g) on wet weight basis.

[a] Oil and water results should not be compared because of differential sampling of white and light in different years. Our sample was only 27% light compared to 54% for Yess (1993).

[b] Our results estimate 89% of mercury as methylmercury, agreeing closely with other estimates. Analyzed results were divided by 1.12 to estimate the MeHg.

[c] Indicates that results from this study are more than 1 SD greater than 1991 results (Yess, 1993).

[d] Analyzed by the Institut national de sante publique due Quebec.

methylmercury by subtraction. The inorganic component was below the detection level of 0.05 ppm for all samples. Using the convention of half the detection level (i.e., 0.025) for the inorganic component yields an estimate of the organic mercury content of 89% for samples, where total mercury was 0.10 ppm or greater. We show the calculated MeHg values for 6 years and 5 years (excluding 2001), as well as the actual analyzed values for 2003 (see Table 5).

3.7. Provenance

Commercial tuna sold in the United States is caught mainly in the Pacific. Most cans of white tuna specified "albacore." Only about $\frac{1}{4}$ of the cans indicate a country of origin—usually Thailand, although a few mentioned New Guinea or the Philippines. Other companies obtain tuna from American Samoa and Ecuador. The fish may have been caught near these countries or may simply have been landed or canned there. There were similar batch numbers on cans from Thailand representing more than one brand, indicating that canneries service more than one company. In most cases, however, we have no idea where the fish were caught other than in the Pacific, or whether the source of tuna shifted from year to year, which might partly explain annual variation.

4. Discussion

Canned tuna amounts to about 20–25% of all seafood consumed in the United States, with average per capita consumption in 2000–2001 of about 1.5 kg (National Marine Fisheries Service [NMFS], 1989; National Oceanic Atmospheric Administration [NOAA], 2002). Although most Americans have relatively low exposure, a small percentage, accounting ultimately for several million people, have excessive mercury levels due in part to fish consumption including canned tuna (Stern et al., 2001; Hightower and Moore, 2002). Our results are consistent with previously published results regarding differences among tuna styles, and although the average size of tuna may have declined, the mercury levels in canned tuna have not, and may have increased. Although our sample size is miniscule compared to the number of cans of tuna sold in the United States, it is relatively large compared with most published studies.

4.1. Mercury in tuna

Many studies have shown that mercury is bioamplified in the food chain with high-trophic-level predatory species (such as shark, swordfish, and tuna) having higher mercury (and organochlorines) than herbivorous species (Braune, 1987; Lacerda et al., 1994; Park and Curtis, 1997; Burger et al., 2001). Within a species, older and larger fish also have higher levels, as Boush and Thieleke (1983) showed for tuna.

Although there are several published reports of mercury in canned tuna, most studies have not distinguished between different styles of tuna; hence comparisons with the literature are difficult. It is often assumed (even in fish advisories) that fresh tuna or tuna steaks have higher mercury levels than canned tuna, but the literature does not provide clear evidence for this. The FDA Web site (FDA, 2001b) reports a value for methylmercury of 0.32 ppm for fresh or frozen tuna compared with its value of 0.17 ppm for canned tuna. However, mean values for white style canned tuna exceed 0.3 (Yess, 1993; this paper).

The National Marine Fisheries Service (1978) measured total mercury in 250 individuals of several species of tuna, yielding a median of 0.12 ppm and a maximum of 0.87 ppm. However, Plessi et al. (2001) reported an average of 0.249 in bluefin tuna (*Thunnus thynnus*) purchased from a fish wholesaler in Italy. Nakagawa et al. (1997) reported levels of mercury in fresh tuna from Japan of 1.11 ppm. Storelli et al. (2002) found levels of 0.85–1.45 ppm (wet weight) in albacore from the Mediterranean (average 1.17 ppm) with 78% exceeding 1 ppm. Consumer Reports (2001) recently published an average value of 0.25 ppm methylmercury in 24 samples of fresh tuna. Moreover, there is evidence of variation among oceans and countries, probably related to the source of the fishery, species, and fish size.

4.2. Mercury in canned tuna

The FDA reports that methylmercury levels in canned tuna fish are normally in the range 0.1–0.2 ppm (Carrington et al., 1997), and the value of 0.17 is given on its Web site as the average for canned tuna (FDA, 2001b). This is based on the study of Yess (1993), which bears closer examination (next section).

Most studies report only total mercury. Yallouz et al. (2001) analyzed data from 39 cans of tuna representing five brands from Brazil, without details on style. The grand mean was 0.65 ppm, with 51% of cans exceeding 0.5 ppm and 15% greater than 1 ppm. Voegborlo et al. (1999) analyzed 50 cans of chunk tuna from the Mediterranean and reported a mean of 0.29 ppm (SD = 0.12), based only on the 20 samples that exceeded the MDL of 0.2. Hence the true mean for their sample would have been substantially lower; we calculated it as 0.12 ppm setting the 30 nondetected values to half the MDL. This is in close agreement with both our data and those of Yess (1993) for light tuna. Acra et al. (1981) reported a mean of 0.30 μg/g (range 0.25–0.49) for canned tuna from Lebanon. Other results from this period include mean values of 0.3 ppm (Kamps et al., 1972; Parvaneh, 1979), but the style was not specified.

