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Balancing the risks and benefits of fish for sensitive populations

Charles R. Santerre

Department of Foods and Nutrition, Purdue University, Stone Hall, 700 W. State St., West Lafayette, IN 47907-2059, USA

Abstract

Correspondence:
Charles R. Santerre, Purdue University, Stone Hall, Rm. 205, 700 W. State St., West Lafayette, IN 47907-2059, USA.
Tel: 765-496-3443; Fax: 765-494-0674; E-mail: santerre@purdue.edu

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In recent years, a number of concerns have been raised about the safety of fish. Environmental pollutants that accumulate in selected seafood products have caused some to regard fish as potentially dangerous for fetuses, nursing infants and young children. Yet, nutritionists contend that seafood can provide benefits which far outweigh the risks. In this review, we will briefly discuss the health benefits of eating fish, and compare these to the risks from two environmental pollutants (mercury and polychlorinated biphenyls or PCBs). In addition, we will provide advice for sensitive populations (women who will become pregnant, pregnant or nursing women, and children younger than 6 years of age), which can help them to make informed decisions involving fish consumption. The ultimate goal is to maximize the benefits and minimize the risks from eating seafood.

Benefits

Some species of fish are a good source of high-quality protein (USDA-ARS 2005), vitamin D (USDA-ARS 1999; British Columbia Ministry of Foods 2005), selenium (USDA-ARS 2005), zinc (Committee on Nutrient Relationships in Seafood: Selections to Balance Benefits and Risks, Food and Nutrition Board 2007), calcium (Committee on Nutrient Relationships in Seafood: Selections to Balance Benefits and Risks, Food and Nutrition Board 2007), astaxanthin and long-chain omega-3 fatty acids (Nettleton 2004; USDA-ARS 2005). These nutrients are important for the good health of the mother, the developing fetus and the infant (Nettleton 2002). Pregnant and nursing women can synthesize long-chain omega-3 fatty acids, like eicosapentanoic acid (C20:5, EPA) and docosahexanoic acid (C22:6, DHA), from α-linolenic acid (C18:3, an omega-3 fatty acid), which is found in plant and animal foods; however, the production of these lipids is inefficient. Alternatively, women can consume fish, which contains the preformed long-chain omega-3 fatty acids, EPA and DHA. DHA is passed on to the developing fetus through the placenta and to the nursing infant in maternal milk. The importance of omega-3 fatty acids in the healthy development of eyes and brain is becoming increasingly apparent. Maternal intake of DHA has been associated with improved visual acuity and sensory motor and cognitive development in the offspring (Committee on Nutrient Relationships in Seafood: Selections to Balance Benefits and Risks, Food and Nutrition Board 2007). Cohen *et al.* (2006) have projected that increases in the maternal intake of DHA may produce measurable increases in offspring IQ. The role of these lipids in infant sleep patterns, or development of allergy, asthma and attention deficit-hyperactivity disorder has not yet been conclusively determined.

The Panel on Micronutrients, Panel on the Definition of Dietary Fiber, Subcommittee on

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Upper Reference Levels of Nutrients, Subcommittee on Interpretation and Uses of Dietary Reference Intakes and the Standing Committee on the Scientific Evaluation of Dietary Reference Intakes Food and Nutrition Board (2005) have described many of the potential cardiovascular benefits from the long-chain omega-3 fatty acids for adults. These benefits include preventing arrhythmias, decreasing platelet aggregation, decreasing plasma triglycerides, moderately decreasing blood pressure, reducing atherosclerosis, slightly increasing high-density lipoprotein cholesterol, modulating endothelial function and decreasing pro-inflammatory eicosanoids. Long-chain omega-3 fatty acids provide some protection for the heart muscle during loss of oxygen, which occurs during a heart attack. The American Heart Association (AHA 2007) reports that over 330 000 people die each year from sudden cardiac death. Sudden cardiac death is defined as death that occurs within 1 hour of a heart attack. Mozaffarian & Rimm (2006) have estimated that the number of deaths could be reduced by 36% if the intake of long-chain omega-3 fatty acids was 250 mg/day or higher. A 36% reduction in sudden cardiac deaths would save 120 000 lives per year.

In addition to the cardiac benefits, it appears that healthy fats may also be important for the maintenance of a healthy brain. Morris *et al.* (2005) conducted a 6-year follow-up study of 3718 subjects who were over 65 years of age. The subjects who consumed one meal per week of fish had a 10% slower cognitive decline, and those who consumed two meals per week had a 13% slower cognitive decline when compared to non-fish eaters. The authors were only able to determine an association between fish consumption and cognitive decline, and not a direct correlation between cognitive decline and the ingestion of healthy fats.

