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Hunting with lead: Association between blood lead levels and wild game consumption

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ABSTRACT

Background: Wild game hunting is a popular activity in many regions of the United States. Recently, the presence of lead fragments in wild game meat, presumably from the bullets or shot used for hunting, has raised concerns about health risks from meat consumption.

Objective: This study examined the association between blood lead levels (PbB) and wild game consumption.

Methods: We recruited 742 participants, aged 2–92 years, from six North Dakota cities. Blood lead samples were collected from 736 persons. Information on socio-demographic background, housing, lead exposure source, and types of wild game consumption (i.e., venison, other game such as moose, birds) was also collected. Generalized estimating equations (GEE) were used to determine the association between PbB and wild game consumption.

Results: Most participants reported consuming wild game (80.8%) obtained from hunting (98.8%). The geometric mean PbB were 1.27 and 0.84 μg/dl among persons who did and did not consume wild game, respectively. After adjusting for potential confounders, persons who consumed wild game had 0.30 μg/dl (95% confidence interval: 0.16–0.44 μg/dl) higher PbB than persons who did not. For all game types, recent (<1 month) wild game consumption was associated with higher PbB. PbB was also higher among those who consumed a larger serving size (≥2 oz vs. <2 oz); however, this association was significant for 'other game' consumption only.

Conclusions: Participants who consumed wild game had higher PbB than those who did not consume wild game. Careful review of butchering practices and monitoring of meat-packing processes may decrease lead exposure from wild game consumption.

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1. Introduction

Wild game hunting is a popular leisure time activity with substantial economic impact in many regions of the country. There are 18.6 million hunters 16 years or older in the United States, 12.5 million of whom were engaged in hunting activities in 2006. In 2006 alone, expenditures associated with hunting were estimated to be approximately $23 billion (US Department of Interior, Fish and Wildlife Service (FWS), 2006). Nationally, the West North Central region (Kansas, Iowa, Minnesota, Missouri, Nebraska, North Dakota, South Dakota) has the highest rate of participation in hunting activities among those ≥16 years of age (12%) compared to any other regions (2–8%) in the United States or the overall national rate (5%) (FWS, 2006). Although the wild game is predominantly consumed by hunters and their families, a large amount is also donated to the local charitable organizations, serving as a source of protein for many low-income families through the *Sportsmen*

Abbreviations: PbB, blood lead levels; FWS, Fish and Wildlife Services; ATSDR, Agency for Toxic Substance and Disease Registry; MN DNR, Minnesota Department of Natural Resources; CDC, Centers for Disease Control and Prevention; GEE, generalized estimating equations

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Against Hunger program in different states in the region (Herzog, 2008; Safari Club International Foundation, 2009).

Recently, fragments of lead particles, presumably from lead bullets or shot used for hunting, were detected in samples of donated meat packs in North Dakota and surrounding states. This discovery raised concerns about potential human health risks from the consumption of wild game (Herzog, 2008; Smith, 2008). Exposure to lead has been found to adversely affect most systems in the human body and some of these effects can be observed at very low levels of lead in blood; most significant are the neuro-cognitive and neuro-developmental deficits observed among children at low blood lead levels (PbB) (Agency for Toxic Substances and Disease Registry (ATSDR), 2007; Canfield et al., 2003; Lanphear et al., 2005; Kordas et al., 2006; Tellez-Rojo et al., 2006; Menke et al., 2006). Among all states, North Dakota has one of the highest rates of hunting participation (17% of residents ≥ 16 years) and the adverse health risk from the consumption of wild game meat contaminated by lead fragments could have a population-wide impact (FWS, 2006; Herzog, 2008).

