Uptake of cadmium from Pacific oysters (Crassostrea gigas) in British Columbia oyster growers

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Abstract

Background: Pacific oysters along the North American coast from Washington to Alaska contain concentrations of cadmium (Cd) that are high by comparison with Atlantic oysters, frequently exceeding 2\(\mu\)g/g wet weight, but it is unclear whether this Cd is absorbed by consumers.

Objectives: To determine the effect of oyster consumption on Cd in blood and urine among a group with high oyster consumption.

Methods: Sixty-one non-smoking oyster growers and family members with a mean age of 47.3\(\pm\)7.6 years (range 33–64) were interviewed by telephone to assess their oyster consumption and other sources of Cd exposure at present and 5 years prior to the start of oyster farming. Their blood and urine Cd concentrations were measured.

Results: The geometric mean Cd concentration in blood was 0.83\(\mu\)g/L and in urine was 0.76\(\mu\)g/g creatinine. Thirty-six percent of participants had urinary Cd levels above 1\(\mu\)g/g creatinine and 5% were above 2\(\mu\)g/g creatinine. Recent (last 12 months) and long-term oyster consumptions were positive predictors of blood Cd but did not directly predict urinary Cd. The optimal model for predicting the variance in blood Cd included recent intake of oyster-derived Cd, serum iron concentration and recent ketchup consumption (\(R^2 = 0.34\), \(p = 0.00004\)), with the latter two variables showing a protective effect. The factors found to predict urinary Cd were blood Cd concentration and duration of oyster farming. A rise in blood Cd was observed after 12 years of farming oysters, likely caused by higher consumption of oysters during this period.

Conclusions: Oyster-derived Cd is bioavailable and affects body stores of the metal.

Keywords: Cadmium; Biomarkers; Oysters; Diet

1. Introduction

Pacific oysters (Crassostrea gigas) are harvested along the northwest coast of North America from Washington to Alaska and accumulate levels of cadmium (Cd) that are high by comparison with Atlantic oysters and may exceed some international tolerances for cadmium. In the province of British Columbia (BC), Canada in 1999, several shipments of oysters were rejected by the Hong Kong Food and Environmental Hygiene Department for exceeding the 2\(\mu\)g Cd/g wet weight import limit. Investigation by the Canadian Food Inspection Agency (CFIA) confirmed these shipments were not an isolated incident; the mean Cd concentration of oysters cultured in various areas of the province ranged from 0.99 to 2.21\(\mu\)g/g wet weight. Fisheries and Oceans Canada concluded that the Cd in BC oysters is mainly due to the geology of the area and...
anthropogenic sources are minor contributors (Kruzynski, 2000). Due to natural global circulation, the North Pacific has a Cd concentration of 100 ng/L, which is three to five times greater than the North Atlantic where Cd concentrations in oysters are generally below 1 µg/g wet weight (Kruzynski, 2003).

Cadmium in foods is of concern because diet is the most significant source of exposure to this known nephrotoxicant in the non-smoking, non-occupationally exposed population (ATSDR, 1999). Ingested Cd is not readily absorbed but due to the long half-life of the metal in the body, even moderate exposure may cause detrimental effects to health over time (Åkesson et al., 2005; Noonan et al., 2002). The Joint Food and Agriculture Organization and World Health Organization Expert Committee on Food Additives established a proposed tolerable weekly intake (PTWI) for Cd of 7 µg/kg of body weight (JEFCA, 2004). Weekly consumption of 6–8 average sized BC oysters (230 g) containing 2 µg Cd/g results in intake of 460 µg of Cd, exceeding the PTWI for anyone under the weight of 65 kg. However, the PTWI is calculated based on the assumption that 5% of Cd from all dietary sources is absorbed (ATSDR, 1999; JEFCA, 2004) and is intended to be applied to long-term consumption and not on a single week. Recent studies have shown that Cd absorption from the intestine may vary anywhere from a fraction of a percent to 30% depending on dietary source, iron status, and possibly many other factors (Kikuchi et al., 2003; Vahter et al., 1996; Vanderpool and Reeves, 2001). Oyster-derived Cd in particular is very inefficiently absorbed (Vahter et al., 1996; Sharma et al., 1983). Smoking has a far more significant impact on Cd body burden (Sharma et al., 1983). Current limits on Cd concentration in oysters do not consider relative absorption efficiencies.

