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Public health evaluation of cadmium concentrations in liver and kidney of moose (*Alces alces*) from four areas of Alaska

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Abstract

Liver and/or kidney samples were collected from 139 hunter-killed moose from four areas of Alaska during 1986. The concentration of cadmium in organ tissue was determined by direct-current plasma atomic emission spectrometry. All results are reported as μg/g wet weight. Concentrations of cadmium in liver ranged from 0.06 μg/g to 9.0 μg/g; in the kidney cortex they ranged from 0.10 μg/g to 65.7 μg/g. Cadmium levels were significantly associated with location and age. The highest geometric mean liver (2.11 μg/g) and kidney cortex (20.2 μg/g) cadmium concentrations were detected in moose harvested near Galena, Alaska. Limited dietary information from Alaska and Canada indicates that the intake of moose liver or kidney does not exceed, in most individuals, the World Health Organization recommendations for weekly cadmium consumption of 400 μg to 500 μg. Additionally, human biomonitoring data from Canada and Alaska indicate exposure to cadmium is low except for individuals who smoke cigarettes. Given the nutritional and cultural value of subsistence foods, the Alaska Division of Public Health continues to support the consumption of moose liver and kidney as part of a well-balanced diet. Human biomonitoring studies are needed in Alaska to determine actual cadmium exposure in populations with a lifelong history of moose liver and kidney consumption.

Keywords: Moose; Cadmium; Liver; Kidney; Alaska; Public health evaluation; Biomonitoring

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1. Introduction

Moose (*Alces alces*) are widely distributed throughout Alaska (Burt and Grossenheider, 1976). The annual moose harvest by humans ranges from 6000 to 8000 animals (ADF&G, 1994). Moose meat is an important source of food for Alaska residents (Caulfield, 1983). Internal organs (such as liver, kidney, heart, etc.) are often consumed as part of a traditional subsistence diet and occasionally by urban hunters (Andrews, 1998; Nobmann, 1989).

Cadmium occurs naturally in the earth's crust but is not known to be essential for plants or animals. Plants take up heavy metals such as cadmium when removing nutrients from the soil (Frank et al., 1981). In addition, human activities (e.g., burning coal and refining ore) can release cadmium into the atmosphere where it can be transported great distances and deposited on soil or plant surfaces (ATSDR, 1999; Eriksson et al., 1990).

Moose are strict herbivores and are exposed to cadmium mainly via ingestion of plant material (Van Ballenberghe et al., 1989; Weixelman et al., 1998). Moose consume a variety of foods depending on the season. In fall and winter, moose consume primarily birch, willow, and aspen twigs. They switch to sedges, horsetail, pond weeds, and grasses in the spring; during summer they feed on birch, willow, and aspen leaves, forbs, and vegetation in shallow ponds (ADF&G, 1994). Willows (*Salix* spp.) accumulate cadmium at higher concentrations relative to other plants (Pugh et al., 2002; Vandecasteele et al., 2002). Once ingested with forage vegetation, cadmium is transported by the blood to all parts of the body and some is stored in the liver bound to metallothionein (Cd-MT). The Cd-MT complex is transported to the kidney (the target and critical organ for cadmium toxicity) and may be reabsorbed following filtration where it accumulates in the cortex (Friberg et al., 1979; Iyengar, 1982; Järup et al., 1998; Kjellstrom, 1976). Thus, cadmium concentrations in kidney cortex are best suited for toxicological and environmental evaluations and comparison of cadmium burden in animals and geographic regions (locations).

The primary sources of cadmium exposure for humans are food and tobacco smoke. In Alaska and other arctic locations, concerns have been expressed regarding the consumption of terrestrial and marine mammal kidney and liver due to higher concentrations of cadmium compared to other commonly consumed foods. In humans, cadmium also accumulates with age in the renal cortex and is the primary target organ for toxicity (JECFA, 2003). In 1998, the Alaska Division of Public Health (ADPH) responded by reviewing all the available scientific information associated with cadmium exposure in traditional foods, and based on its findings endorsed "unrestricted consumption of liver and kidney of arctic wildlife traditionally harvested as part of a varied and well-balanced diet" (ADPH, 1998).

