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Alternative Strategies for PCB Risk Reduction from Contaminated Seafood: Options for Children as Susceptible Populations

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Numerous health benefits have been associated with consumption of fish and seafood. At the same time environmental data show that seafood may be a major source of several contaminants (Dougherty et al. 2000) and marine biotoxins (Altwein et al. 1995). Much attention has been focused on polychlorinated biphenyl (PCB) exposures for pregnant women and children because studies have associated PCBs with developmental neurological and immunological deficits (Weisgals-Kuperus et al. 1995; Darvill et al. 2000). Removing seafood from the diets of young children denies them short-term health benefits of seafood and potentially the longterm benefits as well if seafood is never introduced into their adult diets. Seafood, particularly shellfish, is a major dietary constituent and culturally important food for many communities including Asian and Pacific Islanders (API). PCBs are present in tissues of some shellfish from urban areas at levels exceeding U.S. FDA's tolerance limit of 2 parts per million. Some of the highest concentrations have been found in samples from Elliott Bay, Washington of crab hepatopancreas, a digestive organ of the crab (Ylitalo et al. 1999). A consumption survey of API in King County, WA reported whole crab, including internal organs, is consumed by many API (Sechena et al. 1999). The same survey also reported that consuming the cooking water of the shellfish is also common, which minimizes PCB loss from cooking. Creel studies in King County show that despite advisories from Washington State Department of Health, individuals, including API, continue to catch and consume crab from Elliott Bay (Duwamish River and Elliott Bay Water Quality Assessment Team 1999). There is particular concern for the health of young children since their relative exposure to body weight burden may be greater than adults and they may be more susceptible than adults to immunological and developmental effects (Faustman et al. 2000). In this study, alternatives to consumption reduction for mitigating seafood PCB exposure for potentially highly exposed children were explored through modeling.

MATERIALS AND METHODS

The first step taken in this study was to calculate an average five year old child's PCB exposure from consumption of one crab per year from a polluted, urban site (Elliott Bay) and non-urban site (Useless Bay). Consumption characteristics were

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modeled after those of some API members (Sechena et al. 1999) who may consume cooking water and entire Dungeness crabs from Elliott Bay. Contaminant exposures from the hepatopancreas and muscle of crabs were calculated separately. PCB exposure was calculated using the following equation and parameters in Table 1:

PCB exposure=(PCBs tissue conc.*tissue mass*(1-fraction lost in cooking))/body weight/365 days

Exposure from one whole crab (muscle and hepatopancreas) and its cooking water was assumed to be the sum of hepatopancreas and muscle exposure with no PCB loss due to cooking. Exposure was also calculated for muscle alone assuming consumption of cooking water (no PCB loss due to cooking) and assuming cooking water was discarded (PCB loss of 29%, Table 1). Results were compared to PCB reference dose (Rfd) and cancer benchmark concentration.

Table 1. Parameters used in exposure equations

Parameter	Value	Reference
Mean PCB conc. in Elliott Bay crab muscle (n=10, s.d.[1]= 70 ppb)	120 ppb[2]	Ylitalo et al., 1999
Mean PCB conc. in Elliott Bay crab hepatopancreas (n=10, s.d.=7300 ppb)	8800 ppb	Ylitalo et al. 1999
Mean PCB conc. in Useless Bay crab muscle (n=10, s.d.=1.8 ppb)	5.7 ppb	Ylitalo et al. 1999
Mean PCB conc. in Useless Bay crab hepatopancreas (n=10, s.d.= 220 ppb)	340 ppb	Ylitalo et al. 1999
Mean crab muscle mass (estimate of raw mass)[3]	243 g	Sechena et al.1999
Mean crab hepatopancreas mass (n=4, raw)[4]	45.5 g	D.R.E.T.W.Q.A.T. 1999
Mean body weight of small child (5 year old boys and girls, s.d.= 3 kg)	19.7 kg	USEPA 1997
PCB loss due to cooking when cooking water discarded (blue crabs, n=8, s.d.=3%)	29%	Zabik et al. 1992

[1]s.d.= standard deviation
[2]ppb=part per billion=µg/kg=ng/g
[3]Adjusted from cooked mass (n=5, mean=219 g, s.d.=23g). Assumed same percent mass lost in cooking as for whole crab (n=5, mean=11%)(Sechena et al. 1999).
[4]No individual data or s.d. provided.

