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Seafood intake and blood cadmium in a cohort of adult avid seafood consumers

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ABSTRACT

Although the benefits of fish consumption are widely recognized, seafood may also be a source of exposure to heavy metals such as cadmium. Many types of seafood are rich in cadmium, but bioavailability and potential for toxicity after consumption is less clear. This study investigates the relationship between seafood intake and the level of cadmium (Cd) in the blood in a 252 person cohort of avid seafood consumers in the Long Island Study of Seafood Consumption (New York). Blood cadmium is an established biomarker of cadmium exposure, reflecting both recent and decade-long exposure. Data on the amounts and frequency of eating various types of seafood were self-reported by avid seafood consumers recruited in 2011–2012. After adjusting for age, BMI, sex, current smoking status, and income in a linear regression model, we found no association between regular seafood intake ($\beta = -0.01$; $p = 0.11$) but did identify an association between salmon intake in cups/week (ln transformed) ($\beta = 0.20$; $p = 0.001$) and blood cadmium. After accounting for salmon, no other types of seafood were meaningfully associated with blood cadmium. No association was found between rice intake, blood zinc, or dietary iron or calcium and blood cadmium. Results suggest that seafood is not a major source of cadmium exposure, but that salmon intake does marginally increase blood cadmium levels. Given that cadmium levels in salmon are not higher than those in many other seafood species, the association with salmon intake is likely attributed to higher consumption of salmon in this population.

Introduction

The advantages of eating fish are well-known – not only are fish a healthy source of protein and other nutrients, but eating fish may also confer various health benefits. Fish consumption has been linked to decreased likelihood of developing rheumatoid arthritis (Cleland et al., 2003; Goldberg and Katz, 2007; Rahman et al., 2008; McManus et al., 2011), psychiatric disorders (Cherubini et al., 2007; Peet and Strokes, 2005; Song and Zhao, 2007; Perica and Delaš, 2011), and lung disease (Cerchietti et al., 2007). Perhaps most importantly, eating fish may lead to better cardiovascular health (Harris, 1997; Kinsella et al., 1990; Oomen et al., 2000; Kris-Etherton et al., 2002; Oomen et al., 2000; Kris-Etherton et al., 2002; Mozaffarian et al., 2005; Jarvinen et al., 2006; Mozaffarian and Wu, 2011). The major beneficial cardiovascular effects of eating fish are often attributed to polyunsaturated omega-3 fatty acids, which bioaccumulate up the food chain from algae and phytoplankton (Judé et al., 2006).

At the same time however, heavy metals such as cadmium are also able to bioaccumulate in aquatic organisms via waterborne and dietborne exposure pathways (Buchwalter et al., 2008; Svobodova et al., 1996). The degree of cadmium bioaccumulation in fish is influenced by various factors that include biological habitat, chemical form of cadmium in the water, water temperature, water pH, dissolved oxygen concentration, as well as characteristics of fish physiology (Has-Schön et al., 2006). Such a bioaccumulation of cadmium in fish has been raised as a concern because chronic exposure to cadmium has been shown to have serious deleterious effects on human health (Jarup and Akesson, 2009; Martí-Cid et al., 2007; Wright and Mason, 2000; Satarug et al., 2011).

The International Agency for Research on Cancer classifies cadmium as a category 1 known human carcinogen (WHO/IARC, 1993). Epidemiologic evidence has linked cadmium exposure to renal dysfunction and kidney disease (Buchet et al., 1990; Jarup and Alfven, 2004; Navas-Acien et al., 2009; Thomas et al., 2009; Nordberg

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et al., 2012), decreased bone mineral density (Åkesson et al., 2006; Staessen et al., 1999; James and Meliker, 2013), and metabolic syndrome (Lee and Kim, 2012). Moreover, there is some evidence to suggest that cadmium might be associated with hypertension (Eum et al., 2008; Gallagher and Meliker, 2010), stroke and heart failure (Peters et al., 2010), and even cardiovascular disease (Tellez-Plaza et al., 2010, 2012, 2013) – which suggests that the risks implicated in cadmium exposure might counteract any cardio-protective effects from eating fish (Guallar et al., 2002).

Furthermore, seafood consumption has been suggested to be one of the primary routes for human exposure to cadmium (Ju et al., 2012) and has been estimated to be at levels of concern in risk assessments (Pastorelli et al., 2012; Storelli and Barone, 2013). Other evidence, however, suggests that seafood may not be the primary route of exposure to cadmium (Hellberg et al., 2012) and questions remain about whether and how much of the cadmium eaten in seafood is bioavailable to humans. Absorption of cadmium varies between individuals (JECFA, 2004; Kikuchi et al., 2003), with zinc, iron, or calcium deficiency identified as possible effect modifiers that increase cadmium absorption (Brzóska and Moniuszko-Jakoniuk, 1998; Evans et al., 1970; Fox, 1988; Jacobs et al., 1983; Kello and Kostial, 1977; Koo et al., 1978; Reeves and Chaney, 2008). Thus, in regards to human health, it is more relevant to study a biomarker of cadmium, rather than the levels of cadmium that are present in seafood. Blood cadmium is a reliable biomarker that reflects relatively recent exposure (Madeddu et al., 2011) and is also an indicator of the bioavailability of exposure to cadmium. Blood cadmium, therefore, may reflect the amount of cadmium ingested that is ultimately absorbed to reach systemic circulation. Human studies reported both positive (Birgisdottir et al., 2013; Oyoo-Okoth et al., 2010) and null associations (Sirot et al., 2008; Vahter et al., 1996) between blood cadmium and seafood consumption, indicating evidence is mixed and more research is needed.