This study attempts to clarify the potential impacts of regularly consuming BC oysters by examining oyster consumption and Cd biomarkers among a sample of oyster farmers and their families. This population has consistent access to oysters and is likely to show an above average intake of oysters that is continuous over a period of years. Previous studies may have failed to see significant effects on Cd biomarkers because of oyster intakes that are too low (e.g. Vahter et al., 1996) or too short in duration (e.g. Sharma et al., 1983).

2. Methods

2.1. Sample

British Columbia oyster growers and their family members were identified through the Ministry of Agriculture, Food, and Fisheries (MAFF) and the BC Shellfish Growers Association. Eligible subjects were from 30 to 65 years of age, were not current smokers, and had not smoked in the past (defined as having smoked no more than 20 packs of cigarettes, no more than 12 oz of tobacco in a pipe, and no more than one cigar per week for 1 year). Up to three family members from the same grower’s residence were allowed to participate.

2.2. Exposure assessment

Eligible subjects who agreed to participate completed a telephone interview to assess current and retrospective Cd exposure.

The subjects estimated dietary consumption of various foods over the last 12 months and over a 12-month period 5 years prior to the start of oyster farming by the family. Subjects reported frequency of intake, serving size, and for oysters, the BC growing region. Other foods included in the questionnaire were mussels, scallops, organ meats (beef and pork liver, chicken liver, beef kidney), leafy green vegetables (spinach, lettuce, seaweed; cooked and uncooked), potatoes (French fries, chips, boiled, mashed), carrots, and tomatoes (fresh, processed into sauce, ketchup, or juice). These foods were chosen because of their potential to contribute to dietary Cd intake. An information package was mailed to subjects to assist with estimating portion size. The package included photographs of five possible serving sizes for all food items. A paper cutout of the size of the plate used in the photographs allowed a sense of perspective when estimating portion size. Subjects were also provided with diagrams of oyster shells of varying lengths beside metric and imperial measurements so that subjects could estimate the average size of oysters they consumed.

Non-dietary exposure assessment consisted of a brief history of second hand smoke, occupational, and hobby exposures to Cd. Subjects were also asked about their medical history, specifically kidney and bone disorders and diabetes, as these conditions may affect Cd metabolism.

We estimated dietary exposure to Cd for the past year and for the adult lifetime (since age 18) using the questionnaire data. Recent consumption was estimated by multiplying the participants’ frequency of intake by serving size for the past 12 months. Lifetime consumption for foods other than oysters was estimated by averaging recent and past consumption and multiplying this by the adult age. For oysters, subjects were free to report various periods of differing oyster consumption and total adult consumption was the sum of oysters consumed during each of these periods. The growing region of the oysters (reported by participants) was used to further refine the estimate of the total amount of cadmium they consumed.

2.3. Biological samples

Subjects were asked to visit a local laboratory to provide blood and urine samples. Blood samples were collected in heparinized trace metal-grade Vacutainers (Becton-Dickinson) and urine samples in regular urinalysis containers (Starplex). All samples were shipped for analysis to the Laboratory at BC Children and Women’s Hospital in Vancouver. Cadmium concentration in whole blood and urine was determined by inductively coupled plasma mass spectrometry (ICP/MS) using a Perkin-Elmer ELAN 6100. Samples were diluted 1:50 (whole blood) or 1:100 (urine) in an alkaline Triton X-100/EDTA/gold/n-butanol/rhodium (internal standard) solution followed by gentle mixing and centrifugation prior to analysis by ICP/MS. Quality control samples (Seronorm) were measured with each batch and the accuracy of this method was verified by bi-monthly testing of blood and urine samples from the Quebec Centre de Toxicologie Interlaboratory Comparison Program. Iron and creatinine measurements were performed with the Vitros 950® (Ortho Clinical Diagnostics, Rochester, New York). The limits of detection for cadmium in blood and urine were 0.16 and 0.23 µg/L, respectively.

2.4. Statistical analysis

Descriptive data analysis was completed for all questionnaire data and biomarker data. The distributions of the blood and urine parameters were examined, and where log-normally distributed they were log-transformed (base e) for all analyses. Simple linear regression was used to determine the association between various dietary and personal characteristics vs. blood and urine Cd levels. The exposure variables that significantly predicted biomarker concentrations (p<0.05) were offered in multiple regression models. ANOVA was used to further investigate the factors that most affect long- and short-term Cd biomarkers. All statistical analysis was
completed using the SPlus statistical program v.6.2 (Insightful Corporation, Seattle, WA).