Studies have shown that fragments from lead ammunition can contaminate wild game meat; if bullets impact with bones, the fragments may be scattered further within the body of the hunted animal (Frank, 1986; Scheuhammer et al., 1998; Bjerregaard et al., 2004; Minnesota Department of Natural Resources (MN DNR), 2008; Tsuji et al., 2008a, 2009; Hunt et al., 2008, 2009). The amount of lead ingested through the consumption of contaminated wild game can exceed recommended limits, and such game can be a potential source of lead in blood (Tsuji et al., 2001; Johansen et al., 2001, 2004; Bjerregaard et al., 2004; Mateo et al., 2007; ATSDR, 2008). In Spain, Mateo et al. (2007) manually implanted lead fragments in quail meat and found that half a quail with a single lead fragment can be a source of enough lead to contaminate the meat above levels recommended by the European Commission (0.1 μg/g of wet weight). Terrestrial raptors that fed on wild game carcasses were found to be subject to secondary poisoning from fragments of lead shot (Scheuhammer and Norris, 1995; Fisher et al., 2006; Garcia-Fernandes et al., 2005; Martin et al., 2008). Several studies in the arctic regions (e.g., Canada, Greenland, Russia) have observed that human consumption of hunted bird meat contaminated by lead shot is significantly associated with increased PbB (Scheuhammer et al., 1998; Odland et al., 1999; Hanning et al., 2003; Bjerregaard et al., 2004; Johansen et al., 2006). Johansen et al. (2001) observed that lead shot contamination in birds represents a significant source of lead in the diet of people residing in Greenland. Recently, human exposure from lead ammunition has been confirmed by lead isotope ratio studies by Tsuji et al. (2008a) among the First Nations People in northern Canada. Most of these studies, however, were small in scale; they included select population samples and often focused on small game, especially birds. We conducted a study in North Dakota to determine possible exposure to lead from consumption of wild game hunted with lead ammunition.

2. Materials and methods Materials and methods

2.1. Participant selection

Participants were recruited in six North Dakota cities: Bismarck, Fargo, Minot, Jamestown, Dickinson, and Grand Forks (Fig. 1). Following a press release from the North Dakota Department of Health, participants were recruited in public health clinics in each of the cities. Participants were also recruited among the state laboratory and state government employees in Bismarck, ND. Participants were eligible for inclusion if they (a) were residents of North Dakota, (b) were ≥ 2 years of age, (c) had sufficient knowledge of English language, and (d) agreed to provide blood samples. All participants signed a consent form; for any child <18 years of age, parental consent as well as the child's assent was obtained.

A total of 742 participants were recruited from the six different cities in North Dakota. Capillary blood samples were collected from two of the child participants because their parents refused a venous blood draw; these test results were included in the analysis. Two persons were found to reside in Minnesota and blood draw was incomplete for three children and one adult. They were excluded from all analyses ($N = 736$).

2.2. Data collection

A 42-item questionnaire was used for data collection in a face-to-face interview. Data were collected on demographic and housing characteristics (e.g., age of housing, duration of residence in the same household, renovation, visible peeling of paint), current and previous lead-related hobbies (e.g., hunting, lead soldering, car/boat repair), occupations (e.g., welding, construction, working in lead smelter, refinery, or lead mines), and consumption of wild game. Information on frequency and duration of wild game consumption, meat processing methods, and average serving size (<2 oz vs. ≥ 2 oz) by type of wild game (i.e., venison, other wild game such as moose—'other game', and birds other than waterfowl—'birds') was also collected. Waterfowl consumption was excluded since lead-shot is prohibited from use in hunting waterfowl in North Dakota. Trained phlebotomists, using aseptic precautions, collected venous blood samples in a Monoject™ Lavender Stopper Blood Collection Tube (Covidien, Mansfield, MA, USA) from all participants. Data were collected between May 16, 2008 and May 30, 2008.

2.3. Laboratory methods

Blood samples were stored in refrigerators at ~4 °C until transport in pre-frozen ice packs to the Division of Laboratory Sciences [National Center for Environmental Health, Centers for Disease Control and Prevention (CDC)] where laboratory analysis was performed. Laboratory analyses for whole blood lead were determined using the Perkin-Elmer inductively coupled plasma-dynamic reaction cell-mass spectrometer 6100 ELAN series DRC II, ELAN® DRC II ICP-MS

