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Methylmercury Levels in Fish Tissue and Kidney Toxicity

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Abstract

Recently the Virginia Department of Environmental Quality made available thousands of test results from the 1990's to 2022 that relate to levels of toxins found in fish from various bodies of water in Virginia. Of the numerous chemicals identified mercury, which is converted to methylmercury in the body, is of major concern. Long-term methylmercury exposure can lead to cancer/death, while exposure to small amounts can cause developmental/reproductive toxicity, neurotoxicity, digestive/immune disfunctions, as well as problems with lungs, skin, eyes and kidneys. With respect to the latter concern, this paper focuses on the kidney toxicity linked to methylmercury levels in the human body which may be responsible for up to 47 million Americans having chronic kidney disease. It has been documented that up to 90% of methylmercury in the human body is from seafood ingestion and that the amount of methylmercury in fish is directly related to coal burning powerplant emissions. This process has appeared to cause a significant amount of fish to become contaminated in Virginia's waterways, yielding a mean level of methylmercury in 44,380 fish tested of 195 parts per billion/fish collected over a 23 year period. When this value is compared to what regulatory agencies view as a "safe level" of methylmercury in fish tissue (150 ppb – 500 ppb) one might think that this level of contamination is acceptable. However, when one compares the toxicokinetics of methylmercury at the levels recommended, using a 50 day half-life, with levels known to cause kidney toxicity (0.01 ppb) the levels identified in blood were 4 to 5 times above the toxicity level. Additionally, residual methylmercury levels after one year would roughly double the level in the blood, doubling the potential kidney toxicity dose. Burning coal causes more than just climate change!

Keywords: Mercury, Methylmercury, Fish tissue, Kidney toxicity

Introduction

Mercury is an element which for the most part is indestructible and, therefore, should be considered a "forever chemical". Roughly, up to 90% of methylmercury in a human body is from seafood intake [1]. Additional levels of methylmercury can come from breathing the air, especially for those living near coal burning powerplants. With that said, there are approximately 216 coal burning plants still in use in the United States with about 50 tons per year of mercury being released into the atmosphere [2]. Human exposure is greatest at the power plant facility, but about 80% of the reactive mercury (~40 tons) travels in the air and becomes deposited on the land/water within 1500+ miles of the power plant [3]. This is the main cause of methylmercury bioaccumulation and biomagnification in fish tissue that leads to high levels in human blood, especially in rural areas where families use locally caught fish to supplement their food supply/budget.

Long-term methylmercury exposure can lead to possible carcinogenicity and death, while even exposure to small amounts can cause developmental/reproductive issues in off-spring, neurotoxicity, digestive/immune disfunctions, as well as problems with lungs, skin, eyes and kidneys [4,5]. With respect to the latter, the National Institute of Health has determined that more than 1 in 7 adults in the United States [6] or roughly 47 million people based on 2022 US population demographics have some form of chronic kidney disease with the highest rates of prevalence in Americans with diabetes and high blood pressure; there are several papers in the literature that link methylmercury toxicity directly with both of these disease states [7-10]. Additionally, methylmercury blood levels in adult female participants from a 1999–2000 [11]. Suggests that more than 300,000 newborns each year in the United States are exposed in utero to concentrations that can be linked to neurodevelopmental effects. Methylmercury can also be found in human cord blood, placenta, and breast milk [12].

Methods

Virginia Department of Environmental Quality (VADEQ) has made accessible a significant amount of historical fish tissue data relating to methylmercury content [13]. The database included 44,380 fish samples collected/analyzed from 22 species of fish obtained from 45 Virginia bodies of water from 1995 to 2022 (Table 1); no data was available from 2009 through 2013.

Mathematically, the total number of fish tissue samples collected along with the mean methylmercury levels, expressed in parts per billion (ppb), were calculated for each year of available data (Table 2).