3. Results

3.1. Characteristics of sample

The initial list of potential oyster farmers included 265 people of whom we were able to contact 224. One hundred and fifty-four people on this list were current BC oyster farmers and willing to participate. A further 39 family members were also willing to participate for a total of 193. From this group, 117 people were ineligible due to smoking or age. All the remaining 76 people completed the telephone questionnaire and of this group 59 provided a blood and urine sample and 2 provided only a blood sample. The sample of 61 with blood and questionnaire data included 33 men and 28 women with a mean age of 47.3 ± 7.6 years (ranging from 33 to 64). The mean ages of men (46.8 ± 6.7) and women (47.9 ± 8.8) did not differ significantly ($p = 0.58$).

3.2. Biological samples

Blood Cd, urinary Cd and serum iron concentrations are summarized in Table 1. All were positively skewed and were log-transformed for subsequent regression analyses. Fig. 1 shows the distribution of urinary cadmium levels. The geometric mean Cd concentrations were 0.83 μg/L in blood and 0.76 μg/g creatinine (cr) in urine. Although for both blood and urinary Cd, the geometric means for women were higher than for men, these differences were not statistically significant ($p = 0.18$ for blood, $p = 0.98$ for urine). The geometric mean serum iron in the study sample was 849.2 μg/L, and was lower for women than for men ($p = 0.01$).

Participants’ average yearly consumption of evaluated foods varied widely. Fig. 2 shows the distribution of oyster consumption among the participants. It varied from never eating oysters ($n = 6$) to a maximum of 537 g of oyster/week (approximately 18 oysters/week), with an average of 86.7 ± 105.7 g/week. Of the 55 subjects who consumed some oysters, 52 (95%) ate fresh BC oysters that originated either from their own farm, another farm, or from the wild. Three subjects (5%) did not know the origin of the oysters.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Concentrations of cadmium and iron in urine and blood</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Element</strong></td>
<td><strong>Blood concentration (μg/L)</strong></td>
</tr>
<tr>
<td></td>
<td><strong>BMI</strong></td>
</tr>
<tr>
<td><strong>Cadmium</strong></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>25.3 ± 3.5</td>
</tr>
<tr>
<td>Men</td>
<td>25.9 ± 2.9</td>
</tr>
<tr>
<td>Women</td>
<td>24.6 ± 4.1</td>
</tr>
<tr>
<td>30–39 years</td>
<td>24.6 ± 1.8</td>
</tr>
<tr>
<td>40–49 years</td>
<td>25.7 ± 4.5</td>
</tr>
<tr>
<td>50–59 years</td>
<td>24.8 ± 2.6</td>
</tr>
<tr>
<td>60–69 years</td>
<td>25.3 ± 2.6</td>
</tr>
<tr>
<td><strong>Iron</strong></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>900</td>
</tr>
<tr>
<td>Men</td>
<td>984</td>
</tr>
<tr>
<td>Women</td>
<td>802</td>
</tr>
<tr>
<td>30–39 years</td>
<td>1054</td>
</tr>
<tr>
<td>40–49 years</td>
<td>804</td>
</tr>
<tr>
<td>50–59 years</td>
<td>950</td>
</tr>
<tr>
<td>60–69 years</td>
<td>841</td>
</tr>
</tbody>
</table>

aArithmetic mean ± standard deviation.
bArithmetic mean.
cGeometric mean.
dGeometric standard deviation.
they consumed and were not included in analysis involving oyster Cd concentration. None reported consuming frozen or canned oysters.

Fig. 3 shows the locations from which the ingested oysters originated for the 52 subjects who ate oysters and knew their origin. This map also shows sites where oyster Cd concentrations have been tested (MAFF unpublished results). The Cd concentration of oysters at the site nearest to the reported origin was used as an estimate of the concentration of oysters being consumed (see Table 2). These concentrations were statistically different (ANOVA \(p < 0.0001\)). The average concentration of Cd in oysters from the site locations was 1.62 \pm 0.51 \mu g/g, lower than the BC average of 2.63 \mu g/g found in the investigation by CFIA (Kruzynski, 2003).