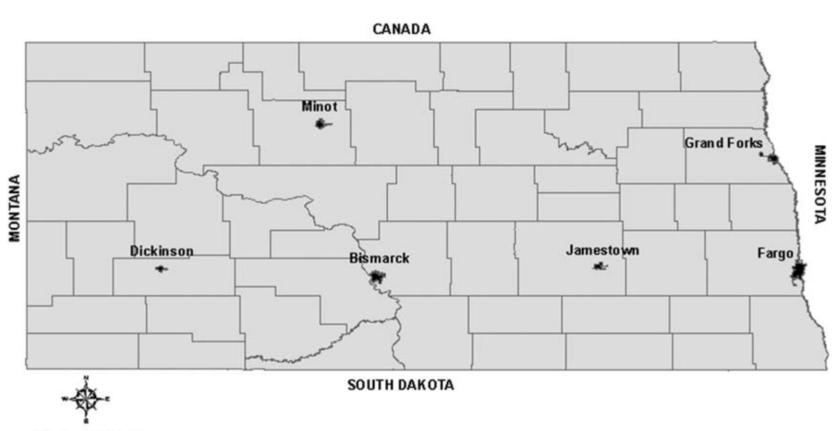

Fig. 1. Participant recruitment in North Dakota.

(Perkin-Elmer SCIEX, Concord, Ontario, Canada) equipped with a Minehart nebulizer and cyclonic spray chamber. During analysis of whole blood samples, two bench quality control pools were analyzed along with 'blind' quality control pools interspersed among the participant samples. Accuracy of analysis results was verified by the analysis of standard reference material (SRM 955 c) from the National Institute of Standards Technology (National Institute of Standards Technology, 2009). The minimum detection level for blood lead was 0.25 μg/dl. For persons with no detectable levels of blood lead ($n = 5$), a value calculated as the detection limit divided by the square root of 2 was assigned (National Center for Environmental Health, 2001).

2.4. Statistical analysis

Frequencies and proportions were reported for all variables: socio-demographic and housing characteristics; lead-related occupations and hobbies; and wild game consumption, including type, frequency, and average serving size. Geometric mean lead levels and frequency for PbB ≥5 μg/dl were reported. To account for potential clustering within families, generalized estimating equation (GEE) methods were used to determine unadjusted and adjusted associations between PbB and other variables using SAS software (version 9.1, Copyright © SAS Institute, Inc., 2002–2003, Cary, NC, USA). Separate GEE models were developed by types of wild game (i.e., venison, other game, birds) to determine the association between frequency, duration, average food serving size, and PbB. Age, sex, race, and income, commonly reported predictors of elevated PbB, were included in the multivariate model based on a priori considerations. Additional variables were included in the multivariate model only if those variables were significant (p-value <0.05) in unadjusted models. Parameter estimates with 95% confidence intervals and significance levels were reported for all models. Two-way interactions with the exposure variable (e.g., consumption of wild game) were considered in multivariate models.

3. Results

3.1. Study population

Almost half of the participants (48.2%) were ≥55 years of age. Participation among males (54.3%) was higher than among females (Table 1). Participants were almost exclusively white (98.4%). The majority of the study participants (65.5%) had at least college degrees and most participants (78%) reported an annual household income of at least $40,000.

In addition to socio-demographic information, we also collected information on housing characteristics. Most of the residences of the participants were built in or after 1950 (83.9%). More than half of the participants reported living in the same household for >10 years (53.5%) and had some renovation done on the home while they were living there (54%). Most participants did not observe any peeling paint inside or outside their homes (85.8%).

Exposure to lead can also occur as a result of particular occupations or hobbies. Approximately 13% of the participants reported that they were currently engaged in at least one lead-related occupation, while another 36.6% reported that they previously had such an occupation (Table 1). Most of the participants (64%) reported currently having at least one lead-related hobby, and 56.3% reported previously having lead-related hobbies. Approximately 22.4% of participants had family members with at least one lead-related occupation, and most (55.5%) reported at least one family member with lead-related hobbies.

3.2. Laboratory results

Among all participants, the geometric mean PbB was 1.17 μg/dl (Table 1); 1.1% ($n = 8$) had PbB ≥5 μg/dl, and none exceeded the Centers for Disease Control and Prevention's level of concern of 10 μg/dl (PbB range of participants: 0.18–9.82 μg/dl). The geometric mean PbB were 1.27 μg/dl (range: 0.18–9.82 μg/dl) and 0.84 μg/dl (range: 0.18–3.92 μg/dl) among persons who did and did not consume wild game, respectively.

