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HONR 499

Preferential fish consumption based on omega-3 fatty acids and mercury concentrations for maximum health benefits

Abstract:

The regular consumption of seafood offers a variety of protective effects, including the reduction of the risk of cardiovascular disease and stroke, due to the presence of omega-3 fatty acids in fish. These protective effects may be diminished by the contamination of seafood by mercury. Mercury increases the risk of cardiovascular problems and impedes neurological development. The objective of this project was to determine the fish species that are appropriate for consumption based on low levels of mercury and recommended intake levels of omega-3 fatty acids. Species that are high in omega-3s and low in mercury include salmon, trout and shrimp. Species with both high levels of omega-3 fatty acids and mercury include tuna, shark, snapper and halibut.

Introduction:

Fish consumption has long been regarded as a healthy alternative to other meat sources, since it is high in protein and low in saturated fats (Domingo et al. 2007a). Along with the high protein content and other essential nutrients, omega-3 polyunsaturated fatty acids are a major contributor to the health benefits of regular fish consumption (Sidhu 2003). However, fish can also be a major dietary source of contaminants, especially mercury (Hg) (Clarkson et al. 2003) that may cause adverse health effects. Levels of both omega-3 fatty acids and contaminants are highly variable and are different for each species of fish (Mahaffey et al. 2008), so obtaining maximum health benefits from seafood consumption can be highly dependent on the species consumed.

Omega-3 fatty acids include eicosapentaenoic acid (EPA), docosahexaenoid acid (DHA) and α-linolenic acid. Marine derived omega-3 fatty acids are EPA and DHA, while α-linolenic acid is consumed mainly from plant oils, poultry and eggs (Kris-Etherton et al. 2002, Mahaffey et al. 2008). Amercians tend to obtain most of their dietary omega-3 fatty acids from plant based sources rather than the marine derived EPA and DHA because of the extensive use of oils in cooking and supplementation in other food sources (Mahaffey et al. 2008). Conversion of α-linolenic acid to EPA and DHA occurs naturally in the body, although transfer is slow, so those plant based fatty acids may be a dietary source of EPA and DHA (Kris-Etherton et al. 2002). The recommended intake of omega-3 fatty acids for healthy adults is 0.3-0.5 g/day of EPA + DHA and approximately 1 g/day for people with or at high risk for coronary heart disease (CHD) (Kris-Etherton et al. 2002). Fish oil supplements may be a potential source of omega-3 fatty acids, although they should be taken cautiously as high doses may have adverse side effects, such as prolonged bleeding times (Kris-Etherton et al. 2002, Mahaffey et al. 2008).

Omega-3 fatty acids have a variety of positive health effects, the foremost being reduction of cardiovascular disease by lowering triglycerides and lipoproteins (Sidhu 2003, American Heart Association 2009). The linkage between omega-3s and reduced risk of cardiovascular disease has been well documented in a wide range of human populations with different levels of fish intake. He et al. (2004) statistically analyzed previously conducted studies and found a positive linear correlation between coronary heart disease and fish consumption. The more fish that were consumed lowered the risk of coronary heart disease; even eating only one fish meal per week lowered the risk of death from CHD by 15% (He et al. 2004).

This risk of cardiovascular disease can be reduced by consuming as little as 2 meals of fatty fish per week, as recommended by the American Heart Association and supported by the findings of several studies (American Heart Association 2009, Kris-Etherton et al. 2002, Domingo et al. 2007a). Psota et al. (2006) found that even lower levels of consumption, just one fish meal a week or even per month, can offer a lower risk of CHD, although greater fish consumption leads to even a lower risk. Meals should be of fatty fish, such as salmon, herring and mackerel, so that the maximum amount of omega-3 fatty acids can be obtained per serving (Kris-Etherton et al. 2002). Fish consumption above this level will continue to reduce the risk of cardiovascular disease.