Forty-six subjects (75\%) were exposed to second hand smoke, either at home or in an occupational setting. Other occupational exposure to Cd was limited to 10 subjects (16\%) who had exposure from welding, soldering, paint removal or Cd glazing. Participation in hobby activities that may increase Cd exposure was more common with 25 subjects (41\%) involved in one or more of welding, soldering, sandblasting, pottery, or Cd glazing. None of these exposures showed a statistically significant difference in blood or urinary Cd (Student’s \(t\)-test \(p > 0.05\)).

Of medical conditions asked about in the questionnaire, arthritis was the most commonly reported condition \((n = 6)\), followed by kidney stones \((n = 4)\), and kidney infection \((n = 2)\). No condition had a statistically significant effect on either blood or urinary Cd (Student’s \(t\)-test \(p > 0.05\)).

### 3.3. Factors related to cadmium in blood and urine

Blood and urinary Cd concentrations were somewhat correlated \((r = 0.375, p = 0.0034)\).

Table 3 shows the results of simple linear regressions examining the relationship between log-transformed blood and urinary Cd concentrations with dietary variables that were statistically significant and non-dietary variables. Of the parameters used to assess recent exposure to oyster-derived Cd, frequency of consumption, 12-month oyster intake and 12-month estimated oyster Cd consumption were significant predictors of Cd in the blood (but not the urine).
Long-term oyster exposure was assessed in terms of duration of exposure and total oyster consumption. Total duration of exposure for oyster consumers is approximated by adult age because they have eaten some oysters throughout this time. Since most subjects reported a significant increase in oyster consumption when they began farming, the duration of oyster farming is an indicator of how long they have been eating a significantly increased quantity of oysters. Age was not a significant predictor of either blood or urinary Cd, but duration of oyster farming was significantly related to both blood and urinary Cd. Mass of oysters ingested in adult lifetime and lifetime estimated oyster Cd consumption were related to blood, but not urinary, Cd.

The only other dietary exposure variable with a statistically significant relationship to body Cd was mass of ketchup consumption, which showed a negative association with blood Cd. Serum concentration of iron also had a negative association with blood Cd.

The optimal multiple regression model for describing blood Cd was:

\[
\text{Blood Cd} = 2.1 + 0.00002(12\text{-month oyster Cd intake}) - 0.35(\ln \text{FeS}) - 0.66(12\text{-month ketchup intake}),
\]

This model explained 34.2% of the variance in blood Cd ($p = 0.00004$).

When ketchup is excluded, the model was: blood Cd $= 2.29 + 0.00001(12\text{-month oyster Cd intake}) - 0.39(\ln \text{FeS})$. It explained 26.4% of the variance in blood Cd ($p = 0.0002$).

Fig. 4a illustrates the influence of the frequency of oyster consumption in the last 12 months on oyster Cd ingestion and on blood and urinary Cd concentrations. Blood and

### Table 2
Average cadmium concentration of oysters consumed by subjects

<table>
<thead>
<tr>
<th>Regiona</th>
<th>Abbreviation</th>
<th>Number of samples tested</th>
<th>No. of participants consuming region’s oysters</th>
<th>Oyster cadmium concentrationb Mean ± SDc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desolation sound</td>
<td>DS</td>
<td>617</td>
<td>35</td>
<td>2.1 ± 0.78</td>
</tr>
<tr>
<td>Poett nook</td>
<td>PN</td>
<td>90</td>
<td>2</td>
<td>1.12 ± 0.60</td>
</tr>
<tr>
<td>Useless inlet</td>
<td>UI</td>
<td>413</td>
<td>1</td>
<td>0.99 ± 0.39</td>
</tr>
<tr>
<td>Webster island</td>
<td>WI</td>
<td>136</td>
<td>4</td>
<td>2.21 ± 0.95</td>
</tr>
<tr>
<td>Sansum narrows</td>
<td>SN</td>
<td>6</td>
<td>5</td>
<td>1.75 ± 0.24</td>
</tr>
<tr>
<td>Tulpana inlet</td>
<td>TI</td>
<td>61</td>
<td>2</td>
<td>2.14 ± 0.93</td>
</tr>
<tr>
<td>Kendrick inlet</td>
<td>KI</td>
<td>94</td>
<td>1</td>
<td>1.56 ± 0.61</td>
</tr>
<tr>
<td>Hecate cove</td>
<td>HC</td>
<td>98</td>
<td>2</td>
<td>1.1 ± 0.60</td>
</tr>
</tbody>
</table>

aSee Fig. 3 for map of regions and testing sites.
bANOVA indicates that concentrations at the various sites are statistically different ($p < 0.0001$).
cStandard deviation.