The data was then used to calculate the daily human blood levels of methylmercury based on the amount present in fish tissue, portion size recommendations for men, women and children made by either the Food & Drug Administration (FDA), the Environmental Protection Agency (EPA) and/or the Virginia Department of Health (VDH) [14,15] (Table 3). The daily blood level of methylmercury was calculated using a 50 day half-life in the human body [19] which was then compared to the level known to cause kidney toxicity (0.01 ppb) based on the Agency for Toxic Substances and Disease Registry [12].

Results

Based on the data obtained (Table 4) using either actual or recommended methylmercury levels from regulatory agencies, the average amount of methylmercury in human blood per day over one 50 day half-life, ranged between 0.04 ppb and 0.05 ppb or roughly 4 to

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Table 1: Bodies of Water and Fish Species Collected.

Bodies of Water Tested (45 total):
Accotink Creek near Rt. 611, Broad Run near Rt. 7 bridge, Coan River near Coan. Dan River near Anglers Park below city of Danville, Dan River above schoolfield Dam, Dan River near Anglers Park below city of Danville, Dan River below South Boston near public boat ramp, Dan River / Kerr Reservoir near State Park upper lake, Dogue Creek Bay, Fourmile Run near Potomac Yards, Hunting Creek near Mt. Vernon Memorial Hwy, Indian Run near Cherokee Avenue, John W. Flannagan Reservoir (Pound River), Kerr Reservoir near Ivy Hill Public Rec Area Sta # Buoy 8, Lake Anna - at Split, Lake Anna - mid lake, Lake Anna - lower lake near second berm, Lake Gaston - Pea Hill Creek near NC-VA stateline, Lake Gaston, off Point (Mecklenburg County), Lake Whitehurst, Leesville Lake near Mill Creek, Leesville Lake near Old Womans Creek, Little Hunting Creek near Mt. Vernon Memorial Hwy, Little Wicomico, River near Sawmill Cove, Machodoc (Upper) Creek near Williams Creek Machodoc (Lower) Creek mid channel off Cherry Orchard Point, Mattaponi River upstream Rt. 647/Rt. 601,, Reedy Mill Road, Monroe Creek at Monroe Bay, Neabsco Creek near RF&P railroad bridge, Nomini Creek at Buoy 8 - Off Hickory Point, Occoquan River near Rt. 1bridge - RR bridge, Occoquan/Belmont bay near Buoy # 6, Pimmit Run near Rt. 120 bridge Pohick Bay Upper Embayment, Potomac Creek near Waughs Wharf, Powell Creek near RF&P railroad bridge, Quantico Creek ~0.6 mile above bridge, Rappahannock River below Fredericksburg, Rappahannock River near Port Royal, Roanoke River ~5 miles upstream of Kerr Reservoir, Roanoke River near public boat ramp at Clover, Va, Roanoke River /Kerr Reservoir near, Clarksville Marina middle upper lake, Shenandoah River - Rt. 7, downstream Castlemans bridge, Swift Creek Reservoir, Station 1, Yeocomico River Off Buoy 3.
Species Tested (22 total):
American Eel, Black Crappie, Blue Catfish, Bluegill Sunfish, Carp, Channel Catfish, Flathead Catfish, Freshwater Drum, Gizzard Shad, Golden Redhorse Sucker, Hybrid Bass (White/Striped), Largemouth Bass, Longnose Gar, Northern Snakehead, Pumpkinseed Sunfish, Quillback Carpsucker, Striped Bass, Walleye, White Bass, White Catfish, White Sucker, White Perch.

Table 2: Historic Levels of Methylmercury in Fish Tissue (1995-2022).