Omega-3 fatty acids may also help to reduce the occurrence of a variety of other health problems. Although the data is limited, the incidence of stroke may be reduced with consumption of omega-3 fatty acids (Kris-Etherton et al. 2002). Continued research must be conducted to discover the nature of the effect of omega-3 fatty acids on stroke (Kris-Etherton et al. 2002, Sidhu 2003). Omega-3 fatty acids may also reduce the incidence of diabetes, rheumatoid arthritis, depression, and cancer as well as promote neurological, optical, and reproductive development (Sidhu 2003). Fetal development can also be aided by the consumption of omega-3 fatty acids by pregnant women. Cognition was shown to increase proportionally with fish consumption by the infant's mother (Oken et al. 2005).

Contaminants are a major concern when consuming fish. Contaminants in fish include methyl mercury (MeHg), polychlorinated biphenyls (PCBs) and a number of other organic molecules, such as polycyclic aromatic hydrocarbons and polychlorinated naphthalenes, that may be carcinogenic or may cause other health problems (Domingo et al. 2007a). When epidemiological studies investigating the effects of omega-3 fatty acids have weak correlations, mercury is typically the attributed cause due to the opposing effects of the two substances (Kris-Etherton et al. 2002).

Mercury contamination varies by fish species and cannot be removed through the cooking process, because MeHg binds to proteins in the muscle tissue of fish (Domingo et al. 2007a). Upon consumption, 95% of MeHg will be absorbed and taken up by body tissues within a two day period following consumption (Hightower and Moore 2003). Mercury remains in the adult body for 70-90 days (Sidhu 2003). Regular consumption of seafood may allow for accumulation of mercury in the body, especially when the rate of consumption exceeds the rate at which the body can eliminate it. Clarkson et al. estimated in 2003 that about 8% of the population of the United States have higher levels of mercury than what is considered safe by the United States Environmental Protection Agency (US EPA) guidelines. Other common sources of mercury exposure include dental amalgams and vaccines containing thiomerosal (Clarkson et al. 2003). A higher risk exists for dental professionals who have prolonged exposure to mercury vapor due to the application and removal of dental fillings (Clarkson et al. 2003). A study using only medical professionals found that dentists had the highest mean mercury levels based on analysis of toenail clippings in comparison to other medical professionals with lower occupational exposure (Yoshizawa et al. 2002). Consumption of fish containing elevated levels of mercury decreases the health benefits of eating fish and works in direct opposition to the benefits of omega-3 fatty acids.

Mercury is released into the atmosphere by the burning of fossil fuels, especially coal and municipal waste incineration. Once in the atmosphere, inorganic mercury can enter waterways through wet or dry deposition and is converted to MeHg by sulfate reducing bacteria. MeHg bioaccumulates in food chains and is eventually consumed by humans who eat fish (Virtanen et al. 2007). According to the US EPA, consumption of MeHg should not exceed 0.1 μg Hg per kg body weight per day to avoid adverse health effects (National Academy of Sciences 2000, Hightower and Moore 2003, Virtanen et al. 2007). Consumption exceeding this limit may cause mercury accumulation in tissues, specifically that of the brain, muscle, hair, nails and kidneys (Hightower and Moore 2003, Virtanen et al. 2007).

Methyl mercury primarily targets the brain when introduced into the body. Toxicity will lead to adverse neurological effects that are often disconnected from the time of exposure to the onset of symptoms (Clarkson et al. 2003). MeHg accumulation in the brain may be responsible for an increased incidence of stroke, however findings are inconclusive possibly due to the opposing effects of omega-3s (Yamagishi et al. 2008).

It is well known that mercury contamination increases the risk of cardiovascular disease. Choi et al. (2009) studied a population of men from the Faroe Islands in the North Atlantic and found that increased consumption of seafood, primarily pilot whale meat, which contains very high mercury levels, promoted the development of cardiovascular disease. Others have supported this finding with a variety of different types of heart disease in several different populations and shown that risk increases as consumption increases (Virtanen et al. 2007, Yamagishi et al. 2008). However, not all studies support these findings. Yoshizawa et al. (2002) found that there was no evidence of a relationship between mercury intake and risk of coronary heart disease in medical professionals, although the authors suggest that the findings may have been skewed by the positive effects of omega-3 fatty acids or the limited mercury exposure of participants.