### Table 3
Simple linear regressions with log transformed BCd or UCd as the dependent variables

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>BCd</th>
<th>Coefficient</th>
<th>$R^2$</th>
<th>$p$-Value</th>
<th>UCd</th>
<th>Coefficient</th>
<th>$R^2$</th>
<th>$p$-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (male = 0, female = 1)</td>
<td></td>
<td>-0.1250</td>
<td>0.0302</td>
<td>0.1808</td>
<td></td>
<td>0.0083</td>
<td>0.0002</td>
<td>0.9180</td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td>0.0101</td>
<td>0.0463</td>
<td>0.0989</td>
<td></td>
<td>0.0133</td>
<td>0.0299</td>
<td>0.1941</td>
</tr>
<tr>
<td>Second hand smoke (years)</td>
<td></td>
<td>-0.0027</td>
<td>0.0078</td>
<td>0.4974</td>
<td></td>
<td>0.0020</td>
<td>0.0015</td>
<td>0.7683</td>
</tr>
<tr>
<td>Occupational exposure (hours)</td>
<td></td>
<td>-0.00001</td>
<td>0.0030</td>
<td>0.6794</td>
<td></td>
<td>-0.00002</td>
<td>0.0163</td>
<td>0.3395</td>
</tr>
<tr>
<td>Hobby activities (years)</td>
<td></td>
<td>0.0048</td>
<td>0.0337</td>
<td>0.1565</td>
<td></td>
<td>-0.001</td>
<td>0.0278</td>
<td>0.2330</td>
</tr>
</tbody>
</table>

Recent exposure to oyster-derived cadmium

| Frequency of oyster intake (meals/year) |  | 0.0025      | 0.0744 | 0.0334    |     | 0.0027     | 0.0298 | 0.1911    |
| Oyster serving size (g/meal) |   | 0.0003      | 0.0187 | 0.2928    |     | -0.0006    | 0.0287 | 0.1993    |
| Oyster cd concentration (ug/g) |  | 0.2339      | 0.0422 | 0.1441    |     | -0.0652    | 0.0011 | 0.8213    |
| 12-month oyster intake (kg) |  | 0.0201      | 0.0933 | 0.0166    |     | 0.0115     | 0.0110 | 0.4294    |
| 12-month oyster Cd intake (ug) | <0.0001 | 0.1247      | 0.0066 | 0.0001    |     | 0.000001   | 0.0110 | 0.4410    |

Long-term exposure to oyster-derived cadmium

| Duration of oyster farming |  | 0.0139      | 0.0800 | 0.0272    |     | 0.0336     | 0.1703 | 0.0012    |
| Lifetime oyster intake (kg) |  | 0.0008      | 0.0939 | 0.0163    |     | 0.0002     | 0.0020 | 0.7358    |
| Lifetime oyster Cd intake (ug) | <0.0001 | 0.1048      | 0.0159 | 0.0001    |     | <0.00001   | 0.0017 | 0.7724    |
| 12-month ketchup intake (kg) | -0.3984 | 0.0677      | 0.0429 | -0.4412   |     | -0.4412    | 0.0133 | 0.3836    |
| Ln (Serum Iron) | -0.3054 | 0.0902      | 0.0187 | -0.3601   |     | 0.0453     | 0.1056 |           |
urinary Cd rise in a nearly linear pattern although average Cd intake rises exponentially. Fig. 4b illustrates the long-term effects of oyster consumption based on the duration of oyster farming. It shows a stronger rise in urinary than blood Cd.

