Audubon Society of Portland
Founded in 1902

May 7, 2017
Senate Committee on Environment and Natural Resources
900 Court St. NE
Salem, OR 97301

Re: HB 2525, Amendment A3

Dear Senators Dembrow, Olsen, Baertschiger, Prozanski, and Roblan,

Thank you for the opportunity to provide comments on House Bill 2525 (HB 2525). Audubon Society of Portland recognizes and supports the contribution made by hunter donation organizations to the reduction of food insecurity in our state through donation of game meat. However, we also believe that it is critical to include amendment A3 to require that the game meat inspection process include screening to ensure that it is free of lead contamination.

Lead is toxic to multiple human organ systems, affecting the central nervous, renal, cardiovascular, reproductive, immune, and hematologic systems, as well as being potentially carcinogenic (Consensus Statement of Scientists 2013). The Center for Disease Control (CDC) has determined that there is no safe blood lead level for children without deleterious effects (CDC 2012). Lead-based ammunition has been shown to pose "a significant source of lead exposure in humans that ingest wild game" (Consensus Statement of Scientists 2013, Cornatzer 2009, Iqbal 2009, Johansen 2005, Levesque 2003, Pain 2010, Tsuji 2008, Verbrugge 2009). It has been posited that "no rational deliberation about the use of lead-based ammunition can ignore the overwhelming evidence for the toxic effects of lead, or that the discharge of lead bullets and shot into the environment poses significant risks of lead exposure to humans and wildlife" (Bellinger 2013). Responsible certification of donated meat as "fit for human consumption" should include verifying that this food source does not expose families to lead.

We believe that it is critical to protect the most vulnerable populations in our state, particularly those that access food via charitable organizations such as those listed in HB 2525, which includes the Department of Human Services, Oregon Health Authority, Oregon Youth Authority, low-income nutritional centers, public school nutritional centers, state hospitals and other charitable organizations. Patrons of food pantries and other low cost sources of food are not currently being adequately or consistently warned about the potential health risk of lead contamination in game meat.

As of 2012, the CDC estimated that 450,000 children in the US between the ages of one and five had significant exposure to lead (Sykes). In addition to well-known exposure pathways like paint and lead pipes, a large body of research also demonstrates that game meat harvested with lead ammunition can be readily contaminated with lead fragments or lead dust, creating a potential exposure pathway for those that ingest game meat. Lead can fragment into hundreds of very small pieces. In a 2009 study on lead fragmentation in venison, radiographs of 30 white-tailed deer shot with lead-core, copper-jacketed bullets, showed lead fragments in all carcasses (mean = 136 fragments, range = 15–409 fragments) as well as widespread fragment dispersion (Hunt 2009). Fragments have been shown to travel an average of 11 inches and up to 14 inches from the wound channel and readily escape detection without the aid of x-ray technology (Cornicelli 2008). Kosnett 2009 found that "regular consumption of game meat harvested with lead ammunition and contaminated with lead residues may cause relatively substantial increases in blood lead compared to background levels, particularly in children." A 2008 study tested 100 randomly selected packages of venison that had been donated to a food pantry program in North Dakota. The study found that "59% of 100 randomly selected packages… were contaminated with lead fragments" (Cornatzer 2009). In 2008, the CDC and the North Dakota Department of Health conducted a field study in which they found that North Dakota residents who consumed wild game shot with lead ammunition had a small but statistically significant increase in blood lead levels compared to residents that did not consume wild game. As a result, the North Dakota Department of Health issued a Fact Sheet indicating that wild game shot with lead ammunition is an important risk factor in elevated lead levels (October 2008). It warns consumers that "most lead particles in venison will be too small to see, feel or sense when chewing" and recommends that pregnant women and children not eat venison harvested with lead bullets. The North Dakota Department of Health is also one of two states (along with Alaska) that include questions about the consumption of game meat in its lead blood level screening process. In 2014, the University of Minnesota Food Policy Research Center issued a brief that evaluated risk potential from different types of ammunition, and cites that "All hunter harvested venison in Minnesota must be x-ray scanned prior to donation" (Ponder, UMN Issue Brief 2014). Health Consultation Letters have been prepared for both the State of Michigan and Wisconsin addressing the risk of lead in venison (ATSDR 2010, ATSDR 2008). Both the CDC and the Advisory Committee for Childhood Lead Poisoning Prevention have indicated that the best way to protect children is to prevent, control or eliminate lead exposures in the first place.

Because of this type of evidence, the Audubon Society of Portland believes that lead screening, as proposed by amendment A3 to HB 2525, is an appropriate precaution to take to ensure that we are not exposing children and families unknowingly to lead risk. This is a common sense amendment to protect Oregon's children.

Thank you for the opportunity to comment in support of House Bill 2525 with amendment A3.

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Health Risks from Lead-Based Ammunition in the Environment

A Consensus Statement of Scientists

March 22, 2013

We, the undersigned, with scientific expertise in lead and environmental health, endorse the overwhelming scientific evidence on the toxic effects of lead on human and wildlife health. In light of this evidence, we support the reduction and eventual elimination of lead released to the environment through the discharge of lead-based ammunition, in order to protect human and environmental health.

1) Lead is one of the most well-studied of all anthropogenic toxins and there is overwhelming scientific evidence that demonstrates:
   a) Lead is toxic to multiple physiological systems in vertebrate organisms, including the central and peripheral nervous, renal, cardiovascular, reproductive, immune, and hematologic systems. Lead is also potentially carcinogenic; lead is officially recognized as a carcinogen and reproductive toxin in California, and the International Agency for Research on Cancer, the National Toxicology Program, and the US Environmental Protection Agency have identified lead as likely to be carcinogenic to humans.
   b) There is no level of lead exposure to children known to be without deleterious effects (CDC, 2012). Exposure in childhood to even slightly elevated levels of lead produce lasting neurological deficits in intelligence and behavior.
   c) Lead is also known to be toxic across different vertebrate organisms, including mammalian and avian species.

2) Lead-based ammunition is likely the greatest, largely unregulated source of lead knowingly discharged into the environment in the United States. In contrast, other significant sources of lead in the environment, such as leaded gasoline, lead-based paint, and lead-based solder, are recognized as harmful and have been significantly reduced or eliminated over the past 50 years.
   a) Lead-based ammunition production is the second largest annual use of lead in the United States, accounting for over 60,000 metric tons consumed in 2012, second only to the consumption of lead in the manufacture of storage batteries (USGS, 2013).
   b) The release of toxic lead into the environment via the discharge of lead-based ammunition is largely unregulated. Other major categories of lead consumption, such as leaded batteries and sheet lead/lead pipes, are regulated in their environmental discharge/disposal.

3) The discharge of lead-based ammunition and accumulation of spent lead-based ammunition in the environment poses significant health risks to humans and wildlife. The best available scientific evidence demonstrates:
   a) The discharge of lead-based ammunition substantially increases environmental lead levels, especially in areas of concentrated shooting activity (USEPA ISA for Lead draft report, 2012).
   b) The discharge of lead-based ammunition is known to pose risks of elevated lead exposure to gun users (NRC, 2012).
   c) Lead-based bullets used to shoot wildlife can fragment into hundreds of small pieces, with a large proportion being sufficiently small to be easily ingested by scavenging animals or incorporated into processed meat for human consumption (Pauli and Burkirk, 2007; Hunt *et al*., 2009; Knott *et al*., 2010).

d) Lead-based ammunition is a significant source of lead exposure in humans that ingest wild game (Hanning *et al*., 2003; Levesque *et al*., 2003; Johansen *et al*., 2006; Tsuji *et al*., 2008), and hunters consuming meat shot with lead-based ammunition have been shown to have lead pellets/fragments in their gastrointestinal tract (Carey, 1977; Reddy, 1985).

e) Lead poisoning from ingestion of spent lead-based ammunition fragments poses a serious and significant threat to California wildlife.

   i. Spent lead-based ammunition is the principal source of lead exposure to the endangered California condor, and lead poisoning in condors is preventing their successful recovery in the wild (Church *et al*., 2006; Woods *et al*., 2007; Green *et al*., 2008; Parish *et al*., 2009; Rideout *et al*., 2012; Finkelstein *et al*., 2012).

   ii. Many other wild scavenging species, such as golden eagles, bald eagles, ravens, turkey vultures, and pumas are known to be exposed to and affected by lead (Wayland and Bollinger, 1999; Clark and Scheuhammer, 2003; Fisher *et al*., 2006; Craighead and Bedrosian, 2008; Stauber *et al*., 2010; Kelly and Johnson, 2011; Burco *et al*., 2012).

Based on overwhelming evidence for the toxic effects of lead in humans and wildlife, even at very low exposure levels, convincing data that the discharge of lead-based ammunition into the environment poses significant risks of lead exposure to humans and wildlife, and the availability of non-lead alternative products for hunting (Thomas, 2013), we support reducing and eventually eliminating the introduction of lead into the environment from lead-based ammunition.

Signed,

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Health Risks from Lead-Based Ammunition in the Environment

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Lead is one of the most studied toxicants, and overwhelming scientific evidence demonstrates that lead is toxic to several physiological systems in vertebrates, including the nervous, renal, cardiovascular, reproductive, immune, and hematologic systems (Health Risks from Lead-Based Ammunition in the Environment—A Consensus Statement of Scientists 2013). Furthermore, there is no level of lead exposure in children known to be without adverse effects [Centers for Disease Control and Prevention (CDC) 2012a, 2012b].

In light of this evidence, there is an urgent need to end a major source of lead for animals and humans: spent lead bullets and shotgun pellets. Notably, production of lead-based ammunition in the United States accounted for > 69,000 metric tons consumed in 2012; this is second only to the amount of lead used to manufacture storage batteries (U.S. Geological Survey 2013). However, there are few regulations regarding the release of lead into the environment through discharge of lead-based ammunition. For other major categories of lead consumption, such as lead batteries and sheet lead/lead pipes, environmental discharge and disposal are regulated. Therefore, lead-based ammunition is likely the greatest largely unregulated source of lead that is knowingly discharged into the environment in the United States. In contrast, the release or distribution of other major sources of environmental lead contamination (e.g., leaded gasoline, lead-based paint, lead solder) have been substantially regulated and reduced since the mid-1970s (Health Risks from Lead-Based Ammunition in the Environment—A Consensus Statement of Scientists 2013).

There is a national discussion—polarized at times—of the health risks posed to humans and wildlife from the discharge of lead-based ammunition. To inform this discussion, a group of 30 nationally and internationally recognized scientists with expertise regarding lead and environmental health recently collaborated to create an evidence-based consensus statement (Health Risks from Lead-Based Ammunition in the Environment—A Consensus Statement of Scientists 2013) supporting the reduction and eventual elimination of lead released to the environment through the discharge of lead-based ammunition.

The discharge of lead bullets and shotgun pellets into the environment poses significant health risks to humans and wildlife. The best available scientific evidence demonstrates that the discharge of lead-based ammunition substantially increases environmental lead levels, especially in areas with higher shooting activity (U.S. Environmetal Protection Agency 2012) and that the discharge of lead-based ammunition poses risks of elevated lead exposure to gun users (National Research Council 2012). When lead-containing bullets are used to shoot wildlife, they can fragment into hundreds of small pieces, many of which are small enough to be easily ingested by scavenging animals or to be retained in meat prepared for human consumption (Hunt et al. 2009; Knott et al. 2010; Pauli and Burkirk 2007). Consequently, lead-based ammunition may be a significant source of lead exposure in humans that regularly ingest wild game (Hanning et al. 2003; Johansen et al. 2006; Levesque et al. 2003; Tsuji et al. 2008). In addition, lead pellets and fragments have been reported in gastrointestinal tracts of hunters who consume meat from animals shot with lead-based ammunition (Carey 1977; Reddy 1985).

The use of lead pellets in shotgun shells for hunting waterfowl posed a serious threat to wetland birds, and secondarily to bald eagles, in the United States, leading to the U.S. Fish and Wildlife Service's 1991 nationwide regulations requiring use of nontoxic shotgun pellets for hunting waterfowl (Anderson 1992). However, lead poisoning from ingestion of spent lead-based ammunition fragments continues to pose a particularly serious health threat for scavenging species. These lead-containing fragments remain the principal source of lead exposure to endangered California condors and continue to prevent the successful recovery of these birds in the wild (Church et al. 2006; Finkelstein et al. 2012; Green et al. 2008; Parish et al. 2009; Rideout et al. 2012; Woods et al. 2007). Other wildlife species, such as golden eagles, bald eagles, ravens, turkey vultures, and pumas, are also exposed to the fragments of spent lead ammunition (Burco et al. 2012; Clark and Scheuhammer 2003; Craighead and Bedrosian 2008; Cruz-Martinez et al. 2012; Fisher et al. 2006; Kelly and Johnson 2011; Stauber et al. 2010; Wayland and Bollinger 1999).

No rational deliberation about the use of lead-based ammunition can ignore the overwhelming evidence for the toxic effects of lead, or that the discharge of lead bullets and shot into the environment poses significant risks of lead exposure to humans and wildlife. Given the availability of non-lead ammunition for shooting and hunting (Thomas 2013), the use of lead-based ammunition that introduces lead into the environment can be reduced and eventually eliminated. This seems to be a reasonable and equitable action to protect the health of humans and wildlife.

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CDC Response to Advisory Committee on Childhood Lead Poisoning Prevention Recommendations in "*Low Level Lead Exposure Harms Children: A Renewed Call of Primary Prevention*"

BACKGROUND

In late 2010, the Centers for Disease Control and Prevention's (CDC) Advisory Committee for Childhood Lead Poisoning Prevention (ACCLPP) formed a workgroup to evaluate new approaches, terminology, and strategies for defining elevated blood-lead levels (BLLs) among children. ACCLPP established the ad hoc Blood Lead Level workgroup on November 10, 2010. The charge of this workgroup was to:

1. Recommend how to best replace the term, 'level of concern,' regarding accumulating scientific evidence of adverse effects of BLLs at < 10 μg/dL in children.
2. Consider laboratory capability for measuring BLLs in establishing new guidance on childhood BLLs.
3. Advise ACCLPP on how CDC should communicate advisories to groups affected by policy changes concerning:
    a. Interpretation of childhood BLLs and trends in childhood BLLs over time;
    b. Screening and follow-up screening intervals;
    c. Requirements and procedures for notifying parents or guardians concerning BLL test results; and,
    d. Interventions known to control or eliminate lead exposure.

June 7, 2012 NOTE: This version of the CDC response has been slightly modified from one released on May 13, 2012. This version reflects the verbatim recommendations made by the ACCLPP on January 04, 2012 and has been formatted to link each recommendation to its response. No other changes were made.

On November 16–17, 2011, the ACCLPP met and deliberated on the ad hoc workgroup draft report. On January 4, 2012, the ACCLPP met and a majority approved the report, including the recommendations.

In brief, the ACCLPP recommendations include:

- Elimination of the use of the term "blood lead level of concern" based on the compelling evidence that low BLLs are associated with IQ deficits, attention-related behaviors, and poor academic achievement. The absence of an identified BLL without deleterious effects, combined with the evidence that these effects appear to be irreversible, underscores the critical importance of primary prevention. This strategy emphasizes preventing lead exposure rather than responding after the exposure has taken place. ACCLPP recommends specific actions that CDC and other local, state, and federal agencies should take to shift priorities to primary prevention and provides guidance to respond to BLLs < 10 µg/dL in children. The ACCLPP recommends that CDC collaborate with these and other stakeholders, and provide advice and guidance. ACCLPP also recommends using a reference value based on the 97.5th percentile of the BLL distribution among children 1–5 years old in the United States (currently 5 µg/dL) to identify children with elevated BLLs using data generated by the National Health and Nutrition Examination Survey (NHANES). Approximately 450,000 children in the United States have BLLs higher than this reference value.
- Additional research is needed to develop and evaluate interventions that effectively maintain BLLs below the reference value in children. Other research priorities should include efforts that better use data from screening programs; develop next-generation,

point-of-care lead analyzers; and improve the understanding of epigenetic mechanisms of lead action.

Herein we describe CDC's response to each of the ACCLPP recommendations. The proposed methods to address recommendations are contingent on the availability of resources. In FY 2012, funding for CDC's Childhood Lead Poisoning Prevention activities was reduced significantly from FY 2011. As a result, funding is not available for state and local Childhood Lead Poisoning Prevention Programs (CLPPPs). In many instances, these reductions limit CDC's ability to fully implement many of these recommendations in the short term. This draft response was prepared by CDC's National Center for Environmental Health (NCEH).

For the purpose of these responses:

Concur – We agree, and we have the funding, staff, and control over the means to implement the recommendation. The response provides potential strategies which are achievable within current FY 2012 or proposed FY 2013 resources.

Concur in principle – We agree, but we do not have the funding, staff, or control over the means to implement the recommendation. The response highlights strategies that have been shown to be effective, however a commitment to implement actions cannot be made due to our lack of control over available resources.

Nonconcur – We disagree with the recommendations and provide the reasons for the disagreement.

CDC concurred or concurred in principle with all of the recommendations approved by the ACCLPP.

RECOMMENDATIONS

I. Recommendation: ***Based on the scientific evidence, the ACCLPP recommends that the term, "level of concern", be eliminated from all future agency policies, guidance documents, and other CDC publications, and that current recommendations based on the "level of concern" be updated according to the recommendations contained in this report.***

Concur

Specific Means to Address or Implement

a. CDC will emphasize that the best way to end childhood lead poisoning is to prevent, control or eliminate lead exposures. Since no safe blood lead level in children has been identified, a blood lead "level of concern" cannot be used to define individuals in need of intervention.

b. In FY2012, CDC will discontinue using the term 'level of concern' in future publications and replace it with the reference value and the date of the NHANES that was used to calculate the reference value. CDC also will make this standard language available to operating divisions across CDC and use the cross-clearance procedure to ensure that authors adopt this language.

c. Publications on the Web site (www.cdc.gov/nceh/lead) will use the terminology in place at the time of their publication. The CDC Lead statement 1975–1991 includes an asterisked note that "these documents are being kept on this website for historical purposes and are no longer in print." In FY2012, CDC will add the asterisk to the 2005 statement and the footnote will be edited to include the words "These documents refer to various blood-lead thresholds and levels of concern for adverse health outcomes in children. This terminology is outdated and readers are referred to the ACCLPP recommendations of 2012." A similar note will be applied to the document, "Managing Elevated Blood Lead Levels Among Children" (CDC, 2002) that states: "This document refers to a blood-lead level of 10 µg/dL as the CDC level of concern for adverse health outcomes in children. This terminology is outdated and readers are referred to the ACCLPP recommendations of 2012. However, the 2012 document does not recommend changes to the guidelines for the evaluation and treatment of children requiring chelation (BLLs ≥ 45 µg/dL) published here."

Status: The statement will be placed on www.cdc.gov/nceh/lead no later than two weeks following agency clearance. A joint publication summarizing the ACCLPP recommendations and CDC's response will be submitted jointly to the *Morbidity Mortality Weekly Review* and the journal, *Pediatrics*, no later than May 2012.

***II. Recommendation:* CDC should use a childhood BLL reference value based on the 97.5th percentile of the population BLL in children ages 1-5 (currently 5 µg/dL) to identify children and environments associated with lead-exposure hazards. The reference value should be updated by CDC every four years based on the most recent population based blood lead surveys among children.**

Concur in principle

Specific Means to Address or Implement

In FY12, CDC will:

a. Use the reference value in recommendations that involve follow-up evaluation of children after BLL testing.

b. Use the reference value as defined to identify high-risk childhood populations and geographic areas most in need of primary prevention.

c. Provide this information, including specific high-risk areas, to a wide variety of federal, state, and local government agencies and nongovernment organizations interested in lead-poisoning prevention.

In addition, CDC will update the value every 4 years using the two most recent NHANES surveys. The updated reference value will be posted at www.cdc.gov/nceh/lead and widely distributed through various Web-based LISTSERV sites, pediatric associations, and partners at the federal, state, and local level. Updated reference values will be reported in the National Report on Human Exposures to Environmental Chemicals and other relevant journals.

Status: CDC's National Center for Health Statistics (NCHS) will continue to monitor BLLs in the United States and make data tapes available on its Web site for public use at 2-year intervals.

CDC publications will use the reference value to provide guidance to clinical health care providers and others as these publications are prepared. Broader dissemination through Web sites, notices to clinical pediatric care providers, and the MMWR will be considered by CDC in the future.

III. Recommendation: ***CDC should develop and help implement a nationwide primary prevention policy to ensure that no children in the U.S. live or spend significant time in homes, buildings or other environments with lead-exposure hazards.***

Concur in Principle

Specific Means to Address or Implement

CDC recognizes the value of primary prevention. As feasible, CDC will develop strategies and guidelines for primary prevention. Implementation of primary-prevention programs is not currently practicable.

Status: CDC may examine the possibilities of working with the U.S. Department of Housing and Urban Development (HUD), the Health Resources and Services Administration (HRSA), state and local governments, and philanthropic organizations to identify opportunities for collaboration on primary prevention in the future.

IV. Recommendation: ***Clinicians should be a reliable source of information on lead hazards and take the primary role in educating families about preventing lead exposures. This includes***

recommending environmental assessments PRIOR to blood lead screening of children at risk for lead exposure.

Concur in Principle

Specific Means to Address or Implement

Although this recommendation is directed to clinicians, CDC may play a supportive role in enhancing the recommendation by working with providers to provide educational material. Some currently available resources can be used to update CDC/ATSDR documents to reflect the primacy of clinical health care providers in educating families about preventing lead exposure. For example, revisions to the ATSDR Lead Toxicity Case Study (available at http://www.atsdr.cdc.gov/csem/csem.html) are scheduled for 2012, and these changes can be incorporated.

Status: Full implementation contingent on funding

***V. Recommendation:* Clinicians should monitor the health status of all children with a confirmed BLL ≥5 µg/dL for subsequent increase or decrease in BLL until all recommended environmental investigations and mitigation strategies are complete, and should notify the family of all affected children of BLL test results in a timely and appropriate manner.**

Concur in Principle

Specific Means to Address or Implement

Although this recommendation is directed to clinicians, CDC may play a supportive role in enhancing the recommendation by working with clinical care providers and professional organizations to achieve this goal. Ensuring that children with BLLs > 5 µg/dL can be retested is feasible within the current resources because these tests are covered by Medicaid and many private health care insurance providers. As discussed earlier, some provider training will be conducted.

Status: Full implementation contingent on funding

VI. Recommendation: ***Clinicians should ensure that BLL values at or above the reference value are reported to local and state health and/or housing departments if no mandatory reporting exists and collaborate with these agencies in providing the appropriate services and resources to children and their families.***

Concur in Principle

Specific Means to Address or Implement

Although this recommendation is directed to clinicians, CDC may play a supportive role in enhancing the recommendation through CDC's continued work with testing laboratories, point-of-care instrument manufacturers, and clinical health care providers to ensure the availability of high-caliber laboratory services. In addition, most of the state CLPPPs funded by CDC have mandatory reporting laws in place, and those that do not are required to implement such laws during this year of funding.

Status: Full implementation contingent on funding

VII. Recommendation: ***Educate families, service providers, advocates, and public officials on primary prevention of lead exposure in homes and other child-occupied facilities, so that lead hazards are eliminated before children are exposed.***

Concur in Principle

Specific Means to Address or Implement

In FY12, CDC will provide available educational materials through its Web site, and seek the assistance of partner agencies and organizations to implement this recommendation. In FY 2012, funding is not available for state and local CLPPPs.

Status: Implementation contingent on funding

VIII. Recommendation: ***CDC should encourage local, state, and other federal agencies to: (a) facilitate data-sharing between health and housing agencies, (b) develop and enforce preventive lead-safe housing standards for rental and owner-occupied housing, (c) identify financing for lead hazard remediation, and (d) provide families with the information needed to protect their children from hazards in the home.***

Concur in Principle (a.-c.)

Specific Means to Address or Implement

a. In FY12, CDC will continue to recommend that health and housing agencies share data that can be used to identify geographic areas where lead-exposure risk is high. In the future, CDC can explore strategies to facilitate data sharing between health and housing agencies. If funds for CLPPPs become available, CDC will require data sharing between CLPPPs and housing agencies in all CLPPP grant programs.

b. CDC has developed guidelines for lead-safe housing and in FY2012 will encourage local, state, and federal agencies to enforce these standards.

c. HUD Lead Hazard Control Program provides approximately $100 million annually and is the most easily identifiable and largest source of federal funding for lead-hazard remediation. Many CLPPPs help property owners complete the HUD application process, help to identify alternative funding sources, and negotiate with local banks. In FY 2012, however, funding is not available for state and local CLPPPs.

Concur (d.)

Specific Means to Address or Implement

d. These materials currently exist and are distributed through a wide variety of networks. Future development of new materials could be considered by CDC in the future.

Status: Implementation contingent on funding

<u>IX. Recommendation:</u> Elected officials and the leaders of health, housing, and code enforcement agencies can help protect the children in their jurisdictions from lead exposure in their homes through many activities. CDC should work with officials to ensure adoption of a suite of preventive policies.

<u>Concur in Principle</u>

<u>Specific Means to Address or Implement</u>

In the future, CDC could consider educating state and local elected officials about the importance of primary prevention and evidenced-based strategies at a national level. In FY 2012, funding is not available for state and local CLPPPs.

<u>Status:</u> Full implementation contingent on funding

<u>X. Recommendation:</u> CDC should (a) emphasize the importance of environmental assessments to identify and mitigate lead hazards before children demonstrate BLLs at or higher than the reference value and (b) adopt prevention strategies to reduce environmental lead exposures in soil, dust, paint, and water before children are exposed.

<u>Concur (a.)</u>

<u>Specific Means to Address or Implement</u>

a. For more than 20 years CDC has emphasized the importance of environmental assessment and mitigation of lead hazards before children are exposed (before their BLLs are at or higher than the reference value) through policies, cooperative agreements, interagency agreements, and publications. CDC will continue these efforts.

Status: Ongoing

Concur in Principle (b.)

Specific Means to Address or Implement

b. In FY12 and FY13, CDC will work with federal agencies that may also be affected by these recommendations including, but not limited to, HUD and the Environmental Protection Agency (EPA). The goal of the summit will be to develop primary prevention strategies. In FY 2012, funding is not available for state and local CLPPPs.

Status: Full implementation contingent on funding

XI. Recommendation:

If lead hazards trigger a response in any unit in a multi-family housing complex, the same response action should be applied to all similar untested units in the housing complex, unless a risk assessment demonstrates that no lead hazards are present in the other units.

(Note: During editing of this document, the wording of this recommendation was changed in the CDC response to the ACCLPP recommendations. On May 23, 2012 this error was corrected and the wording is now the same as that in the original ACCLPP recommendations.)

Concur in Principle

Specific Means to Address or Implement

CDC concurs with the evidence that a building that houses one child with lead poisoning is an indication that other children in that building are likely at risk. In the future, CDC may explore implementing recommendations for increased inspections.

Status: Implementation contingent on funding

***XII. Recommendation:* CDC should encourage additional research directed towards developing interventions capable of maintaining children's BLLs lower than the reference value.**

Concur in Principle

Specific Means to Address or Implement

CDC will work with the National Institute of Environmental Health Sciences (NIEHS) and academic partners to encourage research. This research will be designed to develop and evaluate effective, broadly useful interventions that are effective in the complex lead-exposure situations that are commonly encountered. In the future, CDC may explore strategies to support additional research.

Status: NIEHS is working with other partners to foster collaboration on developing a research agenda that will address the spirit of the recommendation. In the future, CDC may explore strategies to support additional research.

***XIII. Recommendation:* Additional research priorities should include improve the use of data from screening programs, develop next generation point-of-care lead analyzers, and improve the understanding of epigenetic mechanisms of lead action.**

Concur

Specific Means to Address or Implement

As funding permits, CDC will work with NIEHS, academic partners, and laboratory instrument manufacturers to encourage research in these important areas.

Status: There is ongoing interaction with NIEHS and others to foster collaboration on developing a research agenda.

QUALITATIVE AND QUANTITATIVE DETECTION OF LEAD BULLET FRAGMENTS IN RANDOM VENISON PACKAGES DONATED TO THE COMMUNITY ACTION FOOD CENTERS OF NORTH DAKOTA, 2007

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ABSTRACT.—We studied randomly selected ground venison packages donated to the Community Action Food Centers of North Dakota by the Hunters For The Hungry Association. These packages were studied by high resolution computerized tomography imaging and x-ray fluoroscopy for qualitative detection of metal fragments. Quantitative measurements of lead levels in both randomly selected and fluoroscopic image guided site-specific subsamples from packages were performed. This study documented a health risk from lead exposure to humans consuming venison. *Received 30 July 2008, accepted 30 October 2008.*

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Key words: Computed tomography imaging, health risk, humans, lead, venison.