Here we present the results of a previously unpublished study of Alaskan moose liver and kidney cadmium burdens. The objectives of this study were to: (1) determine cadmium burdens in moose kidney and liver; (2) evaluate the influence of geographic location and age on cadmium concentrations; and (3) assess the public health implications of consuming cadmium-containing moose kidney and liver. Preliminary results were presented at the 4th International Moose Conference in Fairbanks, AK in 1997 (A. Frank).

2. Materials and methods

2.1. Sampling areas

Organ samples were collected from hunter-killed moose from four areas of Alaska during 1986. The areas were Galena, Palmer, Kenai, and Yakutat (Fig. 1).

2.2. Organ collection

Liver, kidney, and tooth samples were collected from hunter-killed moose.

2.3. Age determination

Cementum annuli of teeth were counted to determine age by Maston's Laboratory, Milltown, Montana (Gasaway et al., 1978). Calves were assumed to be 4 months old (i.e., born in late May or early June and harvested in September).

2.4. Treatment of tissue material

Collected liver and kidney samples were sent to the Alaska Department of Fish and Game laboratory in

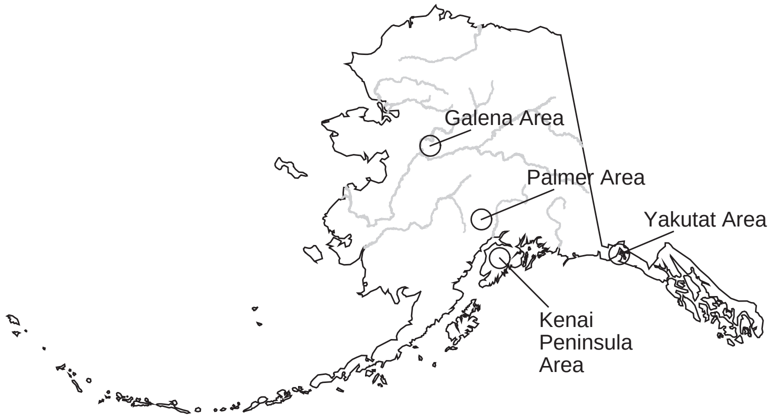

Fig. 1. General areas of hunter-killed moose (*Alces alces*) sampled for this study.

Fairbanks, AK where approximately 50 g was immediately transferred to plastic bags and frozen (− 15 to − 20 °C). Frozen tissue samples were sent to the analytical laboratory at the Chemistry Department, National Veterinary Institute, Uppsala, Sweden on dry ice and kept frozen until analysis.

2.5. Chemical analysis of tissues

2.5.1. Pre-treatment of samples

Thawed kidney tissues were sliced into approximately 1-cm sections, and the medulla was carefully eliminated. Kidney cortex was used for analysis. Combustion of tissue samples (5 g, wet weight) for cadmium analysis was performed by automated wet digestion in boro-silicate glass tubes using a mixture of perchloric and nitric acids, as described previously (Frank, 1976, 1988; Frank and Petersson, 1983).

2.5.2. Analysis of cadmium

Residues from wet ashing were dissolved in ionic buffer (Frank and Petersson, 1983).

Cadmium was determined by direct current plasma atomic emission spectrometry (Frank and Petersson, 1983) (SpectraSpan IIIA, Applied Research Laboratories Inc., Valencia, CA, USA). The determinations were regularly checked against appropriate and certified standard reference materials (bovine liver NIST 1577b, National Institute of Standards, Gaithersburg, MD, USA). The analytical laboratory at the Chemistry Department, National Veterinary Institute, Uppsala, Sweden is an accredited testing laboratory by the Swedish Board for Accreditation and Conformity Assessment, Borås, Sweden. The limit of detection (3× standard deviation of the mean blank value) in 5 g organ wet weight for Cd was 0.020 mg/kg and the limit of determination (10× standard deviation of the mean blank value) was 0.060 mg/kg.

2.6. Statistical analysis

Arithmetic and geometric means of wet weight cadmium concentrations in liver and kidney were calculated. The non-parametric Spearman correlation (SAS version 8.0) was used to correlate cadmium accumulation in liver and kidney with age. We were unable to use regression methods because of poor model fit.