4. Discussion

4.1. Cadmium level in biological samples

Cadmium occurs in most foods with concentrations typically ranging from 2 to 40 ppb (parts per billion) (ATSDR, 1999). Average dietary exposure to Cd in the US is estimated to be 2.8 µg/kg body weight/week (Choudhury et al., 2001) and in Canada, 2.1–2.5 µg/kg body weight/week (Health Canada, 1999). Moschandreas et al. (2002) apportioned dietary Cd exposure among a variety of food items and estimated that shellfish account for only 11.4% of total dietary exposure in a typical US diet, while plant foods usually contribute a far greater portion. Our data suggest that oyster growers and their families have much higher than average exposure to dietary Cd. The average oyster consumption in the current study subjects was 87 ± 106 g/week. Using the average body weights of our subjects and the concentrations of Cd in the oysters they ate, this corresponds to approximately 2.2 ± 2.8 µg Cd/kg body weight/week from oyster-derived Cd alone.

The geometric mean blood Cd was 0.83 µg/L and urinary Cd, 0.76 µg/g creatinine (µg/g cr). These means are higher than usually seen in non-smoking populations but below levels often found for smokers and people who live in areas of higher Cd contamination, such as Japan (see Table 4 for
The elevated urinary Cd level may be attributable to the age of the subjects because this biomarker reflects the amount of Cd that has accumulated in the kidney over decades. Approximately one-third to one-half of all body Cd accumulates in the kidney with a half-life of 15–30 years (ATSDR, 1999). The average age of subjects was 47 ± 7.6 years, about the age at which kidney Cd concentration reaches its peak (Satarug et al., 2002).

Blood Cd on the other hand is mainly determined by recent exposure with a half-life of only 3 months (Jarup et al., 1983). Therefore, the elevated blood Cd cannot be accounted for by the age of the participants; in fact, some evidence indicates that Cd absorption decreases with age (Horiguchi et al., 2004). The study subjects have never smoked and do not live near sites of significant Cd contamination, so the only known additional Cd exposure compared to the general population is above average consumption of oysters. Our analyses indicate that oyster consumption is the main identifiable contributor to the increase in blood Cd.

### 4.2. Recent exposure to oyster cadmium

Of the components used to evaluate recent oyster consumption, the frequency of oyster meals was independently a significant predictor of blood Cd concentrations, whereas serving size and Cd concentration were not. The latter two variables were quite narrowly distributed in comparison to frequency of oyster meals and this may explain why neither showed a statistically significant relationship with blood Cd. However, when the frequency of oyster meals, serving size, and Cd concentration of oysters were combined to estimate the mass of oyster Cd consumed, a somewhat higher proportion of the variance in blood Cd was explained (12% vs. 7%). This indicates that Cd is absorbed and the amount that is absorbed depends at least partially on ingested dose.

When subjects were grouped according to their frequency of consumption, it became evident that blood Cd does not rise in proportion with oyster Cd intake (Fig. 4a). Although the average Cd intake increased exponentially, the increase in blood Cd was essentially linear. Previous studies have similarly found that very high intakes of oyster-derived Cd do not result in corresponding increases to blood Cd or urinary Cd (Sharma et al., 1983; Vahter et al., 1996). Sharma et al. studied the consumers of New Zealand Bluff oysters (*Tiosteria lutaria*) that contain Cd levels frequently reaching 5 μg/g wet weight. Despite Cd intakes as high as 340 μg/day, blood Cd and urinary Cd levels of subjects were not significantly elevated at the end of the 6-month oyster season. Smoking status had a significantly more marked effect on blood Cd than oyster consumption. Similarly, a study by Vahter and colleagues (1996) found that women with high shellfish consumption did not show significantly higher blood Cd or urinary Cd than women with low shellfish consumption, although they were consuming approximately twice the amount of Cd daily (22 μg/day compared with 10.5 μg/day). The authors of these studies suggest that the Cd from oysters is absorbed less efficiently or distributed differently in the body than Cd from other sources. Our results suggest that Cd from oysters may not be efficiently absorbed, but increases in blood Cd do occur with increased oyster intake.