Year	Number Fish Tested	Mean Methylmercury Level In Fish Tissue (ppb)
1995	526	45
1996	693	87
1997	1221	138
1998	3016	74
1999	1159	40
2000	2219	51
2001	2717	54
2002	1987	150
2003	3726	213
2004	2343	280
2005	3075	340
2006	3711	369
2007	3127	454
2008	3975	131
No Data Available From 2009 to 2013		
2014	388	230
2015	325	180
2016	316	210
2017	985	320
2018	1493	180
2019	1474	190
2020	1271	370
2021	2335	190
2022	2298	200
23 Years of Data	Total Fish Tested 44,380	Average of all Means 195 ppb
Note: Data for 2014 to 2016 are based only on the Dan River as a result of a Coal Ash Spill		

5 times the level known to produce kidney toxicity via sub-chronic oral exposure.

Below is an example calculation used to determine daily methylmercury blood levels based on FDA/EPA allowable levels for Pregnant/Nursing Women.

Example calculation (pregnant/nursing women):

Amount of methylmercury per serving:

FDA/EPA Allowable Level for Pregnant/Nursing Women = 12 oz serving/week = 0.34 Kg times 150 ppb (allowable level in fish tissue) = 50 ppb of methylmercury in 3 - 4 ounce servings/week.

Amount of methylmercury metabolized daily:

FDA/EPA Allowable Level for Pregnant/Nursing Women = 50 ppb (amount of methylmercury per week) divided by 2 = methylmercury half-life total; divide initial dose (50 ppb) by 49 days = 0.51 ppb per day metabolized (approximation).

Amount of methylmercury/Kg:

50 ppb (initial methylmercury level) divided by 75 Kg (Pregnant/Nursing Women Body Weight) = 0.67 ppb/Kg

Amount of Available methylmercury per day:

Table 3: Women and Children Technical Information on Development of FDA/EPA Advice about Eating Fish for Those Who Might Become or Are Pregnant or Breastfeeding and Children Ages 1-11 Years [14].

FDA and EPA Advice About Eating Fish and the Closer to Zero Initiative. Closer to Zero is our strategic, long-term, iterative approach to reducing childhood dietary exposure to mercury and other environmental contaminants from foods, while maintaining access to nutritious foods.

Serving size is also consistent with the recommendation for those who are pregnant or breastfeeding of **8-12 ounces of a variety of fish per week** from choices

Table 1. Screening Values for Fish Categories

Weekly fish servings	Screening value (μg/g)	Chart category
0	> 0.46 ppm (460 ppb)	Choices to Avoid
1	≤ 0.46 ppm (460 ppb)	Good Choices
2	≤ 0.23 ppm (230 ppb)	Good Choices
3	≤ 0.15 ppm (150 ppb)	Best Choices

"To prevent children from exceeding the RfD for mercury, these are recommended serving sizes (after rounding) of fish for various age groups when eating fish **2 times a week** from the "Best Choices" category:"

Age 2: 1 ounce per serving

Age 6: 2 ounces per serving

Age 9: 3 ounces per serving / 35 Kg weight

Age 11 and up: 4 ounces per serving

Note: The Virginia Department of Health recommends adults eat two 8 ounce servings a month of fish contaminated with no more than 0.5 parts per million = 500 ppb of mercury [15]. https://www.vdh.virginia.gov/epidemiology/epidemiology-fact-sheets/mercury/?pdf=5989

Table 4: Summary of Results.

Agency ->	FDA/EPA Women Pregnant/Nursing	DEQ Actual Levels in Fish	FDA/EPA Children	VDH Adults
Allowable Exposure Level ->	150 ppb	195 ppb (actual)	150 ppb	500 ppb
Serving Size ->	12 oz/Week (4 oz – 3 x/Week)	8 oz/Week (1 x Week)	6 oz/Week (3 oz – 2 x/Week)	4 oz /Week (8 oz – 2 x/Month)
Body Weight ->	75 Kg	80 Kg	35 Kg	80 Kg
Amount Metabolized Daily	0.51 ppb/day	0.46 ppb/day	0.275 ppb/day	1.17 ppb/day
Avg Blood Level for 50 Days After 1 half-life ->	0.04 ppb	0.04 ppb	0.05 ppb	0.05 ppb
ATSDR Kidney Toxicity (RfD) ->	0.01 ppb	0.01 ppb	0.01 ppb	0.01 ppb

Table 5: Accumulation of Methylmercury Blood Levels after 1 Year - Pregnant/Nursing Women.