Mercury poses another serious threat to pregnant women and fetuses. MeHg may cross from the mother's blood into the blood of the fetus binding to and concentrating in fetal blood cells (Hightower and Moore 2003). Mercury in the fetal brain leads to increased incidence of developmental disorders (Virtanen et al. 2007). According to Oken et al. (2005) higher mercury levels consumed by the mother resulted in lowered infant cognition and brain development. This is in direct opposition to the effects seen for omega-3 fatty acids as discussed earlier. The highest infant cognition scores were seen in children whose mothers had low levels of mercury with high omega-3 intake (Oken et al. 2005).

Education and economic level may also be a risk factor for MeHg accumulation. This association may exist as high end consumers purchase a greater number of high trophic level marine predators that have higher MeHg levels due to bioaccumulation. Species with high mercury levels, including shark and swordfish, are not widely consumed by those in lower economic classes. In the population studied by Hightower and Moore (2003), the mean MeHg level was greater than the national average reflecting both the nature of the consumers and the effect of living in a seaside community.

Fish consumption should be adjusted to maximize the amount of omega-3 fatty acids and minimize the amount of contaminants. Seafood, including salmon, clam, mussels, shrimp and cuttlefish, should be consumed as they are low in mercury and high in omega-3 fatty acids (Domingo et al. 2007a, Mahaffey et al. 2008). Women who are pregnant and children need to be cautious of their seafood consumption as they are especially vulnerable to toxicity. This balance is important and needs to be considered by those who want to consume fish to reduce the risk of cardiovascular disease.

Blood mercury levels may be decreased by changing individual consumption patterns to reduce MeHg intake. These levels, even when exceedingly high, may be reduced to a safe level, by dramatically altering fish intake or ceasing it completely. The safe levels can be reached in a matter of a few months (Hightower and Moore 2003). In order to continue to obtain health benefits from omega-3 fatty acids, a wider variety of dietary omega-3 sources should be consumed including plant based products or those fortified with long chain polyunsaturated acids (Hightower and Moore 2003). Additionally, health professionals should be educated on the risk of high mercury levels in their patients and advise the patients about their diet. This, along with a greater number of mercury advisories for waterways from state and national governmental agencies, may help to reduce mercury risk (Hightower and Moore 2003).

To aid consumers with their fish consumption choices, researchers have developed computer software, RIBEPEIX, that analyzes risks and benefits of current consumption levels (Domingo et al. 2007b). Users input weight, age and sex, along with usual weekly consumption of 14 different fish and shellfish based on frequency and meal size. From this information, consumption of a variety of toxins including cadmium, lead, mercury, dioxins and other organic compounds, is calculated using average body burden of the fish species. The same is done for omega-3 intake. From this the user can navigate to another screen, where recommended dietary changes are made to maximize omega-3 fatty acid intake and reduce the number of pollutants consumed. The program is available at http://www.fmcs.urv.cat/portada/ribepeix.

The objective of this project was to determine the fish species that are appropriate for consumption based on low levels of mercury and recommended intake levels of omega-3 fatty acids.