Cadmium concentrations detected in liver and kidney for each location were compared by one-way ANOVA (SAS version 8.0). Pairwise comparisons were performed using Tukey HSD analysis (SAS version 8.0). We constructed a multivariable general linear model analogous to a two-way ANOVA (SAS version 8.0) to determine the independent effects of location and age on organ cadmium concentrations. Because age data were not collected in Kenai, we were unable to include this location in our model. Age was entered into the model as a nominal variable with two possible values, ≤ 4 years and > 4 years. Four years was selected as the cut-off because this value approximated the median age for our kidney cortex data. We performed pairwise comparisons of age-adjusted cadmium levels by location and for location-adjusted cadmium levels by age by using least square means for effect. For all models, cadmium concentrations were log-transformed to satisfy assumptions of normality.

3. Results and discussion

One hundred thirty-nine moose were harvested during 1986 from multiple locations near Palmer, Galena, Kenai, and Yakutat, Alaska. Sex was determined for 127 animals; 64 were female. Age was determined for 102 animals; the average age was 4.3 years (range = calf to 14 years). Age data were not available for moose from Kenai.

Table 1 presents the summary statistics for cadmium concentrations determined in the kidney cortex and liver of moose from this study. In one-way ANOVA models, cadmium concentrations for both kidney cortex ($P<0.001$) and liver ($P<0.001$) were significantly higher in Galena than for all other locations (Table 1). The correlation between cadmium and age was moderate in magnitude for liver (rho = 0.55, $p<0.001$) and moderate-to-strong in magnitude (rho = 0.70, $p<0.001$) for kidney cortex.

In the multivariable general linear model, age-adjusted cadmium levels for both liver ($p<0.001$) and kidney ($p<0.001$) differed with mean levels higher in Galena than in Palmer and Yakutat (Table 2). Location-adjusted cadmium levels for both liver ($p<0.001$) and kidney ($p=0.012$) were higher in older moose than younger moose. There was no significant interaction between age group and location.

To our knowledge, this is the only study reporting cadmium concentrations for kidney cortex of Alaska moose. O'Hara et al. (2001) reported whole kidney data for moose collected from the Colville River drainage and moose harvested from Nome, Nowitna, Fairbanks, and Barrow (designated "other Alaska moose"). As previously mentioned, cadmium concentrates in the renal cortex, thus our results represent an upper limit of kidney cadmium concentration and are not directly comparable to whole kidney results. However, they are included here for a relative spatial comparison. The arithmetic mean (± standard deviation) cadmium concentration in whole kidney from the Colville River drainage ($n=9$) and "other Alaska moose" ($n=10$) was 21.6 ± 20.8 μg Cd/g and 14.2 ± 11.6 μg Cd/g wet weight, respectively (O'Hara et al., 2001). Note that the data for "other Alaska moose" presented in O'Hara et al. (2001) of 73.1 μg Cd/g reflects the dry weight data (personal communication, Keith Mueller, U.S. Fish and Wildlife Service). The arithmetic mean cadmium concentration detected in whole kidney of moose harvested throughout the Yukon ($n=389$) was 28.5 ± 21.9 μg Cd/g (Mary Gamberg, Gamberg Consulting, Whitehorse, Yukon, personal communication). For a comparison of cadmium concentrations detected in kidney cortex, moose from Nova Scotia ($n=16$) had a median of 26 μg Cd/g (range = 3–148) (Frank et al., 2004). For Galena area moose, the median cadmium concentration detected in the kidney cortex was 19.7 μg Cd/g (range = 9.49–65.7).

For the liver, the arithmetic mean cadmium concentration detected in moose from the Colville River

Table 1
Cadmium concentrations (μg/g, wet weight) in kidney cortex and liver for moose (*Alces alces*) from Alaska

Population	Number of samples	Arithmetic mean	Standard deviation	Geometric mean	Median	Range	Tukey grouping[a]
Kidney cortex							
Palmer	48	4.06	3.80	2.34	2.59	0.10–15.1	B,C
Galena	27	22.8	12.9	20.2	19.7	9.49–65.7	A
Kenai	8	6.57	4.57	5.42	5.45	1.92–16.4	B
Yakutat	16	1.68	1.04	1.41	1.39	0.47–3.96	C
Liver							
Palmer	55	0.44	0.37	0.31	0.37	0.06–1.64	B
Galena	34	2.51	1.77	2.11	1.87	0.68–9.00	A
Kenai	13	0.67	0.40	0.56	0.53	0.11–1.48	B
Yakutat	28	0.47	0.44	0.34	0.28	0.07–2.18	B,C

[a] ANOVA $P<0.001$, groups that do not contain a common letter are significantly different.