STUDIES OF LEAD TOXICITY in the diet of California Condors (*Gymnogyps californianus*) have shown there are small particles of lead in the tissues of deer shot with high velocity rifle bullets (Hunt et al. 2006). Reports from Canada and Greenland have shown a statistically significant correlation between elevated serum lead levels in people and the consumption of wild game killed with lead bullets (Bjerregaard et al. 2004, Dewailly et al. 2001, Tsuji et al. 2008). Preliminary research presented at The Peregrine Fund's Board of Directors meeting in May of 2007 (Parish pers. comm.) showed small metal fragments in processed venison. Based on these data, we conjecture that there might be lead fragments from rifle bullets in venison consumed by the general population.

METHODS AND MATERIALS

One hundred, one-pound ground venison packages were randomly selected from the Community Action Food Pantry program in North Dakota. The venison had been donated by the Hunters for the Hungry Program in the fall of 2007. The sample of 100 was selected from a total of 15,250 donated one-pound packages. High definition CT scan and fluoroscopy were performed on the sample for qualitative detection of metal fragments. In conjunction with the North Dakota Health Department, fifteen of the 100 randomly selected packages were punch biopsied in a blind fashion yielding 4-g tissue biopsies; this gave 15 random sub-samples from within the randomly selected packages. These specimens were sent to the University of Iowa Hygienic Laboratory for flame absorption atomic spectrometry to detect and quantify the mass of lead in sub-samples. An additional five samples obtained from among the 100 CT screened packages using fluoroscopic image-guided retrieval of metal-containing venison were also submitted for analysis. These image-guided biopsies yielded a maximum of four grams of combined ground venison and metal (Figure 1).

Osirix® DICOM® workstation software running on Mac OS X® was used for visual analysis of CT image data for Hounsfield unit assessments of suspected lead fragments. Objects having Hounsfield unit measurements over 1500 were considered suspicious for metal fragments. Color look-up tables from Osirix® were used for color encoding of CT data.

RESULTS

Qualitative analysis of the randomly selected ground venison samples showed 59 packages out of the 100 had one or more visible metal fragments on high definition computed tomography (Figure 2). Quantitative analysis with flame absorption atomic spectrometry of the fifteen random blind biopsies showed one sample with 120 ppm lead (1 ppm = 1 milligram/kilogram). All five fluoroscopic image-guided biopsies showed elevated lead concentrations varying from 4,200 to 55,000 ppm lead dry weight (Table 1).

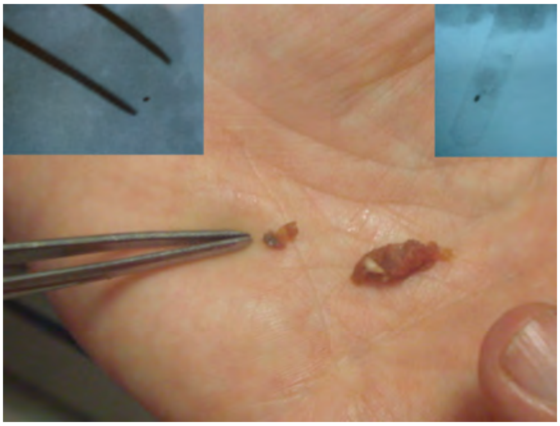

Figure 1. Fluoroscopic image-guided fragment sampling. The fluoroscopic image in upper left shows forceps approaching a metal fragment within a package of ground venison. The upper right image shows a retrieved metal fragment embedded within a small volume of ground venison contained in a glass test tube. Photograph shows forceps pointing to a metal fragment embedded in ground venison.

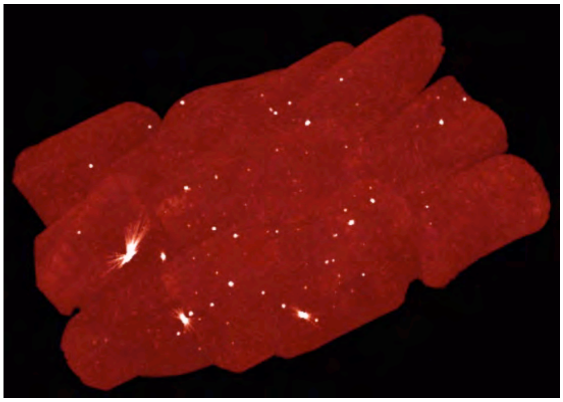

Figure 2. High definition computed tomography (CT) image of *ca.* 20 one-pound venison packages. Bright spots are metal fragments embedded in the tissue.

Table 1. Lead concentrations of five venison samples retrieved by fluoroscopically guided biopsy.

Sample	Lead Concentration (ppm or mg/kg dry weight)
1	52000
2	34000
3	4200
4	55000
5	9700

DISCUSSION

Our study has shown that 59% of 100 randomly selected packages of ground venison donated to the Community Action Food Pantry in North Dakota in the fall of 2007 were contaminated with lead fragments. Venison is a common dietary staple for many families throughout the United States. Lead has been shown to be a major health threat and in children there is no safe minimum threshold of lead exposure. Sources of dietary lead vary from country to country. In the United States, paint chips, dust, jewelry, toys, lead-based gasoline, and lead plumbing (Markowitz 2007) have been identified as sources of lead exposure in the past. Our study reveals lead-based ammunition residues in venison as a source of lead exposure among the USA population that is largely unrecognized as a threat to human health, other than among subsistence hunters of the circumpolar north including Alaska and Canada (Tsuji et al. 2008, Verbrugge et al. 2009, this volume).

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EXAMINING VARIABILITY ASSOCIATED WITH BULLET FRAGMENTATION AND DEPOSITION IN WHITE-TAILED DEER AND DOMESTIC SHEEP: PRELIMINARY RESULTS

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The document is a preliminary assessment of results will be subjected to additional analysis. Results may be published in a peer-reviewed journal; hence, our findings may change as result of further analysis.

SUMMARY OF FINDINGS

Lead (Pb) is a toxic metal and is a primary material in most bullets used to hunt white-tailed deer. We conducted a study to examine bullet fragmentation patterns and to assess lead levels in deer and domestic sheep using different types of bullets and firearms. The firearms we tested included a centerfire rifle, a shotgun, and an inline muzzleloader. For the centerfire rifle, we used lead bullets that were designed to expand rapidly upon impact and were frequently described by manufacturers for hunting mid-sized game such as deer. We also tested lead bullets that were designed to retain a high percentage of their bullet weight, and non-lead (Copper [Cu]) bullets. For the muzzleloader, we chose two bullets that represented common types used during Minnesota's hunting seasons. For the shotgun, we chose the 1-ounce Foster slug, which is commonly used throughout the shotgun-only zone.

INTRODUCTION

This issue of lead in venison surfaced in late winter 2008 when several samples of ground venison from North Dakota's venison donation program tested positive for the presence of lead. Since Minnesota had a similar donation program, we also tested a sample of both ground and whole muscle cuts. Ultimately, 27% of the ground venison and 2% of the whole muscle cuts had detectable metal fragments. Laboratory testing of a sub-sample of product determined the metal fragments were lead. The Minnesota Department of Natural Resources (DNR) initiated this study to improve our understanding of bullet fragmentation patterns in carcasses.

Rifle ammunition varies tremendously in both caliber and bullet design. Although there are numerous types of specific bullets available to hunters, all bullets generally fit into one of two categories. One type of bullet is a "rapid expansion" bullet that is designed to mushroom (expand) quickly upon impact. The other type of bullet is a "controlled expansion" bullet that is designed to mushroom slowly and penetrate through bones and thick muscle tissue. Typically, inexpensive bullets designed for hunting deer have soft points and expand rapidly. In contrast, controlled expansion bullets are generally designed for hunting large mammals such as elk. Some manufacturers also offer bullets that are made entirely from copper or a copper-based alloy. These bullets are often described as: 1) "lead-free" to comply with non-toxic state regulations (e.g., California) and, 2) able to retain >95% of its weight after striking the animal, which implies that the bullet is not designed to fragment inside the animal.

In southern Minnesota, the only legal ammunition for deer hunting during the regular firearms season is a shotgun slug (muzzleloaders are also legal). The traditional slug is often referred to as a “Foster-style Slug”. The Foster Slug is lead-based and is the most common type of shotgun cartridge purchased for deer hunting.

The number of deer harvested in Minnesota during the muzzleloader season has substantially increased over the past decade, particularly over the past 5 years. For this study, we chose two bullet types: 1) lead-core bullet designed specifically for muzzleloaders and 2) jacketed pistol bullet that fits into a plastic jacket.

Our intent was to conduct an experiment that would control for the caliber and focus on examining the variability of lead fragmentation and deposition associated with different categories of bullets and firearms used to harvest deer in Minnesota. Although the amount of lead deposited in animal carcasses will likely vary based on caliber due to different bullet weights associated with different calibers, we believed measuring specific types of bullets (Rapid Expansion, Controlled Expansion, and Copper) would provide meaningful results that may be generalized among various rifle calibers. We selected bullets based on descriptions of their performance and consumer availability. After examining descriptions associated with different types of bullets, we assumed that bullets designed to rapidly expand should be similar among manufacturers. For example, manufactures similarly described the performance of their soft point bullets; therefore we had no reason to believe there would be differences in performance between manufacturers. Similarly, we selected the controlled-expansion bullet based on the manufacturers description of bullet performance (retaining at least 90% of the bullet weight).

Finally, the primary objective of this study was to examine lead fragmentation patterns and to assess lead deposition in carcasses shot with different types of bullets and firearms. Our goal was to provide guidance for those individuals who are concerned about lead exposure by providing information about options that an individual may control to reduce the risk of lead exposure. We did not test the impact distance or angle an animal was standing relative to the hunter as those variables are difficult to control. In contrast, hunters can easily determine the type of bullet they intend to use before entering the deer stand. Thus, examining bullet fragmentation patterns associated with distinctly different types of bullets seemed to be the most reasonable approach because hunters can apply those results immediately, prior to the hunting season.

METHODS

This study began in the spring of 2008 and the goal was to have results available by late summer 2008. It was logistically impossible to obtain an adequate sample size of deer in late spring/early summer 2008. Thus, we used domestic sheep as a surrogate to white-tailed deer. Domestic sheep are ruminants, are anatomically similar to deer, and were available for this study. Further, domestic sheep have comparable weights and thoracic dimensions to white-tailed deer.

Eight deer were killed on 23 April 2008 using a .308 Winchester with 150 grain Nosler Ballistic Tip bullets. The deer were killed in Permit Area 101 as part of a bovine tuberculosis (TB) deer population reduction effort and were transported to the Farmland Wildlife Research Group to be stored in a walk-in freezer. The sharpshooter estimated that deer were shot <100 meters from where the sharpshooter was standing. These deer were not eviscerated until the animals arrived at the necropsy laboratory in July.

We also used 72 euthanized, domestic sheep for this study. We obtained euthanized sheep, marked the coat with a bulls-eye using non-lead spray paint and then marked the carcass for identification purposes. Each sheep was propped up in a broadside position then shot in the thoracic cavity at 50 meters (about 54 yards). A chronograph was used to record velocity, and bullets were recovered using a box filled with sand that was placed immediately behind the carcass. We recognized that sand is not the ideal material for recovering bullets and the sand may cause further disruption of the bullet. However, a more complicated water system or use of ballistic gelatin would have been cost-prohibitive and/or delayed implementation of the project. Since each bullet was recovered in the same manner, we assumed the results were comparable among bullet designs.

The treatments for this study included centerfire rifle, muzzleloader, and shotgun. For the centerfire rifle, we tested three different types of bullets while using a .308 Winchester and 150 grain bullets:

1. Rapid Expansion Bullets – Nosler Ballistic Tip and Remington Core-Lokt (soft point design)
2. Controlled Expansion Bullets – Hornady InterBond and Winchester XP^3
3. Copper Bullets – Barnes TSX

For the muzzleloader, we used a .50 caliber, 100 grains of powder (2, 50 grain Hodgdon 777 pellets), and two different bullet designs:

1. 245 grain Powerbelt Aero-Tip
2. 300 grain Hornady XTP

For the shotgun, we used a 12 gauge and a 1-ounce Foster slug (Remington). Additionally, we shot three sheep in the pelvic region using a Ballistic Tip Bullet, Remington Core-Lokt Bullet, and Remington Foster Slug to describe the dispersion of lead in animals shot in a poor location. While these data were not used in the final data analysis, we believed the associated radiographs from these sheep contributed to our understanding of overall bullet fragmentation. No statistical analyses of lead levels or fragmentation counts were conducted with these radiographs. We intended to simply describe our general observations from the radiographs and include these radiographs in the Appendix.

Bullet fragments were analyzed using radiography (X-ray) at the University of Minnesota. We skinned and gutted each carcass, inserted a carbon fiber tube through the wound channel then took a radiograph on the exit wound side. To test the effects rinsing had on bullet fragment numbers, we thoroughly rinsed the carcasses that were shot with rapid expanding bullets with water, inserted a carbon fiber tube through the wound channel, and then took a second radiograph. Due to logistical constraints, we did not take a second radiograph of sheep shot with non-rapid expansion bullets. A veterinarian measured the maximum distance of fragments in relation to the carbon fiber tube, counted the number of fragments that were observable on radiographs taken using a ventral-dorsal (animal on its back) view of the sheep, and counted the number of fragments within two inches of the exit hole on radiographs taken using a lateral (animal on its side) view of the animal. Radiographs were coded so that the veterinarian did not know the type of bullet used on individual radiographs taken on each sheep.

The extent of lead contamination in muscle tissue was determined by using techniques similar to other published studies. We collected a muscle tissue sample from 2, 10, and 18 inches from the exit wounds (Fig. 1). To assess the effects rinsing has on lead contamination, we rinsed carcasses shot by all bullet types and collected another three muscle tissue samples at the same distances.

We also measured the diameter of the entry/exit holes on each carcass. These measurements were used as a "killing power" index to illustrate the potential effectiveness of each bullet type for killing deer. Finally, we measured the wound channel lengths (linear distance between the entry and exit wound) so that anatomical comparisons could be made between deer and sheep..

RESULTS AND DISCUSSION

General Performance

We observed little variability in bullet velocity among centerfire rifle bullets; however, there were noticeable differences in velocity among firearms. (Table 1). Weight retention of bullets after being recovered in the sand was variable (Table 1). Both rapid expansion bullets (Nosler Ballistic Tip, Remington Core-Lokt) retained about 48% of their weights. We noticed that Nosler Ballistic Tips had almost no variability in bullet weights after being collected in the sand. We believe this was due to the fact that, in all cases, the lead completely separated and all that was left was the copper jacket (Figure 1). In comparison, the Remington Core-Lokt bullets retained about 48% of their weight but there was more variation in recovered bullet weights because in some cases, lead remained adhered to the jacket. There was a substantial difference in bullet weight retention between the controlled expansion bullets. The Hornady InterBond bullet retained about 76% of its weight while the Winchester XP^3 retained about 91% of its weight. For rifle bullets, the Barnes TSX retained most of its bullet weight (96%). Both muzzleloader bullets and the shotgun slug also retained >90% of their original weight (Table 1).

Bullet Fragmentation

There were marked differences in the total number of bullet fragments counted on radiographs among different bullet types (Table 2). Clearly, the Winchester XP^3, Barnes TSX, and the Powerbelt resisted fragmentation whereas the other bullets fragmented. Variability associated with fragment patterns was noteworthy, particularly for the Nosler Ballistic Tip and Hornady InterBond bullets. The number of fragments counted on radiographs of sheep shot with shotgun slugs and muzzleloaders were noticeably lower than the number of fragments counted on radiographs of sheep shot with rapid expanding bullets. Similarly, there were differences in the number of fragments counted within 2 inches around the exit hole among bullet types (Table 3).

The average estimated maximum distance a fragment was observed relative to the exit hole was >5 inches for all bullet types except the Barnes TSX and the Powerbelt (Table 4).

Lead Levels in Muscle Tissue Samples

The level of lead (ppm) in tissue samples varied both across bullet types and at different distances from the exit hole. With the exception of the Winchester XP^3 and Barnes TSX, centerfire rifle bullets had markedly higher levels of lead in tissue samples than bullets shot with other firearms (Table 5). Lead levels were much higher in tissue samples collected 2 inches from the exit hole as opposed to 10 or 18 inches away.

Effects of Rinsing on Fragments and Lead Levels

Rinsing reduced the level of lead in tissue samples; particularly samples collected 2 inches from the exit hole (Tables 5 and 6). However, our data might indicate that rinsing the carcass only spread the lead contamination from highly concentrated levels near the exit hole to other areas of the carcass. Prior to being rinsed (Table 5), only 2 tissue samples from different bullet types tested positive for a low level of lead 18 inches away from the exit hole. In contrast, 5 tissues samples from different bullet types tested positive for lead after the carcass was rinsed (Table 6). Overall, lead levels from sheep shot using non-centerfire firearms, the Winchester XP^3, and Barnes TSX bullets had lower pre-rinse lead levels than Nosler Ballistic Tips, Remington Core-Lokts, and Hornady InterBonds did after the carcass was rinsed (Tables 5 and 6).

Rinsing also tended to slightly reduce the number of fragments counted on radiographs (Table 7). In general, the numbers of fragments observed after the rinse was 5 to 20% lower than the number of fragments counted prior to the rinse. The effect rinsing had on the maximum distance a fragment was observed from the exit hole was negligible.

Killing Power Indices

Carcass weights were higher for deer than for sheep, but wound channel lengths were comparable between species (Table 8). Entry holes were smaller for the controlled expanding centerfire rifle bullets (Hornady InterBond and Winchester XP^3) and highest for the Hornady XTP (muzzleloader bullet). Excluding the Powerbelt (muzzleloader bullet), average exit hole diameters had little variation among bullet types ranging from 1.7 - 2.0 inches on sheep.

Pelvic Region

We observed high levels of fragmentation with both the Nosler Ballistic Tip and Remington Core-Lokt bullets. In fact, the X-rays of both bullets looked similar even though only the Nosler Ballistic Tip hit bone. In other words, the Remington Core-Lokt bullet hit only muscle, yet the fragmentation pattern between both centerfire bullets looked similar. For the Remington slug, both femurs were broken but the degree of fragmentation was low, which further suggests that lower fragmentation levels are associated with bullets that have more mass and are shot at lower velocities.

DISCUSSION

The results from our study suggest that bullet fragmentation patterns are dependent on the type of bullet. We observed few fragments on radiographs of carcasses shot using Winchester XP^3 and Barnes TSX bullets. Both of these bullets were described by manufacturers as retaining >95% of their weight, so these results were expected based on that marketing information. However, the Hornady InterBond bullet was described as retaining >90% of its weight, but in this study, it performed similarly to the bullets that were marketed as those designed to expand rapidly (Nosler Ballistic Tip and Remington Core-Lokt bullets).

Bullet fragmentation patterns were highly variable within and among bullet types. Both rapid expanding bullets (Nosler Ballistic Tip and Remington Core Lokt) and the Hornady InterBond had high fragment counts and the fragments were distributed 5 - 14 inches away from the exit hole. In contrast, the Barnes TSX bullet had low fragment counts and the average maximum distance the maximum was in relation to the exit hole was 4 inches. We also found that the Winchester XP^3 had low fragment counts, but we did observe a metal fragment about 11 inches away from the exit hole. These fragments were likely copper because, 1) recovered bullets did not reveal any exposed lead, and 2) there was no detectable lead in the muscle samples. An important constraint of this portion of the study was that we did not take X-Rays of the entire carcass; therefore, the possibility exists that fragments may have travelled further than we described.

The lead level in the tissue sample data further demonstrates the pattern of lead associated with the wound channel. Bullet fragments were concentrated closer to the exit hole and became less concentrated as the distance away from the exit increased. The probability of having a tissue sample test positive for lead at 10 inches away from the bullet hole was quite low (~7%), but we still detected lead in tissue samples obtained from sheep shot using the Nosler Ballistic Tips and Hornady InterBonds as far as 18 inches away from the exit holes.

We predicted that animals shot with shotgun slugs and muzzleloader bullets would contain less lead as compared to those shot with centerfire rifles due to the greater mass of the bullet and lower velocities associated with the bullets shot from these firearms. Our data confirmed that the number of fragments and lead levels in tissue samples should be lower in deer shot with shotgun slugs or muzzleloaders compared to those shot using rapid expanding centerfire rifle bullets. However, risk of exposure to lead was not eliminated. Fragments were readily apparent in carcasses shot using both shotgun slugs and muzzleloader bullets. We speculate that the biggest difference between these firearms and centerfire rifles is the “lead dust”, or extremely small bullet fragments, created by high velocity centerfire rifle bullets. Although shotgun slugs and muzzleloader bullets will both fragment, small lead dust particles may not be created from the bullets due to the lower bullet velocity. However, this study was not designed to address microscopic fragmentation.

The effects rinsing had on managing risk of lead exposure to humans consuming venison was mixed. This study suggests that rinsing the carcass reduced the level of lead in tissue samples close to the exit hole. However, it appears to have increased the level of contamination in other areas of the carcass. If the muscle tissue immediately surrounding the exit hole is not used for human consumption, it is likely a better option to not rinse the carcass so that the lead is not spread to other areas of the carcass where the muscle tissue will be consumed.   Based on our results, rinsing the carcass is a less effective option than simply choosing a bullet that is designed to resist fragmentation.

With respect to the numbers of fragments and lead levels, there were noticeable differences between deer and sheep carcasses shot with Nosler Ballistic Tip bullets. We believe the variability in distances and angles deer were shot from the sharpshooter explain these differences. Wound channel lengths were comparable between deer and sheep; therefore, we expected bullet fragmentation patterns to be nearly equivalent because the amount of tissue bullets traveled through the cavity of animals would be similar as well. The primary difference between these groups of animals was that all sheep were shot in a broadside position at 50 m from the shooter but all deer were shot at different angles and distances by the sharpshooter. We considered testing the effects different distances had on fragmentation patterns when we initiated the study. However, we could not justify increasing our sample size of sheep to test for the effect distance had on fragmentation patterns because hunters are generally unable to manage the distance an animal is relative to their deer stand. We believed it was more logical to test different types of bullets because individuals can clearly determine which type of bullet they intend use while hunting. The deer used in our sample were frozen for about three months prior to being analyzed and we cannot be certain that freezing did not impact our results. Perhaps more lead was removed from the cavities of deer while the previously frozen organs were removed during the evisceration process. Regardless, we believe that the results of our study would not have been different had we used 72 deer rather than 72 sheep. We are confident that fragmentation patterns and lead level data will be lower in any animals shot by Winchester XP^3 and Barnes TSX bullets compared to bullets that are designed to expand rapidly in any future studies. We believe the results from this study can be used for hunters who intend to hunt other mid-sized game mammals, such as pronghorn antelope or mule deer.

In conclusion, this study suggests that an individual can manage their risk of exposure to lead by selecting an appropriate bullet design. Individuals who wish to reduce their risk of exposure to lead should use a non-lead bullet or a lead-based bullet where the lead is not exposed to the animal (e.g., Winchester XP^3).   Several caveats need to be included with our conclusions. First, previous studies have demonstrated that deer can recover after being shot by a hunter. Thus, hunters who use non-lead bullets still need to recognize that there is some risk of lead exposure because the deer they harvested may have been shot during a previous hunting season. In addition, having venison processed at a meat processor will likely result in an increased risk of lead exposure because venison from different hunters is typically mixed during the grinding process and the vast majority of hunting bullets are made from lead. Our study was not designed to address either of these issues, but concerned hunters should recognize that some level of risk of lead exposure exists even though they chose to purchase a non-lead bullet. The results from this study can be used as a framework to manage risk of exposure, but there are additional risks of exposure to consider.

Implications for hunters

- Hunters can manage their risk of lead exposure by selecting an appropriate bullet design. However, bullets described as high weight retention bullets may still fragment and contaminate carcasses with lead.
- We detected lead in tissue samples that were 18 inches from the exit hole (the maximum we could measure on X-Ray). Therefore, we were not able to conclude that there was a distance from the exit hole where lead would not be detected.
- Levels of lead (ppm) varied among bullet types with lowest lead levels (0) associated with the Winchester XP^3 and Barnes TSX (non-lead bullet).
- Slugs and muzzleloader bullets fragmented less than rifle bullets; however, lead was detected in tissue samples of carcasses shot with these firearms. Our data confirm that the mass of these bullet weights and the lower velocities associated with these projectiles affect bullet fragmentation patterns.
- Rinsing the carcass did not eliminate lead from carcasses. Our data suggest rinsing the carcass may have spread the contamination to other areas of the carcass. Selecting a proper bullet design is more important than a hunter's decision to rinse the carcass to reduce lead contamination. Hunters who normally rinse their carcasses should also be aware that rinsing will likely spread lead to other areas of the carcass.
- Controlled expansion and copper bullets created exit holes that were comparable in size to rapid expansion bullets.

Table 1. Bullet speed (feet per second) and recovered bullet weights.

	Rifle					Muzzleloader		Shotgun
	Nosler Ballistic Tip	Remington Core-Lokt	Hornady Inter-Bond	Winchester XP^3	Barnes TSX	Hornady XTP	Powerbelt Aero-Tip	Rifled Slug
Mean (fps)	2,875	2,902	2,806	2,932	2,856	1,590	1,558	1,483
Std. Dev.	32.7	55.3	38.0	63.8	99.4	11.0	53.0	126.3
Min	2,825	2,834	2,717	2,875	2,781	1,576	1,489	1,219
Max	2,938	3,014	2,838	3,078	3,111	1,601	1,616	1,714

Recovered Bullet (Weights in grains)								
Original Weight	150	150	150	150	150	300	245	440
Recovered Weight	72.4	72.6	114.6	136.7	144.7	272.5	235.4	423.7
Std. Dev.	3.1	25.8	23.5	11.2	5.9	9.1	18.8	14.7
% Retained	48%	48%	76%	91%	96%	91%	96%	96%

Table 2. Total number of bullet fragments counted on lateral radiographs.

Species	Bullet Type	Sample Size	Average	Standard Error	Minimum	Maximum
Deer	Nosler Ballistic Tip	8	60	30	7	261
Sheep	Nosler Ballistic Tip	9	141	45	74	498
Sheep	Remington Core-Lokt	10	86	11	28	138
Sheep	Hornady Interbond	10	82	20	21	218
Sheep	Winchester XP^3	10	9	2	2	28
Sheep	Barnes TSX	10	2	<1	1	4
Sheep	Foster Slug	8	28	15	3	127
Sheep	Powerbelt Aero-Tip	6	3	1	1	9
Sheep	Hornady XTP	6	34	15	6	105

Table 3. Total number of bullet fragments counted within 2 inches of the exit hole on lateral radiographs.

Species	Bullet Type	Sample Size	Average	Min.	Max.	Percent 2" around exit hole
Deer	Nosler Ballistic Tip	7	18	2	43	30%
Sheep	Nosler Ballistic Tip	9	41	13	86	29%
Sheep	Remington Core-Lokt	10	43	15	92	50%
Sheep	Hornady Interbond	10	36	11	83	44%
Sheep	Winchester XP^3	10	<1	0	3	11%
Sheep	Barnes TSX	10	<1	0	2	50%
Sheep	Foster Slug	9	12	1	31	43%
Sheep	Powerbelt Aero-Tip	6	2	0	10	67%
Sheep	Hornady XTP	6	21	3	62	62%

Table 4. Maximum distance (inches) a bullet fragment was observed from the exit hole.

Species	Bullet Type	Sample Size	Average Maximum	Standard Error	Minimum	Maximum
Deer	Nosler Ballistic Tip	7	8	1	6	10
Sheep	Nosler Ballistic Tip	9	11	1	7	14
Sheep	Remington Core-Lokt	10	11	1	9	13
Sheep	Hornady Interbond	10	9	1	5	11
Sheep	Winchester XP^3	10	7	1	4	11
Sheep	Barnes TSX	10	<1	1	0	3
Sheep	Foster Slug	9	5	1	0	11
Sheep	Powerbelt Aero-Tip	6	1	1	0	5
Sheep	Hornady XTP	6	6	1	0	12

Table 5. Average parts per million of lead in tissue samples collected at different distances away from the exit hole of animals shot using different types of bullets.