Table 1
Characteristics of the study participants ($N = 736$).

Variables	n (%)
Age (years)	
2–5	5 (0.7)
6–14	11 (1.5)
15–24	21 (2.9)
25–34	78 (10.6)
35–44	89 (12.1)
45–54	177 (24.0)
55–64	202 (27.4)
65 or more	153 (20.8)
Male sex	400 (54.3)
White race	723 (98.4)
Education	
Less than high school	12 (1.6)
High school graduate or equivalent	75 (10.2)
Some college	167 (22.7)
College grad or more	482 (65.5)
Income	
Less than $15,000	10 (1.5)
$15,000–$24,999	38 (5.5)
$25,000–$39,999	104 (15.0)
$40,000 or more	540 (78.0)
House construction year	
1949 or before	118 (16.1)
1950 to 1977	296 (40.6)
1978 or after	316 (43.3)
Duration of living in current residence	
2 months or less	7 (0.9)
3 months to a year	37 (5.0)
≥1–5 years	164 (22.2)
≥5–10 years	135 (18.2)
>10 years	396 (53.5)
House renovation/remodeling	
No renovation done	336 (46.0)
Currently undergoing renovation	42 (5.7)
Done within the last 12 months	75 (10.3)
Done beyond the last 12 months	278 (38.0)
House has peeling paint or paint chips	**104 (14.2)**
Have lead-related occupations[a]	**93 (13.0)**
Had lead-related occupations	**262 (36.6)**
Household members with any lead-related occupations	**164 (22.4)**
Have lead-related hobbies[b]	**471 (64.0)**
Had lead-related hobbies	**414 (56.3)**
Household members with any lead-related hobbies	**408 (55.5)**
Geometric mean PbB (μg/dl)	**1.17**

[a] Auto repair, battery manufacture/repair, construction, home construction/painting, working in lead smelter/refinery/mine, plumbing or pipe fitting, radiator repair, welding, working in brass/copper foundry, gas station attendant, military/police officer, etc.

[b] Car/boat repair, casting (bullets, fishing weights, etc.), casting lead figures (toys, soldiers), furniture finishing, home remodeling/paint job, hunting, jewelry making, lead soldering, pottery/stained glass making, reloading, target shooting, welding, etc.

3.3. Wild game consumption

Approximately 80.8% ($n = 594$) of the participants reported consuming at least one type of wild game (i.e., venison, other game, birds), of whom 86.4% ($n = 513$) reported consuming more than one type (Table 2). Among those who consumed wild game, almost all reported consuming venison (98.8%), and 64.7% and 84.3% reported consuming other game and birds, respectively. Study participants indicated that they primarily hunted the wild game they consumed, or else that it was hunted by family members or by friends (98.8%). Most of these participants (81.8%) reported that the meat was processed by themselves or family members. Some of the participants also reported having some of their meat processed by meat packers/lockers (19.9% among self-processors and 31.8% overall) or local butchers (4.5% among self-processors and 9.1% overall). Among those who reported processing their own meat, 92.1% reported discarding the meat around the wound channel.

With respect to frequency of consumption, most participants consumed venison throughout the year (80.8%). Nearly half reported consuming other game (49.7%) or birds (52.3%) occasionally or only during the hunting season (Table 3). In a given month, 62.3% of participants reported consuming venison at least once a week; they also reported consuming other game (70.2%) and birds (78%) at a frequency of less than once a week. Within the month preceding the survey, 82.7% of participants had consumed venison; by comparison, 45.7% and 40.6% had consumed other game and birds, respectively. Most of the participants reported grinding their venison (57.5%) but not grinding other game meat (57.3%) or birds (97.2%). When asked about approximate serving size, participants predominantly reported consuming an average of ≥ 2 oz of wild game per serving. Most of the participants reported consuming all three types of wild game for >10 years.

Table 2
Wild game consumption by type, source, processing, and cleaning methods.