Next, the number of crabs that could be eaten without exceeding the Rfd or cancer benchmark dose was calculated. The impacts of three PCB exposure reduction options were also considered: changing seafood source location from urban to non-urban site, not consuming cooking water, and removal of the crab hepatopancreas. The Rfd and cancer benchmark concentration were divided by exposure per crab (calculated from the first equation) from Elliott Bay or Useless Bay to estimate number of crabs consumed that would exceed these guidelines. This was done for whole crab and crab muscle only, assuming consumption of cooking water, and for muscle only assuming cooking water was not consumed.

RESULTS AND DISCUSSION

Table 2 presents average annual exposure calculations for a young child (5 year old of average weight) assuming consumption of one crab per year using the exposure equation and parameter values from Table 1. Exposure from muscle from one Elliot Bay crab (with or without consumption of cooking water) or one whole Useless Bay crab is below the Rfd. Exposure from muscle from one Useless Bay crab (with or without consumption of cooking water) is below the cancer benchmark concentration; all other exposures from a single crab per year exceed it substantially. Consumption of one whole Elliott Bay crab exceeds the benchmark by over one hundred-fold.

Table 2. PCB exposure from one crab, including cooking water (unless specified), per year for a young child

Exposure or regulatory guide	μg PCB/kg * day
Elliott Bay	
whole crab	0.060
Muscle-cooking water consumed	0.0041
Muscle-cooking water discarded	0.0029
Useless Bay	
whole crab	0.0023
Muscle-cooking water consumed	0.00019
Muscle –cooking water discarded	0.00014
USEPA Rfd[1]	0.02
Cancer benchmark conc.[2]	0.0005

[1]Based on clinical signs and immunological alternations seen in exposed primates (USEPA Integrated Risk Information System, substance file for Aroclor 1254, accessed online 1/2002).
[2]Benchmark concentration for carcinogenic effects equals 10^{-6} divided by the cancer risk slope factor (2 per mg/kg/d) (USEPA, Integrated Risk Information System, substance file for PCBs, accessed online 1/2002) and represents the exposure concentration at which upper bound lifetime cancer risk is one in one million.

Table 3 presents the number of crabs (including cooking water) consumed annually by a small child which would exceed the PCB Rfd and cancer benchmark concentration from Elliott Bay, including and excluding the hepatopancreas, and from Useless Bay, including and excluding the hepatopancreas. The number of crabs that could be consumed if only muscle is eaten and cooking water is discarded (assume PCB loss due to cooking) was also calculated. With the exception of consumption of muscle only from Useless Bay crab, consumption of less than one crab per year would exceed the cancer benchmark concentration. When only muscle is consumed (including cooking water), over 100 crabs from Useless Bay could be consumed without exceeding the Rfd.

Table 3. Number of crabs consumed by a small child to exceed PCB exposure guidelines

Item Consumed	Minimum number consumed to exceed Rfd[1]	Minimum number consumed to exceed cancer benchmark conc.[2]
Elliott Bay		
Number whole crabs	<1	<1
Number crabs muscle only	5	<1
Number crabs, muscle only, if cooking water discarded	7	<1
Useless Bay		
Number whole crabs	9	<1
Number crabs muscle only	103	3
Number of crabs, muscle only, if cooking water discarded	145	4

[1]Based on clinical signs and immunological alternations seen in exposed primates (USEPA Integrated Risk Information System, substance file for Aroclor 1254, accessed online 1/2002).
[2]Benchmark concentration for carcinogenic effects equals 10^{-6} divided by the cancer risk slope factor (2 per mg/kg/d) (USEPA, Integrated Risk Information System, substance file for PCBs, accessed online 1/2002) and represents the exposure concentration at which upper bound lifetime cancer risk is one in one million.

These results demonstrate quantitatively that the hepatopancreas may be a major toxicity contributor from consumption of whole crab. In the examples presented here, consumption of one or more of this highly contaminated organ may lead to exceedances of cancer benchmark even when crabs are collected from nonurban areas. The effect of consuming cooking water on PCB exposure was minimal compared to the effect of source location and consumption of the hepatopancreas.

The use of cooking water is common for several Asian communities (Marien 1996; Sechena et al., 1999) and its use may be essential for some culturally important dishes. In addition to using crab cooking water in soups and other dishes, the crab butter (liquid surrounding internal organs) is sometimes drank directly from the carapace (Sechena et al. 1999). Cooking alone is not expected to reduce PCBs. One of the commercially desirable characteristics of PCBs is their heat resistance; most PCB congeners have melting points well above the boiling point of water (Erickson 1997).