		Distance from exit hole (inches)		
Species	Bullet Type	2	10	18
Deer	Nosler Ballistic Tip	1	0	0
Sheep	Nosler Ballistic Tip	67	18	1
Sheep	Remington Core-Lokt	157	2	0
Sheep	Hornady Interbond	95	1	1
Sheep	Winchester XP^3	0	0	0
Sheep	Barnes TSX	0	0	0
Sheep	Foster Slug	1	0	0
Sheep	Powerbelt Aero-Tip	0	0	0
Sheep	Hornady XTP	0	2	0

Table 6. Level of lead (ppm) in tissue samples collected after carcasses were rinsed at different distances away from the exit hole of animals shot using different types of bullets.

		Distance from exit hole (inches)		
Species	Bullet Type	2	10	18
Deer	Nosler Ballistic Tip	7	1	0
Sheep	Nosler Ballistic Tip	14	5	83
Sheep	Remington Core-Lokt	5	23	1
Sheep	Hornady Interbond	11	3	1
Sheep	Winchester XP[3]	0	0	0
Sheep	Barnes TSX	0	0	0
Sheep	Foster Slug	2	1	3
Sheep	Powerbelt Aero-Tip	0	0	0
Sheep	Hornady XTP	0	1	1

Table 7. The average number of fragments counted, and the average estimated maximum distance (inches) a fragment was from the exit hole before and after rinsing the carcass, using different bullet types on white-tailed deer and domestic sheep.

		Fragments within 2 inches of the exit hole		Total fragments counted		Maximum distance from exit hole	
Species	Bullet Type	Pre-rinse	Post-rinse	Pre-rinse	Post-rinse	Pre-rinse	Post-rinse
Deer	Nosler Ballistic Tip	18	19	60	57	8	10
Sheep	Nosler Ballistic Tip	41	39	141	120	11	10
Sheep	Remington Core-Lokt	45	39	86	70	11	10
Total		36	33	97	83	10	10

Table 8. Average entry and exit hole diameters (in inches), wound channel lengths (distance between entry and exit holes in inches), and weights (in pounds) of white-tailed deer and domestic sheep shot with different bullet types and weapons, Minnesota, 2008.

Weapon	Bullet Type	Species	N	Carcass Weight	Entry Hole	Exit Hole	Wound Channel
Rifle	Nosler Ballistic Tip	Deer	8	68	1.0	2.7	8.6
	Nosler Ballistic Tip	Sheep	10	43	1.0	2.0	8.9
	Remington Core-Lokt	Sheep	10	34	1.1	1.9	7.2
	Hornady Interbond	Sheep	10	29	0.6	1.8	7.8
	Winchester XP^3	Sheep	10	45	0.7	1.7	9.3
	Barnes TSX	Sheep	10	38	0.8	2.0	7.7
Shotgun	Foster Slug	Sheep	10	48	1.3	1.7	7.8
Muzzleloader	Powerbelt Aero-Tip	Sheep	6	37	0.9	1.2	6.0
	Hornady XTP	Sheep	6	46	1.3	1.7	7.4

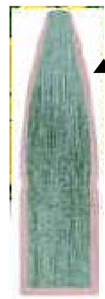
Figure 1. Anatomy of centerfire rifle bullets used in this study.

Rapid Expansion

Nosler Ballistic Tip

Poly-carbonate tip, thin copper jacket that tapers toward the base. Lead core.

Remington Core-Lokt



Thin copper jacket, lead core that is ‘locked’ by the jacket to increase expansion.

Controlled Expansion

Hornady InterBond

Poly-carbonate tip, thick copper jacket with a ring to increase expansion. Lead core is bonded to the jacket so it does not separate.

Winchester XP[3]

Poly-carbonate tip, copper jacket is bonded to lead core. Design is such that the copper completely surrounds the lead core.

Copper

Barnes TSX

All-copper design. Upon impact, the bullet expands into four petals that are designed to not separate.

Letter Health Consultation

LEAD IN VENISON IN MICHIGAN

Prepared by the
Michigan Department of Community Health

MARCH 18, 2010

Prepared under a Cooperative Agreement with the
U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Agency for Toxic Substances and Disease Registry
Division of Health Assessment and Consultation
Atlanta, Georgia 30333

Health Consultation: A Note of Explanation

A health consultation is a verbal or written response from ATSDR or ATSDR's Cooperative Agreement Partners to a specific request for information about health risks related to a specific site, a chemical release, or the presence of hazardous material. In order to prevent or mitigate exposures, a consultation may lead to specific actions, such as restricting use of or replacing water supplies; intensifying environmental sampling; restricting site access; or removing the contaminated material.

In addition, consultations may recommend additional public health actions, such as conducting health surveillance activities to evaluate exposure or trends in adverse health outcomes; conducting biological indicators of exposure studies to assess exposure; and providing health education for health care providers and community members. This concludes the health consultation process for this site, unless additional information is obtained by ATSDR or ATSDR's Cooperative Agreement Partner which, in the Agency's opinion, indicates a need to revise or append the conclusions previously issued.

LETTER HEALTH CONSULTATION

LEAD IN VENISON IN MICHIGAN

Prepared By:

Michigan Department of Community Health
Division of Environmental Health
Under Cooperative Agreement with
U.S. Department of Health and Human Services
Agency for Toxic Substances and Disease Registry

STATE OF MICHIGAN
DEPARTMENT OF COMMUNITY HEALTH
LANSING

JENNIFER M. GRANHOLM
GOVERNOR

JANET OLSZEWSKI
DIRECTOR

January 22, 2009

Stephen M. Schmitt, D.V.M.
Michigan Department of Natural Resources
4125 Beaumont Road, Room 250
Lansing, MI 48910-8106

Dr. Schmitt,

At your request, I have reviewed the Michigan Department of Natural Resources (MDNR) analytical data for lead concentrations in venison (deer meat) harvested during the 2008 firearm season. My comments and recommendations follow.

Background - The Michigan Sportsmen Against Hunger (MSAH) program was developed as a mechanism to allow hunters to donate venison, which is typically processed into one pound packages of ground meat and distributed to food pantries around the state. Small lead fragments are often found in venison from deer shot with lead bullets and people may ingest lead when they eat the meat. Venison donated to charity food pantries is a particular concern because people using food pantries may also be exposed to lead from other sources such as lead paint.

Discussion - In 2008, the MDNR collected 89 one pound packages of venison from game meat processors who had received deer from the MSAH: 87 packages of ground venison and two packages of butterfly loins. Each package was screened for the presence of lead fragments using a fluoroscope. Twenty-seven of the 89 packages showed fragments that appeared to be lead. These were x-rayed, then analyzed for lead along with 30 packages that did not show lead fragments. Lead was found only in ground venison samples. No lead was detected in the venison loin packages. Table 1 provides the results of the lead analysis.[1]

Table 1. Summary of lead content analysis in Michigan hunter-killed deer.

Sample group	Number of samples[a]	Range of lead concentration (ug/gm)[b]	Mean ±SD[c] in lead-positive samples (ug/gm)	Prevalence of lead-positive samples
Lead fragments	27	ND[d] to 235	19.7 ± 45.1	96 %
No lead fragments	30	ND to 0.66	0.22 ± 0.18	3.3 %
All samples analyzed	57	ND to 235	9.1 ± 32.2	60 %

[a]Each sample represents a one pound package.
[b]micrograms per gram or parts per million (ppm)
[c]SD = Standard Deviation
[d]ND = Non-detect

[1] MDNR (Michigan Department of Natural Resources) 2009. Unpublished Data.

Lead is a cumulative toxin that increases in concentration in the body with frequent or prolonged exposure. People may be exposed to lead in drinking water, in the air they breathe, and in food. Children may ingest lead in worn or peeling lead-based paint in their home, daycare, or school. Exposure to lead can cause neurological and developmental problems, especially in children and the fetus before birth. The Centers for Disease Control and Prevention (CDC) has identified a blood lead concentrations at or above 10 micrograms per deciliter of blood (ug/dl) as a level of concern for children. Blood lead concentrations greater than this level have been associated with developmental delays in learning and cognition.[2]

The Wisconsin Department of Health and Family Services (WDHFS) used the United States Environmental Protection Agency's Integrated Exposure Uptake Biokinetic (IEUBK) model to predict the blood-lead level that might result from frequent consumption of lead-contaminated venison.[3] The model was run using default inputs and assumptions for all exposure parameters except dietary consumption of lead-contaminated game meats as a percentage of total meat consumption. The model predicted that 58% of children who ate two meals of venison containing 16.7 ug/g of lead per month would have a blood-lead level greater than 10 ug/dl. If the venison contained 6.2 ug/g lead, 38% of children who ate this meat twice per month were predicted have a blood-lead level greater than 10 ug/dl.

In response to reports of lead fragments in wild game meat, the Centers for Disease Control and Prevention (CDC) collected blood samples from wild game consumers in North Dakota. CDC also administered a questionnaire designed to provide demographic information and wild game consumption habits. CDC found that eating wild game was associated with a small (0.30 ug/dl) but significant rise in blood lead levels. The increase was highest in people who ate all three types of game meat included in the study (venison, birds, and other game), but no linear trend was detected with an increase in the number of game types eaten. In addition, people who reported having eaten game meat within the month prior to blood testing had significantly higher blood lead levels compared to people who had not.[4]

Conclusions - MDCH cannot currently conclude whether eating lead-contaminated venison in Michigan could harm people's health because it is difficult to predict the impact of eating lead-contaminated venison on a child's blood-lead level without knowing what other lead exposures a child may have. Modeling conducted by the WDHFS suggests that, at the average lead concentration of 9.1 ug/g shown in Table 1, between 38 and 58 percent of Michigan children eating this meat twice per month could have unacceptable blood-lead levels as a result. However the CDC study in North Dakota found only a slight elevation in blood lead levels associated with eating game meat. These findings could be concerning for children in families frequenting the food pantries who may have additional exposures from lead sources in their homes that contribute to an elevated blood lead level.

Recommendations - The best course of action would be to stop using lead bullets to harvest venison. However, there are no immediate plans to change state of Michigan law that permits

[2] ATSDR (Agency for Toxic Substances and Disease Registry). 2007. Toxicological Profile for Lead. Atlanta: US Department of Health and Human Services; 2007 Aug.

[3] ATSDR (Agency for Toxic Substances and Disease Registry). 2008. Health Consultation: The Potential For Ingestion Exposure To Lead Fragments In Venison In Wisconsin. Prepared by: the Wisconsin Department of Health and Family Services.

[4] Iqbal, S., et al. Hunting with lead: Association between blood lead levels and wild game consumption. Environ. Res. (2009), doi:10.1016/j.envres.2009.08.007.

hunters to use this ammunition. Alternatively, MDCH makes the following recommendations to inform the affected groups of people so that they can make choices to protect themselves and their families:

- Hunters should be encouraged to select ammunition that does not contain lead and should be provided with information to help them reduce the potential for lead contamination in game meat.
- Consumers of game meat, particularly those who use food pantries, should be made aware of the potential hazards of eating lead-shot meat for children and women of childbearing age.
- Meat processors should be provided with guidelines for processing lead-shot venison that will reduce the lead contamination in the finished meat.

Public Health Action Plan – MDCH was pleased to work with you and Dr. Daniel O'Brien as well as several other stakeholders to develop three public information brochures to address these recommendations:

"What every hunting family should know about lead bullets and venison"

"Protect your child from lead in venison"

"Food service providers: What you need to know about lead in venison"

Attached are the final drafts of each of these brochures, which will be distributed both in print and on the internet. In addition, at your recommendation the Michigan Department of Agriculture (MDA) has provided meat processors with information to minimize lead contamination in ground game meat.

Please contact me by phone at 517- 335-8566 or by e-mail at dykemal@michigan.gov if I can be of further assistance in this matter.

Sincerely,

Linda D. Dykema

Linda D. Dykema, Ph.D., Manager
Toxicology and Response Section

cc: Dr. Daniel O'Brien, MDNR
Dr. David R. Wade, MDCH
Mr. Kory Groetsch, MDCH

If you use high-velocity lead bullets, here are some ways to remove or reduce lead fragments:

- Place your shots carefully. Shots that go through large bones, like the hindquarters of a deer, elk, or bear, will cause more fragmentation.
- Fragments are often found farther from the wound channel than expected. This makes it impossible to recommend a safe distance for trimming. However, liberally trimming around the wound channel should remove some fragments.
- Do not rinse the carcass. Rinsing the meat will not necessarily remove lead fragments. It may spread lead fragments to other parts of the animal, causing more of the meat to have lead.
- Ground venison has been found to have more lead fragments. Venison steaks and chops usually contain less lead.
- Some commercial processors combine several deer. Venison that contains lead fragments could be mixed into venison that you receive. Ask the processor not to combine meat from other deer with yours.
- Acids make it easier for the human body to absorb lead. Avoid using acidic substances (like vinegar or wine) when cooking venison.

For more information about lead:
Call 1-800-MI-TOXIC (1-800-648-6942)
Or visit www.michigan.gov/leadsafe

Michigan Department of Community Health
MDCH
Jennifer M. Granholm, Governor
Janet Olszewski, Director

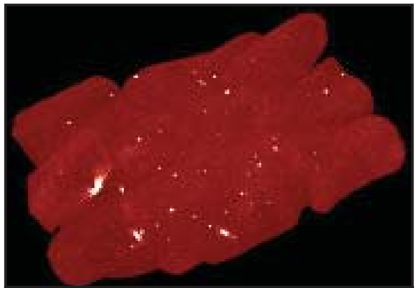
Lead Bullets and Venison

Deer, Elk & Bear

What Every Hunting Family Should Know

New studies show that lead fragments are often found in venison shot with lead bullets.

These pieces of lead are too small to be seen or felt while chewing. Ground venison has the most lead fragments (see photo).



Using a medical imaging device, lead fragments (bright spots) are shown scattered within the ground venison shot with lead bullets.*

Who is most at risk of health problems from lead?

- Women who are pregnant or can become pregnant
- Children ages 6 and under

In pregnant women, lead can cause low birth-weight babies, premature births, miscarriages, and stillbirths.

In young children, lead can cause learning disabilities, lower IQs, and stunted growth. Even the smallest amount of lead can harm children and babies.

<u>Public Health Advice</u>

If you harvest deer, elk, or bear with high-velocity lead bullets, women of childbearing age and children ages 6 and under should avoid eating that venison.

Older children and adults should use caution when eating ground venison shot with lead bullets.

Choose ammunition that will not leave lead fragments in the meat

Worst	Better	Best
• Rapidly expanding bullet - Ballistic tip - Soft point	• Shotgun slug • Muzzleloader bullet • Non-exposed lead core bullet	• Copper bullet • Lead-free bullet
These bullets leave the most lead fragments in the meat. The lead can be found throughout the meat, not just along the wound channel.	These fragment much less due to slower velocity, higher mass, or a metal completely covering the lead. However, there is still some risk of lead fragments.	Copper and lead-free bullets leave no lead in the meat.

Bow hunting does not leave lead in venison.

More good choices on the back. →

*Photo (top left): Cornatzer et al. 2008 Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans. The Peregrine Fund, Boise, Idaho, USA.

More About Lead:

You may find lead in other places. Homes built before 1978 likely contain lead-based paint. Lead dust falls to the floor and gets on children's hands and toys. It can enter their bodies when they put their hands or toys into their mouths.

Lead plumbing, solder or fixtures can put lead into drinking water.

A child with lead poisoning may seem healthy or have any of these signs:

- Upset stomach
- Tiredness
- Loss of appetite
- Hearing Problems
- Weight loss
- Hyperactivity
- Irritability
- Difficulty sleeping

If you are concerned about lead poisoning in you or your child, talk to your physician about getting a blood lead test.

For more information about lead:
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or visit www.michigan.gov/leadsafe

Michigan Department of Community Health
MDCH
Jennifer M. Granholm, Governor
Janet Olszewski, Director

Protect your Child from Lead in Venison

Lead in Venison

Venison (deer meat) can be a healthy source of food for you and your family. But new facts show that lead bullets can leave small pieces of lead in the venison. These small lead pieces cannot be seen in the meat or felt in your mouth while chewing. When you swallow this lead, it absorbs into your body.

Ground venison usually has more lead fragments.

Steaks and chops usually have fewer lead fragments.

- Even the best attempts to remove the lead fragments before processing can still leave lead in the meat. Most lead fragments are too small to be seen or felt while chewing.

What are the dangers of lead?

- Lead affects the nervous system, and can cause problems with brain function.
- In children, lead can cause developmental problems like lowered IQ and learning disabilities.
- Lead is unhealthy for adults too, but women beyond childbearing age and adult men are at less risk of health problems from small amounts of lead.

Who is at greatest risk from lead in wild game?

Lead, even in the smallest amounts, is a serious health risk for:

- Children ages 6 and under
- Pregnant women and unborn babies

- Women of childbearing age and children ages 6 years old and under should avoid eating venison that has been shot with lead bullets.
- Ask if venison (deer meat), is used in the meals served to you. You can request that store-bought meat be served to you and your children. Store-bought meat does not contain lead.

What about children over 6 and adults?

- Older children and adults also can have health problems caused by lead, but it takes much more lead to cause problems in these people. Eating a few meals of lead-shot ground venison will not harm older children and adults. However, if they eat lead-shot ground venison every week, that may be harmful.
- Older children and adults should use caution when eating ground venison that was shot with lead bullets.

Give the brochure
“Protect your Child from Lead in Venison”
to your clients.

Please call the
Michigan Department of Community Health
1-800-648-6942
for more information.

Michigan Department of Community Health
MDCH
Jennifer M. Granholm, Governor
Janet Olszewski, Director

What you need to know about **Lead in Venison**

for
Food Service Providers

What do I need to know before serving venison?

- Deer shot with lead bullets can have small lead fragments in the meat.
- Some of the venison donated to your organization may have lead in it.
- Venison steaks and chops tend to have less lead than ground venison.

Ground venison usually has more lead fragments.

Steaks and chops usually have fewer lead fragments.

- Even the best attempts to remove the lead fragments before processing can still leave lead in the meat. Most lead fragments are too small to be seen or felt while chewing.

Who is at greatest risk from lead in wild game?

Lead, even in the smallest amounts, is a serious health risk for:

- Children ages 6 and under
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What are the dangers of lead?

- Lead affects the nervous system, and can cause problems with brain function.
- In children, lead can cause developmental problems like lowered IQ and learning disabilities.
- Lead is unhealthy for adults too, but women beyond childbearing age and adult men are at less risk of health problems from small amounts of lead.

As a food service provider, you can help reduce the chance of lead exposure in your clients.

- Do not serve any venison to children ages 6 and under or to pregnant women. Serve these clients store-bought meat or a type of meat that was not shot with lead bullets.
- For clients of all ages, serve ground venison no more than once a week.
- Try to use whole cuts (like steaks and chops) of venison rather than ground meat. Ground venison tends to have more lead fragments.
- Serve venison in soups, stews, or casseroles rather than in burgers and meatloaves. This will reduce the amount of venison eaten by each person, which will reduce the chance of lead exposure.
- Acids (like vinegar or wine) make it easier for a person's body to absorb lead. Avoid using acidic substances like vinegar when cooking venison.

Certification

The Michigan Department of Community Health prepared this Letter Health Consultation, Lead in Venison, under a cooperative agreement with the Agency for Toxic Substances and Disease Registry (ATSDR). At the time this Health Consultation was written, it was in accordance with the approved methodologies and procedures. Editorial review was completed by the Cooperative Agreement partner.

Technical Project Officer, Cooperative Agreement Team, CAPEB, DHAC, ATSDR

The Division of Health Assessment and Consultation, ATSDR, has reviewed this public health consultation and concurs with the findings.

Team Leader, Cooperative Agreement Team, CAPEB, DHAC, ATSDR

Health Consultation

THE POTENTIAL FOR INGESTION EXPOSURE
TO LEAD FRAGMENTS IN VENISON IN WISCONSIN

NOVEMBER 4, 2008

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Agency for Toxic Substances and Disease Registry
Division of Health Assessment and Consultation
Atlanta, Georgia 30333

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You May Contact ATSDR TOLL FREE at
1-800-CDC-INFO
or
Visit our Home Page at: http://www.atsdr.cdc.gov

HEALTH CONSULTATION

THE POTENTIAL FOR INGESTION EXPOSURE TO LEAD FRAGMENTS IN VENISON IN WISCONSIN

Prepared By:

Wisconsin Department of Health and Family Services
Under cooperative agreement with the
Agency for Toxic Substances and Disease Registry

Table of Contents

Summary and Statement of Issues

Bullet fragments in rifle-killed deer have led to concerns about risks of lead exposure associated with human consumption of venison. The presence of lead bullet fragments in venison intended for human consumption has been confirmed, and indicates a completed exposure pathway for the ingestion of lead-contaminated meat. A modeled exposure estimate, based on currently available field data, suggests a significant risk of elevated lead levels in blood among children consuming venison shot with lead ammunition. Because elevated blood lead has not been confirmed among consumers of venison, and because the measured lead content in venison varies greatly, there is an *indeterminate public health hazard* among those consumers. The Wisconsin Department of Health Services (DHS) recommends the use of non-lead ammunition as the simplest and most effective solution to lead poisoning, in both humans and wildlife, arising from the consumption of deer killed with lead ammunition. In addition, food pantries and their clients should be made aware of possible lead fragments in venison; processors of deer should use best practices to avoid lead exposure from venison.

The presence of lead in venison is a topic that has implications for deer hunters and their families, food pantries and their clients, meat processors, and others with a public or private interest in hunting. The purpose of this report is to determine the health implications of eating lead-contaminated venison, based upon laboratory analysis of venison samples and a modeled exposure assessment.

Background

Wisconsin ranks near the top of all states in the popularity and economic importance of White-tailed deer hunting (WDNR 1998, 2007). Deer hunting is an important part of Wisconsin recreation and tourism, and is a long-held tradition in many families. In addition, the large size of the state's deer population has effects such as crop damage and road vehicle accidents that demand population management. Most of that management is conducted via hunting, traditionally with rifle and shotgun using lead ammunition, as well as bow and arrow.

The issue of human exposure to lead ammunition fragments in venison came to the attention of Public Health indirectly. Hunt *et al.* (2006), concerned about reports of lead poisoned avian scavengers, investigated hunter-shot deer for the presence of lead, hypothesizing that eagles and other birds consumed lead from deer killed but unrecovered, or from discarded entrails. They reported that tiny metal fragments were prevalent in the wounds of these deer, particularly those shot with copper-jacketed and hollow point bullets. Subsequently, concerns were raised in North Dakota, South Dakota, Iowa, Minnesota, and Wisconsin about the potential for human exposure to lead among those consuming venison. North Dakota was the state taking the earliest public health position (NDDOH 2008):

> "Earlier this year, Dr. William Cornatzer, a Bismarck physician and hunter, contacted the Department of Health with concerns about the potential of lead fragments from bullets in ground venison. Dr. Cornatzer collected 95 packages of ground venison donated for food pantries. Of those, X-rays detected the presence

> of metal in 53 packages. The Department of Health recently took five samples targeting the metal pieces, all five of which tested strongly positive for lead….The Department of Agriculture sent a letter to all state- and federal-inspected meat processing plants in North Dakota informing them about the situation, and the Department of Health sent a letter to food pantries with recommendations for disposing of the meat. Additional studies concerning lead in wild game and lead levels in children are being planned by the Department of Health. In addition, the Game and Fish, Health, and Agriculture departments are working to develop guidance about how to properly clean and dress wild game to reduce the chances of lead in meat."

Venison donated to charity food pantries is a particular concern, as this program is an important outlet for harvested deer while also serving a population having a greater than average exposure to lead in the home. In Wisconsin, food pantry venison is not regulated, unlike commercial and retail meats, which must be inspected before and after processing. The 2006 Wisconsin deer harvest was approximately 500,000 deer (WDNR 2007). From these, about 400,000 pounds of venison were donated to food pantries via 126 meat processors participating in the Department of Natural Resources (WDNR) program.

The Wisconsin Department of Health Services (DHS, formerly Dept. Health and Family Services) has a comprehensive *Childhood Lead Poisoning Prevention Program* devoted to identifying those at risk and interrupting all sources of lead exposure (DHFS 2008). Metallic lead in food is not a new issue. Lead solder in canned foods and lead leachate from ceramic and glass vessels were important sources that were addressed starting in the 1970s. Consumers of wild game are familiar with lead pellets, bullets, and slugs to be avoided in meat. However, the presence of nearly invisible lead fragments in wild game, to our knowledge, had not been widely considered.

Because this issue has implications for an important food distribution program, on April 11, 2008 the DHS asked food pantries to hold venison pending the analysis of venison samples from food pantries (Appendix 1). As the analysis proceeded (see below), DHS concluded that due to the prevalence and concentration of lead seen in venison samples, the frozen venison held in food pantries and other facilities should not be released without further screening. This was conveyed in a second letter to food pantries (Appendix 2). In cooperation with the WDNR, an appeal was made to local veterinarians throughout the state (Appendix 3) for their assistance in screening the venison using their X-ray facilities.

Venison sampling. In Wisconsin, the Departments of Natural Resources and Health Services cooperated to sample and analyze lead in venison from around the state. One hundred eighty three (183) nominal one-pound ground venison samples were collected from freezer stocks of 5 food pantries and 6 meat processors located around the state ("pantry samples"). The samples were screened radiographically by WDNR staff. Of these, 46 samples with radiopaque fragments were submitted to the Wisconsin State Laboratory of Hygiene (WSLH) for lead analysis. Each of the 46 packages was subdivided into nominal ¼ lb "portions" for chemical analysis. Each ¼ lb sample (approx. 0.113 kilograms) was digested in KOH. Any metal fragments recovered following digestion were dissolved in acid and analyzed for Pb (See USDA

2004 for method). The lab reported lead concentration as milligrams Pb per kilogram fresh meat (mg/kg). Means ± standard deviation are reported in terms of the ¼ pound samples. Reported prevalence was calculated from ¼ pound samples normalized to the 1 pound x-ray screened package size.

One hundred fourteen (114) additional samples of ground and whole cut venison were solicited from WDNR employees in order to more directly sample the hunter population ("hunter samples"). These were screened and analyzed as above. Sixteen of the 114 hunter samples were identified by the submitter as "commercially processed." Therefore, for the purpose of calculating averages, these sixteen were grouped with the pantry samples, for an adjusted total of 199 pantry (or commercially processed) samples and 98 self-processed samples (from hunters).

Results. Lead was ultimately detected in 30 of 199 commercially processed samples, a prevalence of 15% (Table 1). The mean lead concentration found among those pantry samples positive for lead was 15.9 mg/kg ± 32.5 std. dev. The mean lead concentration found among *all* pantry samples was 2.4 mg/kg ± 13.8 std. dev.

Lead was detected in 8 of 98 hunter samples, a prevalence of 8%. Seven of the eight positives were from ground meat; one was from a whole cut. The mean lead concentration found among those hunter samples positive for lead was 21.8 mg/kg ± 67.1 std. dev. The mean lead concentration found among *all* hunter samples was 1.8 mg/kg ± 19.8 std. dev.

Table 1. Summary of lead content analysis in Wisconsin hunter-killed deer.

Sample group	***Number of samples****	***Mean lead conc., lead-positive samples mg/kg ±std. dev.***	***Mean lead conc., all samples mg/kg ±std. dev.***	***Prevalence of lead-positive samples***
Commercial processor	*199*	*15.9 ± 32.5*	*2.4 mg/kg ± 13.8*	*15%*
Hunter processed	*98*	*21.8 ± 67.1*	*1.8 mg/kg ± 19.8*	*8%*

*Each sample represents a nominal 1 pound package.

Discussion

Venison sampling. The presence of quantified lead bullet fragments in venison intended for human consumption indicates that a completed exposure pathway exists for the ingestion of lead-contaminated meat. To date, there has been no corresponding sampling of blood lead among consumers of venison in Wisconsin. This work represents an initial assessment of the risks of lead in venison.

This health consultation emphasizes the implications of lead found in donated venison. However, it is noteworthy that donated venison represents approximately 2% of the total deer harvest in Wisconsin. The potential exposed population extends well beyond clients of food pantries. Changes in practices that result in lower lead concentrations in venison will have positive effects in the broader population.

The analytical results of lead in venison conducted to date in Wisconsin are characterized by high variability. Each hunter-killed deer is a unique interaction of the anatomical placement of the shot, the type of ammunition used, the ballistics of the individual shot, and details of the processing method. Each of these variables affects the passage of the bullet through the wound, the degree of fragmentation, and ultimately the concentration of lead. As more data is gathered from deer carcasses and processed meat, it may later be possible to state the prevalence of lead in venison killed in a particular way, and to predict whether there are exposure risks to a processed lot of meat based upon samples taken from that lot. Despite these limitations, it is clear that many venison samples contained unhealthy levels of lead.