Variables	*n* (%)
Wild game consumption (*N* = 736)	**594 (80.8)**
Venison	587 (98.8)
Other wild game	384 (64.7)
Birds	501 (84.3)
Types of wild games consumed (*N* = 594)	
One	81 (13.6)
Two	148 (24.9)
Three	365 (61.5)
Source of wild game	
Food pantries or similar	1 (0.2)
Hunting	587 (98.8)
Other sources	8 (1.3)
Meat processing by	
Self/family members	486 (81.8)
Meat packers/processors/lockers	189 (31.8)
Butcher	54 (9.1)
Removes wound channel (self/family members) (*N* = 486)	447 (92.1)

3.4. Generalized estimating equation (GEE) analysis

In the unadjusted generalized estimating equations (GEE) models, variables including age, sex, education, age of housing, duration of residence in the household, home renovation, current and previous lead-related occupations, current lead-related hobbies, family members with lead-related occupations or hobbies, and consumption of wild game were significantly ($p<0.05$) associated with PbB. In a multivariate-adjusted GEE model, age, sex, age of housing, current lead-related hobbies, and wild game consumption were significantly ($p<0.05$) associated with PbB (Table 4).

Results from the overall GEE model was illustrated in Table 4. Compared to other age categories, participants aged ≥ 65 years had the highest geometric mean PbB. After adjusting for other factors, participants 2–5 years of age, 6–24 years of age, 25–44 years of age, and 45–65 years of age, respectively, had 0.84, 1.10, 1.10, 0.44 μg/dl lower PbB on average than those ≥ 65 years of age. On average, males had 0.28 μg/dl higher PbB than female participants. Participants living in residences built between 1950 and 1977 or before 1950 had higher PbB (0.19 and 0.43 μg/dl higher, respectively) than participants living in residences built after 1977. Participants who currently had lead-related hobbies also had higher PbB than those without current lead-related hobbies.

Participants who consumed any wild game had 0.30 μg/dl higher PbB than those who did not consume wild game (Table 4). Participants who consumed all three game types had 0.50 μg/dl higher PbB than those who did not consume any (data not shown). The scaled deviance and the scaled Pearson χ^2 did not improve (further away from 1.0) when all two-way interactions between

Table 3
Wild game consumption frequency, recent consumption, meat processing method, average serving size, and duration.

Variable	Venison (*N* = **587**)	Other game (*N* = **384**)	Birds (*N* = **501**)
Consumption in a year			
Occasionally	101 (17.3)	162 (42.6)	180 (36.1)
Hunting season only	11 (1.9)	27 (7.1)	81 (16.2)
Year round	472 (80.8)	191 (50.3)	238 (47.7)
Consumption in a given month			
<1 time/week	221 (37.7)	266 (70.2)	387 (78.0)
1–3 times/week	277 (47.3)	84 (22.2)	90 (18.2)
>3 times/week	88 (15.0)	29 (7.7)	19 (3.8)
Last time consumed wild game			
<1 month ago	484 (82.7)	174 (45.7)	202 (40.6)
1–6 months	68 (11.6)	103 (27.0)	189 (38.0)
>6 months ago	33 (5.6)	104 (27.3)	107 (21.5)
Meat processing method			
Ground	336 (57.5)	105 (27.9)	11 (2.2)
Not ground	91 (15.6)	216 (57.3)	484 (97.2)
Both	157 (26.9)	56 (14.9)	3 (0.6)
Portion size in average serving			
<2 oz	56 (9.7)	34 (9.1)	48 (9.8)
≥2 oz	520 (90.3)	340 (90.9)	444 (90.2)
Duration of consumption			
<1 year	3 (0.5)	10 (2.7)	5 (1.0)
1–3 years	16 (2.8)	14 (3.7)	18 (3.6)
4–10 years	48 (8.3)	32 (8.5)	40 (8.1)
>10 years	513 (88.5)	321 (85.2)	431 (87.3)

wild game consumption and other variables were considered in the model (data not shown). For all three game types, participants with more recent (<1 month) wild game consumption had higher PbB (Table 5). Among those who reported consuming other game, a 0.40 μg/dl increase in PbB was associated with having an average serving size of ≥2 oz, compared with those who consumed a lesser amount (Table 5).

Table 4
Geometric mean (μg/dl) and associations between PbB and other variables in multivariate generalized estimating equations (GEE) model[a] ($N = 736$).