The primary aim of the current study is to investigate the association between seafood consumption and level of blood cadmium among those who consume high amounts of seafood – specifically whether eating fish would appreciably and significantly raise blood cadmium levels. Moreover, given dangers associated with heavy metals exposure, it is also of interest to examine whether human consumption of certain species of fish might meaningfully contribute to any differences in blood cadmium levels. We hypothesized that the correlation between seafood consumption and blood cadmium is not significant since bioaccessibility studies suggest that cadmium from seafood is not bioavailable to humans and therefore not a meaningful source of exposure.

Materials and methods

Sample

Individuals from the general population of Long Island, New York were recruited over a 13-month period between September 2011 and October 2012. This purposive sampling process excluded people who could not read or write in English, were not over the age of 18, or were pregnant. Prospective participants were sought via print advertisements, online through the study's website, and also in person at seafood markets, fishing piers, and seafood restaurants. Participants were screened using a basic food frequency questionnaire that queried how often and how much they ate various types of seafood over the last year. Data on age, gender, and self-reported weight were also obtained during screening. To provide adequate power to study mercury-related health effects (not presented here), estimated daily mercury intake (μg/kg body weight/day) based on their self-reported seafood consumption pattern was determined and individuals with exposure levels that fell under the EPA reference dose of 0.1 μg/kg body weight/day (IRIS, 1994) were excluded from the study. All participants with estimated mercury levels above the reference dose were considered eligible for participation. A total of 996 individuals completed the screening questionnaire, with the majority being eligible ($n = 746$). Of those deemed eligible, 290 participants enrolled in the study and completed a clinical appointment at the Clinical Research Core at Stony Brook University Medical Center. Of these, complete data were available for 252 individuals in the analyses presented here. We obtained informed consent from all participants; the study was approved by Stony Brook University's Institutional Review Board for human subjects (IRB# 185935).

Participants provided blood for analyzing blood cadmium and other trace metals and questionnaires to characterize demographics and food frequency consumption. Participants were asked to not eat any seafood for 3 days prior to their blood test.

Measures

The main dependent variable is blood cadmium, which is a continuous quantity measured in μg/L using an Inductively Coupled Plasma Mass Spectrometry at RTI International's Trace Inorganic Laboratory (RTP, NC, USA), with an average detection limit of 0.05 μg/L. Samples below detection limit ($n = 29$) were calculated as the detection limit/$\sqrt{2}$. The primary independent variable is total cups of seafood consumption regularly eaten on a weekly basis. Consumption of various types of seafood was also asked, and includes anchovy; bluefish; canned light/white tuna; catfish; croaker; eel; flounder; halibut; herring; lobster; mackerel; monkfish; mussels; orange fish; whitefish that includes cod, tilapia, sole, and haddock; pollock; porgy; red snapper; sablefish; salmon; scallops; sea bass; sea trout; shellfish; shrimp; squid; striped bass; sturgeon; swordfish; tilefish; tuna steak; and weakfish; as well as a separate category that included fish that were self-caught. The total consumption of each type of seafood was measured categorically by frequency (never; few per year; once per month; 2–3 times per month; once per week; twice per week; 3–4 times per week; 5–6 times per week; or everyday), as well as quantitatively by the number of cups eaten for each type of seafood (calculated based on answers to frequency and serving size). We performed a natural-log transformation on cups eaten of each seafood type.

Since blood zinc, iron, and calcium are implicated as having an interactive effect on the absorption of cadmium, the level of blood zinc (measured in μg/L), as well as dietary iron and calcium intake (levels determined from food frequency questionnaire, NutritionQuest, Berkeley, CA, USA), were confounders controlled for in our analysis. Moreover, smoking (whether the participant is a current smoker) and vegetable intake (measured as servings per day) may be significant sources of cadmium exposure (ATSDR, 2008) and are therefore included in our analysis to control for potential confounding of the relationship between cadmium exposure and seafood consumption. Other covariates include age (continuous), gender (binary), BMI (continuous), income category (less than $25k; $25k–$70k; $70k–$110k; $110k–$200k; $200k+), educational attainment (some high school; high school graduate; some college or trade school; college graduate), and employment status (employed, which includes self-employed; unemployed, which includes homemaker; student; retired).

Statistical analysis

Analyses were performed using Stata version 13.0 (College Station, TX). A linear regression was performed to examine whether the quantity of seafood consumption was associated with blood cadmium levels. Linear regressions were also carried out separately