U.S. Food and Drug Administration regulatory position. There is no single standard for permissible amounts of lead in food. Furthermore, FDA regulatory standards and guidelines for lead in food are complicated by the relatively recent recognition (ATSDR 2007, EPA 2008) of lead as a probable human carcinogen.

Health and environmental agencies rely on several standards and guidelines, including FDA guidelines for tolerable levels of daily dietary lead intake, and FDA guidance suggesting specific limits for lead in certain foods such as shellfish and candy (ATSDR 2007, FDA 2007).

For meat and fat products, an international consensus standard of 0.05 mg/kg is under discussion (FDA 2000). While there is no known endogenous role for lead, and no known level of exposure that is without effect, the variety of standards and guidelines acknowledges that some exposure to lead is unavoidable. The FDA's *provisional total tolerable intake levels* provide the following limits on daily lead intake: for adults, 75 µg/day; for pregnant women, 25 µg/day; and for children age five and under, 6 µg/day (FDA 1998).

Exposure analysis. Blood lead levels that could result from ingesting Pb-contaminated venison were predicted using the U.S. EPA *Integrated Exposure Uptake Biokinetic Model* (IEUBK, EPA 2007). The model has 100 input parameters that account for the various sources of ingested and inhaled lead in the environment. Default inputs and assumptions were used for all parameters save dietary consumption of Pb-contaminated game meats as a percentage of total meat consumption. The model was run using inputs for game meats at the mean concentrations observed in Wisconsin (Table 1), at an ingestion frequency of either once (3.5%) or twice (7.0%) per month. The ingestion frequency assumes one meat meal per day. The model was also run using the maximum concentrations found in venison (Table 2). Running the model at these maximum concentrations and at the once- or twice-per-month consumption frequency resulted in a model error, and were therefore calculated using a lower exposure frequency.

Table 2. Childhood blood lead concentrations predicted from consuming venison containing lead fragments at concentrations found in Wisconsin. [1]

Exposure scenario	*Pb conc. in venison mg/kg*	*Consumption frequency (meals/month)*	*% children with blood Pb above 10 µg/dL*	*Average blood lead (geometric mean, µg/dL)*
maximum	*265*[3]	*1 per 2 months*	*100%*	*34*[2]
maximum	*265*	*1 per 4 months*	*96%*	*23*
maximum	*169*[4]	*1 per 2 months*	*98%*	*27*
medium	*21.8*[5]	*2 per month*	*90%*	*18*
medium	*21.8*	*1 per month*	*65%*	*12*
medium	*15.9*[6]	*2 per month*	*81%*	*15*
medium	*15.9*	*1 per month*	*50%*	*10*
low	*2.4*[7]	*2 per month*	*11%*	*6*
low	*2.4*	*1 per month*	*5%*	*5*
low	*1.8*[8]	*2 per month*	*8%*	*5*
low	*1.8*	*1 per month*	*4%*	*4*
standard	*0.05*[9]	*2 per month*	*1%*	*3.5*

Shaded area is "medium" exposure scenario. See uncertainty discussion.
mg/kg: milligram lead per kilogram fresh venison. µg/dL: micrograms lead per deciliter of blood.
[1]*Predictions modeled using U.S. EPA Integrated Exposure Uptake Biokinetic Model (EPA 2007).*
[2]*Exposures associated with blood lead levels above 30 µg/dL are above the range of values calibrated and validated for the model.*
[3]*Maximum lead concentration found in hunter samples.*
[4]*Maximum lead concentration found in pantry samples.*
[5]*Average lead concentration among hunter samples that were positive for lead, n=8.*
[6]*Average lead concentration among pantry samples that were positive for lead, n=30.*
[7]*Average lead concentration among all pantry samples, n=199.*
[8]*Average lead concentration among all hunter samples, n=98.*
[9]*International consensus standard for lead in meat (FDA 2000).*

Results. As shown in Table 2., the model predicts that consuming venison with 21.8 mg/kg (hunter samples) lead every 15 days will result in 90 % of children less that 7 years old having blood lead greater than the 10 µg/dL level of concern. If the ingestion frequency is reduced to once every 30 days, the predicted percentage of children with blood lead >10 µg/dL is 65%. A comparable statement for adult blood lead is not included, as the model is designed only for the pharmacokinetic fate of lead in children.

At the mean lead concentration found in pantry samples, the model predicts that consuming venison with 6.2 mg/kg lead every 15 days will result in 80 % of children less that 7 years old having blood lead greater than 10 µg/dL level of concern. If the ingestion frequency is reduced to once every 30 days, the predicted percentage of children with blood lead >10 µg/dL is 50%.

Uncertainty. The conditions used in the modeled predictions (Table 2) were chosen to reflect a range of risk levels among the wide variation in prevalence and concentration of lead in venison samples. The assumed ingestion frequency may over- or underestimate any particular child. The overall means would tend to underestimate exposures to those consuming venison from pantries and processors having a high prevalence of lead in meat samples. The venison Pb concentrations used in the model are means of only those samples that were positive for lead and are not overall means. However, these averages were 10-42 fold lower than the maximum concentrations of lead seen in some samples (maximum 169 mg/kg in pantry samples; 265 mg/kg in hunter samples). Calculated lead exposure to those children consuming venison with the highest levels of lead measured was at or near 100%, even with a lower frequency of consumption (Table 2). At the lowest calculated lead levels, using the same 15 and 30 day exposure frequencies, the model predicts that most children would have measurable increases in blood lead that are *below* 10 ug/dL. However, this lower estimate is skewed away from the possibility of ingesting venison having very high lead levels. For the purpose of this exposure estimate, it is assumed that a realistic exposure, or the calculated averages of 21.8 and 15.9 mg/kg Pb in venison, lies somewhere between the minimum and the maximum permitted by our data.

Toxicological effects expected from lead fragments in venison. Lead is a well-established developmental neurotoxin, and also affects the kidneys, blood formation, reproduction, humoral immunity, and the peripheral nervous system. Due to variation in lead uptake among individuals and among the various chemical forms of lead, the toxicity of lead exposure is usually expressed in terms of its resulting concentration in blood (PbB), and the toxic endpoints corresponding to those blood concentrations. Ten micrograms per deciliter of blood (10µg/dL) is commonly cited as the level of concern in children (CDC 1991). However, numerous studies (*e.g.* Finkelstein *et al.* 1998; Fels *et al.* 1994) report subtle biochemical, nephric, neuromotor, and cognitive effects in children (and in some studies, adults) chronically exposed to lead corresponding to blood lead levels as low as 2 µg/dL.

Although we know of no formal studies of lead poisoning resulting from ingestion of lead bullet fragments in large game animals, the presence of lead in game birds is well established (Tsuji *et al.* 1999) and some studies (*e.g.* Johansen *et al*. 2006) have measured elevated blood lead (>10 µg/dL in adults) among subsistence hunters who regularly consume waterfowl shot with lead pellets. Several reports have demonstrated clinical lead poisoning among adults retaining two or more lead shot in the appendix (Madsen *et al.* 1988, Hilman 1967). Other reports (*e.g*. Mowad *et al.* 1998) have documented cases in which medical intervention was required for children who intentionally ingested lead fishing sinkers or other metallic lead objects. A recent Minnesota case resulted in a fatality (CDC 2006).

A variety of effects of lead in children and adults correspond to various blood lead levels (see Appendix 4, from ATSDR 2006). Within the limitations of modeled blood lead predictions presented here, some of these effects can be reasonably expected among children and adults consuming venison contaminated with lead fragments.

Child Health Considerations

In communities faced with air, water, or food contamination, the many physical differences between children and adults demand special emphasis. Children could be at greater risk than are adults from certain kinds of exposure to hazardous substances. Children play outdoors and sometimes engage in hand-to-mouth behaviors that increase their exposure potential. Children are shorter than are adults; this means they breathe dust, soil, and vapors close to the ground. A child's lower body weight and higher intake rate results in a greater dose of hazardous substance per unit of body weight. If toxic exposure levels are high enough during critical growth stages, the developing body systems of children can sustain permanent damage. Finally, children are dependent on adults for access to housing, for access to medical care, and for risk identification. Thus adults need as much information as possible to make informed decisions regarding their children's health.

Developing fetuses and young children are particularly vulnerable to the effects of lead (ATSDR 2006). Children are more sensitive to the effects of lead than adults, have absorb more ingested lead into the body than adults, and no safe blood lead level in children has been determined (see Appendix 5, for a child-specific public health statement).

Conclusions

- The quantified presence of lead bullet fragments in venison intended for human consumption indicates that a completed exposure pathway exists for the ingestion of lead-contaminated meat.
- The modeled exposure estimates, based on currently available field data, indicate that even at the lowest exposure scenario, there is predicted risk of elevated lead levels in blood among children consuming venison shot with lead ammunition.
- Because elevated blood lead has not been confirmed among consumers of venison, and because the measured lead content in venison varies greatly, there is an *indeterminate public health hazard* among those consumers.

Recommendations

- Food pantries and their clients should be made aware of possible lead fragments in venison, to include consumption recommendations to protect young children and fetuses from lead exposure.
- Identifying and discarding those portions of the deer carcass most likely to contain bullet fragments is one way to avoid lead exposure from venison. Best practices for butchering deer should be provided to commercial processors and to hunters.
- Future venison donations to charity food pantries should be from processors using methods shown to minimize bullet fragments in meat.
- DHS recommends the use of non-lead ammunition as the simplest and most effective solution to lead poisoning, in both humans and wildlife, arising from the consumption of deer killed with lead ammunition. To address this issue, DHFS recommends the eventual transition to non-lead ammunition.

Public Health Action Plan

- Advice to hunters for minimizing the amount of lead in venison has been included in the WDNR 2008 Deer Regulations.
- To verify the effect of revised meat processing recommendations, DHS, in cooperation with WDNR, DATCP, and local and state health agencies, will analyze ground venison samples for the presence of lead following the 2008 deer hunting season.
- DHS will continue to work with state and local health and environmental agencies, with the hunting community, and with food relief programs in providing education on this topic.
- DHS will work with state agencies to encourage the public's awareness of and availability to non-lead hunting ammunition.

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Appendix 1. Venison and lead information distributed to local health officers and posted to the Wisconsin Health Alert [Internet] Network

TO: Local and Tribal Health Officers, DPH Regional Office Directors

FROM: Chuck Warzecha, Bureau of Environmental and Occupational Health

RE: Possible lead contamination in processed venison at food pantries.

DATE: April 11, 2008

Please forward this alert to food pantries in your jurisdictions.

By now you may have heard or seen news out of North Dakota or Minnesota related to lead contamination in venison donated to food pantries in those states. Wisconsin has been in contact with those states and we are also conducting sampling of venison from processors in this state. We are taking the reports from the other states seriously. There have been no reports of illness associated with lead in venison. But, as a precaution we have advised that food pantries with donated venison on their shelves hold any remaining product until we have more information.

The concern stems from studies that show bullet fragments (particularly from high velocity rifles) dispersing widely in the meat, and then incorporated into the ground meat from processors. We are working with the DNR and DATCP to better understand the issue and formulate clearer advice for the public. We are testing venison to determine if bullet particles in wild game pose a health issue. If we get similar results to what Minnesota has received, it is possible we will recommend disposal of the remaining venison at food pantries.

Because of the extensive blood lead surveillance we have done, we are confident that the primary source of lead poisoning in the state comes from chipping and peeling lead paint. Eating venison has not been identified as a concern from this surveillance. However, we are unable to rule this issue out as a possible source of unsafe lead exposure.

We have sent messages to the food pantries in the TEFAP program (The Emergency Food Assistance Program). However, that does not include all food pantries. Please pass this advisory on to other food pantries in your area.

Please address any questions on this matter to Chuck Warzecha (608/264-9880) in the Bureau of Environmental and Occupational Health. Thank you.

Appendix 2. DHS (formerly DHFS) letter to food pantry managers.

TO: Food Pantry Managers

Local and Tribal Health Officers
DPH Regional Office Directors
Please forward this alert to food pantries in your jurisdictions.

FROM: Chuck Warzecha, Rob Thiboldeaux,

Bureau of Environmental and Occupational Health

SUBJECT: Health Concerns about Lead in Venison

June 20, 2008

Thank you for your patience while the Department of Health and Family Services works with the Department of Natural Resources, the Department of Agriculture, Trade, and Consumer Protection, and neighboring states to develop recommendations regarding lead in venison.

At this time, processing guidelines are being established so that food pantries and meat processors can continue their involvement in venison donation programs when hunting season opens again in the fall.

In addition, based on what we currently know about the health implications of eating venison containing lead, we recommend that remaining venison from food pantries not be consumed or distributed unless the meat has been tested. If it is not possible to test the meat, pantries have the discretion to discard it.

Using X-ray equipment and lab tests, we have analyzed more than 200 venison samples from food pantries and meat processors throughout the state. The number of samples with lead present was fairly low, about 4%, but not low enough to eliminate the potential for exposure under the right set of circumstances.

Resources are not available for screening all remaining venison stocks. If a food pantry has access to X-ray equipment through a local veterinarian, it may be possible for them to screen their remaining venison and still release uncontaminated meat. A plan to offer this screening is underway, but may take several months to implement.

Although lead in venison does not rival lead paint in older homes as a health risk for Wisconsin children, the risk is not low enough to ignore. Wisconsin's health and environmental agencies continue to study this concern to determine the actual risk.

We do know that pregnant women and children less than six years old are most at risk. These two groups in particular should avoid consuming venison shot with lead bullets or slugs, or venison from an unknown source. Lead poisoning can cause health symptoms that may not immediately be noticed by a casual observer. Lead exposure in young children is known to affect brain development and cause reduced IQ and attention span, impaired growth, reading and learning disabilities, hearing loss, and a range of other health and behavioral effects.

We again thank you for patience while DHFS, DNR, and DATCP work to understand this issue. If you have questions please call Chuck Warzecha 608/264-9880 or Rob Thiboldeaux 608/267-6844.

Appendix 3. DHS (formerly DHFS)/DNR letter to Wisconsin Veterinarians.

TO: Wisconsin Veterinarians

FROM: Department of Health and Family Services

SUBJECT: Radiographic Screening for Lead in Food Pantry Venison

July 1, 2008

Dear Wisconsin Veterinarian,

The Wisconsin Division of Public Health (DHFS) and the Department of Natural Resources (DNR) request your assistance with an issue of public health concern. Recent studies have shown a prevalence of tiny lead fragments in venison shot with lead ammunition. These are typically too small to be seen or removed during meat processing, and can disperse far from the wound channel. This first came to light from studies investigating the potential for eagles to be poisoned by feeding on deer carcasses.1 More recently, preliminary investigations in Minnesota and Wisconsin, using X-ray screening followed by chemical analysis, have found lead in processed venison stored at charity food pantries and from hunter's home freezers.

Venison to be distributed from charity food pantries is of particular concern to state health and environmental agencies. Based on what we currently know about the health implications of eating venison containing lead, we recommend that venison currently remaining in food pantries not be consumed or distributed *unless the meat has been screened radiographically.* DHFS and DNR do not currently have the resources to screen all the venison remaining at state food pantries from the last season. In order to allow food pantries to confidently release donated venison to the needy, *we seek to enlist the voluntary services of local vets willing to offer their X-ray services to screen packaged meat.*

The lead fragments occur with relatively low incidence (4-20% of 1 lb. meat samples in preliminary work), but often at a high concentration (up to 169 milligrams per kilogram , compared to a FDA-recommended 0.05 mg/kg in meat products). Because this source of lead exposure has not been considered until recently, we do not understand all of its health implications. Most current examples of human lead poisoning involve exposure to lead paint. We do know that subsistence hunters that regularly consume waterfowl from areas where lead shot is used are at high risk lead poisoning, both from ingestion of lead pellets and from meat tainted by pellets in the gizzard.2 We have little information about the effects of infrequent lead

1 Hunt GW, Burnham W, Parish CN, Burnham KK, Mutch B, Oaks JL. 2006. Bullet Fragments in Deer Remains: Implications for Lead Exposure in Avian Scavengers. *Wildlife Soc. Bull. 34(1):* 167-70.

2 Johansen P, Pedersen HS, Asmund G, Riget F. 2006. Lead shot from hunting as a source of lead in human blood. *Environ. Polution 142:* 93-97.
Madsen, *et al.* 1988. Blood lead levels in patients with lead shot retained in the appendix. *Acta Radiologica 29:* 745-46.

exposure at the concentrations we see in venison, but our best information is that there is a level of concern, and that the exposure is to be avoided, especially by those most sensitive.

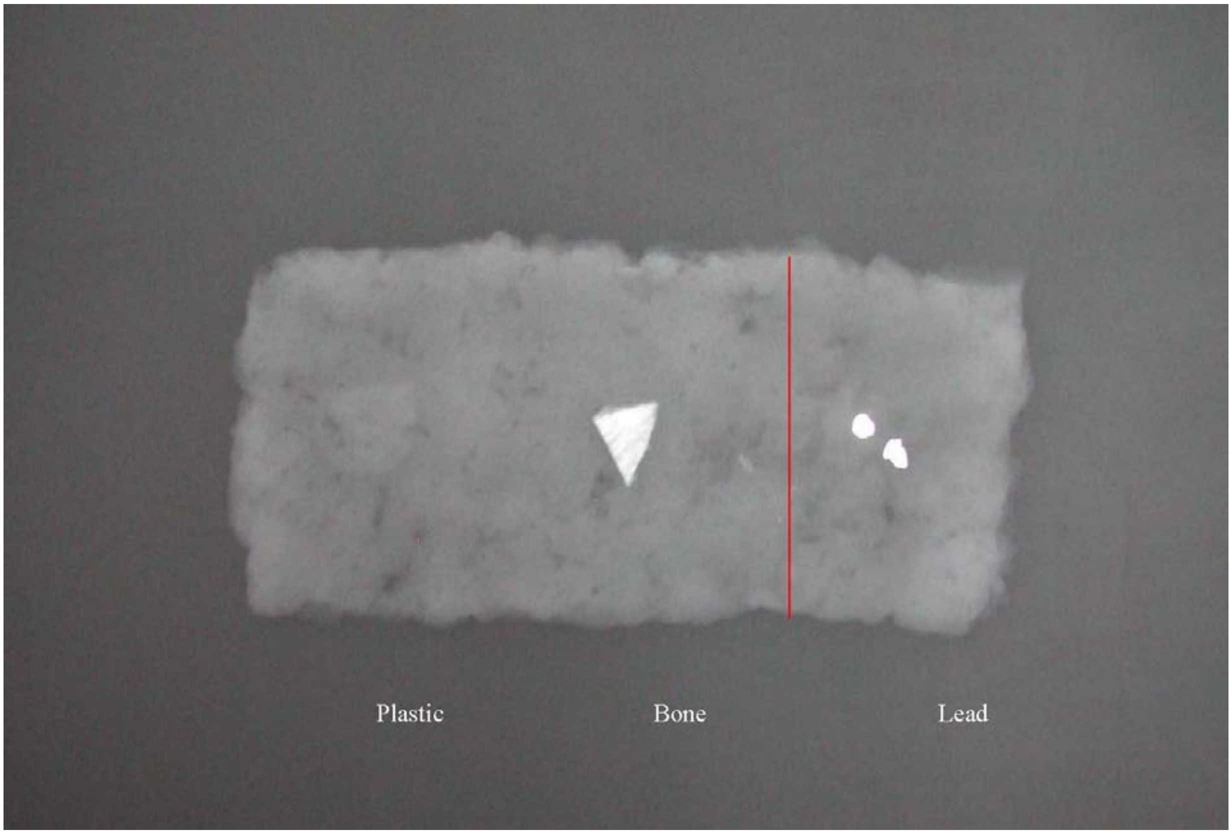
In order to prevent this source of lead exposure, DHFS is working with the DNR, the Department of Agriculture, Trade, and Consumer Protection (DATCP), and neighboring states to develop recommendations regarding lead in venison. Processing guidelines are being established so that food pantries and meat processors can continue with the venison program when hunting season opens in the fall. New processing guidelines should avoid the need for future X-ray screening.

We hope that food pantries who are interested in having their current stores of venison screened for lead will be able to find a veterinary clinic in the community that is willing to provide radiography services. This request for assistance would apply only to the period prior to the 2008 deer season. For the upcoming season, we are working on a separate plan that will include recommendations to meat processors, along with spot checks by the state lab of hygiene to see how well processing techniques are able to eliminate lead from venison.

Screening guidelines. Based on preliminary work by the DNR, radiography of the wrapped frozen packages of venison is a simple process. Lining up several packages on a large cassette works well, as long as identification of the individual packages is recorded on the film, so that those containing fragments can be later identified. The exposure technique will vary with different equipment, but since the goal is to differentiate metal from soft tissue, details of the exposure technique are not critical. As an aid to interpreting X-ray images, this letter includes a "radiographic scale" demonstrating the appearance of small fragments of plastic, bone, and lead-containing bullets on a background of ground venison.

The goal of the venison radiography is to identify those packages with ANY fragments compatible with lead. These packages should be separated and identified as possibly containing lead when results are communicated to the food pantry. Using this information, *it will be the pantry's responsibility to decide which packages are distributed for consumption and which are discarded.* DHFS recommends that all packages possibly containing lead be discarded.

Thank you for considering helping your local food pantry and your community by participating in this program. In closing, please note that DHFS and DNR make no presumption of commitment from individual veterinarians. The choice is yours, as you will not be reimbursed for your donated time and resources. Nonetheless, if you do choose to provide this support to local food pantries, we are very interested in learning the results of your screening. There is still much to learn on this issue, and your experience will add to our understanding. If you have questions about the program or your clinic's role, please contact Robert Thiboldeaux, PhD, Department of Health and Family Services (Robert.Thiboldeaux@wi.gov; 608-267-6844). If you have questions about the radiographic screening techniques, please contact Julie Langenberg, VMD, Department of Natural Resources (Julia.Langenberg@wisconsin.gov; 608-266-3143).



Radiography scale illustrating opacities of plastic, bone, and lead fragments in ground venison. Venison containing any objects with an opacity similar to that of lead (to the right of the red line) should be discarded.

Appendix 4. Blood Lead Concentrations Corresponding to Adverse Health Effects

From: **Agency for Toxic Substances and Disease Registry/Division of Toxicology and Environmental Medicine. 2006. Lead ToxFAQs: /Chemical Agent Briefing Sheet.**

Blood Lead Concentrations Corresponding to Adverse Health Effects		
Life Stage	**Effect**	**Blood lead (µg/dL)**
Children	Depressed ALAD* activity	< 5
	Neurodevelopmental effects	<10
	Sexual maturation	<10
	Depressed vitamin D	>15
	Elevated EP**	>15
	Depressed NCV***	>30
	Depressed hemoglobin	>40
	Colic	>60
Adult	Depressed ALAD*	< 5
	Depressed GFR****	<10
	Elevated blood pressure	<10
	Elevated EP (females)	>20
	Enzymuria/proteinuria	>30
	Peripheral neuropathy	>40
	Neurobehavioral effects	>40
	Altered thyroid hormone	>40

	Reduced fertility	>40
	Depressed hemoglobin	>50
Elderly Adult	Neurobehavioral effects	> 4

*aminolevulinic acid dehydratase (ALAD)
**erythrocyte porphyrin (EP)
***nerve conduction velocity (NCV)
****glomerular filtration rate (GFR)
Source: ATSDR Toxicological Profile for Lead (Draft for Public Comment), 2005.

Appendix 5. How can lead affect children?

A public health statement from the Agency for Toxic Substances and Disease Registry's *Toxicological Profile for Lead* (ATSDR 2007).

1.6 HOW CAN LEAD AFFECT CHILDREN?

This section discusses potential health effects in humans from exposures during the period from conception to maturity at 18 years of age. Studies carried out by the Centers for Disease Control and Prevention (CDC) show that the levels of lead in the blood of U.S. children have been getting lower and lower. This result is because lead is banned from gasoline, residential paint, and solder used for food cans and water pipes. However, about 310,000 U.S. children between the ages of 1 and 5 years are believed to have blood lead levels equal or greater than 10 μg/dL, the level targeted for elimination among young children in the Unites States by 2010.

Children are more vulnerable to lead poisoning than adults. Children are exposed to lead all through their lives. They can be exposed to lead in the womb if their mothers have lead in their bodies. Babies can swallow lead when they breast feed, or eat other foods, and drink water that contains lead. Babies and children can swallow and breathe lead in dirt, dust, or sand while they play on the floor or ground. These activities make it easier for children to be exposed to lead than adults. The dirt or dust on their hands, toys, and other items may have lead particles in it. In some cases, children swallow nonfood items such as paint chips; these may contain very large amounts of lead, particularly in and around older houses that were painted with lead-based paint. The paint in these houses often chips off and mixes with dust and dirt. Some old paint contains as much as 50% lead. Also, compared with adults, a bigger proportion of the amount of lead swallowed will enter the blood in children.

Children are more sensitive to the health effects of lead than adults. No safe blood lead level in children has been determined. Lead affects children in different ways depending on how much lead a child swallows. A child who swallows large amounts of lead may develop anemia, kidney damage, colic (severe "stomach ache"), muscle weakness, and brain damage, which ultimately can kill the child. In some cases, the amount of lead in the child's body can be lowered by giving the child certain drugs that help eliminate lead from the body. If a child swallows smaller amounts of lead, such as dust containing lead from paint, much less severe but still important effects on blood, development, and behavior may occur. In this case, recovery is likely once the child is removed from the source of lead exposure, but there is no guarantee that the child will completely avoid all long-term consequences of lead exposure. At still lower levels of exposure, lead can affect a child's mental and physical growth. Fetuses exposed to lead in the womb, because their mothers had a lot of lead in their bodies, may be born prematurely and have lower weights at birth. Exposure in the womb, in infancy, or in early childhood also may slow mental development and cause lower intelligence later in childhood. There is evidence that these effects may persist beyond childhood. Children with high blood lead levels do not have specific symptoms. However, health workers can find out whether a child may have been exposed to harmful levels of lead by taking a blood sample. They can also find out how much lead is in a child's bones by taking a special type of x-ray of the finger, knee, or elbow. This type of test, however, is not routine.

CERTIFICATION

This Health Consultation was prepared by the Wisconsin Department of Health Services under a cooperative agreement with the Agency for Toxic Substances and Disease Registry (ATSDR). It is in accordance with approved methodology and procedures existing at the time the health consultation was begun. Editorial review was completed by the Cooperative Agreement partner.

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CAT, CAPEB, DHAC, ATSDR

The Division of Health Assessment and Consultation, ATSDR, has reviewed this health consultation and concurs with its findings.

Alan Yarbrough
Team Lead
CAT, CAPEB, DHAC, ATSDR

LEAD BULLET FRAGMENTS IN VENISON FROM RIFLE-KILLED DEER: POTENTIAL FOR HUMAN DIETARY EXPOSURE

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Abstract.—Human consumers of wildlife killed with lead ammunition may be exposed to health risks associated with lead ingestion. This hypothesis is based on published studies showing elevated blood lead concentrations in subsistence hunter populations, retention of ammunition residues in the tissues of hunter-killed animals, and systemic, cognitive, and behavioral disorders associated with human lead body burdens once considered safe. Our objective was to determine the incidence and bioavailability of lead bullet fragments in hunter-killed venison, a widely-eaten food among hunters and their families. We radiographed 30 eviscerated carcasses of White-tailed Deer (*Odocoileus virginianus*) shot by hunters with standard lead-core, copper-jacketed bullets under normal hunting conditions. All carcasses showed metal fragments (geometric mean = 136 fragments, range = 15–409) and widespread fragment dispersion. We took each carcass to a separate meat processor and fluoroscopically scanned the resulting meat packages; fluoroscopy revealed metal fragments in the ground meat packages of 24 (80%) of the 30 deer; 32% of 234 ground meat packages contained at least one fragment. Fragments were identified as lead by ICP in 93% of 27 samples. Isotope ratios of lead in meat matched the ratios of bullets, and differed from background lead in bone. We fed fragment-containing venison to four pigs to test bioavailability; four controls received venison without fragments from the same deer. Mean blood lead concentrations in pigs peaked at 2.29 μg/dL (maximum 3.8 μg/dL) 2 days following ingestion of fragment-containing venison, significantly higher than the 0.63 μg/dL averaged by controls. We conclude that people risk exposure to lead from bullet fragments when they eat venison from deer killed with standard lead-based rifle bullets and processed under normal procedures. At risk in the U.S. are some ten million hunters, their families, and low-income beneficiaries of venison donations. *Reproduced with permission from PLoS ONE 4(4): e5330.*[6]

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Key words: Bullet fragmentation, bush meat, game meat, lead, lead exposure, venison.