Variables	Geometric mean (μg/dl) (95% CI)	Parameter estimates (95% CI)
Age		
2–5 years	0.88 (0.66, 1.11)	−0.84 (−1.12, −0.56)††
6–24 years	0.60 (0.41, 0.79)	−1.11 (−1.52, −0.71)††
25–44 years	0.75 (0.65, 0.85)	−1.05 (−1.30, −0.80)††
45–65 years	1.29 (1.23, 1.35)	−0.44 (−0.68, −0.20)†
65 years or more	1.77 (1.69, 1.85)	Ref.
Sex		
Male	1.49 (1.43, 1.54)	0.28 (0.08, 0.48)*
Female	0.89 (0.81, 0.96)	Ref.
House construction year		
1978 or after	1.00 (0.93, 1.07)	Ref.
1950–1977	1.31 (1.24, 1.38)	0.19 (0.02, 0.37)*
1949 or before	1.39 (1.27, 1.50)	0.43 (0.16, 0.70)*
Current lead-related hobbies		
No	0.88 (0.81, 0.96)	Ref.
Yes	1.38 (1.32, 1.44)	0.34 (0.17, 0.50)††
Consumes wild game		
No	0.84 (0.74, 0.94)	Ref.
Yes	1.27 (1.22, 1.33)	0.30 (0.16, 0.44)††

*p-value < 0.05; †p-value < 0.001; ††p-value < 0.0001.

[a] After adjusting for race, education, income, home renovation/remodeling, duration of living in the current home, current and previous lead-related occupations, previous lead-related hobbies, household members with lead-related hobbies or occupations.

4. Discussion

In this study, the consumption of wild game was significantly associated with an increase (0.30 μg/dl) in PbB. Another study reported a similar increase for adults consuming two game meat meals per week containing 1 μg/g lead using a lead biokinetic model (Kosnett, 2008). The observed increase in our study could not be attributed to one single game type, since there was substantial overlap in the types of wild game that the participants reported consuming. Previous studies have also reported difficulty in teasing out the effects of any single type of game due to diet habits of participants and collinearity between consumption of different kinds of game (Kosatsky et al., 2001; Tsuji et al., 2008b). However, no linear increase in PbB was observed with an increase in the number of wild game types consumed. Nevertheless, after adjusting for other factors, the associated increase in PbB was significant ($p < 0.05$) and highest among participants who consumed all three game types (i.e., venison, other game, and birds) (data not shown).

Recent lead isotope ratio studies reported that wild game meat can be contaminated by lead fragments from ammunition sources, which can contribute significantly to PbB (Tsuji et al., 2008a, 2008b, 2009). Hunt et al. (2009) reported that in venison-fed pigs, lead fragments in contaminated meat were present in bioavailable form and significantly increased blood lead concentration. This has important public health implications as previous studies have consistently reported wild game birds as a significant source of population PbB (Scheuhammer et al., 1998; Odland et al., 1999;

Table 5
Multivariate-adjusted association between PbB and frequency, proportion, and duration of wild game consumption by game type[a]

Variables	Parameter estimates (95% CI)		
	Venison ($N = 584$)	Other game ($N = 378$)	Birds ($N = 494$)
Consumption in a given year			
Occasionally	Ref.	Ref.	Ref.
Hunting season only	−0.01 (−0.54, 0.51)	0.07 (−0.28, 0.42)	0.16 (−0.06, 0.38)
All year round	0.01 (−0.27, 0.28)	−0.01 (−0.33, 0.31)	0.15 (−0.12, 0.42)
Consumption in a given month			
<1 time/week	Ref.	Ref.	Ref.
1–3 times/week	0.08 (−0.14, 0.30)	−0.07 (−0.38, 0.23)	0.05 (−0.21, 0.32)
>3 times/week	0.15 (−0.13, 0.43)	−0.19 (−0.71, 0.32)	0.02 (−0.64, 0.67)
Most recent consumption			
<1 month ago	Ref.	Ref.	Ref.
1–6 months ago	−0.18 (−0.48, 0.11)	−0.46 (−0.79, −0.13)*	−0.28 (−0.52, −0.04)*
>6 months ago	−0.34 (−0.66, −0.01)*	−0.38 (−0.73, −0.03)*	−0.36 (−0.64, −0.08)*
Most often processed			
Ground	Ref.	Ref.	Ref.
Not ground	0.05 (−0.21, 0.30)	0.12 (−0.14, 0.39)	0.14 (−0.35, 0.63)
Both	−0.03 (−0.22, 0.17)	0.08 (−0.25, 0.41)	0.08 (−0.61, 0.77)
Average serving			
<2 oz	Ref.	Ref.	Ref.
≥2 oz	0.10 (−0.15, 0.35)	0.40 (0.07, 0.74)*	0.23 (−0.01, 0.48)
Years of consumption			
<1 year	Ref.	Ref.	Ref.
1–3 years	−0.08 (−0.95, 0.80)	0.51 (−0.13, 1.16)	0.02 (−0.50, 0.54)
4–10 years	−0.07 (−0.99, 0.85)	0.13 (−0.38, 0.65)	0.18 (−0.40, 0.75)
>10 years	−0.11 (−1.02, 0.79)	0.15 (−0.27, 0.56)	0.18 (−0.28, 0.65)