The major factor believed to affect absorption and distribution of oyster-derived Cd is that a significant portion of Cd in oysters is bound to proteins such as metallothionein (Cherian, 1979; Ohta and Cherian, 1991). Metallothionein is a small molecular weight protein (6–7 kDa) that can be induced by exposure to Cd in a wide variety of species. It is believed to play a role in protecting cells from metal damage due to its ability to

### Table 4

Comparison of cadmium concentrations

<table>
<thead>
<tr>
<th>Reference</th>
<th>Location</th>
<th>Age range (mean ± SD)</th>
<th>Smoking status</th>
<th>BCd GM&lt;sup&gt;c&lt;/sup&gt; (sample size)</th>
<th>UCd GM&lt;sup&gt;c&lt;/sup&gt; (sample size)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current study</td>
<td>BC, Canada</td>
<td>33–64 (47.3 ± 7.6)</td>
<td>Never smoked</td>
<td>0.83 μg/L (61)</td>
<td>0.76 μg/g cr (59)</td>
</tr>
<tr>
<td>NCEH (2005)</td>
<td>United States</td>
<td>20 +</td>
<td>Smokers and non-smokers</td>
<td>0.47 μg/L (4207)</td>
<td>0.27 μg/g cr (1299)</td>
</tr>
<tr>
<td>Becker et al. (2002)</td>
<td>Germany</td>
<td>18–69</td>
<td>Never smoked</td>
<td>0.28 μg/L (3061)</td>
<td>0.15 μg/g cr (2102)</td>
</tr>
<tr>
<td>Becker et al. (2003)</td>
<td>Germany</td>
<td>18–69</td>
<td>Smokers</td>
<td>1.06 μg/L (1584)</td>
<td>0.21 μg/g cr (1606)</td>
</tr>
<tr>
<td>Becker et al. (2002)</td>
<td>Germany</td>
<td>18–69</td>
<td>Smokers and non-smokers</td>
<td>0.38 μg/L (820)</td>
<td>0.67 μg/g cr (820)</td>
</tr>
<tr>
<td>Akesson et al. (2005)</td>
<td>Sweden</td>
<td>53–64</td>
<td>Smokers and non-smokers</td>
<td>NA</td>
<td>1.3 μg/g cr (10753)</td>
</tr>
<tr>
<td>Ezaki (2003)</td>
<td>Japan</td>
<td>35–60</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

<sup>a</sup>Standard deviation.<br>
<sup>b</sup>Mean and SD provided were available.<br>
<sup>c</sup>Geometric mean.
bind and sequester various metal ions (Cobbett and Goldsborough, 2002). It appears that at least a portion of ingested Cd–metallothionein (Cd–MT) complexes can remain stable in the gastrointestinal tract despite strong proteolytic enzymes (Cherian, 1979; Ohta and Cherian, 1991) and this may decrease absorption. Evidence of absorption differences between Cd–MT and inorganic Cd are inconclusive when exposure occurs in a single dose (Groten et al., 1991; Sullivan et al., 1984) but repeated exposure to Cd–MT does appear to decrease absorption (Ohta and Cherian, 1991). This may result from the induction of endogenous metallothionein by exposure to either inorganic Cd or Cd–MT, though Ohta and Cherian (1991) reported that absorption decreases more after exposure to Cd–MT. Metallothionein may also affect distribution, as 50–60% of inorganic Cd accumulates in the liver while Cd–MT is preferentially distributed to the kidney (Ohta and Cherian, 1991; Sullivan et al., 1984). Increased intake of Cd–MT may therefore decrease total absorption and cause a larger portion of absorbed Cd to be deposited in the kidney with the overall result that blood Cd does not rise in proportion with intake.

Cadmium from oysters may also be poorly absorbed due to the presence of other elements in oysters that appear to decrease cadmium absorption, including iron, manganese, and calcium (Barany et al., 2004; Dong, 2001; He et al., 2006; Leslie et al., 2006; Martin et al., 2006).

Reporting bias may also contribute to the finding of a non-linear relationship between blood Cd and oyster Cd intake. Subjects with the lowest and highest oyster consumption may report consumption more accurately because they are more aware of their consumption patterns than people who are eating an intermediate amount of oysters. Intermediate consumption is more difficult to assess simply because consumers may be less familiar with the average serving size and frequency of their oyster meals.

4.3. Long-term exposure to oyster cadmium

We also found evidence that blood Cd is influenced by long-term intake of oysters. The total amount of oysters consumed during the adult lifetime was as significant in predicting blood Cd as consumption during the past year. One would expect this to be true if long- and short-term consumption are correlated. Total oyster consumption reflects the age of subjects as well as variation in oyster consumption over time. Another long-term exposure variable, duration of farming, was unrelated to individual variation in oyster consumption but still had a positive correlation to blood Cd. This suggests that blood Cd is partially determined by long-term body stores of Cd. Previous evidence supports this finding (Jarup et al., 1983; Shimbo et al., 2000).