LEAD HAS BEEN IMPACTING the health of humankind since the Romans began mining it 2500 years ago, and despite early knowledge of its harmful effects, exposure to lead from a wide variety of sources persists to this day (Warren 2000). Government-based guidelines for acceptable degrees of exposure prior to the 1970s were based upon thresholds of overt toxicity and on apparent acceptance that norms in lead concentrations in a society enveloped in lead-permeated exhaust fumes and lead paint must somehow reflect organic tolerance. Medical science has since concluded that virtually no level of lead exposure can be considered harmless in consideration of its many sublethal, debilitating, and often irreversible effects (Needleman 2004). Lead quantities formerly regarded as trivial are associated with permanent cognitive damage in children (Lanphear et al. 2005), including those prenatally exposed (Schnaas et al. 2006). Lead is associated with impaired motor function (Cecil et al. 2008), attentional dysfunction (Braun et al. 2006), and even criminal behavior (Needleman et al. 2002, Wright et al. 2008). Release of lead stores from bone exposes fetuses during pregnancy (Tellez-Rojo et al. 2004), and adults late in life (Schwartz and Stewart 2007, Shih et al. 2007). Lead is implicated in reduced somatic growth (Hauser et al. 2008), decreased brain volume (Cecil et al. 2008), spontaneous abortion (Borja-Aburto et al. 1999), nephropathy (Ekong et al. 2006), cancer, and cardiovascular disease (Menke et al. 2006, Lustberg and Silbergeld 2002).

Ingested residues of lead ammunition are a recently identified pathway of lead exposure to human consumers of gun-killed game animals. An analysis of North Dakota residents showed that recent (≤ 1 mo) consumers of game meat had higher covariate-adjusted blood lead concentrations than those with a longer interval (> 6 mo) since last consumption (Iqbal 2008). Studies have linked elevated blood lead concentrations of subsistence hunters in northern Canada, Alaska, Greenland, and elsewhere to consumption of shotgun-killed birds (Hanning et al. 2003, Levesque et al. 2003, Johansen et al. 2004, 2006, Bjerregaard et al. 2004, Tsuji et al. 2008a, 2008b, 2008c; see Burger et al.1998, Mateo et al. 2007). The hypothesis that rifle bullet fragments are an additional source of human lead exposure is suggested by radiographic studies of deer killed with standard lead-based bullets, which show hundreds of small metal fragments widely dispersed around wound channels (Hunt et al. 2006, Dobrowolska and Melosic 2008, Krone et al. 2009). The possibility of inadvertent lead contamination in prepared meat consumed by hunters and their families is noteworthy, considering the millions of people who hunt big game in the USA (USFWS and USCB 2006) and the thousands of deer annually donated to food pantries for the poor (Cornatzer et al. 2009, Avery and Watson 2009). In this report, we test two hypotheses: (1) that fragments of lead from rifle-bullets remain in commercially processed venison obtained under normal hunting conditions in the USA, and (2) humans absorb lead when they eat venison containing bullet fragments.

MATERIALS AND METHODS

Ethics Statement.—Nine licensed hunters provided the deer carcasses analyzed in this study, and obtained them during the established hunting season and in accordance with normal practices as permitted under the authority of the Wyoming Game and Fish Commission, Cheyenne, Wyoming. The latter institution also granted permission to the authors to convey the processed meat from each carcass to the Washington Animal Disease Diagnostic Laboratory at Washington State University, Pullman, for analysis. The Washington State University Institutional Animal Care and Use Committee approved the lead bioavailability experiment involving eight swine.

Deer Collection.—Hunters used conventional center-fire hunting rifles to kill 30 White-tailed Deer (*Odocoileus virginianus*) under normal hunting conditions in Sheridan County, Wyoming in November 2007. All bullets were of 7-mm Remington Magnum caliber and of identical mass (150 grains, 9720 mg); cartridges were of a single brand reported in local mass-market vendor interviews as the most widely sold to deer hunters. Bullets consisted of a lead core (68% of mass) and a copper jacket (32%); lead was exposed only at the 1.7-mm-diameter tip of the bullet. Reported shot distances averaged 116 m (range = 25–172 m). All deer were eviscerated according to the hunters' normal practice. Weights of 29 eviscerated deer averaged 33.8 kg (SD = 7.1). We recorded the positions of bullet entry and exit wounds; 26 deer (87%) were shot in the thorax, and some portion of the projectile exited the animal in 92% of shots. We removed the skin and head, and we excised from each animal a ≥4 cm section of tibia for isotope analyses and a ≥30 g sample of muscle (shank) along the tibia to determine background lead levels in each deer.

Carcass Radiography.—We radiographed with conventional veterinary equipment the area of the wound channel (lateral view) of eviscerated deer and adjusted exposures to maximize contrast. We included along the margin of each radiograph a strip of clear plastic tape containing arrayed samples of lead bullet fragments (obtained by shooting through light plastic jugs filled with water), comparably-sized samples of bone fragments, and locally-obtained sand and gravel; only the lead fragments were clearly visible in the radiographs at the applied settings. We scanned radiographs into digital format and counted unambiguous metal fragments under 400% magnification. We did not attempt to distinguish between copper and lead in fragment counts.

Commercial Processing.—We transported each deer carcass to a different commercial meat processing plant in 22 towns throughout Wyoming and requested normal processing into boneless steaks and ground meat in 2-pound (0.91 kg) packages; we retrieved the processed, frozen, and packaged meat usually within 4 days.

Radiography of Processed Meat.—We used digital radiography (EDR6 Digital Radiography, Eklin Medical Systems, Santa Clara, California) and fluoroscopy (MD3 Digital Fluoroscopy, Philips Medical Systems, Best, Netherlands) to scan all the thawed ground meat packages (N = 234); we scanned an additional 49 loin steak packages from 16 carcasses in which radiography had revealed fragments near the spine. We unwrapped every package showing visible radiodense fragments in a subsample of 13 deer, flattened the meat to c. 1-cm thickness on a light plastic plate, and rescanned. We marked the vicinity of each visible fragment with a stainless steel needle and then used a 2.8-cm diameter plastic tube as a "cookie-cutter" to obtain samples of meat with radiodense fragments.

Analysis of Metal Samples.—Each of the fragment-containing meat samples was weighed and then divided into approximately 5-g subsamples, each of which was completely digested in a known volume of concentrated nitric acid. Inductively coupled plasma (ICP) analysis was then used to measure the concentrations of lead and copper in each subsample. The lower detection limit for both metals was 2 µg/g. The analysis was performed commercially by the Analytical Sciences Laboratory, University of Idaho, Moscow, where quality management conforms with applicable Federal Good Laboratory Practices (40 CFR Part 160); the Laboratory is accredited through the American Association of Veterinary Laboratory Diagnosticians, which stipulates ISO 17025 quality assurance measures.

Lead Isotope Analysis.—We analyzed bullet, bone, and meat samples for lead isotope compositions. Bullet fragments were cleaned in dilute (1M) HCl, leached with 2 ml of 7M HNO_3, and then removed from the acid leachate. The leachate was then dried and treated with 2 drops of 14M HNO_3. Bone and meat samples were digested in 14M HNO_3, dried and treated with 2 drops of 14M HNO_3. Lead was separated using standard HBr and HCl on an anion-exchange column (Bio Rad, AG 1X8). Isotope compositions were determined with a ThermoFinnigan Neptune MC-ICPMS at the Washington State University GeoAnalytical Laboratory. Reproducibility of the lead standard (NBS-981), run before, during, and after the samples, was <0.012% (2 SE, n = 4) for Pb^{206}/Pb^{204}, and <0.018% for Pb^{208}/Pb^{204}.

Lead concentrations in the procedural blanks were negligibly small.

Bioavailability Experiment.—We tested the bioavailability of ingested bullet fragments by feeding processed venison known by radiography to contain radiodense fragments to pigs. The latter were considered a good model for the absorption of lead from the human gastrointestinal tract (USEPA 2007). We used eight female Yorkshire/Landrace and Berkshire/Duroc cross-bred pigs, 70–82 days of age and weighing 28.2–32.7 kg (mean 30.3 kg) at the termination of the experiment. All were initially fed 1.36 kg of standard pelleted pig grower ration divided into two meals per day, then acclimated for 7 days to consuming cooked ground commercial beef patties mixed with the pellet ration. We gradually increased the amount of ground meat from 113 g per meal to 500 g, as pellet amounts were correspondingly decreased. We withheld all food for 24 hours prior to the venison feeding trial.

Ground venison and venison steaks from four deer were used in the feeding trial. Each of the eight pigs consumed 1.26–1.54 kg of meat over two feedings 24 hours apart on days 0 and 1 of the experiment; no pig consumed meat from more than one deer. Four pigs received venison containing fluoroscopically visible metal fragments. The total amount of lead fed to each pig was unknown, but quantitative analysis of similar packages from other deer in the study showed 0.2–168 mg (median 4.2 mg) of lead. The four control pigs were simultaneously fed equivalent amounts of venison with no fluoroscopically visible fragments from the same four deer. We assessed background levels of lead in each deer from shank meat, collected well away from any potential bullet contamination. All venison for the test and control pigs was either already ground, or finely chopped if steaks, and cooked in a microwave oven until brown. For feeding, we mixed the cooked venison in a bowl with small amounts of pig ration to improve palatability. We verified that all meat was eaten, and we monitored the pigs for signs of illness.

We collected anticoagulated blood samples (2 ml whole blood in EDTA) from each pig at 1 hour prior to feeding venison on day 0, and on days 1, 2, 3, 4, 7 and 9 after feeding venison, and stored the samples at 4^{o}C until testing. Lead levels were determined by inductively coupled plasma mass spectrometry (ICP-MS) with a lower detection limit of 0.5 µg/dL; we assigned all values below the detection limits as 0.5 µg/dL. We compared mean blood lead concentrations between control pigs and test pigs on days 0 through 9 using 2-way ANOVA with repeated measures and restricted maximum likelihood (REML) estimation; we performed linear group contrasts for each day. A single outlier datum among control pigs on day 4 (6.8 µg/dL) was an order of magnitude higher than a retest of the same sample (0.54 µg/dL); the latter was consistent with all other control samples. We omitted both results from statistical analysis, resulting in a sample of three rather than four control pigs on day 4. We used JMP (SAS Institute, Cary, NC, USA, Vers. 7.0.1) for all statistical analyses.

RESULTS

Bullet Fragments in Venison.—Wound radiographs of all 30 eviscerated deer showed metal fragments (median = 136 fragments, range = 15–409) and offered a measure of fragment dispersion, albeit two-dimensional. Extreme distance between fragment clusters in standard radiographs averaged 24 cm (range ± SD = 5–43 ± 9 cm), and maximum single fragment separation was 45 cm. Radiography revealed visible metal fragments in the ground meat of 24 (80%) of the 30 deer. At least one fragment was visible in radiographs of 74 (32%) of 234 packages of ground meat; 160 (68%) revealed no fragments, 46 (20%) had one, 16 (7%) had two, and 12 (5%) showed 3-8 fragments. An average of 32% of ground meat packages (N = 3–15 packages, mean 7.8) per deer showed metal fragments (range = 0–100% of packages). The ground meat derived from one deer showed more fragments (N = 42) than counted in the radiograph of the carcass (N = 31), and two ground meat packages (2 deer) each contained a single shotgun pellet which had not been detected on the carcass radiographs. No relationship was apparent between the number of metal fragments counted in carcasses and those subsequently counted in ground meat from the same individual (correlation coefficient 0.06). In the aggregate, we observed 155 metal particles in the ground meat packages, 3.1% of the 5074 we counted in the carcasses. Of 16 deer carcasses with metal frag-

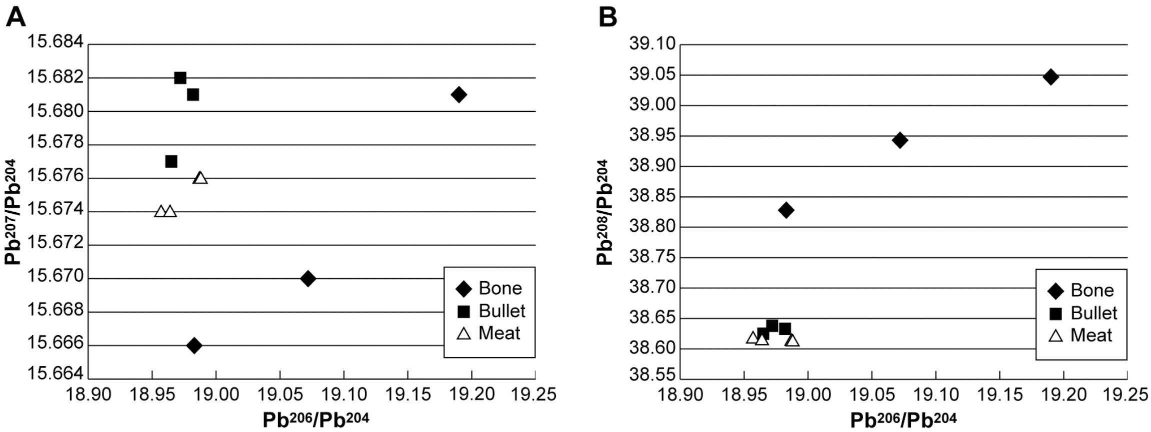

Figure 1. Plots of lead isotope ratios in ground meat samples containing radiodense fragments from four deer. Ratios from lead-in-meat samples clustered with those of unfired bullets but were distinct from bone lead ratios. Note that there are four meat data points (open triangles) in each graph, but two have almost identical positions and are superimposed.

ments near the spine, four (25% of selected deer, 8% of 49 packages) showed fragments in processed loin steaks (1–9 fragments). Additional fragments may have occurred in 220 unscanned packages of steaks derived from all animals.

ICP analysis of radiodense fragments excised from ground meat packages from 13 deer identified lead in 25 (93%) of 27 samples; aggregate lead fragment mass per package averaged 17.2 mg (range ± SD = 0.2–168 ± 39.8 mg) or 0.03% of the lead component of bullet mass. Nine samples contained copper at levels above background values, including the two samples with no detectable lead. Lead concentrations in unprocessed muscle tissue collected from the shank and well away from the bullet path of the same 13 deer were all below the detection limit of 2.0 µg/g and served as internal controls for measures of lead in ground meat.

The ratio of lead isotopes 206/204 plotted against 207/204 ratios (Figure 1a) and 208/204 ratios (Figure 1b) showed that meat samples with elevated lead levels from four deer, and lead from bullets from the same boxes (N = 3) supplying the bullets used to kill those deer, formed tight clusters distinct from ratios of background lead in tibial bone. Variation in the bone ratios apparent in Figure 1 likely represent long term, cumulative lead exposure encompassing varied sources of natural and anthropogenic lead.

Bioavailability Experiment.—All the pigs consumed all the venison provided to them within 2 hours. None of the experimental animals showed any signs of lead toxicosis or other illness for the duration of the experiment; none exhibited vomiting or diarrhea which might have affected gastrointestinal physiology or retention times in the stomach or intestines.

Blood lead concentrations in the four control pigs ranged from below the level of ICP-MS detection (0.5 µg/dL) to 1.2 µg/dL throughout the experiment (mean ± SD = 0.63 ± 0.19 µg/dL; Figure 2). Blood lead concentrations in pigs fed metal fragment-containing venison ranged from below the level of detection to 1.4 µg/dL on day 0, immediately prior to feeding venison. The 2-way ANOVA revealed a significant interaction between treatment (feeding venison either with fragments or no fragments) and day ($F_{6,35.32}$ = 3.413, P = 0.009; Figure 2). Mean blood lead concentrations in the pigs fed fragment-containing venison were significantly elevated above those of control pigs on days 1, 2 and 3 post-exposure (linear contrast: $F_{1,39.79}$ = 10.39, P = 0.003, $F_{1,39.79}$ = 17.76, P = 0.0001, and $F_{1,39.79}$ = 14.71, P = 0.0004, respectively; Figure 2); the maximum observed value was 3.8 µg/dL. Blood lead concentrations did not differ (P >0.05) between the control pigs and exposed pigs on days 0, 4, 7 and 9 (Figure 2).

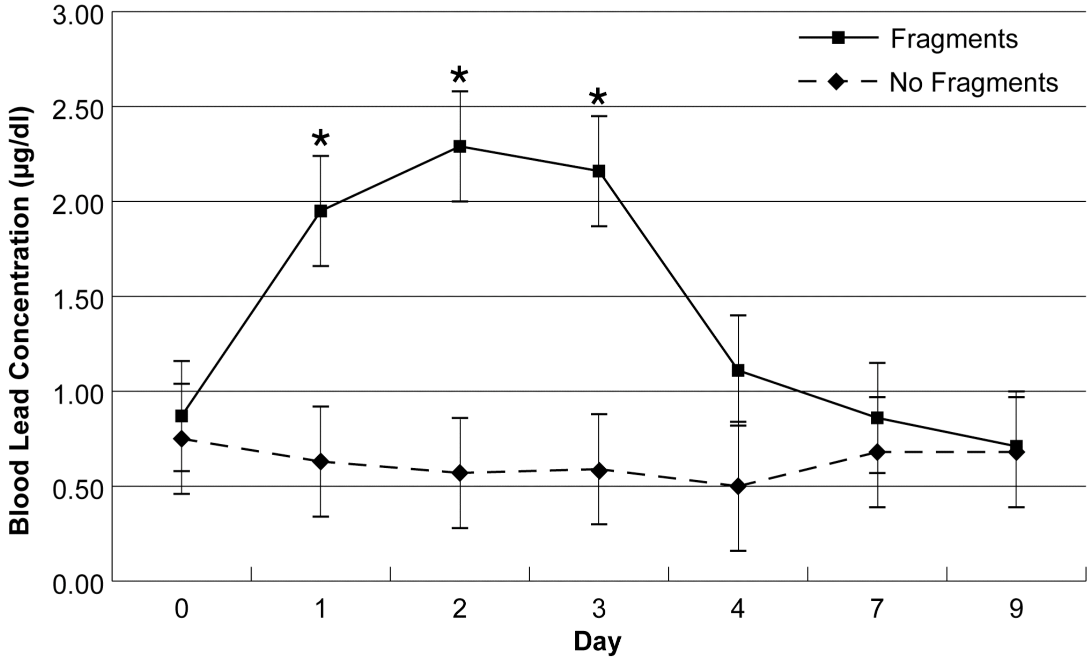

Figure 2. Mean blood lead concentrations observed during swine feeding experiment. Mean (± SE) blood lead concentrations (μg/dL) in four pigs fed venison containing radiographically dense fragments (Fragments) compared with four control pigs fed venison without visible fragments (No Fragments) on days 0 and 1. Asterisks indicate days when means differed significantly between test and control groups.

DISCUSSION

Our findings show that people risk exposure to lead when they eat venison from deer killed with standard lead-based rifle bullets and processed under normal commercial procedures. Evidence includes a high proportion (80%) of deer showing at least one bullet fragment in one or more ground meat packages, a substantial frequency of contamination (32% of all ground meat packages), a majority (93%) of assayed fragments identified as lead, isotopic homogeneity of bullet lead with that found in the meat, and increased blood lead concentrations in swine fed fragment-containing venison. Considering that all the carcasses we brought to the processors contained fragments (15-409 fragments counted in radiographs), the high rate of removal evident in the ground meat implies meticulous care on the part of the processors to avoid contamination, but an apparent inability of 80% of them to do so entirely. We conclude that, in a majority of cases, one or more consumers of a hunter-killed, commercially-processed deer will consume bullet lead.

We interpret the absorption of lead into the bloodstream of all four test pigs as clear evidence of the bioavailability of lead from ingested bullet fragments (Figure 2), and we infer that human consumption of venison processed under prevailing standards of commerce results in increased blood lead concentrations. The rate of bioavailability cannot be calculated from our experiment because the exact amounts of lead in the meat packages were unknown. Rather, we directed our test at the condition experienced by human consumers of venison from rifle-killed deer of variable amounts of lead patchily distributed as fragments in ground meat or steak.

Depuration of lead in blood does not imply its excretion, but rather the sequestration of a substantial proportion in soft tissues and ultimately in bone from which it may eventually be mobilized, as during pregnancy (Tellez-Rojo et al. 2004) or in old age (Schwartz and Stewart 2007). The observed elevations in blood lead concentrations, while not considered overtly toxic, would nevertheless contribute to cumulative lead burdens, and would be additive with further meals of contaminated venison. Observed blood lead concentrations of up to 3.8 µg/dL, and daily means of 2.3 and 2.2 µg/dL in the experimental animals, do approach what is considered significant with respect to adverse effects in humans by contemporary assessments (Gilbert and Weiss 2006, Levin et al. 2008). Whereas the CDC advisory level for intervention in individual children is 10 µg/dL in blood (CDC 1991), studies now associate as little as 2 µg/dL with increased risk of cardiovascular mortality in adults (Menke et al. 2006) and impaired cognitive function in children (Jusko et al. 2008). Hauser et al. (2008) detected an impact threshold of 5 µg/dL on male maturation rates, and Lanphear et al. (2005) concluded that "…lead exposure in children who have maximal blood lead concentrations <7.5 µg/dL is associated with intellectual deficits." These latter values would appear attainable with the repeated consumption of venison possible among deer hunting families, especially those incurring additional exposure from other sources.

Factors that may influence dietary lead exposure from spent lead bullets include the frequency and amount of venison consumption, degree of bullet fragmentation, anatomical path of the bullet, the care with which meat surrounding the bullet wound is removed, and any acidic treatments of the meat that would dissolve lead, i.e., coating the hanging carcass with vinegar or the use of acidic marinades in cooking. Exposure to lead from spent bullets is easily preventable if health-minded hunters use lead-free copper bullets now widely available and generally regarded as fully comparable to lead-based bullets for use in hunting (Carter 2007). The potential for toxic exposure to copper from these bullets is presumably insignificant because little or no fragmentation occurs (Hunt et al. 2006), and there is no meat wastage from having to discard tissue suspected of contamination.

Fragmenting lead bullets have been in use for hunting since the early 1900s (Stroud and Hunt 2009). Although hunter numbers have diminished slightly in recent years, there were 10.7 million big game hunters in the United States in 2006, the majority of whom still use lead-based bullets (USFWS 2006, Watson and Avery 2009). Many state wildlife agencies annually issue multiple deer harvest permits to individuals, effectively offering venison as a year-round protein staple for some families; game meat is the principal source of protein for a considerable proportion of Alaska's population (Titus et al. 2009). Hunter-donated venison to food pantries and shelters for low income families in most states produced an estimated minimum of 9 million venison meals associated with the 2007/08 hunting season (Avery and Watson 2009). With these concerns, we anticipate that health sciences will further examine the bioavailability of lead from bullets and shot, the epidemiology of exposure, and the possible consequences among hunters, their families, and others who consume venison.

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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

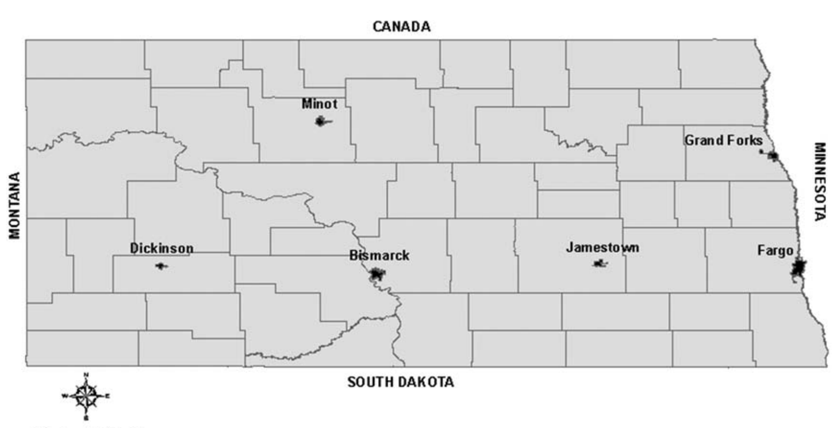

Fig. 1. Participant recruitment in North Dakota.

(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 (≥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 ≥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 ≥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 (≥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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Lead shot from hunting as a source of lead in human blood

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Birds hunted with lead shot and consumed are a source of lead in human blood.

Abstract

This study investigates the relationship between the intake of birds hunted with lead shot and the lead concentration in human blood. Fifty adult men from Nuuk, Greenland took part in the study. From September 2003 to June 2004 they regularly gave blood samples and recorded how many birds they ate. We found a clear relationship between the number of bird meals and blood lead and also a clear seasonal variation. The concentration was highest in mid-winter when bird consumption is at its highest. Blood lead was low (15 μg/L, mean concentration) among the participants reporting not eating birds. Among those reporting to eat birds regularly, blood lead was significantly higher, up to 128 μg/L (mean concentration). Concentrations depended on the frequency of bird meals: the more the bird meals, the higher the resulting blood lead. This clear relationship points to lead shot as the dominating lead source to people in Greenland.

Keywords: Lead shot; Blood lead; Bird hunt; Bird meals; Human exposure

1. Introduction

The risk of health effects of lead traditionally is assessed by analyzing the concentration of lead in the blood. This concentration will reflect recent exposure, as the biological half-life for lead in blood is about 35 days (Gordon et al., 2002). Lead poisoning occurs at high lead concentrations in the blood. Gordon et al. (2002) describe symptoms like lethargy, anemia, headache and abdominal cramps at concentrations about 850 μg/L, but chronic effects have been seen at significantly lower blood concentrations, down to 100 μg/L and lower (ATSDR, 1999). These include effects on the hematological system, hypertension and renal function (ATSDR, 1999).

The most critical risk appears to be effects on the central nervous system of fetuses and children. Intelligence, reaction time, visual–motor integration, fine motor skills and attention in children were affected by blood lead concentrations between 50 and 100 μg/L, but also as low as 30 μg/L (Lanphear et al., 2000; Canfield et al., 2003; Chiodo et al., 2004). U.S. Centers for Disease Control (USCDC, 1991) has defined 100 μg/L as a level of medical concern, but mentions that there may not be a "safe" lower limit.

For centuries, humans have been exposed to man-made sources of lead in the environment, among these, mining and refining of lead, tubes and house hold articles, batteries, gasoline, paint and ammunition. Today several of these sources, for example, leaded gasoline, are not important because their use has been regulated. As a result human lead exposure has decreased. For example, during the past two decades, the proportion of US children who have blood lead concentrations of 100 μg/L or higher declined by over 80% after the elimination of leaded gasoline, lead solder from canned foods and leaded paint used in housing and other consumer products (Lanphear et al., 2003). However, certain socio-economic groups still have a disproportionate number of people with elevated tissue-lead levels, such as minority groups in North America (Pirkle et al., 1998) and substance hunting groups in Canada (Tsuji et al., 2001).

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In Greenland the sources mentioned have also been important. In the late 1970s, the blood lead levels in Greenland were as high as in large West European cities (Hansen, 1981; Hansen et al., 1983). Also in Greenland blood lead levels are declining, but were at the most recent study generally higher than in other Arctic regions and Scandinavia (AMAP, 2003; Bjerregaard and Hansen, 2000). Bjerregaard et al. (2004) consider it most likely that a phasing out of leaded gasoline in the late 1990s causes this decline and that this was a significant source earlier, both from combustion and from handling of gasoline.

Another important lead source to humans in Greenland has been and still is the use of lead shot in bird-hunting. In a study conducted in 1993–1994, Bjerregaard et al. (2004) found a positive correlation between the number of bird meals and the lead concentration in blood from 228 randomly selected Greenlanders. In this study there was no correlation between blood lead and other local diet items (fish, seal or whale) or imported food. This is in accordance with the finding that the lead concentration in local Greenland diet is very low (Dietz et al., 1996). Consequently, human lead intake from the local diet is very low, estimated to be 15 μg per person per week (Johansen et al., 2000), while the intake of lead from birds hunted with lead shot is high. Johansen et al. (2004) estimated an average lead intake of 146 μg from one meal of thick-billed murre (*Uria lomvia*) and of 1220 μg from one meal of common eider (*Somateria mollissima*). This was even after having removed whole shot pellets and visible fractions of these from the bird meat before analyzing it. Based on these studies, Johansen et al. (2004) conclude that birds hunted with lead shot probably is the most important lead source to humans in Greenland. Studies in other Arctic regions (Canada and Russia) indicate that this is also the case here (Hanning et al., 2003; Odland et al., 1999b; Scheuhammer et al., 1998; Tsuji and Nieboer, 1997). In Canada analyses of teeth have been used to assess chronic lead exposure. Tsuji et al. (2001, 2003) saw elevated lead in deciduous teeth from remote communities in northern Ontario and associated this to lead intake from game hunted with lead shot.