Table 2
Moose (*Alces alces*) kidney cortex and liver cadmium concentrations by location (adjusted for age) and age (adjusted for location)

	Kidney ($n=72$)			Liver ($n=97$)		
	Palmer	Galena[a]	Yakutat	Palmer	Galena[a]	Yakutat
Number	32	24	16	37	32	28
Least-square mean (μg/g, wet weight)[b]	2.59	16.11	2.10	0.34	1.86	0.42
	Age ≤ 4 years	Age > 4 years	p-value	Age ≤ 4 years	Age > 4 years	p-value
Number	38	34		61	36	
Least-square mean (μg/g, wet weight)[c]	2.83	6.95	< 0.001	0.44	1.02	0.012

[a] Cadmium levels were higher in Galena than for all other locations ($p<0.001$). Multiple comparisons were performed using least square means for effect.
[b] Means approximate geometric mean because cadmium levels were log-transformed. Means are adjusted for age.
[c] Means approximate geometric mean because cadmium levels were log-transformed. Means are adjusted for location.

drainage ($n=9$) and "other Alaska moose" ($n=12$) was 3.13 ± 2.5 μg Cd/g and 3.61 ± 3.1 μg Cd/g, respectively (O'Hara et al., 2001; personal communication, Keith Mueller). Yukon moose ($n=60$) had an average liver concentration of 5.11 ± 4.10 μg Cd/g (Mary Gamberg, personal communication).

Geographical differences in cadmium concentrations in liver and kidney likely reflect underlying geology of the moose range (Woolf et al., 1983). The Galena area is known to contain mineral deposits generally associated with cadmium such as galena (lead sulfide) and sphalerite (zinc sulfide) (USGS, 2005).

Older moose will have higher cadmium concentrations in liver and kidney, which explains the correlation between cadmium levels and age in our study. This finding was confirmed in our multivariable general linear model. A. Frank will present a more sophisticated analysis of age and cadmium accumulation in moose in a forthcoming paper. Although cadmium levels differed by both age and location for kidney and liver content of cadmium, it appears from our data that the effect of location on cadmium concentration is more important than age. The magnitude of the difference between means for age-adjusted location were higher than the magnitude of the difference for location-adjusted age for both organs (Table 2).

4. Public health evaluation

Traditional foods have many social, cultural, and economic benefits, and are an important source of valuable nutrients and lean protein (ADPH, 1998; AMAP, 2003). Documented health benefits from consumption of traditional foods include protection from diabetes and heart disease, as well as improved maternal nutrition and fetal and infant development (ADPH, 1998; AMAP, 2003). When developing dietary guidelines for traditional foods that contain trace chemical contaminants, public health officials continue to emphasize the benefits of these foods (ADPH, 1998; AMAP, 2003; Archibald and Kosatsky, 1991; Berti et al., 1998; Kim et al., 1998; Receveur et al., 1998).

Results from previous public health evaluations conducted in the Northwest Territories (Berti et al., 1998; Kim et al., 1998; Larter and Nagy, 2000), Northern Quebec (Archibald and Kosatsky, 1991), and the Yukon (Receveur et al., 1998) indicate that the highest potential exposure to cadmium from terrestrial mammal-based diets is moose and caribou liver and kidney. Based on dietary surveys or harvest information and the analytical results of food sampling, these evaluations concluded that consumption of liver and especially kidney were low, and in most cases total dietary exposure was below the World Health Organization (WHO) provisional tolerable weekly intake (PTWI) of 400 to 500 μg Cd (JECFA, 2003). Based on the many associated benefits, the researchers encouraged continued harvest and consumption of traditional food.