Now that we have established the importance of long-chain omega-3 fatty acids from the early stages of life to the senior years, let us discuss the recommended intake of these fats. The National Academy of Sciences – Institute of Medicine (NAS-IOM) (Panel on Micronutrients, Panel on the Definition of Dietary Fiber, Subcommittee on Upper Reference Levels of Nutrients, Subcommittee on Interpretation and Uses of Dietary Reference Intakes and the Standing Committee on the Scientific Evaluation of Dietary Reference Intakes 2005) has established an adequate intake of α-linolenic acid for pregnant or nursing women of 1400 or 1300 mg/day respectively. In addition, the NAS-IOM recommends that 10% of these fatty acids be consumed as EPA plus DHA. Thus, the ‘effective’ adequate intake of EPA plus DHA for pregnant or nursing women is 140 or 130 mg/day respectively. The Dietary Guidelines Advisory Committee (US Department of Health and Human Services 2005) recommends that healthy adults eat 8 oz (227 g) of fish per week in order to obtain 500 mg/day of long-chain omega-3 fatty acids. However, only the following fish species would provide 500 mg of the desired fats from 8 oz (227 g) of fish: anchovy, herring, mackerel, sablefish, shad, whitefish and salmon. AHA recommends that healthy individuals eat two servings [2–3 oz (57–85 g) per serving] per week of ‘fatty’ fish. The term ‘fatty’ should be discontinued because some ‘fatty’ fish, like catfish, are poor sources of omega-3 fatty acids. For cardiac patients, the AHA recommends an intake of 1000 mg/day of EPA plus DHA. Consuming 8 oz (227 g) of farmed salmon per week provides 700 mg of EPA plus DHA per day, which is nearly five times the recommended amount for pregnant or nursing women, and 70% of the amount recommended for cardiac patients. The International Society for the Study of Fatty Acids and Lipids (Simopoulos *et al.* 1999) recommends a minimum DHA intake of 300 mg/day for pregnant or lactating women. So, there are a number of different recommendations regarding the intake of EPA and DHA. Consumers and healthcare professionals should be aware that not all fish species are good sources of EPA and DHA.

If consumers were to follow the Dietary Guidelines Advisory Committee’s recommendation and eat 8 oz (227 g) of fish per week, the annual per capita consumption of fish would increase from the current per capita consumption of 16.5 lb (7.5 kg) (NFI 2007) to 26 lb (11.8 kg). Based upon current consumption rates, the 10 most popular fish include shrimp (4.4 lb, 2 kg), canned tuna (2.9 lb, 1.3 kg), salmon (2.0 lb, 0.9 kg), pollock (1.6 lb, 0.7 kg), tilapia (1.0 lb, 0.4 kg), catfish (1.0 lb, 0.4 kg), crab (0.7 lb, 0.3 kg), cod (0.5 lb, 0.2 kg), clams (0.4 lb, 0.2 kg) and scallops (0.3 lb, 0.1 kg). Of the most popular species, only salmon and canned Albacore/white tuna provide adequate amounts of long-chain omega-3 fatty acids based upon the recommended intake of 140 mg EPA plus DHA for pregnant or nursing women (NFI 2006). As we shall discuss in the next section, canned Albacore/white tuna is moderately high in mercury, and consumption of this fish by sensitive populations should be limited to no more than 4–6 oz/week. Those individuals who are not included in the 'sensitive population' have a much lower risk from mercury and would likely benefit from the healthy fats and other nutrients when consuming Albacore/white tuna.

Risks

Mercury is an environmental pollutant that is released into the atmosphere by anthropogenic (primarily emissions from coal-fired electricity generators and waste incinerators) and natural sources (Clarkson & Magos 2006). Mercury enters the aquatic environment where it is converted into methylmercury, which then moves rapidly up the food chain. The primary route of mercury exposure for humans is through the consumption of fish. Generally, all fish contain some mercury, of which >90% is found as methylmercury (Committee on the Toxicological Effects of Methylmercury, Board on Environmental Studies and Toxicology, Commission on Life Sciences, National Research Council 2000); however, long-lived predatory marine fish species tend to have higher mercury levels than other fish. Similar to humans, the primary route of exposure to mercury for fish is their diet. Fish that are farm-raised tend to have lower concentrations of mercury because the ingredients used in their feed are lower in mercury (Santerre *et al.* 2001).