In Greenland birds are primarily eaten seasonally. Therefore, the relationship between the average consumption of seabirds and the blood lead levels measured at one point in time in an earlier study (Bjerregaard et al., 2004) may not be a true description of the relationship. This was the background for initiating this study. Here bird consumers were followed before, during, and after the bird-hunting season in order to establish the association between consumption of birds and blood lead concentrations as well as peak concentrations. A seasonal variation of blood lead levels related to a hunting season is indicated in a study of Northern Quebec First Nation Cree inhabitants. Their blood lead levels increased during the two months following the goose hunt, when compared to initial levels (Kosatsky, 1998).

2. Materials and methods

The Primary Health Care Center in Nuuk selected 50 men to take part in the study together with KNAPK (The Fishermen and Hunters Association). The mean age of the participants was 55, varying from 35 to 78. All were ethnic Greenlanders and in good health status. Some were hunters supplying the local market with birds hunted near Nuuk. The criterion was to include persons who would eat many birds and persons who would eat few. The plan of the study was to follow the individual person's blood lead in the months before, during and after the bird-hunting season, which is mainly from November to April, by taking blood samples in September, November, January, March and May.

Ethical approval was obtained from the Commission for Scientific Research in Greenland. Informed consent was obtained verbally and in writing.

Each participant was handed a dietary questionnaire developed specifically for this study because there are no standardized questionnaires on traditional Greenlandic diet available. The questionnaire was of the food frequency type and included a list of the following diet items: murre, eider, kittiwake, ptarmigan, "other bird species", musk ox, caribou, hare, fish, seal, whale and "Danish food". The participant was asked to report daily which of these were parts of the diet from September 2003 through May 2004.

At the Primary Health Care Center in Nuuk, blood samples were taken by venous puncture in fossa cubitti in polyethylene test tubes with EDTA as an anticoagulant (terumo venoject) and frozen at −78 °C. They were transported frozen to the National Environmental Research Institute in Roskilde, where they were kept at −20 °C until analyzed for lead.

All samples were analyzed by Inductively Coupled Plasma-Mass Spectrometry, ICP-MS, Agilent 7500 ce. The lead isotopes 206, 207 and 208 were used to quantify the results against commercial standard solutions. About half of the samples were also analyzed by means of atomic absorption spectrometry, AAS, Perkin Elmer graphite furnace model Aanalyst 800 (Asmund and Cleemann, 2000). Good agreement was obtained between the two methods, but with a tendency of lower concentrations (mean 8.4%) for the ICP-MS compared to the AAS method (correlation coefficient 0.96). All samples were supplemented by blanks and one or two certified reference materials for every 13 samples. The certified materials were Tort-2, Dorm-2 and Dolt-3 from the National Research Council of Canada. The detection limit, defined as 3 times the standard deviation for blanks, of the AAS method was calculated to be 5 μg/L and that of the ICP-MS method to 9 μg/L. Results for both the AAS and the ICP-MS methods were used in the data analysis.

Prior to the statistical analyses, concentrations were logarithmic (base e) transformed to reduce skewness and better fit parametric requirements. In most cases the log-transformed concentrations did not differ significantly (Shapiro–Wilk test, $p > 0.05$) from normality. Data analyses included linear regression to assess the relationship between the mean number of bird meals and the mean blood lead concentration. The parametric Pearson correlation analysis was used to evaluate the relationship between bird intake and the resulting lead blood concentration. One-way analysis of variance followed by Tukey's Studentized Rank test was used to test differences in blood lead between different groups of exposure, defined from the mean number of bird meals per month of the group. Finally, a moving average smoother using a fixed window of 30% of the largest independent variable range was applied to graphically describe blood lead concentrations before, during and after the bird-hunting season.

3. Results

Only about half of the participants made daily recordings of their diet. The diet composition per month therefore in several cases was reconstructed by interviewing people when sampling their blood. After this we critically evaluated all dietary questionnaires and computed the frequency of the different diet items. As the objective of this study was to correlate blood lead with bird intake, we have only included diet data, which we consider to describe the monthly intake of birds. This means that some monthly diet data were excluded from the data analysis, including all data from three participants.

3.1. Diet composition

Birds were recorded to be part of the diet of 1300 meals from 1 October 2003 to 31 May 2004. These were composed of 61% murres and 29% eiders. Other bird species thus constitute an insignificant part and they have been left out from the data analysis. It is notable that murres are mainly eaten from November to March, while eiders are part of the diet later in the season (mainly January to June) as illustrated in Fig. 1.

3.2. Human lead exposure and blood lead levels

We have evaluated the relationship between the participant's bird intake and their blood lead concentration in different ways.

Firstly, we have made a regression analysis of the mean number of bird meals per month and the participant's mean blood lead concentration (logarithmic transformed) over the whole study period (Table 1). There is in all cases a positive relationship between these two variables, and only in the case of murre the relationship was not significant at the 5% level.

Secondly, we have made an analysis where we have correlated the blood lead concentration with "recent exposure" from murre and eider meals. We used this procedure to simulate that the blood lead concentration of a person at a given point of time is expected to reflect this person's lead intake before the blood sample is taken. If the blood sample was taken between the 1st and the 20th in a month, we have defined "recent exposure" as the number of bird meals in the preceding month. If the blood sample was taken after the 20th in a month, "recent exposure" is the number of bird meals in the same month.

In an earlier study we found significantly higher lead concentrations in eiders than in murre, in average a factor of 8.31 (Johansen et al., 2004). This means that the lead exposure depends on the species eaten. To take this into account when evaluating blood results, we have made a calculation of the lead exposure from what we call "a bird equivalent", which we define as the sum of murre meals per month and eider meals per month multiplied by 8.31.

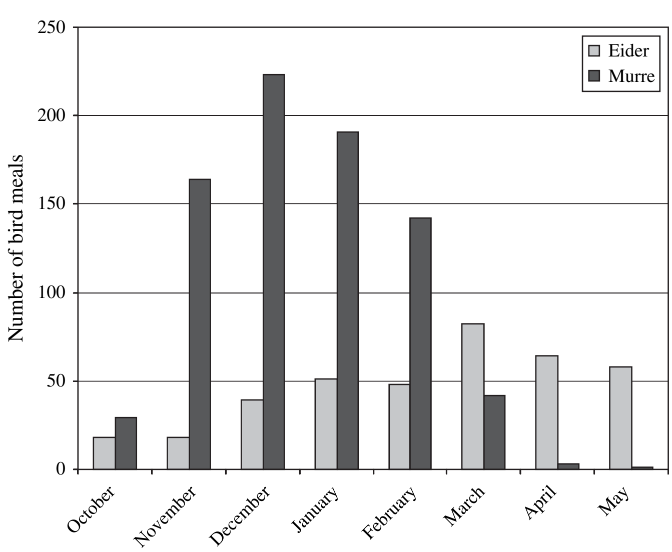

Fig. 1. Number of meals of murre and eider per month.

Table 1
Regression analysis of the mean blood lead concentration on the mean number of bird meals per month

	Mean no. of bird meals (min–max)	Slope of regression line	R^2	Sign. level
Murre + eider	0–9	0.098	0.14	0.011
Eider	0–4	0.208	0.15	0.007
Murre	0–7.5	0.101	0.07	0.075

Pearson's correlation analyses showed that in all cases there is a significant positive correlation between most recent bird meals and the resulting blood lead level, lowest for murre and highest for the calculated "bird equivalent" (Table 2). Table 2 (like Table 1) shows that eider meals are more important than murre meals as a lead source in the blood.

In the third analysis we have divided the participants into five so-called exposure groups from their average number of meals per month of murre and eider, computed as "bird equivalents" as defined above. The exposure groups were defined from the data. We selected a group eating no birds as one and a group eating many (>30 birds) as another. The three groups in-between we defined with increasing number of bird meals in each group (0.1–5, 5.1–15, 15.1–30) in order to obtain similar number of observations in each group. The five groups and their computed mean blood lead concentrations are shown in Table 3. It is seen that the mean blood lead concentration increases from group A (0 bird equivalents per month) to group E (>30 bird equivalents per month). An analysis of variance of log-transformed blood lead concentrations shows that there is a very significant difference between the exposure groups ($F = 6.79$, $p < 0.0001$). Tukey's test revealed that group A is significantly lower than all other groups, while group B does not differ from group C and groups C, D and E do not differ significantly (Table 3). To illustrate the seasonal variation we have computed the blood lead concentration of the five exposure groups in the study period. The result is shown in Fig. 2. Over season the pattern is the same with group A as the lowest increasing through groups B, C and D towards the highest concentrations in group E. The unexposed group (A) shows no clear seasonal pattern, while blood lead in the most exposed group (group E) continues to increase throughout the study period. This fits with the observation that eiders gives the highest exposure and at the same time mainly are eaten late in the bird-hunting season.

Table 2
Correlation between bird intake and the resulting blood lead concentration

	Pearson corr. coefficient	Sign. level
Murre	0.19	0.004
Murre + eider	0.30	<0.001
Eider	0.29	<0.001
Bird equivalent	0.32	<0.001

Table 3
Exposure groups and their blood lead concentrations (μg/L)

	Bird equivalents per month	N	Mean conc.	St.dev.	Min.	Max.
Group A	0	4	15	7	7	2
Group B[a]	0.1–5	73	62	48	25	211
Group C[a,b]	5.1–15	31	74	47	12	221
Group D[b]	15.1–30	42	82	45	20	190
Group E[b]	>30	5	128	36	87	154

Groups with same superscript letter did not differ significantly (Tukey's test).

In the three medium exposed groups (B, C and D) the tendency is an increase of the blood lead concentration from September to March followed by a decrease until June.

4. Discussion and conclusions

There is a clear relationship between the number of bird meals and the blood lead concentration of the participants in this study, which also shows that eiders are more important as a lead source than murres. These findings support our conclusion from an earlier study of lead in murre and eider meat, indicating that lead shot used to kill these birds are an important lead source to people in Greenland (Johansen et al., 2004). This was also indicated in a study in Greenland conducted in 1993–1994 (Bjerregaard et al., 2004).

4.1. Concentration levels

The blood lead concentration is low (mean 15 μg/L) in the group of participants reporting not to eat birds. This is comparable to the level (median 12 μg/L) found in young mothers from Northern Norway and among the lowest reported levels in adult populations (Odland et al., 1999a) and lower than in a study of Danes in the late 1990s (mean 35 μg/L, Nielsen et al., 1998). In contrast the blood lead concentration in bird eaters from Greenland are significantly higher (mean 62–128 μg/L, see Table 3). This clear difference points to lead shot as the dominating lead source to people in Greenland.

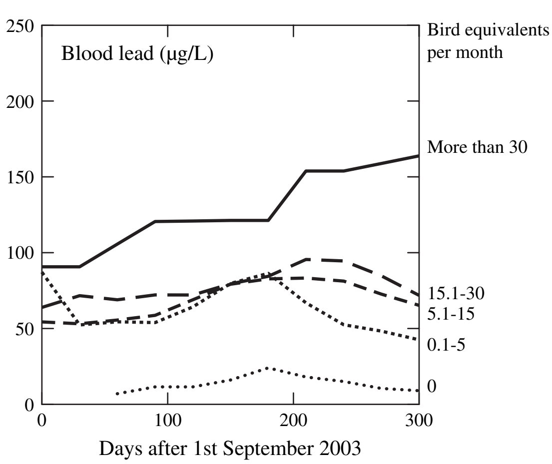

Fig. 2. Blood lead concentration (μg/L) depicted against date of blood sampling, expressed as the number of days after 1 September 2003 for each exposure group as defined in Table 3. Lines represent mean smoothing functions as described in Section 2.

There is, however, individual deviations from the general pattern found in this study. Some of the participants have relatively high blood lead concentrations in spite of reporting low bird intake. This indicates that one or more other lead sources affect them. One possibility is that they carry lead shot in the intestine. A way to test this would be to X-ray their abdomen, however, this is not done for that purpose on the hospitals. Another way could be to study the isotopic composition of the blood lead.

Other studies have shown that lead shot in the intestine leach lead to the blood and it has been claimed that this may cause lead poisoning (Madsen et al., 1988; Hillman, 1967). This is also mentioned in a case from Greenland, where the blood lead concentration decreased and the symptoms of lead poisoning disappeared in a patient, when his appendix with six lead shot pellets was removed (Johansen and Nygård, 1987). In Greenland it has not been systematically studied to what extent people carry lead shot in their intestine. In a study of a Canadian group of First Nation's people where traditional diet including hunted game is significant, Tsuji and Nieboer (1997) found that 15% carried lead shot in the intestine.

This phenomenon may also explain that the exposed groups in Greenland already have a relatively high blood lead concentration before the start of the bird-hunting season (see Fig. 1). Another possibility is that they have eaten kittiwake. This species is mainly hunted (killed with lead shot) in August and September. It was also recorded as a diet item in this study and may thus have been a source before the start of the main bird-hunting season.

Another explanation that some of the people reporting eating few birds have relatively high blood lead levels could be that the specific birds these people did consume were highly contaminated with lead. The variation of lead concentration in the birds is very large (Scheuhammer et al., 1998; Tsuji et al., 1999; Johansen et al., 2004). The amount of lead pellets or fragments embedded in the tissue is likely to be related to the experience of the hunter. For example, experienced hunters can shoot down birds in the head and not destroy the body with lead pellets. People consuming birds hunted that way would have a low lead exposure. In our data there are indications that this could be the case, as some people have relatively low blood lead levels in spite of reporting eating many birds.

4.2. Health effects

The highest single measured blood lead concentration in this study was 221 μg/L. This is 3–4 times lower than the level that could be expected to cause lead poisoning, but effects on the hematological system, hypertension and renal function is a possibility among the participants with the highest blood lead concentrations.

However, the most critical risk of lead in humans appears to be effects on the central nervous system of fetuses and children. Blood lead concentrations between 50 and 100 μg/L, but also as low as 30 μg/L may have an impact (Lanphear et al., 2000; Canfield et al., 2003; Chiodo et al., 2004). This is also potentially a risk in Greenland, as fetuses will be exposed to elevated blood lead concentrations when the mother consumes birds hunted with lead shot. In an earlier study of mothers and their newborns, the mean blood lead concentrations of different mother groups varied from 24 to 50 μg/L, with single values varying from 9 to 180 μg/L (Deutch, 2003). This study also showed that the fetus has almost the same blood lead concentration as the mother. It thus seems likely that blood lead levels found in Greenland might affect development of the central nervous system in fetuses among the mothers most exposed to lead.

It is also likely that there is a risk to children, as some of these will consume birds hunted with lead shot as part of their meals. However, there are no blood lead data from Greenland children, so possible health effects cannot be assessed. Therefore, a study on blood lead of children should be initiated.

Acknowledgments

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HEALTH EFFECTS OF LOW DOSE LEAD EXPOSURE IN ADULTS AND CHILDREN, AND PREVENTABLE RISK POSED BY THE CONSUMPTION OF GAME MEAT HARVESTED WITH LEAD AMMUNITION

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ABSTRACT.—Research findings have heightened public health concern regarding the hazards of low dose lead exposure to adults and children. In adults, studies have established the potential for hypertension, decrements in renal function, subtle decline in cognitive function, and adverse reproductive outcome at blood lead levels less than 25 micrograms per deciliter (µg/dL). The developing nervous system of the fetus and young child is particularly sensitive to the deleterious effects of lead, with adverse impacts on physical growth and neurocognitive development demonstrable at blood lead levels less than 10 µg/dL. No low dose threshold for these adverse developmental effects has been discerned. Epidemiological studies, and risk assessment modeling presented in this paper, indicate that regular consumption of game meat harvested with lead ammunition and contaminated with lead residues may cause relatively substantial increases in blood lead compared to background levels, particularly in children. Because lead-free ammunition is an available substitute, this risk is amenable to the public health strategy of primary prevention. *Received 2 December 2008, accepted 12 December 2008.*

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ALTHOUGH THE TOXICITY OF LEAD has been known for millennia, recognition and management of the adverse effects in adults and children have often posed a clinical and public health challenge. This arises from two main features. Even at moderate to high levels of exposure, many of the overt multisystemic effects of lead, such as headache, fatigue, myalgias, arthralgias, abdominal discomfort, constipation, anemia, peripheral neuropathy, and renal insufficiency, are nonspecific, and might be attributable to other relatively common acute and chronic diseases. At the lower levels of exposure that are prevalent today, the effects of lead may not only be nonspecific, but also subclinical or asymptomatic. Nevertheless, these effects, which may include hypertension, decrement in renal function, subtle decline in cognitive function, and adverse reproductive function in adults, and developmental delay in children, are of considerable public health concern.

This article presents a short overview of selected health impacts of lead exposure. In this context, the focus is on some of the adverse effects of the low to moderate levels of lead exposure that might possibly result from the ingestion of lead residues remaining in the flesh of game birds or mammals harvested with lead ammunition. A detailed discussion of the vast literature on the health effects of lead exposure is well beyond the scope of this article, but may be accessed in part from other recent sources (EPA 2006, ATSDR 2007).

Whole Blood Lead as a Common Metric of Lead Dose.—Studies of lead in humans have often, though not exclusively, related the clinical effects of lead to the level measured in whole blood. Whether obtained through venipuncture or a capillary pinprick, lead in blood remains the mainstay of human biomonitoring. As such, it is useful to begin with a brief discussion of the levels of lead in blood that have been encountered in the general population. Large population studies conducted in the United States in the late 1970s found that most of the general population had a blood lead concentration between 10 to 20 micrograms per deciliter (µg/dL). In the NHANES II study conducted by the US Centers for Disease Control and Prevention (CDC) between 1976 to 1980, the geometric mean blood lead level in children age 1 to 5 was 15.0 µg/dL (NCHS 1984). As shown in Figure 1, this level fell dramatically over the following decade, largely due to the phase out of leaded gasoline, as well as to declining encounters with lead in residential paint, canned food, and other sources (EPA 2006). In its Third National Report on Human Exposure to Environmental Chemicals, the CDC estimated that the geometric mean blood lead concentration of children aged 1 to 5 years was 1.70 µg/dL, while that of adults aged 20 years and older was 1.56 (CDC 2005a).

For several decades, the US CDC has issued guidance that identified levels of lead in the blood of young children that were of concern with respect to public health intervention. In 1970, that value was 40 µg/dL. It fell to 30 µg/dL in 1975, 25 µg/dL in 1985, and 10 µg/dL in 1991 (CDC 1991). In a statement on the topic in 2005, the CDC noted that adverse effects of lead on cognitive development, a key health endpoint of concern, extend to blood lead concentrations less than 10 µg/dL, and that there is no value that constitutes a threshold or no-effect level (CDC 2005b). With respect to lead exposure to adults in the workplace, the U.S. Occupational Safety and Health Administration (OSHA), established general industry standards for lead in the late 1970s. Under the OSHA general industry lead standard, which remains in effect to the current time, a worker requires removal from lead exposure if a single blood lead level exceeds 60 µg/dL, or if the average of the three most recent blood lead measurements exceeds 50 µg/dL (provided the last is greater than 40 µg/dL). Nevertheless, studies conducted in recent decades, some of which are discussed below, demonstrate that the OSHA lead standards offer inadequate protection against the adverse effects of lead at low dose to adults (Kosnett et al. 2007).

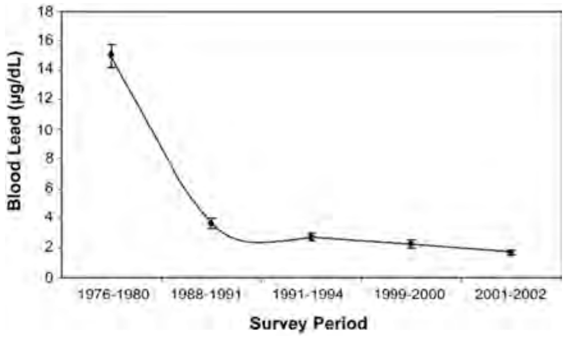

Figure 1. Blood lead concentration in U.S. Children. From: EPA, 2006 (Figure 4-3).

Health Effects of Lead at Low Dose in Adults: Hypertension, Decrements in Renal Function, Cognitive Dysfunction.—Based on numerous recent studies, there is growing concern that the chronic impact of cumulative low dose lead exposure in adults may contribute to hypertension, decrements in renal function, and cognitive dysfunction. Evidence for the causal impact of lead on hypertension has emerged from multiple lines of investigation. From a mode of action standpoint, studies have identified impacts of lead on vascular smooth muscle (possibly mediated by interaction with intracellular calcium), and multi-organ oxidative stress (possibly effecting mediators such as nitrous oxide that influence vascular tone) (Chai and Webb 1988, Vaziri and Khan 2007). Laboratory studies have demonstrated that feeding lead to animals induces elevations in blood pressure. For example, a small but well designed study was conducted in six young female dogs and their matched litter mates (Fine et al. 1988). The animals were dosed with lead acetate (1 mg/kg/day x 5 months) or placebo. Blood pressure was measured regularly by Doppler in the foreleg without anesthesia or trauma by a blinded investigator. At 15 weeks, blood lead level of the exposed animals was 35.8 µg/dL versus 9.2 µg/dL in controls. The blood pressure of the exposed animals was consistently elevated compared to the controls. When the study was completed at 20 weeks, their mean blood pressure was 120 ± 2.1 mm Hg, compared to 108 ± 1.5 in controls.

Numerous human epidemiological studies have observed a robust relationship between blood lead and blood pressure. Findings obtained from the NHANES II survey are illustrative. NHANES II was a representative cross-sectional survey of the noninstitutionalized United States population examined between 1976 and 1980. Of the 20,322 persons examined, a blood lead sample was obtained in 9,933. In adults males aged 18 to 74, the geometric mean blood lead was 15.8 µg/dL (NCHS 1984). Blood lead was significantly associated with systolic and diastolic blood pressure, after controlling for age, body mass index, and demographic and nutritional factors (Schwartz 1988). Meta-analyses based on studies conducted on subjects with environmental and occupational lead exposure have found that the relationship between blood lead concentration and blood pressure can be described by a log-linear model. As blood lead level doubles (e.g. from 5 to 10 µg/dL), there is a corresponding increase in systolic blood pressure of either 1.0 mm Hg (Nawrot et al. 2002, see Figure 2), or 1.25 mmHg (Schwartz 1995). It should be realized that in studies such as these, the mean blood pressure increase (which from a clinical standpoint appears small) reflects observations in some individuals who may exhibit no pressor response, as well as those for whom the impact may be much higher. A mean blood pressure increase across the general population of only a few mmHg is of public health concern, since elevated blood pressure is a significant risk factor for cardiovascular, cerebrovascular and renovascular disease (Pirkle et al. 1985, EPA 2006). A recent 12-year follow-up study of subjects greater than 40 years of age enrolled in NHANES III (n = 9,757) observed that the subgroup with blood lead concentration ≥10 µg/dL (median 11.8) had a relative risk of cardiovascular mortality of 1.55 (95% C.I. 1.16–2.07) compared with subjects with blood lead <5 µg/dL (Schober et al. 2006).

Our understanding that the impact of lead on blood pressure is predominantly influenced by long-term, cumulative exposure has been derived in part from investigations that utilized noninvasive x-ray fluorescence measurement of lead in bone as a biomarker of exposure. Greater than 90 percent of the body lead burden is found in bone, where it resides with a half-life of years to decades. In a nested case-control study conducted in a subcohort of the Normative Aging Study, 146 hypertensive men were compared to 444 normotensive controls (Hu et al. 1996). The mean age of the study subjects was 66.6 ±7.2 years, and their mean blood lead concentration, 6.3 µg/dL, reflected background environmental lead exposure. Logistic regression analysis revealed three significant risk factors for hypertension: body mass index, family history of hypertension, and tibia bone lead concentration. From the lowest to the highest quintile of bone lead, the odds of being hypertensive increased by 50 % (O.R. = 1.5, 95% C.I. 1.1-1.8). The results of this and other studies conducted in middle aged to older adults suggest that long-term blood lead concentrations in the range of 10 to 25 µg/dL pose a significant risk of hypertension and cardiovascular disease (Navas–Acien et al. 2007).

Several studies conducted in general population samples have reported an association between blood lead concentration and biomarkers of renal function. For example, Staessen et al. (1992) examined the relationship between blood lead and creatinine clearance in 965 men and 1,016 women (age 20 to 88) recruited from a region with environmental cadmium exposure. The geometric mean blood lead concentration was approximately 10 µg/dL (range 1.7 - 72.5 µg/dL). There was a significant inverse correlation between age-adjusted creatinine clearance and blood lead, which persisted after excluding subjects with occupational lead exposure, or those with the highest tercile of blood lead (geometric mean 18.4 µg/dL). Some recent studies have suggested that the relationship between low level lead exposure and renal dysfunction may be accentuated in subjects with other risk factors for renal disease, such as hypertension or diabetes (Muntner et al. 2003, Tsaih et al. 2004).

Recent studies conducted in older adults have found cumulative lead exposure, as reflected by the concentration of lead in bone, to be a risk factor for poorer performance on some tests of cognitive function. The Baltimore Memory Study (Shih et al. 2006) examined 991 randomly selected, sociodemographically diverse community-dwelling adults aged 50 to 70 years. Blood lead (mean = 3.5 ±2.2

µg/dL) was not a predictor of neuropsychological performance. However, increasing tibia bone lead concentration was associated with deficits in visuoconstructive skill, such that an increase of 13 ppm bone lead yielded an impact equivalent to 4.8 years of aging. In a subcohort of the Normative Aging Study, 1089 older, mainly white men, (mean age 68.7 ±7.4 years) under repeat neuropsychological testing over an approximately 3.5 year interval (Weisskopf et al. 2007). Tibia bone lead concentration, but not blood lead concentration, was significantly associated with decreased visuospatial performance over time.

Adverse Reproductive Outcome in Women.—Concern over the adverse reproductive effects of low level lead exposure to women has emerged from studies of multiple endpoints. In a well-designed nested case control study conducted in Mexico City, 562 women seeking prenatal care were prospectively followed for the first 20 weeks of pregnancy (Borja-Aburto et al. 1999). The average blood lead at enrollment was 11 µg/dL. Using the quartile of women with blood lead <5 µg/dL as the referent group, the odds ratio for spontaneous abortion for the quartiles with blood lead of 5 - 9 µg/dL, 10 - 14 µg/dL, and ≥15 µg/dL were 2.3, 5.4, and 12.2 respectively (test for trend, P = 0.021). Overall, an increase in maternal blood lead of 5 µg/dL was associated with an odds ratio for spontaneous abortion of 1.8 (95% C.I. 1.1, 3.1). Other studies have associated maternal lead exposure with adverse effects on physical growth and neurocognitive development during infancy and childhood. Two long-term prospective studies examined the impact of low-level prenatal lead exposure on neurobehavioral development during childhood. In the Yugoslavia Prospective Lead Study, childhood IQ assessed at 3 to 7 years of age declined 1.8 points (95% C.I. 1.0, 2.6) for every doubling of prenatal blood lead, which was defined as the average of maternal blood lead at midpregnancy and delivery (mean, 10.2 ±14.4 µg/dL, n = 390) (Wasserman et al. 2000). Similarly, the Mexico City Prospective Lead Study found that IQ declined 2.7 points (95 C.I. 0.9, 4.4) for every doubling of third trimester maternal blood lead (geometric mean 7.8 µg/dL, n = 150) (Schnaas et al. 2006). In both studies, the relationship between prenatal blood lead and postnatal childhood IQ was characterized by a log-linear model, such that IQ decline was steepest at maternal blood lead levels less than 10 µg/dL.

Adverse Effects on Neurocognitive and Neurobehavioral Development in Children.—Much of the public health concern over low-level lead exposure in recent years has focused on adverse impacts to children. Children have heightened susceptibility to environmental lead exposure for several reasons. The developing nervous system of the fetus and young child is the human organ system most sensitive to the deleterious effects of lead. Compared to that of adults, the juvenile gastrointestinal tract absorbs a higher percentage of lead that is ingested. Normal mouthing behavior of young children results in greater intake of lead in environmental media such as soil or dust. Finally, in proportion to body size, children breathe more air, drink more liquid, and consume more food than adults.