Existing, albeit limited, consumption data for moose liver and kidney indicate ingestion of these organs is low in Alaska as well. Informal surveys and reports conducted throughout Alaska by the Alaska Department of Fish and Game Subsistence Division

(ADF&G) document broadly ranging consumption rates. However, ADF&G estimated it is most likely that the average individual will consume two to three liver meals (1–1.5 lb) and one kidney meal (0.5 to 1.0 lb) per year (personal communication, Mr. Terry Haynes, Regional Supervisor, ADF&G, Division of Subsistence, Fairbanks, AK). While some people may eat more, this corresponds to 0.019 lb (8.7 g) to 0.029 lb (13 g) consumed per week for liver and 0.0096 lb (4.4 g) to 0.019 lb (8.7 g) consumed per week for kidney. Anecdotal information indicates most people consume whole kidney. Our study evaluated cadmium concentrations in kidney cortex, which represents the upper limit of cadmium concentration and thus exposure, providing the most conservative approach to evaluating possible public health implications. An individual consuming liver (2.11 μg Cd/g) and kidney cortex (20.2 μg Cd/g) of moose from Galena at the above intake rates would ingest approximately 46% of the WHO cadmium guideline (Table 3). Ingesting liver (0.56 μg Cd/g) and kidney cortex (5.42 μg Cd/g) from the Kenai Peninsula at this intake level would correspond to 2% and 11% of the WHO guideline.

Table 3
Estimated cadmium intake relative to the World Heath Organization (WHO) Provisional Tolerable Weekly Intake (PTWI) of 450 μg for individuals consuming moose liver and kidney

Source of exposure	Cadmium intake (μg/week)	Cadmium intake relative to the WHO PTWI of 450 μg/week
Moose liver from the Galena area[a]	27	0.06 (27/450)
Moose kidney cortex from the Galena area[a]	181	0.40
Kenai moose liver from the Kenai Peninsula[a]	7	0.02
Kenai moose kidney cortex from the Kenai Peninsula[a]	49	0.11
Typical diet[b]	90	0.20
Smoking[c]	230	0.51

[a] Cadmium intake was calculated using the geometric mean concentration (see Table 1) and a consumption rate of 3 liver meals (1.5 lb) and 1 kidney meal (1 lb) per year or 13 g of liver and 9 g of kidney per week (personal communication with Mr. Terry Haynes, Regional Supervisor, ADF&G, Division of Subsistence, Fairbanks, AK).

[b] Typical U.S. diet (Gunderson, 1995).

[c] Approximately 2 μg of Cd is absorbed per pack of cigarettes smoked (ATSDR, 1999). Thus, smoking one pack of cigarettes per day (7 packs/week) is roughly equivalent to ingesting 230 μg Cd/week via the diet (Table 3), assuming an intestinal absorption rate of 6% (230 μg Cd/week × 0.06 = 14 μg/week) (Elinder, 1992; Morgan and Sherlock, 1984).

To estimate total cadmium intake relative to the WHO PTWI, two additional factors need to be considered: other cadmium sources in the diet and tobacco smoking (Table 3). Cadmium intake from the typical U.S. diet is approximately 90 μg Cd/week (Gunderson, 1995). Thus, individuals consuming kidney or liver at the concentrations present in Galena area moose may exceed the WHO PTWI; however, actual dietary consumption data are lacking. Smoking cigarettes is a significant source of cadmium exposure (ATSDR, 1999). Cadmium absorption from the diet is relatively low, ranging from 3% to 7% (Elinder, 1992; Morgan and Sherlock, 1984), whereas absorption of inhaled cadmium is much higher, ranging from 10% to 60% (Elinder, 1992). Approximately 2 μg of Cd is absorbed per pack of cigarettes smoked (ATSDR, 1999). Thus, smoking one pack of cigarettes per day (7 packs/week) is roughly equivalent to ingesting 230 μg Cd/week via the diet (Table 3), assuming an intestinal absorption rate of 6% (230 μg Cd/week × 0.06 = 14 μg/week) (Elinder, 1992; Morgan and Sherlock, 1984). Approximately 27% of all Alaskan adults and 43% of Alaska Native adults smoke (Peterson et al., 2004), making smoking an important source of cadmium exposure in Alaska.