Methylmercury is efficiently (>90%) absorbed in the human gut (Committee on the Toxicological Effects of Methylmercury, Board on Environmental Studies and Toxicology, Commission on Life Sciences, National Research Council 2000). Pregnant women can pass methylmercury through the placenta to the fetus. Nursing women can pass mercury through their milk. Mercury is a neurodevelopmental toxicant, which can cause injury to the nervous system at high levels. Much of the debate that rages today involves the proper setting of a safe level of exposure that would be expected to protect the developing baby from excessive risk. Some believe that all fish are safe, and that fish consumption advisories scare sensitive populations away from eating fish, which provides important nutrients for the developing baby. Others believe that there is sufficient scientific evidence to warrant a prudent approach that encourages pregnant or nursing women to make an informed decision about the fish that they consume. Consumers should not be too distracted by the debate because it is clear that women can choose the safest course of action and eat fish that is lower in mercury and higher in healthy fats. Adding to this controversy is the inability of federal agencies to agree on a safe limit of exposure to mercury by sensitive populations (Committee on the Toxicological Effects of Methylmercury, Board on Environmental Studies and Toxicology, Commission on Life Sciences, National Research Council 2000).

There are a number of safety and regulatory limits established for methylmercury. In the USA and Canada, methylmercury limits in commercial fish have been established. The US Food and Drug Administration (FDA) has established an action level for methylmercury in the edible portion of commercial fish (fish that enters interstate commerce) of 1000 ppb (Committee on the Toxicological Effects of Methylmercury, Board on Environmental Studies and Toxicology, Commission on Life Sciences, National Research Council 2000). Health Canada has established a limit of 500 ppb (About Health Canada 2004). The FDA is somewhat constrained in their ability to set a 'protective' limit for mercury in commercial fish. For instance, if the FDA was to set a single limit, which protected all consumers, it would be forced to ban a large amount of seafood from the marketplace. Much of the banned seafood could be an important part of a healthy diet for 'non-sensitive' consumers. Thus, setting a limit that attempts to protect babies could actually come at a cost of many lives. The FDA has taken the approach of informing healthcare professionals and sensitive populations of the risks from mercury exposure in order to protect public health.

The US Environmental Protection Agency (USEPA) has established a safety limit, called the reference dose (RfD), for methylmercury. Unlike the FDA's action level, this limit is based upon a dosage and not on the concentration of mercury in fish tissue. The RfD, which was determined using a non-cancer end point (like developmental delays in a child), is 0.1 μg mercury/kg body weight-day (Committee on the Toxicological Effects of Methylmercury, Board on Environmental Studies and Toxicology, Commission on Life Sciences, National Research Council 2000). According to the USEPA, this is the safe limit of exposure for a woman who wishes to minimize the risk from mercury for her fetus or nursing infant. The RfD should not be interpreted as a 'line-in-the-sand' (i.e. if you cross the line, you will be injured), but rather, exceeding the RfD will increase the risk to the developing baby. To determine how the USEPA's safe limit for methylmercury corresponds with the methylmercury concentration in fish, one has to do some calculations and make some assumptions. For a 132-lb (60 kg) woman who consumes 12 oz (340 g) of fish per week, the maximum concentration of methylmercury in the edible flesh to remain below the RfD is 120 ppb. For the same woman who eats 8 oz (227 g) per week, the limit is 185 ppb. Note that the concentrations of 120 and 185 ppb are much lower than the FDA's action level of 1000 ppb. The Agency for Toxic Substances and Disease Registry has set a minimal risk level of 0.3 μg/kg body weight-day (Committee on the Toxicological Effects of Methylmercury, Board on Environmental Studies and Toxicology, Commission on Life Sciences, National Research Council 2000).

There are a number of studies that have reported mercury concentrations in commercial fish. The FDA (2006) has provided the most comprehensive data available for fish sold in the USA. Shim *et al.* (2005) reported levels of mercury and omega-3 fatty acids in fish sandwiches purchased from six restaurant chains. As expected, they found low mercury concentrations that ranged from 4 to 132 ppb. The fried fish sandwiches were also low in EPA and DHA. Shim *et al.* (2004) reported mercury and omega-3 fatty acid concentrations in canned tuna ($n = 240$), salmon ($n = 16$) and mackerel ($n = 16$). The average mercury concentration in canned tuna was 188 ppb, and Albacore/white tuna concentrations were higher than those in light tuna. Carrington & Bolger (2002) estimated that 34% of the mercury that is ingested in the USA comes from canned tuna. One solution that has been proposed for the canned tuna industry is that they develop a 'kid healthy' canned tuna product, which contains lower mercury 'light' tuna (<80 ppb) that has been fortified with (300 mg/oz) DHA. This product could then be distributed through school lunch programs to children and through the Special Supplemental Nutrition Program for Women, Infants and Children (WIC) Centers to lactating women. The mercury concentrations in salmon and mackerel were 45 and 55 ppb respectively.