The adverse effect of lead on children's intellectual function is well established by decades of extensive study. A recent analysis examined this association by pooling data on blood lead and intelligence quotient (IQ) on 1,333 children enrolled in seven prospective cohort studies from birth or infancy to age 5 to 10 years (Lanphear et al. 2005). The primary analysis examined full scale IQ as a function of concurrent blood lead level at 4 to 7 years of age, adjusting for HOME score (a measure of the child-rearing environment), birth weight, maternal IQ, and maternal education. The median concurrent blood lead level was 9.7 µg/dL (range 2.5 to 33.2). The relationship between blood lead and IQ was described by a log linear multiple regression model. This indicated a loss of 6.2 IQ points as blood lead increased from <1 to 10 µg/dL, and a loss of 3.0 IQ points as blood lead increased from 10 µg/dL to 30 µg/dL.

The impact of these decrements in IQ, which may be difficult to clinically discern in any one individual, is best appreciated in a broader societal context. Lead-related decrements in IQ are relatively uniform across a range of intelligence, and thus an overall downward shift in IQ in the general population not only increases the number of children with low test scores, but also decreases the number scoring in the gifted range. As illustrated in Figure 2, a five point IQ shift in the bell-shaped distribution of

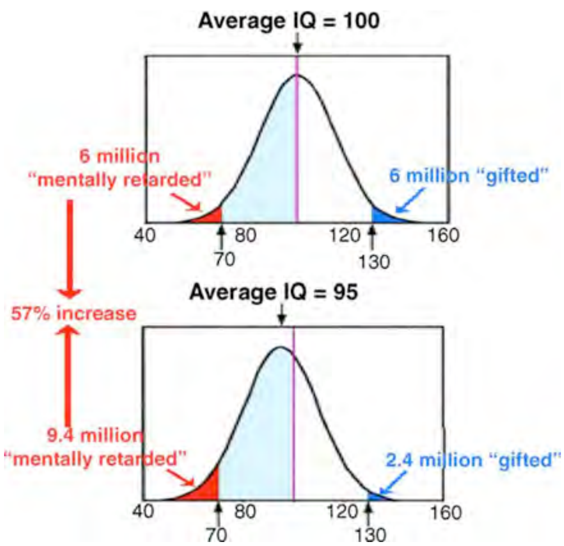

Figure 2. Changes in the number of children with IQ <70 and >130 per 100 million population based on a drop in the mean IQ of five points. Reprinted with permission, from Gilbert and Weiss, 2006.

IQ has its greatest impact at the tails of the distribution, increasing by approximately 57% the number of children with extremely low IQ scores (IQ <70), and decreasing by approximately 60% those with an IQ in the very superior range (IQ >130) (Gilbert and Weiss 2006). Given the capacity of individuals at the extremes of intelligence to have a disproportionate influence on societal function and resources, the overall cost of elevated lead exposure to society has been judged to be considerable.

The neurobehavioral effects of lead on child development, while less intensively studied than effects on cognition, may also have a significant societal impact. For example, some evidence suggests that blood lead levels in the mid-teens or higher may be associated with an increased risk of antisocial behavior and delinquency (Deitrich et al. 2001, EPA 2006).

Lead Ammunition and Primary and Secondary Prevention.—Public health action to reduce the risks associated with low level lead exposure may include elements of both primary and secondary prevention. With respect to adults, a recent recommendation has called for individuals to be removed from occupational lead exposure if a single blood lead concentration exceeds 30 µg/dL, or if two successive blood lead measurements over a 4 week interval are ≥20 µg/dL. It is further recommended that removal from lead exposure be considered to avoid long-term risk to health if exposure control measures over an extended period do not decrease blood lead concentrations to <10 µg/dL (Kosnett et al. 2007).

In its 2005 Statement on Preventing Lead Poisoning in Young Children, the US Centers for Disease Control and Prevention acknowledged that the effort to eliminate childhood lead poisoning would require a multitiered approach that included secondary prevention through case identification and management of elevated blood lead levels. However, because no threshold for the adverse effect of lead on neurodevelopment has been found, the CDC emphasized that "primary prevention must serve as the foundation of the effort" (CDC 2005b). It further noted that "efforts to eliminate lead exposures through primary prevention have the greatest potential for success….Ultimately, all nonessential uses of lead should be eliminated."

There is growing concern that the use of lead ammunition for the hunting of wild game, a nonessential use of lead, may increase the lead exposure of adults and children who consume the harvested meat. Case reports have described the occasional consumer of wild game who had markedly elevated blood lead concentrations and associated symptoms that were attributed to lead shotgun pellets retained in the appendix or ascending colon (Hillman 1967, Durlach et al. 1986, Gustavsson and Gerhardsson 2005). However, the more widespread public health issue is the risk of subclinical, low level lead exposure associated with the ingestion of lead-contaminated meat. Johansen and his colleagues (Johansen et al. 2004) measured the lead concentration in cooked whole breast tissue of seabirds from Greenland killed with lead shot. Visible lead pellets were identified by x-ray and removed by dissection prior to analysis. Breast tissue of the thick-billed murre (n =32) contained a mean lead concentration of 0.73 ±2.9 µg/g (wet weight), while that of the common eider (n = 25) contained 6.1 ±13 µg/g. By comparison, the lead content of breast meat in 25 common eiders that were accidentally drowned in fishing nets rather than being shot contained 0.14 ±0.13 µg/g. Another recent investigation measured the lead concentration in samples of raw muscle meat freshly harvested from red deer killed with lead bullets (Dobrowolska and Melosik 2008). Lead concentration in the muscle declined as a function of radial distance from the bullet pathway. However, at a radius of 15 cm (approximately 6 inches) from the bullet path, the muscle contained lead at a mean concentration of 8.5 µg/g wet weight (n = 10) above lead levels found in muscle far distant from the bullet pathway (mean = 0.16 µg/g). At a radius of 25 cm (approximately 10 inches) from the bullet pathway, the meat contained a mean lead concentration that was 1.16 µg/g above the values found in the far distant muscle.

A recent experimental study by Mateo and colleagues in Spain (Mateo et al. 2007) observed that cooking meat containing imbedded lead pellets of lead shot contributes to the transfer of lead contamination to other portions of the meat. In this investigation, 1, 2 or 4 pellets of pre-fired #6 lead shot were manually imbedded in the breast of non-shot farm raised quails obtained from a supermarket. The breasts (n = 3 per group) were subsequently cooked by boiling in a solution of water, sunflower oil, and spices. The lead pellets were then removed, and the breast meat was analyzed for lead. Compared to breast meat cooked without an imbedded pellet (mean lead concentration <0.01 µg/g wet weight, range <0.01 to 0.01), the breast cooked with 2 imbedded pellets contained 0.49 µg/g (range 0.10 to 1.19), and that with 4 pellets contained 1.64 µg/g (range 1.07 to 2.12). Substantially higher lead values were found when vinegar was added to the boiling water in a traditional pickling recipe.

A portion of game meat for an adult might weigh 141 g (approximately 5 ounces) (EPA 1997, Hogbin et al. 1999), and that for a 3 to 5 year old child might weigh 100 g (approximately 3.5 ounces). It can therefore be seen that a single serving of game meat containing 1 µg/g lead may result in ingestion of 141 µg lead in an adult and 100 µg lead in a child. These amounts are markedly elevated compared to the estimated daily dietary intake of 2 to 10 µg lead now considered prevalent in the American diet (EPA 2006).

Studies conducted in native peoples who regularly consume game birds harvested with lead ammunition have observed a relationship between blood lead concentration and bird meat consumption. In a study of adult male ethnic Greenlanders, mean blood lead was 1.5 µg/dL (n = 4) among control subjects consuming no bird meals, compared to 7.4 ±4.7 µg/dL (n = 31) among those consuming 5.1 to 15 bird meals per month, and 8.2 ±4.5 µg/dL among those consuming 15.1 to 30 bird meals per month (Johansen et al. 2006). In a study of native Cree adults residing in northern Ontario, Canada, the geometric mean blood lead concentration of adult males was approximately 6.3 µg/dL, compared to 2.1 µg/dL in a control group (n = 25) from the industrialized city of Hamilton, Ontario (Tsuji et al. 2008a). Isotopic lead ratio analysis of the blood lead samples, locally used lead ammunition, and lichen (an environmental biosensor) determined that ammunition was the main source of lead exposure in the native group (Tsuji et al. 2008b).

The extent to which human consumption of venison and breast meat from game birds such as mourning doves harvested with lead ammunition may contribute to lead exposure in the United States is a topic of increasing interest, sparked in part by the recent detection of lead fragments in ground venison submitted by hunters to food pantries in several Midwestern states (Bihrle 2008). The North Dakota Department of Health, in conjunction with the National Center for Environmental Health of the US CDC, recently conducted a survey of blood lead concentrations among a convenience sample of 740 individuals, 80.8% of whom reported a history of wild game consumption, predominantly venison (Iqbal et al. 2008). Almost all of the subjects were adults, with the exception of 7 subjects between the ages of 2 to 5 years (0.9%), and 12 subjects between the ages of 6 to 14 years (1.6%). The geometric mean blood lead concentration was 1.17 µg/dL (range 0.18 to 9.82 µg/dL), lower than the US population geometric mean of 1.56 µg/dL for adults 20 years of age and older (CDC 2005a). Eight participants (1.1%) had blood lead concentrations ≥ 5 µg/dL. In multivariate analysis that adjusted for age, sex, race, age of housing, and lead-related occupations and hobbies, individuals who reported consuming game meat had an increment in blood lead of 0.3 µg/dL (95% C.I. 0.157, 0.443). In like manner, individuals who had consumed game meat within the past month had a covariate-adjusted blood lead concentration that was 0.3 to 0.4 µg/dL higher than those who had last consumed it more than 6 months ago. Based upon the findings of this survey, the North Dakota Department of Health advised that pregnant women and children younger than 6 years of age should not eat venison harvested with lead bullets (NDDH 2008).

The magnitude of the health risk associated with consumption of game harvested with lead ammunition is likely to be influenced by multiple factors including, but not limited to the lead content of the ingested meat, the particle size and solubility of any ingested lead residues, the manner in which the meat is cooked or prepared, the frequency of consumption, and the age of the consumer. In a further effort to understand the potential impact, the LeadSpread model of the California Department of Toxic Substance Control (DTSC 2007) was used to estimate the median (50^{th} percentile) and 95^{th} percentile increment in blood lead concentration in adults and children consuming two or five portions of game meat per week containing *soluble* lead at a concentration of 1 µg/gram wet weight. This concentration was selected for modeling based on the findings of some analytical studies, summarized above, that suggest that a value of this magnitude might exist in servings of game meat harvested with lead ammunition, after intact pellets have been removed.

Table 1 presents estimates of the 50^{th} percentile and 95^{th} percentile blood lead concentrations of children and adults associated with consumption of either two or five game meals per week at two different levels of bioavailability. The relative bioavailability of lead residues present in cooked game meat harvested with lead ammunition has not been examined experimentally. However, a rough estimate of 0.2 was utilized after comparing the blood lead increment of rats fed a diet of 0.075% lead derived from small particles of metallic lead to that found in rats fed a diet of 0.02% lead derived from small particles of lead acetate (Barltrop and Meek, 1979). For purposes of discerning the upper bound of the influence of relative bioavailabilty of metallic lead, Table 1 also presents results obtained by setting relative bioavailability to 1.0.

The blood lead values in Table 1 represent the sum obtained by *adding* the estimated increment in blood lead attributed to the game meat consumption to the median (50^{th} percentile) blood lead concentration for children or adults found in a recent U.S. population National Health and Nutrition Evaluation Survey (NHANES) (CDC 2005a). Although the NHANES general population estimates might have included some individuals who consume game meats, their impact on the general population median value can, for purposes of this example, be considered minor. The increment in blood lead attributed to game meat consumption in Table 1 can be found by subtracting 1.5 from the child values, and 1.6 from the adult values. It is notable that the median (50^{th} percentile) increment calculated by the LeadSpread model for adults consuming two game meat meals per week containing 1 µg/g lead at a relative bioavailability of 0.2 is 0.3 µg/dL. This is the same increment in blood lead associated with game meat consumption in the North Dakota survey cited above (Iqbal 2008).

The main implication of the results yielded by the model is that regular consumption of game meat harvested with lead ammunition and contaminated with lead residues may cause relatively substantial increases in blood lead compared to background levels, particularly in children. Additional epidemiological investigations of potentially affected populations to further define the magnitude of the risk are warranted. Any such risk would be entirely avoidable by the use of the available alternatives to lead ammunition.

Table 1. Estimated blood lead distribution associated with regular consumption of game meat containing 1 ppm lead due to contamination from lead ammunition (background level plus game meat increment).[1]

Game meat meals per week[2]	Relative Bioavailability[3]	Estimated child blood lead level (µg/dL)[4]		Estimated adult blood lead level (µg/dL)[5]	
		50th percentile	95th percentile	50th percentile	95th Percentile
2	0.2	2.4	3.5	1.9	2.3
2	1.0	6.1	11.4	3.2	5.1
5	0.2	3.8	6.4	2.4	3.3
5	1.0	12.5	26.5	5.6	10.3

[1] Estimates derived from use of LeadSpread Version 7 (DTSC. 2007), assuming geometric standard distribution of 1.6; ingestion constant (µg/dL)/µg/day) of 0.16 for child (age 3 to 5 years); and ingestion constant for adult of 0.04.
[2] Child meal consists of 100 g of game meat with a lead concentration of 1 ppm. Adult meal consists of 141 g of game meat with a lead concentration of 1 ppm
[3] Relative to bioavailability of dietary lead acetate in rats (DTSC, 2007)
[4] Values shown represent blood lead increment attributed to game meat consumption *added* to 50th percentile blood lead reported in CDC Third National Report on Human Exposure to Environmental Chemicals, 2001 – 2002 (1.50 µg/dL for child 1-5 years of age) (CDC, 2005)
[5] Values shown represent blood lead increment attributed to game meat consumption *added* to 50th percentile blood lead reported in CDC Third National Report on Human Exposure to Environmental Chemicals, 2001 – 2002 (1.60 µg/dL for adults 20 years and older) (CDC, 2005)

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SHORT REPORT

Monitoring of umbilical cord blood lead levels and sources assessment among the Inuit

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Analyses completed on samples collected between 1993 and 1996 showed that about 7% of 475 Inuit newborns from northern Quebec (Canada) had a cord blood lead concentration equal to or greater than 0.48 µmol/l, an intervention level adopted by many governmental agencies. A comparison between the cord blood lead isotope ratios of Inuit and southern Quebec newborns showed that lead sources for these populations were different. Our investigation suggests that lead shots used for game hunting were an important source of lead exposure in the Inuit population. A cohort study conducted in three Inuit communities shows a significant decrease of cord blood lead concentrations after a public health intervention to reduce the use of lead shot. Lead shot ammunition can be a major and preventable source of human exposure to lead.

For many years, lead contamination of the environment has become a major public health preoccupation, notably concerning neurobehavioural effects during infancy and childhood.

Nunavik is a territory located in the northern part of the province of Quebec (Canada) that is inhabited by about 8000 Inuit. A previous study done in Nunavik showed that 24% of 198 women aged between 18 and 39 years had blood lead levels equal to or greater than 0.48 µmol/l (10 µg/dl),[1] the intervention level adopted by the Canadian authority for young children.[2] Therefore, lead was a contaminant included in a cord blood monitoring programme undertaken to assess the body burden of organochlorine compounds and heavy metals in newborns in this population. We present here the results of this programme for lead and those of a subsequent investigation aimed at determining the main sources of lead exposure.

METHODS

Mothers were recruited in the two health centres of Nunavik. Almost all women approached agreed to participate in the study. In all, 475 newborns from 14 communities in Nunavik (59% of all births from Nunavik during the time of the study) were recruited. Following informed consent from the mothers, blood lead levels were evaluated in the umbilical cord. Sampling was done between November 1993 and December 1996. Blood lead concentrations were determined by graphite furnace atomic absorption spectrometry using a Perkin-Elmer instrument, with a detection limit of 0.01 µmol/l.

Information on the mother's age, obstetric anamnesis, and tobacco consumption (yes or no) before and during pregnancy, and on the village of residence was obtained from medical files. After log transformation of the cord blood lead level data, regression analysis was performed to analyse these variables in relation to cord blood lead concentrations. Nutritional aspects, as well as haemoglobin, iron, and calcium balance were not assessed because of the exploratory nature of the monitoring and the logistical difficulties of collecting data in this area.

Blood lead isotope ratios can help identify the origin of human exposure. This was done for Nunavik newborns using a subset of 60 samples from those which had a sufficient quantity of blood. All samples (n = 29) with high cord blood lead concentrations (⩾0.48 µmol/l) from 11 communities were included. For each of these 29 samples, at least one randomly selected sample from the low lead level group (lower than 0.48 µmol/l) of the same community were also included. Blood lead isotope ratios were therefore determined. The mean cord blood lead concentrations (geometric) and the mean ^{206}Pb:^{207}Pb ratios (arithmetic) of the high and low exposure groups of newborns were compared with each other, and with 89 randomly selected samples (at least three samples for each most exposed Inuit) taken from a survey carried out in southern Quebec during the same period.[3] Comparisons were made using Student's *t* test. The statistical significance level was set at 0.05. The ^{206}Pb:^{207}Pb isotope ratios were evaluated by ICP-MS using a Perkin-Elmer SCIEX Elan 5000 A instrument.

RESULTS

Table 1 presents cord blood lead concentrations by community of residence. The geometric mean was 0.19 µmol/l (95% confidence interval (CI): 0.18 to 0.20). Thirty three newborns (6.9%) had cord blood lead concentrations ⩾0.48 µmol/l, with eight (1.6%) exceeding 0.72 µmol/l. No significant difference was found between the community of residence and cord blood lead levels according to the 95% CI.

Of the variables analysed through multivariate analysis, only maternal age ($p < 0.0001$; partial $r^2 = 0.14$) and tobacco smoking during pregnancy ($p < 0.001$; partial $r^2 = 0.05$) were associated with cord blood lead concentrations.

The geometric mean of cord blood lead levels and the average ^{206}Pb:^{207}Pb ratio for the 60 Inuit newborns were respectively 0.34 µmol/l (95% CI: 0.29 to 0.41) and 1.195 (range

Main message

- The ingestion of lead shot or lead fragments from game hunted with lead ammunition seems responsible for the high cord blood lead levels found in Nunavik.

Policy implications

- The use of lead ammunition should be banned for all hunting using shotguns, and the use of non-toxic alternatives should be actively promoted.

Table 1 Cord blood lead levels by community of residence in Nunavik

Community	n	Geometric mean (μmol/l)	Range (μmol/l)	95% CI
Kuujuarapik	16	0.28	0.08–1.02	0.20 to 0.38
Umiujaq	12	0.17	0.04–0.43	0.11 to 0.28
Inukjuak	47	0.17	0.01–0.64	0.14 to 0.21
Povungnituk	69	0.22	0.05–1.21	0.19 to 0.25
Akulivik	20	0.19	0.09–1.31	0.14 to 0.25
Ivujivik	16	0.23	0.11–0.69	0.17 to 0.30
Salluit	30	0.21	0.06–0.94	0.17 to 0.27
Kangiqsujuaq	23	0.15	0.05–0.33	0.13 to 0.18
Quaqtaq	21	0.19	0.05–0.72	0.14 to 0.25
Kangirsuq	27	0.20	0.07–0.64	0.16 to 0.25
Aupaluk	9	0.25	0.09–0.89	0.16 to 0.40
Tasiujaq	13	0.19	0.07–0.42	0.15 to 0.25
Kujjuaq	90	0.15	0.04–1.01	0.13 to 0.17
Kangiqsualujjuaq	38	0.25	0.07–0.77	0.21 to 0.30
Unknown	44	0.19	0.02–1.28	0.16 to 0.24
Total	475	0.19	0.01–1.31	0.18 to 0.20

1.166–1.230; 95% CI: 1.190 to 1.200). For the high and low exposed Inuit groups, lead levels were 0.62 μmol/l (95% CI: 0.57 to 0.67) and 0.20 μmol/l (95% CI: 0.17 to 0.23), respectively. The difference was significant ($p \leqslant 0.0001$). For these two samples, the average ^{206}Pb:^{207}Pb ratios were 1.199 (range 1.166–1.230; 95% CI: 1.192 to 1.205) and 1.192 (range 1.174–1.212; 95% CI: 1.187 to 1.196). The difference was non-significant ($p = 0.09$). In comparison, mean cord blood lead levels and ^{206}Pb:^{207}Pb ratio for the southern Quebec newborn population were respectively 0.11 μmol/l (95% CI: 0.10 to 0.11) and 1.166 (range 1.126–1.230; 95% CI: 1.163 to 1.168). The difference observed for cord blood lead concentrations as for the ^{206}Pb:^{207}Pb ratio with the average of all the Inuit samples were statistically significant ($p \leqslant 0.0001$).

DISCUSSION

About 7% of the 475 newborns had a cord blood lead concentration ≥0.48 μmol/l. In comparison, only 0.16% of a population of 1109 Caucasian newborns surveyed in the same period in the southern regions of the Quebec province had cord blood lead levels equal to or greater than that level.[3] In both studies, maternal age and tobacco smoking were positively associated with cord blood lead levels. However, these variables explained only a fraction (19%) of the variance in cord blood lead concentrations in Nunavik.

The blood lead isotope study showed that the average ^{206}Pb:^{207}Pb ratio was significantly lower in the population of newborns from southern Quebec than in a selected group of the Nunavik population. These results indicated that the two populations are probably exposed to different sources of lead. The mean ratio of 1.166 found in the southern population is probably a mixture of atmospheric lead coming from southern Ontario and the USA, and urban lead found in paint, dust, tyres, etc. In the Arctic, the mean ^{206}Pb:^{207}Pb ratio of atmospheric lead is approximately 1.16.[4] Hence, atmospheric sources cannot explain the mean ratio found in cord blood of Nunavik newborns.

Drinking water is a negligible source of lead exposure for most Canadians. When a lead in drinking water problem arises, it is usually related to water distribution systems constructed and/or soldered with lead. Water samples collected between 1990 and 1998 after flushing the faucets of Nunavik houses ($n = 65$), yielded a geometric mean concentration of 0.009 μmol/l (0.19 μg/l) (Quebec Department of Environment database). Based on this concentration, the daily exposure by water ingestion for Nunavik women can be estimated at 0.05 μg/kg body weight/day, much lower than the World Health Organisation (FAO/WHO) tolerable daily intake (3.5 μg/kg body weight/day).[5] Water consumption is therefore unlikely to explain the high cord blood lead levels found in Nunavik.

Soil and dust contamination are also unlikely to represent significant sources of lead exposure: there are no industrial activities in Nunavik such as smelters, refineries, or battery recycling plants, which are generally associated with high lead soil and dust concentrations. Moreover, almost all houses in Nunavik were built after 1972, when lead addition to paint was banned in Canada.

The main source of lead contamination in Nunavik is very likely related to dietary habits. The Inuit are heavy consumers of meat from wildlife species. However, available data indicate that lead concentrations are low in all wildlife species consumed in Nunavik.[6] A study using a nutritional diary conducted in Qikiqtarjuak, on Baffin Island to the north of Nunavik, concluded that women of this community had a weekly lead exposure from food ingestion of 4.4 μg/kg body weight/week,[7] far below the FAO/WHO provisional tolerable weekly intake of 25 μg/kg body weight/week.[5] Nevertheless, a study carried out among Inuit women as part of a Santé Québec investigation including a nutritional diary, revealed that only two variables were significantly related to blood lead concentrations for women of childbearing age. These variables are the age of the individuals (partial $r^2 = 0.13$) and the level of consumption of geese and ducks (partial $r^2 = 0.13$).[1]

Lead shots pellets are regularly seen in the digestive system of the Nunavik Inuit when abdominal *x* ray examinations are performed (personal communication, Dr Normand Tremblay, Nunavik Regional Board of Health and Social Services). Lead shot pellets were also detected in the digestive system of Cree Indians from northern Ontario, Canada.[8] Studies have shown that ingestion of lead shot or other small metallic lead objects, can result in increased blood lead concentrations.[9] Only one to two lead shot pellets trapped in the appendix can be sufficient to increase the blood lead concentration to more than 0.48 μmol/l.[9]

The average ^{206}Pb:^{207}Pb ratio for the Inuit newborns was 1.195 with a relatively wide range (1.166–1.230). Lead isotope data were also collected by the Canadian Wildlife Service for lead shot pellets from different brands of shotshell ammunition.[10] Their results showed that the range of ^{206}Pb:^{207}Pb ratios for pellets from four brands of shotgun cartridges used by Nunavik hunters (personal communication, Dr Daniel Leclerc, Makivic Society) were also very wide (range 1.125–1.233). However, eight of the 10 samples of analysed cartridges yielded relatively high ratios of ^{206}Pb:^{207}Pb, ranging from 1.164 to 1.233 (six over 1.201). This information, together with epidemiological data which showed an association between blood lead levels in Nunavik women and the consumption of ducks and geese, suggest that the ingestion of lead shots or lead bearing fragments from game meat may be in a large part responsible for the high lead levels found in Nunavik Inuit newborns.

In 1999, in order to protect fauna, the use of lead shot cartridges was banned in Canada for the hunting of migratory birds. During the winter of 1999, public health authorities of Nunavik actively informed Inuit hunters and ammunition retailers about the possible impact of lead shot ammunition on the newborn's blood lead levels. As part of a cohort study in progress in Nunavik newborns on neurobehavioural effects of heavy metals and organochlorine exposure, we were able to gather new information about the cord blood lead levels in three communities from the beginning of 1997 to the beginning of 2001. The geometric mean of 28 newborns born after the public health intervention (April 1999) (0.12 µmol/l; 95% CI: 0.09 to 0.16) was significantly lower ($p < 0.0001$) than the geometric mean of 214 children (including the 158 children recruited in the monitoring study before 1997) born before this period (0.20 µmol/l; 95% CI: 0.19 to 0.22). Even after controlling for maternal age, tobacco smoking, and community of residence, the decrease in cord blood lead levels remained significant ($p < 0.0001$). Although preliminary, these results indicate that efforts to reduce lead exposure from game hunting in Nunavik should continue.

The results of this study suggest that lead shots may be a major source of lead exposure for humans that consume hunted game animals. From a public health perspective, use of lead cartridges shotguns (to hunt migratory birds and other small game) should be replaced internationally with a non-toxic metal or alloy. This is particularly important for those populations where game birds constitute an important dietary component.

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OEM

Monitoring of umbilical cord blood lead levels and sources assessment among the Inuit

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NORTH DAKOTA
DEPARTMENT *of* HEALTH

BLOOD LEAD LEVEL STUDY RESULTS

FACT SHEET

In May 2008, 738 North Dakotans participated in a study conducted by the U.S. Centers for Disease Control and Prevention (CDC) and the North Dakota Department of Health designed to measure the risk of higher blood lead levels caused by consuming wild game harvested with lead bullets. On Nov. 5, 2008, the CDC released a preliminary analysis of the lead levels.

The study shows a link between eating wild game shot with lead bullets and higher blood lead levels.

Study Results

In the study, people who ate a lot of wild game tended to have higher lead levels than those who ate little or none. The study also showed that the more recent the consumption of wild game harvested with lead bullets, the higher the level of lead in the blood.

Wild game is not the only or most important risk factor for human lead exposure; however, the study findings suggest that it is one important risk factor.

The correlation is statistical and adjusts findings for other potential sources of lead exposure; consequently, some individuals who eat a great deal of wild game may have lower blood lead levels than some other individuals who eat little or no wild game but who have other sources of lead exposure.

The lead levels among study participants ranged from none detectable to 9.82 micrograms per deciliter. Wild game consumption among study participants ranged from zero to heavy consumption. Some study participants had no identifiable risk factors for lead exposure, while others had more than one potential risk factor for lead exposure.

No single study can claim to be the final answer; however, this represents the best information we have to date to guide policy recommendations. As more information becomes available, these recommendations may change.

Background

In late March 2008, the North Dakota departments of Health, Agriculture, and Game and Fish advised food pantries across the state not to distribute or use donated ground venison because of the discovery of contamination with lead fragments. The agencies also suggested that anyone who had concerns about how their venison was cleaned and processed should not serve it to children and may decide whether to eat it themselves. A few weeks later, Minnesota made a similar advisory after laboratory tests discovered lead in venison that had been donated to food pantries in Minnesota.

The steps that were taken in response to the discovery of lead are similar to precautions taken when any food product is found to be contaminated. According to the North Dakota Department of Agriculture, if these lead fragments had been found in beef, the meat would have been recalled.