Human cadmium biomonitoring data provide evidence that when compared to smoking, diet becomes a relatively minor contributor to overall cadmium exposure. For example, blood cadmium concentrations of individuals presumed to consume locally harvested terrestrial or marine mammal liver and kidney in Eastern Greenland (Hansen et al., 1985), northern Quebec (Benedetti et al., 1994), Nunavik (Rey et al., 1997), and Southern Ontario (Cole and Kearney, 1997) were no different from control groups from other locations. But, smokers had 2 to 20 times the amount of cadmium in their blood (Benedetti et al., 1994; Cole and Kearney, 1997; Hansen et al., 1985; Rey et al., 1997).

One small biomonitoring assessment has been conducted to date in Alaska. The ADPH analyzed urine and blood samples from St. Lawrence Island residents ($n = 10$) known to have a lifetime history of whale, seal, and walrus liver and kidney meat consumption (Middaugh et al., 1986). Pacific walrus sampled in this area of Alaska had a mean liver and kidney cadmium concentration of 9.5 μg/g (n=65) and 46.5 μg/g (n=42) (Taylor et al., 1989). Despite the resident's potential exposure, blood and urine cadmium concentrations were low, ranging from 0.4 to 1.8 μg Cd/L and 0.05 to 2.5 μg Cd/L, respectively. The World Health Organization assumes a urinary excretion of 2.5 μg Cd/g creatinine as the threshold for tubular renal dysfunction (JECFA, 2003) (for a rough comparison, 1 g creatinine/L urine can be used to convert from μg Cd/L urine to μg Cd/g creatinine). While information on the participant's smoking history was not collected, when taken with other human biomonitoring data, the results indicate cadmium exposure from dietary sources is less than predicted from dietary surveys and tissue concentration data, and smoking is a more important source of cadmium exposure than the diet.

5. Conclusions and recommendations

The concentration of cadmium detected in liver and kidney cortex was significantly higher in moose harvested from the Galena area compared to other locations in our study. The most likely explanation for the geographical difference of cadmium concentration is the underlying geology of the moose range. The correlation between liver and kidney cadmium concentrations and age were also statistically significant, but age had a smaller effect compared to location on the cadmium concentration.

The information presented here supports our general conclusions regarding the consumption of liver and kidney from Alaska terrestrial and marine mammals, which are summarized as follows (ADPH, 1998). Since the concentrations of cadmium in moose kidney and liver from some areas of Alaska are relatively high, it is conceivable that some consumers of these organs could exceed the WHO PTWI. However, the WHO PTWI incorporates a margin of safety, which we believe could be larger. These organs are rich in elements (such as selenium, zinc, iron, copper, and calcium) as well as in vitamin D, protein, and fiber which are known to reduce the absorption and/or toxicity of cadmium (Berglund et al., 1994; Flanagan et al., 1978; Fox, 1997; Friberg et al., 1974; Nordberg et al., 1985; Reeves and Chaney, 2002; Vahter et al., 1996). Consumption of these organs appears to be generally low, and human biomonitoring data from subsistence populations in Canada and Alaska indicate actual exposure via the diet is low.

ADPH recommends continued consumption of kidney and liver from subsistence species as part of a well-balanced diet (ADPH, 1998). These organ meats are excellent sources of protein, vitamins, essential elements, and calories, and they can have great cultural value to those who consume them. To reduce cadmium exposures, a well-balanced diet that includes meals rich in calcium, fiber, protein, and iron will help decrease cadmium absorption. Also, limiting consumption of kidney and liver from older moose or consuming liver instead of a kidney will reduce overall exposure. For those who smoke, the most effective way to lower cadmium exposure is to quit.

Additional research that could aid in the determination of cadmium exposure in Alaska includes:

- Development of a biomonitoring program to establish baseline cadmium exposure by measuring urine and/or blood cadmium concentrations and early markers of renal effects (e.g., urinary beta-2-microglobulins) in populations with a history of lifelong organ consumption and monitor trends overtime;
- A survey of moose kidney and liver consumption and smoking habits by individuals in areas of Alaska where cadmium concentrations in moose are relatively high; and
- An evaluation of the nutrient value of liver and kidney from terrestrial and marine mammals harvested in Alaska.

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