Number of ½ Lives	Blood Level - Day 1 of Each ½ Life	Remaining Methylmercury - After Each ½ Life
1st ½ Life (Day 1 - 50)	50 ppb of Methylmercury	25 ppb of Methylmercury
2nd ½ Life (Day 51 to 100)	75 ppb of Methylmercury	37.5 ppb of Methylmercury
3rd ½ Life (Day 101 to 150)	87.5 ppb of Methylmercury	43.8 ppb of Methylmercury
4th ½ Life (Day 151 to 200)	93.8 ppb of Methylmercury	46.9 ppb of Methylmercury
5th ½ Life (Day 201 to 250)	96.9 ppb of Methylmercury	48.4 ppb of Methylmercury
6th ½ Life (Day 250 to 300)	98.4 ppb of Methylmercury	49.2 ppb of Methylmercury
7th ½ Life (Day 301 to 350)	99.2 ppb of Methylmercury	49.6 ppb of Methylmercury

0.67 ppb (amount of methylmercury/Kg) divided by 50 days (half-life) = 0.01 ppb Daily Blood Level (ppb/day)

Daily/average amount of methylmercury in human blood per day:

Over the course of 50 days half-life daily levels ranged from 0.01 to 0.07 ppb; Average blood level = 0.04 ppb or 4 times the dose known to cause kidney toxicity.

Using the initial and end half-life totals for the "allowable" methylmercury levels in fish tissue (Table 5) set by FDA/EPA/VDH would virtually double the level of methylmercury in the blood within approximately 1 year (350 days).

Discussion

Regulations relating to methylmercury ingestion from contaminated fish tissue range from 150 ppb to 500 ppb. As one may summarize, the recommended values do not appear to be based on the cumulative toxicity potential of methylmercury, but would appear to be based more on other concerns, possibly economic and/or nutritional. What is most concerning is that following these guidelines a pregnant or nursing mother would have a methylmercury blood level that is 4 times higher than the renal toxicity dose. Likewise, the recommendations for children would yield daily methylmercury blood levels 1 to 8 times higher than the dose that is associated with renal toxicity.

Another point of concern is how our regulatory agencies could be so far off the mark when it comes to determining a "safe" level of exposure to methylmercury. One possible explanation is the misuse of kinetic modeling. For example, the regulatory agencies appear to employee a "threshold kinetics" model, whereby, environmental toxicity is controlled by some type of balancing act between the known toxic and non-toxic doses of a substance. This type of modeling is excellent when there is only "one" chemical involved from "one" exposure source. Unfortunately this is not the case; since our environment simultaneously exposes humans/animals to numerous chemicals from multiple sources. This causes an underestimation of the toxicity while ignoring potential synergistic interactions. The latter is a significant scientific concern when addressing toxicity associated with endocrine disrupting chemicals which commonly cause toxicity at doses well below the level of "known" toxicity when mixed together [16-18].

Conclusion

It is unfortunate that from a public health perspective our "regulatory" agencies do not concur on the risks of exposure to numerous toxic substances. Nor do they listen to the findings of toxicology groups, like ATSDR who establish limits based on published scientific data. The concept of pumping the "maximum" amount of toxic chemicals into our water, land and/or air based on current regulatory practices is inappropriate and unsafe at best. "Dilution is the solution to pollution" is not only inaccurate, it is dangerous and defies the "precautionary principle" of do no harm as well as violates all basic principles of toxicology. Continuing these practices will continue to cause increases in disease/death to humans and to all things that live in the environment. How we handle exposure to toxic chemicals needs to change!

Acknowledgment

None

Conflict of Interest

None

Raw data available upon request at jmjdinardo@aol.com

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