The Centers for Disease Control and Prevention's National Health and Nutrition Examination Survey for 1999–2002 found that 5.7% of childbearing-aged women had concentrations of mercury in their blood (>5.8 μg/L) that would be expected if these women consumed an amount of mercury that exceeded the USEPA's RfD (CDC 2004). While cases of mercury toxicity are rare in the USA, Hightower & Moore (2003) reported that adults who frequently consumed higher-mercury species experienced symptoms that are consistent with mercury toxicity. In addition, these symptoms disappeared when the patients modified their diet to reduce mercury exposure. Because adults are more tolerant to mercury than fetuses and infants, the risks to the fetuses and nursing infants of symptomatic lactating women as reported in this study would be high.

Now let us turn our attention to another contaminant that is found in fish. Since 2002, there have been reports that farm-raised salmon contain excessive levels of polychlorinated biphenyls (PCB). PCBs are a class of chlorinated organic chemicals that includes 209 compounds (commonly called congeners). PCBs were manufactured until the late 1970s and sold as mixtures (commercially known as Aroclors®), each of which contained around 40–60 congeners (van den Berg *et al.* 1998). PCBs are environmentally persistent, but concentrations in fish have decreased by 90% since production was banned. PCBs are lipophilic (fat loving) and easily move up the food chain. They are efficiently absorbed in the human gut and move easily through the placenta and into milk. Like methylmercury, PCBs are developmental toxicants that can harm the developing fetus or nursing infant at higher levels of exposure. Unlike mercury, which can be cleared from the body within 1 year, PCBs can take six or more years to clear from the body. Thus, a woman could be nursing her infant today and be passing a larger dose of PCBs to her infant than she received 3 years prior.

Hites *et al.* (2004) reported average (PCB) concentrations in farmed salmon as 37 ppb, and in wild salmon as 4 ppb. Average PCB concentrations in farmed salmon from Chile (~20 ppb) and Canada (~20 ppb) were lower than those from Europe (~45 ppb). Because most of the farmed salmon consumed in the USA is produced in Chile and Canada, exposure to PCBs from farmed salmon closely resembles exposure to PCBs from consumption of wild salmon. The PCB concentrations reported by the Hites study came from samples collected during 2001, which were slightly inflated because of inclusion of salmon skin in the samples. Skin holds fat, which is a repository for PCBs, and it is a common practice to remove the skin when measuring residues because most consumers do not consume the skin. Removing the skin and associated fat will likely reduce the PCB levels by up to 20%. Shaw *et al.* (2006) reported levels of PCBs in wild and farmed salmon to be lower than those reported by Hites *et al.* (2004). Shaw *et al.* reported average PCB levels in farmed Atlantic salmon from North America as 16 ppb. These lower levels are likely because of changes in salmon feed, which resulted after the publication of the Hites study; the use of a standard sample preparation procedure (i.e. skinless filets); and a more representative sampling design than used in the Hites study.

The FDA and Health Canada have established a tolerance/limit for PCBs in commercial fish of 2000 ppb. The USEPA (1999) has established two safety limits for PCBs. One safety limit (which we will discuss first) is based upon non-cancer end points (like developmental delays), and the other limit is based upon cancer as an end point. Similar to mercury, both of the USEPA safety limits are based upon a dosage and not on the concentration of PCBs in fish (as used by the FDA limits). The RfD, which is determined using a non-cancer end point (like developmental delays in a child), is 0.02 μg/kg body weight-day. According to the USEPA, this is the safe limit of exposure for a woman who wishes to minimize the risk to her fetus or nursing infant. Thus, for a 132-lb (60 kg) woman who consumes 12 oz (340 g) of cooked (assume 50% loss of PCB during cooking based upon findings by Zabik *et al.* 1995) fish per week, the maximum safe concentration of total PCB in the raw edible flesh is 50 ppb. This protective limit is higher than the average level reported by Hites *et al.* (2004) of 37 ppb or Shaw *et al.* (2006) of 16 ppb. Note that the USEPA's RfD of 50 ppb is much lower than the FDA tolerance for commercial fish of 2000 ppb.

While the concentrations of PCBs in fish are often higher than in other foods, the overall contribution of selected PCBs and dioxin-like compounds may be higher from other foods. The Committee on the Implications of Dioxin in the Food Supply Food and Nutrition Board (2003) reported that Americans receive 42% of dioxin-like compounds (which includes some of the PCBs) from meat products; 17% from dairy products; 12% from fruits and vegetables; 10% from poultry and eggs; 13% from other foods; and only 8% from fish products. Thus, when eating fish and not one of these other foods, consumers may actually be reducing their intake of dioxin-like compounds including PCBs.