Materials and Methods

Fish Mercury Concentration

13 fish species (light tuna, albacore tuna, wild ahi tuna, canned mackerel, catfish, cod, trout, halibut, canned salmon, fresh salmon, seabass, swordfish and tilapia) and shrimp were purchased from several local grocery stores for analysis. Two more species, shark and snapper, were obtained from an individual who fishes locally in Long Bay, South Carolina. Samples were acid digested using a CEM microwave digester. The acid digestion matrix contained 6 mL concentrated trace metal grade HCl, 4 mL concentrated trace metal grade HNO_3 and 30 mL ultra pure water (Guentzel et al. 2007). Acid digests were analyzed using stannous chloride reduction and cold vapor atomic absorption spectrometry (Clesceri et al. 1998). Mercury concentrations were calculated based on a calibration curve developed from mercury solutions with known concentrations. The standard reference materials used were NIST 2976 Marine Mussel Tissue and IAEA-435

Tuna. The percent recoveries were 98.6 ± 1.45% for NIST 2976 Mussel Tissue and 100.4 ± 1.32% for IAEA-435 Tuna.

Mercury concentrations for these 13 species were also obtained from the FDA database (United States Food and Drug Administration 2009). Because of our limited sample size, our measured values were compared to the FDA mean, minimum and maximum values for these species.

Fish Omega-3 Values

All omega-3 values were obtained from a literature search (Connor, et al., 1993; Harris, et al., 2008; Kris-Etherton, et al., 2002; Mahaffey, et al., 2008; Psota, et al., 2006). Data from sources in which omega-3 content was reported as grams EPA + DHA per 100 grams of fish were converted into grams EPA + DHA per 3 oz serving. When a species was found in multiple literature sources, values were averaged.

Omega-3 and Mercury Servings per Month

The number of servings of fish that can be safely consumed per month was calculated based on the mercury levels determined in samples, the US EPA reference dose of 0.1 μg per kg body weight per day, a 68 kg person, and a serving size of 7 ounces. The omega-3 content obtained from literature was used to calculate the number of servings (7 oz.) per month needed to reach the recommended intakes for CHD (1 g/day) and non-CHD (0.3-0.5 g/day) individuals as suggested by Kris-Etherton et al. (2002). The recommended consumption levels based on fish mercury concentration were compared to the omega-3 fatty acid content of the fish species.

Results and Discussion

The measured range for mercury in the samples was 0.011-0.541 ppm (Table 1). 14 of the 16 measured mercury concentrations were within the range reported by the FDA. The measured mercury in the canned salmon was higher than the reported FDA range (0.076 ppm Hg measured in comparison to not detected). The canned mackerel measured value (0.044 ppm) was slightly lower than the reported FDA range (0.05-0.73ppm) (Table 1). The mercury concentrations measured in this study were similar to the results of other studies (Domingo, et al. 2007a; Hightower and Moore 2003; Mahaffey et al. 2008) and most of the measured concentrations were within the FDA range, indicating the samples used were representative of average samples available throughout the United States.

The omega-3 content in the seafood ranged from 0.115-1.582 g EPA+DHA per 3 oz fish (Table 2). Ideally, the seafood that a person consumes should be on this high end of the range, so fewer meals are needed each month to obtain the recommended amount of omega-3s. For species with lower concentrations, it becomes unreasonable to consume the necessary number of servings to reach the suggested amount of omega-3 fatty acids within a month's time. For example, if tilapia were the only source of omega-3s in the diet, an individual without CHD would have to consume 56 servings each month and an individual with CHD would have to consume 111 servings per month to obtain the recommended amount.

By comparing the meals that can be consumed per month based on the mercury concentrations and the number of meals necessary to obtain the protective benefits of the omega-3 fatty acids, it is possible to determine which species of fish should be preferentially consumed. Calculations were based on a 68 kg (150 pound) person, so individuals with a different body weight would have a different number of meals per month for mercury. If the mercury limit is lower than the servings per month needed based on omega-3s, then those species are good candidates for consumption. For example, 4 meals of farmed salmon should be consumed each month by people without CHD for the benefits from omega-3s. This is less than the number of meals that can be safely consumed based on the mercury level (37 for measured concentration and 73 for the FDA mean concentration). The same comparison can be made for individuals with CHD. Those individuals would need 8 servings per month, which is still lower than the both mercury limits (Table 3). Other species that have high mercury consumption limits and low servings per month for omega-3s are canned salmon, trout, shrimp and tilapia for those not suffering from CHD. If a person has CHD, this list becomes even more limited to include only farmed salmon, trout and shrimp.