White tuna is albacore, a species somewhat larger than those that are canned as light tuna. Albacore generally weigh 10–20 kg, but can reach 40 kg. Skipjack, the main component of light tuna, accounts for about half of all tuna harvested worldwide. It averages about 8–10 kg in weight, occasionally reaching 30 kg (International Foundation for Conservation of Natural Resources [IFCNR], 2003). Albacore tends to have high mercury levels (Storelli et al., 2002).

4.3. FDA's 1991 study

Between 1978 and 1990, FDA determined methylmercury in 42 samples of canned tuna (ranging from <0.10 to 0.67 ppm, with an average of 0.14 ppm reported in Yess, 1993). The FDA's 1991 study (Yess, 1993) is the single largest and best study of mercury in canned tuna. Yess (1993) analyzed 220 samples, each a composite of 12 cans (12 additional cans were archived). The cans were purchased in 1991 from around the United States. The sampling was nonrandom and emphasized water-packed tuna and popular brands. She found that samples ranged from the detection level of 0.1 ppm up to 0.75 ppm of methylmercury; 3.6% of her composite samples exceeded 0.5 ppm methylmercury. The overall mean was reported as 0.17 ppm (median of 0.15 and a maximum of 0.90 ppm; Yess, 1993). Yess (1993) also reported that chunk white tuna averaged 0.31 (SD = 0.17) and solid white averaged 0.26 (SD 0.16), while chunk light tuna and chunk averaged 0.10 (SD = 0.11). The light styles made up 2/3 of her sample, resulting in an unweighted mean of 0.17. She arbitrarily set all nondetectable values to 0 rather than to the more commonly used convention of one-half the MDL or 0.05 ppm; hence her results are biased downward. None of the samples exceeded the current 1 ppm FDA action level (Yess, 1993).

Based on the Yess (1993) paper, the FDA posts 0.17 ppm on its Web site as the value for canned tuna (FDA, 2001b) and uses this value in its exposure and risk assessments (Carrington et al., 1997; Carrington and Bolger, 2002; Bolger and Schwetz, 2002). No mention is made of the white versus light discrepancy, even though it was recognized by Yess (1993).

4.4. Oil versus water packing

We did not find a difference in the mercury concentration of oil-packed versus water-packed tuna within each of the three styles (Table 1). Yess (1993) reported a mean of 0.06 ppm for 26 oil-packed composites versus 0.11 ppm for 106 water-packed composites of chunk light tuna. However, the FDA study blended the oil into the fish sample, whereas water was drained. Hence this would serve to dilute the mercury somewhat.

4.5. Drained versus undrained

Advice to consumers sometimes mentions draining to reduce contaminants. In 2001 we analyzed 11 cans of tuna undrained and again after draining. The results (Table 4) show no appreciable change ($P > 0.25$). All other analyses were performed after the contents were manually drained, but not squeezed. Liquid volume varied among cans.

4.6. Interyear variation

We found a statistically significant peak in the 2001 samples of white tuna ($\chi^2 = 33$; $P < 0.001$). This may be a statistical artifact of sample size, but more likely reflects exploitation of a different population of tuna due to the vagaries of the fish movements and fishery targets.

For several reasons, when we began the study, we expected a decline in mercury levels over time. We anticipated that a decline in mercury contamination through the gradual reduction in mercury use and industrial effluents would be reflected in a decline in the mercury content of tuna. We suspected also that mercury levels might have declined as a result of overfishing large tuna and the need to target smaller fish (Safina, 1998). Moreover, in New Jersey common terns (*Sterna hirundo*), a fish-eating seabird, we found that mercury levels in eggs had declined since the early 1970s (Burger and Gochfeld, in press).

In recent years, however, mercury emissions, mainly from coal-fired power plants have actually increased (NJDEP, 2001), resulting in short- and long-range atmospheric transport, which may offset declines in use and effluent. To the extent our data show a temporal trend, it has been upward since 1991 (Burger and Gochfeld, in press). Yess (1993) suggested that FDA data might have shown a decline from a calculated mean of 0.21 for methylmercury in 1973 to 0.17 in 1991. However, the composition of the 1973 sample with respect to white and light was not given.

4.7. Methylmercury in tuna

This study was not primarily designed to evaluate methylmercury per se, since we initially followed the conventional wisdom that about 90% of the mercury in fish is methylmercury. However, we did measure the methylmercury content in a subset of cans and found that methylmercury composed 83–89%. Considering only cans with total mercury > 0.10, the value was about 89%. Storelli et al. (2002) reported a range of 75–100% MeHg (average 91%) and Hall (1974) reported a mean of 89%. Using 89% results in a correction factor of 1.12, and the methylmercury content of our samples can be estimated by dividing total mercury by 1.12. It is not clear how much of the methylmercury in tuna (or other marine fish) is anthropogenic in origin.