The USEPA (1999) has determined that PCBs are a B-2 carcinogen (sufficient evidence for animals and probable evidence for humans) and established a Cancer Health Endpoint for a total PCB of 0.005 μg/kg body weight-day. This limit is not useful for predicting cancer risk for the fetus or the developing infant. For an adult who receives this dosage of PCB for 70 years (lifetime), the predicted increase in their risk of cancer would be 1 in 100 000. To put this in perspective, the current cancer rate in the USA is 25 000 cases for every 100 000 people. So, at the Cancer Health Endpoint dosage, the rate would increase by 1 case to 25 001 cases for every 100 000 people. Now, let us do the same thing that we previously did to derive a safe concentration in fish. Because we are attempting to lower cancer risk during a 70-year lifespan, we will apply the Cancer Health Endpoint (remember, this model is based upon 70 years of exposure). For our example, we will use a 158-lb (72 kg) body weight person and assume that they are consuming 8 oz (227 g) of cooked fish (we have also included a 50% loss of PCB during cooking based upon the findings by Zabik *et al.* 1995) per week. Thus, the limit in the fish that we eat would be 22 ppb. So, for a person who consumes 8 oz (227 g) of cooked, farmed-raised salmon every week over 70 years, which contains 44 ppb of total PCB, the risk of cancer would increase by <2 in 100 000. Remember that the current consumption rate is only 10% of the amount that was used in this model. Also, note that salmon farming is only 20+ years old, so 70 years of exposure will take another 50 years.

From this discussion, you can see that farmed salmon is relatively safe for all consumers, whereby the risks from contaminants is much less than the health benefits that are obtained from the nutrients. Any recommendations to consumers (especially childbearing-aged women) that they avoid farm-raised salmon would be irresponsible and would likely increase the risk for sudden cardiac death, interfere with healthy brain/eye development in the very young or increase cognitive decline in seniors. The only species of fish that are currently sold commercially, which may pose a greater risk from PCBs, are striped bass and bluefish from the Atlantic. We are waiting for results of a multistate study that should be published in the near future that may suggest that sensitive populations limit their intake of these species because of PCBs. However, there are many states where an angler can catch ‘recreationally caught’ fish, which contains excessively high levels of PCBs. For instance, in Indiana, there have been fish analyzed which have been found to contain 35–425 ppm (35 000 – 425 000 ppb) of total PCB (Stahl 2002). Fish with concentrations of this magnitude are typically found in waters near Superfund sites, and this is not an uncommon occurrence for locations in most states. Thus, it is important that consumers, especially those in the sensitive population, consult with their local health department before consuming locally caught fish.

Fish consumption advisories

Now that we have discussed the risks and benefits of eating fish, let us attempt to describe the guidance that we have developed for consumers, especially for sensitive populations. If our advice is too conservative (overly protective) or scares childbearing-aged women or seniors away from eating fish, then we have failed because the risks from not eating fish may be greater than the risks from a low-level exposure to mercury or PCBs. On the other hand, if the advice is not adequately protective, we will increase the risk to our most sensitive individuals, i.e. fetuses and infants.

The FDA & USEPA (2004) have developed a joint fish consumption advisory, which states ‘Advice for women who are pregnant, or who might become pregnant, and nursing mothers . . . do not eat shark, swordfish, king mackerel or tilefish . . . eat up to 12 ounces (340 g) (two average meals) of a variety of fish and shellfish that are lower in mercury . . . for recreationally-caught fish . . . check local advisory . . . eat up to 6 ounces (170 g) of Albacore/white tuna per week’. This advice is lacking because it does not include some of the higher mercury species. It does not recommend the consumption of those species that are higher in EPA and DHA. Finally, it does not mention the risk from eating raw fish for pregnant women or young children.

The *Fish for Your Health*™ wallet card provides advice for pregnant or nursing women, women who will become pregnant and children under age six (Purdue University 2007). Fish are categorized into three main categories [do not eat; eat up to 4 oz (110 g)/week; eat up to 12 oz (340 g)/week] based upon mercury concentrations that were provided by the FDA (2006) and other published studies. The grouping of fish into these categories was determined using the US EPA’s RfD. Overall, the goal of this advice is to recommend that childbearing-aged women eat fish, but that they select those species that are lower in contaminants and higher in long-chain omega-3 fatty acids. This wallet card has been widely distributed (1/3 of a million) to healthcare professionals including dietitians and physicians. One of the best parts of this card is that it can be easily carried to grocery stores and restaurants, and focus groups have found it to be clear to understand and easy to use.

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