The effects of long-term oyster consumption on urinary Cd were less clear. The results of simple linear regressions demonstrated that the amount of oysters consumed over the adult lifetime did not have a significant relationship with urinary Cd. This is likely an indicator of the difficulty in assessing long-term oyster intake rather than evidence that oyster consumption does not have an impact on Cd body burden. Furthermore, when Cd exposure is quite low the effects of genetic factors related to uptake and storage, iron stores, and other absorption factors can further obscure the relationship between dietary intake and body stores (ATSDR, 1999; Björkman et al., 2000). However, a relationship was found between duration of oyster farming and urinary Cd. This suggests that consistently above average oyster consumption does lead to increased body burden of Cd after about 12–18 years. There was a trend for subjects to be slightly older and consume more oysters the longer their family had been farming, but neither trend was statistically significant.

It is uncertain how high intake must be to cause appreciable increases to body burden in the long term. It appears that the level of consumption prior to oyster farming was not enough to increase urinary Cd significantly because the relationship to urinary Cd only surfaced when considering the period of time when subjects have been oyster farmers and increased their oyster consumption. Duration of farming was likely more accurately reported by subjects than consumption of oysters over the adult lifetime and this may also account for why it was the only statistically significant predictor of urinary Cd.

4.4. Other factors affecting cadmium level

Serum iron level was negatively correlated with blood Cd and this finding is well supported by previous evidence (Barany et al., 2004; Satarug et al., 2004). The geometric mean serum iron in the study was within the normal range of 600–1700 μg/L for both sexes (MedLinePlus, 2005). Ionic Cd is a divalent metal like ferrous iron and can enter systemic circulation by means of ionic mimicry using iron transporters. Decreased iron stores leads to induction of transporter proteins, thereby increasing absorption of Cd as well as iron (Ryu et al., 2004; Park et al., 2002). Serum iron was not correlated with urinary Cd but this is not unexpected as serum iron can vary over time.

The results showed a moderate protective effect of ketchup consumption on blood Cd ($F = 0.059, p = 0.0429$); this has not to our knowledge been previously identified in the literature. Ketchup contains very low amounts of the nutrients thought to have a protective effect against Cd absorption, such as iron and calcium, and could not increase body stores of these components enough to alter absorption at the reported levels of consumption. It is more plausible that when oysters and ketchup are ingested together a component in ketchup reduces the absorption of Cd. This constituent could function by binding Cd or affecting the functioning of transporters used for Cd absorption. Citric acid is an organic acid in tomatoes and its ionic form, citrate, has been shown to bind Cd in the presence of iron (Martinez et al., 2001). Pacific oysters are
quite high in iron with approximately 5.1 mg/100 g (Dong, 2001). The presence of this iron along with the citrate from tomatoes may therefore reduce the absorption of Cd (Martinez et al., 2001). Vitamins A and C are also present in ketchup and both have been associated with evidence of enhancing iron absorption (Teucher et al., 2004; Garcia-Casal et al., 1998), which may decrease the availability of iron transporters for Cd transport. These hypotheses rely on consumption of oysters with ketchup, a combination that was not queried in our interview. However, they are likely to be consumed together as oysters are commonly eaten with a cocktail sauce that is mainly made of ketchup and horseradish. More research is needed to test the robustness of this finding.

5. Conclusions

These results clearly indicate that the Cd in oysters is absorbed by the body and increases long- and short-term body stores of the metal when consumed in above average quantities. Based on a review of the literature, Lauwerys et al. (1994) recommended a maximum urine cadmium level of 2 μg/g creatinine for the general public. Ninety-five percent of current participants had cadmium levels below this guideline and all subjects were below occupational guidelines, generally set at 5 μg/g creatinine (OSHA). Urinary excretion of low molecular weight proteins has been reported at levels from 0.6 to 2 μg/g cr in urine (Åkesson et al., 2005; Noonan et al., 2002), although the clinical significance of this is unclear. Mean levels in our subjects were at the low end of this range. Since our study examined exposures, not health endpoints, our results do not provide evidence about the presence or absence of health effects at the exposure levels in our study.

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References