*p-value <0.05; †p-value <0.001; ††p-value <0.0001.

[a] After adjusting for age, sex, race, age of housing, current and previous lead-related hobbies, current and previous lead-related occupations, household members with lead-related hobbies or occupation.

Hanning et al., 2003; Bjerregaard et al., 2004; Johansen et al., 2006). In Greenland, where subsistence hunting is common, Bjerregaard et al. (2004) found that people who ate hunted seabirds several times a week had >50% higher PbB than those who reported less than weekly intake. Dewailly et al. (2001) conducted a study of the Inuit population of Arctic Quebec and found that consumption of water fowl significantly affected blood lead levels. Evidence from these scientific studies suggests that consumption of wild game meat contaminated by fragments of lead shot is a potential source of environmental lead exposure and can contribute to the levels of lead in the body. However, studies beyond subsistence populations have been few; and the fact that this environmental source of lead exposure is often not recognized is likely due to the longstanding belief that fragments of lead particles did not travel a far distance within the wild game and that discarding the meat around the wound channel was sufficient to remove all lead fragments.

Recent consumption of wild game and the amount consumed per serving were also significant factors associated with higher PbB. For all game types, participants who reported consuming wild game within a month prior to the study had significantly higher PbB in comparison with those who did not consume wild game within that time frame. This could be explained by the fact that blood lead is an indicator of more recent exposure; in adults, the half-life of lead is approximately 30 days (ATSDR, 2007; Rabinowitz et al., 1976). Among participants who reported consuming other game (e.g., elk, moose, etc.), an increase in PbB was also associated with a larger average serving size ($\geq$2 oz). Previously, Johansen et al. (2006) reported a clear relationship between the number of hunted bird meals and lead concentrations in participants. Also, an increase in PbB was found among participants immediately after hunting season, when consumption of wild game is highest (Kosatsky, 1998; Johansen et al., 2006). In our study, the lack of association between PbB and frequency of meals or proportion of serving size for all game types could be due to the fact that blood samples were collected approximately 4–5 months after the hunting season. This lag time may have led to decreased PbB among some participants and a smaller effect size. Tsuji et al. (2009) hypothesized that lack of correlation between use of lead bullets and lead-tissue contamination can be attributed to the heterogeneous distribution of lead in wild game tissue. In our study, this heterogeneity may have influenced the association between PbB and frequency of meals and proportion of serving size.

Over the last three decades, the population PbB in the United States (geometric mean 1.45 μg/dl in 2001–2002) has declined considerably due to federal legislation and public health interventions (Centers for Disease Control and Prevention (CDC), 2005a, 2005b). A substantial proportion of children and adults, however, continue to be exposed to other sources of lead, and these children and adults remain at-risk for adverse health effects, since there is no clinical threshold of lead in the human body that is considered safe (Centers for Disease Control and Prevention (CDC), 2005a; CDC, 2007; Iqbal et al., 2008). An increase of 0.30 μg/dl in PbB may have limited significance in a clinical setting; nonetheless, the mean PbB in the population is several orders of magnitude higher than the levels of preindustrial human societies (0.016 μg/dl) and the natural background of PbB in humans (Flegal and Smith, 1992; Bellinger, 2004). Among adults, increased risk of myocardial and stroke mortality have been observed to be associated with PbB $\geq$2μg/dl (Menke et al., 2006). Furthermore, studies have consistently reported adverse neurocognitive effects in children at PbB <10 μg/dl (Canfield et al., 2003; Lanphear et al., 2005; Tellez-Rojo et al., 2006; Kordas et al., 2006). Due to high-risk hand-to-mouth behavior, increased absorption, and an under-developed blood brain barrier, children <6 years of age are considered to be more susceptible to the adverse effects of lead exposures (ATSDR 2007; CDC, 2005a).