If more meals are needed for omega-3s than can be eaten to remain below the mercury limit, then this fish species is not a good candidate for reaching the recommended daily intake of omega-3s. Based on our measurements, species to avoid include shark, swordfish, wild Ahi tuna, canned albacore and light tuna as they are a good source of omega-3s but also high in mercury. For those not at risk for CHD, canned albacore tuna should be consumed at a rate of 9 meals per month, or roughly 9 tuna fish sandwiches, a reasonable amount for a regular consumer. However, based on the mean mercury level found by the FDA, consumption should not exceed 3 meals per month.

To increase the omega-3 intake to reach the target amount of either 0.5 or 1 g EPA + DHA per day, omega-3s can be obtained from other dietary sources. Foods that are naturally rich in omega-3 fatty acids including flaxseed, flaxseed oil, soybean oil and walnuts (Hightower and Moore 2003; Mahaffey et al 2008). Additionally, some foods are artificially enriched such as eggs, cereal, chicken and other products marketed as heart healthy (Mahaffey et al. 2008). Infant formula may also be enriched with DHA to promote neurological development (Mahaffey 2004). Obtaining omega-3 fatty acids from other sources is also important for vegetarians or those concerned about the sustainability of fisheries, so that non-fish sources will become increasingly common and necessary (Mahaffey et al. 2008).

Another option to increase a person's omega-3 intake is the use of fish oil capsules. Several different brands fish oil capsules have very low to non-detectable measurements for mercury concentrations and the researchers concluded that even large dosages of fish oil supplements would not cause harmful levels of mercury in the blood (Foran et al. 2003). Too much omega-3 fatty acids may be consumed, especially if consumption includes an array of sources, so caution should be taken as omega-3s are added to more and more products (Mahaffey et al. 2008). Health risks include oxidative damage to tissues and excessive bleeding to more mild symptoms such as gastrointestinal irritation and decreased immune system response (Sidhu 2003).

Further investigations should focus on determining the effects of mercury and omega-3 fatty acids on weak statistical correlations in areas, such as stroke, diabetes and other health problems. Additionally, more species that are high in omega-3 fatty acids should be analyzed for mercury content focusing on those suggested by other sources such as by Sidhu (2003) including sardines, trout, anchovy, sablefish and bluefish.

Conclusions

A healthy diet should include a balance of foods from a variety of different sources. Fish are an important dietary source of omega-3 fatty acids that provide protective health effects including reducing the risk of coronary heart disease. Additionally, omega-3s may reduce the incidence of stroke, diabetes, rheumatoid arthritis, depression, aid in fetal and reproductive development and promote optical development in children (Sidhu 2003). However, the neurotoxin, mercury, may also be present in the muscle tissue of fish and cannot be removed through the cooking process. Mercury increases the risk of coronary heart disease and causes developmental problems in fetuses and children. Fish must be carefully chosen to reduce the risk of mercury toxicity and obtain the maximum benefits from omega-3s. Fish that are high in omega-3s and low in mercury include salmon, trout and shrimp. Species to avoid are high in omega-3s but also contain a high concentration of mercury including tuna, shark, snapper and halibut. To supplement the omega-3s in ones diet, it is possible to obtain them from other sources such as eggs, chicken, walnuts and flaxseed oil (Hightower and Moore 2003; Mahaffey et al 2008).

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Table 1. Measured concentrations of mercury as compared to the FDA mean, minimum and maximum concentrations obtained from (United States Food and Drug Administration 2009).