4.8. Action levels and tuna as an exemption

The regulatory control of tuna, as well as shark and swordfish, is problematic. For example, in Japan, Canada, and Europe, tuna are exempted from the 0.4 ppm or 0.5 ppm regulations (Nakagawa et al., 1997; Canadian Food Inspection Agency, 2002; Plessi et al. 2001). In the U.S., the FDA (1987) level of 1 ppm is normally high enough so that tuna falls below this level, although this was not always the case. In 1969 FDA developed administrative guidance of 0.5 ppm for commercial fish, and in the early 1970's millions of cans of fish exceeding this level were seized. In 1974 this was converted to an Action Level, but in 1979 FDA raised its Action Level to 1.0 ppm.

Many countries have set the maximum permitted level of mercury in fish at 0.5 ppm, including Australia (Denton and Burdon-Jones, 1996), Canada (Institute of Medicine [IOM], 1991), Sweden (Hylander et al., 1994), and the United Kingdom (Collings et al., 1996). Many states in the U.S. have also set 0.5 ppm or lower limits, including Florida (Lange et al., 1994), Maine (DiFranco and Mower, 1994), Minnesota (Minnesota Department of Health [MDH], 1997), and Wisconsin (Gerstenberger et al., 1993). Of the cans of tuna we examined, 50% exceeded 0.3 ppm and 25% of white style exceeded 0.5 ppm. In 2001, half of the samples were above 0.50 ppm, the limit many states and countries set for safe consumption.

People must balance potential mercury exposure with the need for a healthy diet. Our study provides additional data that the levels of mercury in tuna can be both variable and high, lessening the predictability of the mercury a pregnant women consumes when eating canned tuna.

The variability in mercury levels in canned tuna is particularly worrisome because there are sensitive periods for neurobehavioral development when the developing fetus is more susceptible to the disruptive effects of mercury, and when a single pulsed dose may have more of an effect than the same amount over a longer timeframe (Dey et al., 1999).

4.9. Risk and risk reduction

Recently, the Agency for Toxic Substances and Disease Registry [ATSDR] (1999) has proposed a Minimal Risk Level of 0.3 μg/kg/day mercury based on the Seychelles neurodevelopmental study (Davidson et al., 1998), without incorporating an uncertainty factor for interindividual variation. That study has not found neurobehavioral deficits in a fish-eating population (Myers et al., 2003). The Faroe Island study (Weihe et al., 1996; Grandjean et al., 1998) supports a lower Reference Dose (RfD), which the EPA has calculated at 0.1 μg/kg/day, and Stern (1993) computed an RfD of 0.07 based on data from Iraq. The National Research Council (2000) concluded that 0.1 μg/kg/day was scientifically sound.

There is often a gap between how the fish-consuming public and the agencies responsible for advisories perceive risk (Reinert et al., 1991; Ebert, 1996; Burger, 2000). The public views eating fish as a less serious hazard than does the scientist or environmental manager, but more seriously than some regulators. People continue to consume the fish even though they know about the consumption advisories or bans (Reinert et al., 1991; Burger and Gochfeld, 1991; Burger et al., 1992, 1999a; Velicer and Knuth, 1994; May and Burger, 1996; Burger et al., 2001). Until 2003, however, almost no attention was devoted in the media to the risks from tuna fish.

Reducing risk from the consumption of fish is obviously a partnership between risk assessors and resource managers (Ebert, 1996), as well as the public (Burger, 1998), and involves balancing the risks versus the advantages (Egeland and Middaugh, 1997; Bolger and Schwetz, 2002). We suggest that the problem of risk perception concerning tuna will be particularly difficult because it is such a common and accepted food and has always been considered safe and healthy. Over the years the tuna industry has provided a significant reduction in risk by reducing the amount of tuna in cans by about 15%, to the current industry standard of 6 oz (170 g).

4.10. Recommendations

Our data indicate that people who are not in high-risk categories (most adults and adolescents) may consume several cans of light style tuna a week and white tuna occasionally with impunity. Pregnant or soon-to-be pregnant women, infants, and small children should limit canned tuna intake and select light rather than white tuna. These data (particularly their variability) indicate the desirability of instituting a regular monitoring program for commercial tuna and other species. Whereas canned fish is nutritious, tasty, and convenient, we found that mercury levels in canned mackerel were substantially lower than in tuna. FDA and other agencies should clarify the difference between mercury levels in white versus light tuna.

Acknowledgments

We thank T. Shukla and C. Dixon for mercury analysis and computer assistance, and A. Stern, K. K. Pflugh, B. Buckley, C. Chess, C. Powers, B. D. Goldstein, B. Friedlander, C. Powers, and A. Upton for comments on the research and manuscript. Alain LeBlanc (Institut national de santé publique du Québec) provided valuable quality control assistance. Our research with fish consumption was also influenced by discussions with members of the Savannah River Site's (SRS) Citizen's Advisory Board. This research was partly funded by the Consortium for Risk Evaluation with Stakeholder Participation (CRESP) through the Department of Energy (AI DE-FC01-95EW55084, DE-FG 26-00NT 40938), NIESH (ESO 5022), and the Environmental and Occupational Health Sciences Institute. The results, conclusions, and interpretations reported herein are the sole responsibility of the authors, and should not in any way be interpreted as representing the views of the funding agencies.

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