The source location of commercial crab is often unknown to the consumer, although commercial fishing is generally restricted from areas known to be polluted. Anglers do catch and consume crab from Elliott Bay despite warnings from the Washington State Health Department (Duwamish River and Elliott Bay Water Quality Assessment Team, 1999). Many factors including economic necessity and language barriers (preventing understanding of warnings) may contribute to this continued practice. The calculations presented here demonstrate that consumption of the hepatopancreas from urban areas presents a significant exposure and potential health concern.

In addition to concentrating PCBs, the hepatopancreas also concentrates domoic acid (Altwein et al. 1995). Domoic acid, also known as amnesic shellfish poison, is a neurotoxin produced by a diatom that may lead to septic shock, pneumonia, and mortality after consumption of contaminated seafood (Mos 2001). High levels of domoic acid were detected in Dungeness crab in Washington State in 1994, more than 350 California sea lions from the Monterey Bay, California region died from causes related to domoic acid exposure in 1998, and domoic acid was the cause of beach closures for shellfish collection in September 2000 on Prince Edward Island on the west coast of Canada (Mos 2001). This biotoxin may be present in the hepatopancreas of crab at levels 5 to 10 times higher that those found in the corresponding muscle (Altwein et al. 1995). The diatom producing domoic acid is widely distributed and its blooms cannot currently be well predicted (Mos, 2001), further justifying removal of the hepatopancreas from crab from any location as a risk reduction measure. Removal of this organ may be protective of exposure to both PCBs and domoic acid.

For some whole crab (including hepatopancreas) and even some muscle only consumption scenarios, the PCB cancer benchmark concentration was exceeded with consumption of a single crab even when the Rfd was not exceeded. The cancer benchmark concentration was calculated by dividing the PCB cancer risk slope factor for prediction of an upper bound cancer risk by one million and is intended to represent the minimum dose which may present a cancer risk of one in a million. This is a very conservative estimate of PCB cancer risk and therefore should be interpreted with caution.

In making dietary decisions, health concerns about contaminants in crab should be weighed carefully against their many health benefits. Dungeness crab is particularly low in fat, with a measured lipid content of 1.2 percent, and high in protein, with a measured protein content of almost 18 percent (King et al. 1990). Lipid in Dungeness crab is over fifty percent polyunsaturated fatty acid (PUFA). PUFA, especially long-chain n-3 fatty acids, decrease plasma triglycerides and are believed to have antiatherogenic properties (King et al. 1990). In a study of normolipidemic men whose protein intake was substituted by crabmeat for 3 weeks, a 12% reduction in low density lipoprotein (LDL) was seen. Shellfish are also good sources of zinc and magnesium (Childs et al. 1990). Inclusion of shellfish in children's diets may have a major impact on lifetime dietary patterns and therefore heart disease risk. This is especially true for API, since shellfish are major dietary components (Sechena et al. 1999).

Due to the nature of available contaminant data, the PCB risk discussion here has been limited in scope to Aroclor or total PCB based risk assessment. PCBs in mixtures are known to weather differentially, leading to very different relative concentrations of constituent PCB congeners than is found in original commercial formulations (Sinkkonen and Paasivirta 2000). Some studies indicate that weathered PCBs are more toxic than original mixtures on a mass basis due to relative concentration of more toxic congeners (Jordan and Feeley 1999). These findings have lead to the increased use of congener specific analysis despite its great expense. The use of congener specific analysis also allows for consideration of a common mode of action with dioxin and dioxin like compounds through the use of toxic equivalency factors (TEFs)(Van den Berg et al. 1998).

This study has quantitatively shown that removal of the crab hepatopancreas may be a more effective method for PCB exposure reduction for young children consuming whole crab than discarding cooking water or changing source location of crab. Consumption of even a few whole Puget Sound crabs per year by a five year old child, may lead to PCB health risks of concern. Much of this risk may be mitigated by removal of the hepatopancreas, which concentrates contaminants. Removal should reduce potential exposure to the biotoxin, domoic acid, which also concentrates in the hepatopancreas. Changing seafood source location and discarding cooking water may also reduce exposure. If these options, particularly hepatopancreas removal, are culturally acceptable and can be communicated effectively, they may provide a good alternative or addition to standard consumption advisories. Crab and other shellfish may be part of a healthy lifetime diet, are important culturally for many communities including Asian and Pacific Islanders, and may be an important protein source for low income and subsistence families.

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