Seafood	Measured Hg Concentration (ppm)	FDA Mean Concentration (ppm)	FDA Minimum Value (ppm)	FDA Maximum Value (ppm)
Shrimp	0.012	ND	ND	0.050
Salmon (Canned)	0.076	ND	ND	ND
Tilapia (farm raised)	0.011	0.010**	ND	0.070
Salmon (farm raised)	0.027	0.014**	ND	0.190
Catfish (farm raised)	0.014	0.049**	ND	0.314
Catfish (farm raised)	0.015	0.049**	ND	0.314
Trout	0.020	0.072	ND	0.678
Cod	0.026	0.095	ND	0.42
Light Tuna (canned)	0.030	0.118	ND	0.852
Light Tuna (canned)	0.102	0.118	ND	0.852
Mackerel (canned)	0.044	0.182+	0.05+	0.73+
Snapper	0.465	0.189	ND	1.366
Halibut	0.069	0.252	ND	1.520
Halibut	0.160	0.252	ND	1.520
Albacore Tuna (canned)	0.148	0.353	ND	0.853
Albacore Tuna (canned)	0.259	0.353	ND	0.853
Ahi Tuna (wild)	0.291	0.383§	ND§	1.3§
Seabass	0.194	0.386	0.085	2.180
Swordfish	0.293	0.976	ND	3.220
Shark	0.541	0.988	ND	4.540

ND refers to a concentration of mercury that was not detectable in the sample.
**FDA does not specify farm raised vs. wild caught.
+ FDA does not have data for canned mackerel, the FDA value for N. Atlantic Spanish mackerel is used for comparison.
§ FDA does not have data for wild ahi tuna, the FDA value for tuna (fresh/frozen, all) is used for comparison.

Table 2. Omega-3 content of the seafood species used for mercury analysis given in grams of EPA and DHA per 3 oz serving of seafood. Values were obtained from literature and averaged when multiple data points were available (Connor, et al., 1993; Harris, et al., 2008; Kris-Etherton, et al., 2002; Mahaffey, et al., 2008; Psota, et al., 2006).

Seafood	**Omega-3 Content (g EPA+DHA/ 3oz seafood)**
Tilapia	0.115
Snapper	0.170
Cod	0.204
Catfish	0.238
Light Tuna (canned)	0.260
Shrimp	0.301
Seabass	0.417
Swordfish	0.493
Shark	0.711
Ahi Tuna (wild)	0.716
Albacore Tuna (canned)	0.732
Halibut	0.800
Trout	0.818
Salmon (canned)	1.090
Mackerel (canned)	1.251
Salmon (farm raised)	1.582

Table 3. Servings per month of seafood that should be consumed by individuals both with and without CHD to obtain maximum health benefits. Additional columns show mercury limits in servings per month based on the measured and FDA mean mercury concentrations. If bold number appears in omega-3 column, these species are will not exceed the mercury limit if consumed for omega-3s. If bold number appears in one of the mercury limit columns, then the mercury limit would be exceeded before obtaining the recommended amount of omega-3s.

Seafood	Omega-3, no CHD (servings/month)	Omega-3, CHD (servings/month)	Measured Hg Limit (servings/month)	FDA Hg Limit (servings/month)
Salmon (farmed)	**4**	**8**	37	73
Salmon (canned)	**6**	**12**	13	ND
Trout	**8**	16	51	14
Shrimp	**21**	**43**	86	ND
Tilapia	**56**	111	93	103
Shark	9	18	**2**	**1**
Swordfish	13	26	**3**	**1**
Snapper	37	75	**2**	**5**
Ahi Tuna (wild)	9	18	**3**	**3**
Albacore Tuna (canned)	9	17	**4-7**	**3**
Seabass	15	31	**5**	**3**
Halibut	8	16	6-14	**4**
Mackerel (canned)	5	10	23	5
Light Tuna (canned)	25	49	10-34	**9**
Cod	31	63	39	**11**
Catfish	27	54	70-73	**21**

All calculations were based on a 68 kg person and a serving size of 7 oz. ND means the concentration of mercury in the FDA samples was not detectable. Omega-3 intake (servings/month) for non CHD was based on recommended consumption of 0.5 g/day of EPA + DHA and approximately 1 g/day for people with CHD.