Most lead in adults is stored in the bones, and the concentration of lead increases with age. In comparison with an average of 8 mg in children <16 years of age, the average body burden of lead is estimated to be approximately 200 mg in adults 60–70 years of age (ATSDR, 2007; Barry, 1975). Lead released from bone storage can therefore contribute to circulating PbB (ATSDR, 2007; O'Flaherty et al., 1982; Hernandez-Avila et al., 1998); in one study, lead from tissue store, primarily bone, was found to contribute up to 70% of lead in blood among adult females (Gulson et al., 1995). In our study population, participants aged $\geq$65 years frequently reported consuming all wild game types for more than a decade (data not shown). This long-term cumulative exposure may have contributed to the observed higher PbB in this age group, compared to the PbB of younger participants. However, the older age group ($\geq$65 years) may also have been exposed to higher amount of environmental lead from the period before removal of lead from gasoline and paint (US Department of Housing and Urban Development, 2000). Bone lead isotope studies may shed light on the sources of long-term cumulative exposure of both environmental and diet-related lead among population exposed to multiple sources.

In addition to wild game consumption, the age of housing, male sex, and current lead-related hobbies were other significant factors associated with an increase in PbB. Specifically, increased PbB was associated with increase in housing age; this is consistent with our knowledge of environmental exposure to lead (CDC, 2005a). Higher PbB in males can likely be explained by the fact that males were almost four times more likely to report consuming wild game than females (data not shown). Hunting (53.5%), target shooting (32%), home remodeling or painting (18.6%), and reloading (15.7%) were the most commonly reported lead-related hobbies that may have contributed to the observed association of lead-related hobbies with PbB.

Findings from this study have limited generalizability. The study cohort was predominantly white, educated, and included few low-come families. Persons who received donated wild game meat from food pantries or other charitable organizations were under-represented in the study sample. As high levels of lead were detected in the meat packs donated to local food pantries in North Dakota and the surrounding states, those who receive donated meat may have greater exposure to lead-contaminated wild game meat (Smith, 2008). Also, this study included a small number of children <6 years of age; however, all of them reported consuming wild game meat. Due to an increased rate of lead absorption, children as a whole may be potentially more vulnerable to exposure to lead from wild game consumption. Further research is needed to determine the magnitude of the risk associated with wild game consumption among children and among the population receiving donated meat. Finally, most of the data collected were self-reported, and the data may be subject to recall or information bias.

Among those who consumed wild game, most reported hunting as their source. Most participants reported processing the meat themselves and discarding the meat around the wound channel. Despite these precautions and the fact that a wide range of potential confounders were controlled for in the analyses, participants who consumed wild game had higher PbB in comparison to those who did not consume wild game. A recent study has found that fragmented lead particles from bullets can disperse up to 18 inches within the body of the hunted animals. This spread of lead fragments is larger than previously believed (MN DNR, 2008). Therefore, a revision of the current butchering practices may be important. It has been suggested that the use of specific types of bullets or shot (i.e., non-lead, weight-retaining, or low-velocity bullets or shot) may reduce an individual's risk of exposure to lead (MN DNR, 2008). Additionally, review and monitoring of meat packing processes may be warranted, since meat from different hunters is typically mixed together during grinding (MN DNR, 2008). These findings have population-wide implications, since a substantial proportion of the population in the United States, including hunters and their families as well as low-income families, consume wild game as a major source of protein and may be exposed to this environmental source of lead.

Disclaimer

The findings and conclusions in this article are those of the author(s) and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

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