Because no study had ever been done to determine if there is a link between consuming wild game shot with lead bullets and higher lead levels in the blood, the Department of Health asked the CDC to help with a study analyzing the blood lead levels of North Dakotans.

Health Concerns Related to Lead Exposure

Swallowing lead can cause serious health problems and, in extreme cases, even coma and death. Most of the time, however, the effects are subtle and can't be easily seen. Studies show that pregnant women and younger children are especially sensitive to the effects of exposure to lead because they absorb most of the lead they take in, and the brains of infants and young children are still developing.

For children 6 and younger, any exposure to lead is considered too much. In young children, lead can cause:

- Lower IQs.
- Learning disabilities.
- Stunted growth.
- Kidney damage.
- Attention deficit disorder (ADD) and attention deficit hyperactivity disorder (ADHD).

In pregnant women, high lead exposure can cause:

- Low birth-weight babies.
- Premature births.
- Miscarriage.
- Stillbirth.

Although lead is also toxic for adults, they are less sensitive to the effects of lead and absorb less of the lead they take in. Adults may experience a wide range of potential health effects, depending on the blood lead level, including:

- High blood pressure.
- Hearing loss.
- Infertility.

Anyone who is concerned about possible exposure to lead may want to talk to his or her doctor about testing for blood lead levels.

Minnesota Bullet Fragmentation Study

In October 2008, the Minnesota Department of Natural Resources released results of a study to determine how different types of bullets commonly used for deer hunting might fragment.

- The study indicated lead particles commonly are found farther from the wound channel than previously thought and that the number of lead fragments varies widely by bullet type.
- In addition, the study indicated that most lead particles in venison will be too small to see, feel or sense when chewing.

Recommendations

Based on the results of the CDC blood lead level study and the Minnesota bullet study, the North Dakota Department of Health has developed the following recommendations to minimize the risk of harm to people who are most vulnerable to the effects of lead:

- Pregnant women and children younger than 6 should not eat any venison harvested with lead bullets.
- Older children and other adults should take steps to minimize their potential exposure to lead, and use their judgment about consuming game that was taken using lead-based ammunition.

- The most certain way of avoiding lead bullet fragments in wild game is to hunt with non-lead bullets.
- Hunters and processors should follow the processing recommendations developed by the North Dakota Department of Agriculture.
- If food pantries choose to accept donated venison or other wild game, they should follow these recommendations:
    - Shot with lead bullets – Accept only whole cuts rather than ground meat. (Studies indicate that whole cuts appear to contain fewer lead bullet fragments than ground venison.)
    - Shot with bows – Accept whole cuts or ground meat.

These are recommendations only; they are intended to help the citizens of North Dakota to make informed choices. Not every state will necessarily issue the same recommendations.

Next Steps

- The Department of Health has added questions about eating venison to the screening process used when investigating cases of high blood lead levels.
- During the next year, the departments of Health, Agriculture, and Game and Fish plan to conduct further testing of venison to evaluate and refine the cleaning and processing guidelines.
- The Department of Agriculture has developed guidance for processors about how to properly clean and dress wild game to reduce the changes of lead in meat.

Additional Information

Information about lead can be found on the following websites:

- U.S. Environmental Protection Agency – www.epa.gov/lead/
- National Institutes of Health – www.niehs.nih.gov/health/topics/agents/lead/index.cfm
- U.S. Centers for Disease Control and Prevention – www.cdc.gov/lead/

The following websites have information about lead bullet fragments and wild game:

- North Dakota Department of Health – www.ndhealth.gov/lead/venison/
- Minnesota Department of Natural Resources – www.dnr.state.mn.us/hunting/lead/index.html

Questions about the health effects of lead can be directed to the North Dakota Department of Health at 701.328.2372.
Questions about venison processing can be directed to the North Dakota Department of Agriculture at 701.328.2231.
Questions about cleaning wild game can be directed to the North Dakota Game and Fish Department at 701.328.6300.

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UNIVERSITY OF MINNESOTA
Driven to Discover℠
ISSUE BRIEF Food Policy Research Center

March 2014

Hunting Ammunition and Implications for Public Health.

Author: Julia Ponder, School of Public Health, University of Minnesota (UMN).
Multidisciplinary Review Team and References available on the FPRC Website.

Summary of Findings:

- Multiple types of hunting ammunition are available with varying ballistics and public health implications
- Game meat harvested with lead ammunition may be contaminated with lead fragments
- Ingestion of lead fragments in game meat may present health risks, especially to women and children. There is no level of lead exposure in children known to be without adverse effects
- Public health risks can be mitigated by use of alternative hunting ammunitions

Background:

Hunting is a popular outdoor recreational activity throughout the United States, providing both benefits to human health (enjoyment of the outdoors, exercise, social interactions) and a source of food (lean protein). There are over 10 million deer hunters in the United States spending $33.7 billion annually which supports state and local economies as well as natural resource management. Hunter-harvested game is used as a source of meat for individual families, and also, through donations, is an important source of protein for food shelves. More than 2.5 million pounds of game meat is donated annually in the United States and Canada. Minnesota's Department of Natural Resources (DNR) coordinates a venison donation program, recognizing that it helps families in need as well as provides additional management for deer populations. Following the discovery that tiny lead fragments are frequently dispersed throughout the meat harvested with lead ammunition, the potential threat to public health spurred new requirements for venison donations. Currently all hunter harvested venison in Minnesota (MN) must be x-ray scanned prior to donation. The magnitude of the public health risk varies based on the type of ammunition used and its metal content.

Hunting ammunition

	Common Use	Exposure potential	Risk potential
Lead shot	Upland game birds, deer	Minimal fragmentation of pellets and dispersal	Lead: toxic* Easily detected
Steel shot	Waterfowl	Minimal fragmentation of pellets and dispersal	Steel: non-toxic Easily detected
Lead bullet	Deer hunting, large game	**Fragmentation of bullet and broad dispersal, up to 14" from bullet path[4]	Lead: toxic * Fragments not always detectable by consumer
Copper bullet	Deer hunting, large game	No fragmentation of bullet or dispersal	Mammals tightly regulate copper storage, thus only long-term high dose exposure poses a potential health threat.

* Lead toxicity - Interferes with development of nervous system; Toxic to heart, intestines, kidneys, and nervous system

** See images

The Food Policy Research Center, University of Minnesota, is supported by the National Institute on Food and Agriculture, USDA.

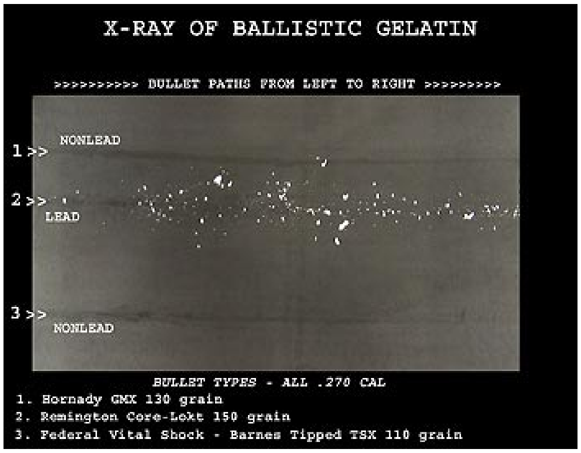
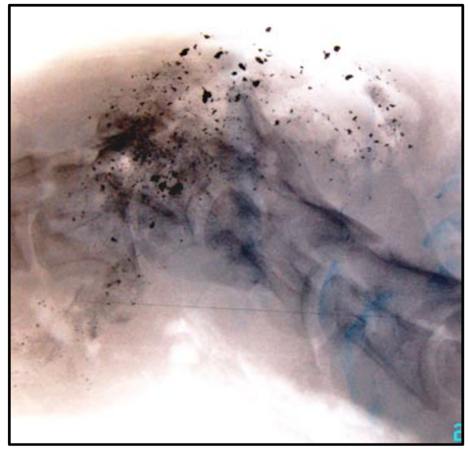


Image showing fragmentation of lead and non-lead ammunition passing through ballistic



Radiographic demonstration of lead bullet fragmentation in sheep carcass

Public Health Considerations:

Lead hunting bullets fragment upon impact. Wildlife officials investigating lead toxicity in non-target species (eagles, condors) discovered that lead fragments disperse widely in the carcass and gut pile of deer shot by hunters, causing adverse health effects for animals that scavenge these carcasses. These same health risks apply to humans because fragments may be ingested when the meat is processed for food. While lead shot is usually detected while eating and discarded, the lead ‘dust’ dispersed in meat by fragmentation of lead rifle bullets cannot be easily detected. Fragmentation leads to increased bioavailability of the lead and associated public health risk. Studies have shown:

- Elevated blood lead levels in hunters who regularly consume game meat shot with lead ammunition.
- Elevated blood lead levels in pigs after ingestions of venison shot with lead ammunition.
- Fragments of lead bullet in 26–60% of ground venison packages from commercial processors.

At risk populations include 10 million deer hunters and their families in the United States, as well as low income recipients of donated venison. In 2008, food banks had to remove venison contaminated with lead from their shelves. The Centers for Disease Control and Prevention (CDC) states there is no level of lead exposure in children known to be without adverse effects. Based on these recognized health risks, **MN, Wisconsin and North Dakota wildlife agencies and state health departments have recommended that pregnant women and children do not eat any game harvested with lead ammunition.** Additional human health studies are needed to determine the extent of ill health effects that lead ammunition is having.

Alternatives to lead rifle bullets are available; costs of ammunition types vary with copper rifle ammunition comparable to premium grade lead ammunition. Copper rifle ammunition has been demonstrated to be effective with excellent ballistics and quick kill, two issues important to hunters. Another important issue is availability in terms of calibers and bullet weights, which is improving, but small retailers need to carry non-lead ammunition in addition to the larger ‘big box’ stores.

Policy options

Non-lead ammunition is recommended to help ensure both a healthy environment for wildlife and safe food for humans, especially when deer-hunting with rifles. Multiple professional and scientific organizations have passed resolutions recommending the phasing out of lead ammunition. Policy options adopted by other states include:

- Voluntary grassroots efforts through hunter education and ammunition exchange programs.
- Regulation of lead in ammunition – in 2013, California became the first state to ban lead ammunition for hunting throughout the state.

Pediatric Lead Screening in the United States: A Comparative Analysis

Genevieve Sykes

Project

University of Alaska Anchorage

Committee Chair:

Angelia Trujillo, DNP

Committee Member:

Bethany Buchanan, DNP

Abstract

The purpose of this project is identification of approaches to pediatric lead screening in the United States by each of the fifty states and evaluation of whether best practice is being utilized. Data was obtained from publicly available state based websites and interaction with state departments; there were no participants in this project. The data was compared and contrasted among each of the fifty states and against current screening recommendations from the Centers for Disease Control and Prevention [CDC]. Only one state, Delaware, has screening recommendations current with CDC standards. There is a large amount of variation between how state approaches pediatric lead screening. Several recommendations were proposed for the improvement of pediatric lead screening in the United States, including the following; all test results be reported in every state, states should assess need for screening universally versus screening Medicaid-eligible children only, states update their geographic risk areas yearly, screening recommendations be made available in a single area, and all questionnaire include questions about symptoms, lead sources, hand washing, and children with risk.

Introduction

Lead is a common metal found in the environment. In the United States an estimated 450,000 children aged one to five had a significant exposure to lead (Centers for Disease Control [CDC], 2012). Lead exposures, even to the extent of poisoning, have no hallmark presentation, which makes this diagnosis unclear; complaints are often vague, making identification challenging (Warniment, Tsang, & Glazka, 2010). There is no exposure level of lead that is without negative effects on children and all side effects from lead exposure are irreversible (Advisory Committee on Childhood Lead Poisoning Prevention, 2012).

Between 1960 and 1991, the Centers for Disease Control and Prevention (CDC) incrementally lowered the blood lead level of concern from 60µg/dL to 15µg/dL (2005). In 2005, the CDC set the new level of concern at 10 µg/dL. Although it was stated that adverse effects were being shown at levels lower than 10µg/dL, there was concern that categorizing these children as exposure cases would limit resources needed by children with higher levels (CDC, 2005). In their most recent report (2013), the CDC recommended no longer using the term "level of concern" and instead set the upper limit of normal to the 97.5^{th} percentile, which is 5µg/dL for children aged one to five.

Lead based paint, dust contaminated with lead, water which runs through lead pipes, traditional folk medicines, jewelry, toys, and exposures to caregivers who work with lead are some of the most common ways children come into contact with lead (CDC, 2013). The most common route of lead exposure to children is ingestion (CDC, 2013; World Health Organization [WHO], 2010). Younger children are more frequently affected this way because of their instinct to put foreign objects, such as soil or lead-based paint, into their mouths (Howarth, 2012; United States Environmental Protection Agency [EPA], 2013; WHO, 2010). Eating wild game, including fish, has also been significantly associated with an increase in blood lead levels (Iqbal, 2008; Watson & Avery, 2009). Children also absorb a greater percentage of the lead they ingest than their adult counterparts, causing higher exposures from the same amount of lead, though it is unclear why (Carlisle, Dowling, Siegel, & Alexeeff, 2009; Dikshith, 2013; EPA, 2013; Howarth, 2012; WHO, 2010). Other routes of exposure for children include inhalation and direct contact with skin to items containing lead (Dikshith, 2013; WHO, 2010).

Literature Review

Pediatric population screening practices

In 1991, the CDC suggested that all children aged 12-72 months be screened for lead exposure (CDC, 1997). In 1997, the CDC's data demonstrated that certain subpopulations of children, including minorities and the poor were at higher risk for lead exposures than other children. The CDC therefore recommended that children who receive public assistance, such as the Special Supplemental Nutrition Program for Women, Infants, and Children [WIC] or Medicaid, continue to receive universal lead screening, while other children be screened only if they met certain criteria (CDC, 1997). In 2000, the CDC's data indicated that 83% of children with blood lead levels $\geq$20 µg/dL were Medicaid-eligible, differentiating the designation between pediatric subpopulations as Medicaid-eligible and non-Medicaid-eligible.

In 2009, data from the CDC no longer demonstrated a disparity in risk for lead exposures between Medicaid-eligible and non-Medicaid-eligible children. The CDC suggested that states with lead screening plans in place should decide individually whether to continue to require universal screening of Medicaid-eligible children or to screen them the same way they do non-Medicaid-eligible children (CDC, 2009). They suggested that states without lead screening plans in place continue to universally screen Medicaid-eligible children while continuing to acquire data assessing risk in their individual communities (CDC, 2009).

Effects of lead exposure

Gump et al. found that lead levels below 10μg/dL in children aged nine to eleven caused an inappropriate stress response resulting in negative cardiac outcomes, including reduced cardiac output, reduced stroke volume, and increased peripheral resistance (2011). Environmental exposures to lead at "low levels" caused arterial hypertension that manifests years after the exposure, making proof of causation from childhood exposures difficult; "little is known" about childhood exposures and future development of arterial hypertension (Vaziri, 2008, p. 455).

Lead exposures at levels below 10 have also been found to affect the renal endocrine systems as well. Fadrowski et al. found that children with lead levels below 10μg/dL had lower glomerular filtration rates (GFRs) and decreased kidney function following exposure (2010). Additionally, the damage occurs at a significantly lower level in children than it does in adults, though the effects are the same (Fels et al., 1998). Naicker et al. established that lead exposures, 99% of which were below 10μg/dL, led to delayed puberty in girls; these delays predisposed them to obesity, short stature, and psychological issues (2010).

Lead poisoning in children has been linked to brain damage, developmental delays, behavioral problems, violence, and death (Sanders et al., 2009). Jusko et al. (2007) established a negative correlation between intelligence and lead exposure and estimated that the difference in IQ from a lead exposure level between 5μg/dL to 9.9 μg/dL was 4.9 points. A five point shift downward on all children's IQ scores is estimated to cause a 57% increase in the amount of children designated with mild mental retardation and a 40% reduction in the number of children who are considered “gifted” (Jusko et al., 2007). Gould (2009) estimated that loss of IQ from lead exposures and resultant need for special education, health care costs, and a loss of productivity will potentially cost the United States $192-$270 billion dollars.

Lead exposures below 10 µg/dL have also been associated with a reduction in reading and writing scores in children aged seven to eight (Chandramouli, Steer, Ellis, & Emond, 2009). Nigg et al. found lead exposure, as little as 0.73 µg/dL to 2.2 µg/dL in children aged six to seventeen, was associated with Attention Deficit Hyperactivity Disorder-combined type (2010). According to the Advisory Committee on Childhood Lead Poisoning Prevention (2012), there is no lead exposure level that does not cause cognitive defects in humans.

Risk assessment questionnaires

The CDC has been recommending the use of risk assessment questionnaires to screen children for lead exposures since 1997. The CDC (2009) proposed that each state become more aware of its’ specific lead risks and produce guidelines that address these risks while incorporating the following criteria in all state risk assessment questionnaires:

- Children suspected by parent or provider to be at risk
- Child with a sibling or playmate who had an established exposure
- Child with recent immigration as an adoptee, immigrant, or refugee
- Child whose parent or caregiver works with lead
- Household use of traditional remedies, ethnic remedies, folk remedies, or imported cosmetics
- Children who routinely eat imported food carried from out of country
- Children who have been deemed at risk by the health department due to local risk factors including living in a high-risk area

In addition to the CDC, other advisory groups have given opinions on lead screening. The American Academy of Pediatrics Committee on Environmental Health supports pediatricians using local or state guidelines for screening children for lead exposures (2005). The US Preventative Task Force (USPSTF) also advises that providers follow local or state screening policies (Rischitelli, Nygren, Bougatsos, Freeman, & Helfand, 2006). Regarding the use of lead risk assessment questionnaires, the USPSTF's latest standpoint states that they "may" lead to more appropriate screening (Rischitelli et al., 2006).

Purpose

At this time no state-by-state comparison of approaches to pediatric lead screening exists, nor does a comparison of whether each state's recommendations meet current CDC recommendations. The purpose of this project is to provide insight into current pediatric lead screening practices in all 50 United States. This is performed with the impetus of increasing awareness to health care providers and policy makers about how pediatric lead screening is currently being approached. Ideally, awareness of discrepancies between current guidelines and current practice will create opportunities for practice change that may better serve the pediatric population.

Nursing Significance

Due to the irreversible damage suffered by lead exposures and the often asymptomatic presentation in affected children, it is important for health care providers in every state to have screening protocols in place. Appropriate screening will accurately identify those who will benefit from lead screening and those who will not in an effort to provide timely interventions, limit negative outcomes, and best allocate resources to limit cost. The intent of this analysis is to provide health care providers, policy makers, and legislators with an overview of state-based pediatric lead screening practices and identify whether these approaches are meeting current CDC recommendations.

Methods

Data Collection

The project was approached through method of comparative analysis. A comparative analysis is a systematic approach that compares two or more systems, in this case pediatric lead screening approaches per state and CDC guidelines, in order to identify emerging trends and disparities. These findings were documented and placed into context.

All data were acquired from state-sponsored websites. Only data concerning children, defined by the age range of newborn to eighteen years old, were included. Data were obtained from all 50 states pertaining to the following:

- The threshold µg/dL level required for reporting
- The sub-populations of children required to be screened
- The availability of a lead risk assessment questionnaire
- The additional questions included in lead risk assessment

Data were organized by development of tables. The first table included screening information and the second recorded the individual risk assessment questions. Data were collected from August to October in 2014 and therefore any changes to screening approaches produced after this time were not included.

Data Analysis

After initial data collection, individual state information was compared and contrasted. Common themes and unique approaches were identified. The data were then compared to current recommendations put forth by the CDC, as described above.

Framework

The theory underlying this comparative analysis is the Social Ecological Model (SEM) as seen in Figure 1 (Coreil, 2010; McLeroy, Bibeau, Steckler, & Glanz, 1988). The SEM was adapted from a conceptual model originally created by Urie Bronfenbrenner (Bronfenbrenner, 1979). This model emphasizes multi-level approach to health promotion; in order to create positive changes in the individual there must also be changes in the surrounding environment, which include the individuals, relationships, communities, and society (McLeroy, Bibeau, Steckler, & Glanz, 1988).

Results

Data collection

Data were collected from the 47 states with available lead reporting databases. However, there were five states with differing levels of reporting requirements: Arkansas, Nevada, South Dakota, Montana and Louisiana. Arkansas had a lead level-reporting threshold available for providers, but nothing regarding populations to be screened or a questionnaire. Nevada and South Dakota had no information available pertaining to pediatric lead screening either on their website or upon calling their state department. Arkansas and Montana made no recommendations about lead screening beyond mandatory reporting. Louisiana had lead screening recommendations available, but were not posted onto a state run website. LA recommendations were received by email upon request and were then included in this project.

Navigating state websites in search of lead screening protocols seemed to have two extremes: either all information was presented in a clear, comprehensive manner in a single document or was spread out over several places. At times data were missing completely. The Louisiana Department of Health and Hospitals created a tool kit which was not posted to their website; a direct phone call was necessary to retrieve it.

The Delaware Health and Social Services has all of the necessary screening information available on their website, yet the risk assessment questionnaire, populations that need to be screened, and reporting thresholds are located in three separate places.

Reporting Thresholds

As seen in Table 1, the majority of states require that health care providers report all lead results, regardless of number, to their health department (*N* = 39). Nine states request that only levels over a certain number (5-25µg/dL) be reported. Arizona, Pennsylvania, and Virginia use twenty-five µg/dL or greater as a reporting threshold for specific subpopulations: children over sixteen, children under sixteen, and children over fifteen. All children in Alabama, Idaho, North Dakota, and Utah along with children under sixteen years in Arizona, children under six in Arkansas, and children under fifteen in Virginia must report at 10 µg/dL or greater. Arkansas, Montana, Nevada, South Dakota and Pennsylvania do not require any reporting of lead levels on the following subpopulations respectively: children over six, children over thirteen, all children, all children, and children over sixteen. While Montana has no mandatory reporting over age thirteen, for children less than thirteen all results five µg/dL or above must be reported.

Populations

<u>Universal Screening</u>

Universal screening (Table 1, column 3) of all children residing within the state at certain ages is recommended by fifteen states. Of these states, none utilized only universal screening; there was inclusion of at least one other identified population. Children who were not previously tested in a universal screening environment (Table 1, column 4) were tested by eleven states. This population was tested alongside the universal screening population the majority of the time (*N* = 11).

<u>Children with Disabilities or Symptoms</u>

There are several subpopulations of children (Table 1, column 5) who are at increased risk for lead exposures. Their risk is increased either due to their established disabilities and subsequent behaviors or by the possibility that their current symptoms might be from current lead exposures. These subpopulations are the following: 1) children with unexplained illness 2) children who eat non-food substances 3) children with behavioral problems 4) children with developmental delays and 5) children with symptoms that could be from lead poisoning. Nine states ask about at least one of these subpopulations. The Oregon Health Authority recommends testing of several of these subpopulations, including children at any age when they have the following symptoms: history of foreign body ingestion, developmental delays, symptoms that could be caused by lead exposures such as seizures, or behavioral issues such as attention deficit (2009).

Children with Increased Risk

This population (Table 1, column 6) includes children with identified risk as well as those who self-identified as unknown or those whose risk status changed. Minnesota utilizes questions related to changing risk status. The Minnesota Department of Health requests that providers test children who have moved from a “major metropolitan area” or a foreign country within the last year to their state; these children may be living in a low risk area now but their past indicates risk (2011). Forty-three states test this population, which makes it the most screened of the ten populations.

Three of the states that screen this population do not utilize a risk assessment questionnaire. The Colorado Department of Public Health and Environment includes children with low-income, regardless of participation in publicly supported programs, and children who live in older homes that may or may not be undergoing renovation (2008). The South Carolina Department of Health and Environmental Control defers determination of risk to the health care provider’s discretion, which is their only recommended approach to screening (n.d.). While the

Virginia Department of Health does not provide a questionnaire, their at risk groups are similar to those asked about in other states' risk questionnaires: older housing, friends or family with diagnosed lead poisoning, living with adults that work with lead, or living near an industry that releases lead (2013).

Participation in Public Programs

Children who participate in publicly supported programs (Table 1, column 7), most prevalently Medicaid, are tested by the majority of states (*N* = 30). This population is not screened alone, but rather included amongst other populations. Children who participate in publicly supported programs that were not previously tested (Table 1, column 8), were also included as a population to be tested. Twenty-four states require that these populations be tested concurrently. The remaining six states do not require a child to be tested if he/she missed the initial screening period.

Geographic High-Risk

Children who live in high-risk areas of the state (Table 1, column 9), defined by either specific zip codes or entire cities, are another population designated to be tested. Twenty states screen these children. Massachusetts, Minnesota, and Nebraska ask providers to check yearly for changes as they update risk areas with new data. Texas refers health care providers to the United States Census Bureau's website (n.d.), which shows children's risk by entering their physical address. The other sixteen states do not routinely provide updated risk areas to providers.

School Aged Children

Children entering school (Table 1, column 10) are another population that is being tested. They are the least screened of any population (*N* = 4). The Iowa Department of Public Health (n.d.) and Massachusetts Department of Public Health (2002) require proof of prior testing or screening before a child enters kindergarten. The Delaware Department of Health and Social Services require children entering any of the following to be tested: kindergarten, preschool, childcare facility, a private nursery or a public nursery (n.d.). The Maryland Department of Health and Mental Hygiene requires screening for children entering the following: first grade, kindergarten, or pre-kindergarten (2004).

Parent or Provider Suspicion

Children whose parents have requested a blood test or with health care provider suspicion (Table 1, column 11) make up another population. Of the nine states that screen them, five require testing only with parental request. The other four states require testing with either parental request or provider suspicion.

Additional Risk Groups

Immigrants, foreign adoptees, refuge children, children of migrant workers, or children in foster care (Table 1, column 12) are the last designated population and are screened by eight states. The Vermont Department of Health is the only state that specifically asks about children whose parents are migrant workers (n.d.). The Colorado Department of Public Health and Environment (2008) only screens refugees, while seven other states screen two or more of the above mentioned children.

CDC Risk Questionnaire Recommendations

Of the thirty-nine states that provide lead risk questionnaires, only one, Delaware, asks about all of the seven recommended CDC criteria discussed previously (Delaware Health and Social Services, n.d.). All states ask about at least one of the recommended criteria. The most utilized criterion from the CDC's recommendation list asks whether a child has a parent or caregiver who works with lead; thirty-three states ask about this. The least utilized criterion asked about is whether the child is suspected by the parent or provider to be at risk for lead exposure; five states included it.

Risk Assessment Questionnaires

A total of forty-five different questions were identified as being used in risk assessment questionnaires available in the United States (see Table 2). The most common question is whether the child lives in a home or frequently visits a building that is or has been remodeled or renovated (36 states) Seventeen of the questions were identified by individual states

Several themes appeared, including: 1) questions about children with current signs or symptoms of possible lead poisoning and children with established exposures, 2) oral sources that might introduce lead, 3) housing questions, 4) risk in surrounding environment, and 5) other established lead sources both specific to the region and universal. These themes were identified by the researcher and used to organize the data.

Signs or symptoms and established exposures

Three questions (8, 38, and 42) address signs or symptoms of possible lead poisoning and established exposure. Five states asked about whether the child has had an elevated blood level in the past. Two states asked generally about symptoms of lead poisoning. Two other states asked more specifically about delayed development, behavioral disabilities, or learning disabilities. The Wyoming Department of Health was the only state to ask more than one of these questions; they used both 8 and 42 on their questionnaire (2013).

Oral Sources of Exposure

Eleven of the questions screen children for interaction with oral sources of lead. They include questions 6, 20, 26, 27, 28, 29, 30, 31, 33, 39, and 40. Both questions 20 and 26 are the most used, with fifteen states including each of them. The Louisiana Department of Health and

Hospitals is the only state to ask question 29, which addresses whether children's hands are washed before they eat (n.d.). Two states, the State of Alaska Department of Health and Social Services (2013) and North Dakota Department of Health (n.d.), ask about children eating wild game, which has been established to increase blood lead levels (Iqbal, 2008; Watson & Avery, 2009).

Housing

Seven questions ask questions about housing, including 11, 12, 13, 14, 15, 36, and 37. Thirty-one states asked a question about living in or visiting an older building (question 11). A question about whether these homes have been renovated either recently or in the recent past (question 13) was asked by thirty-six states. Questions 12 and 14 rephrase questions 11 and 13, asking instead if the child has ever lived in these conditions. These are both unpopular questions, with only one state asking each. Sixteen states ask question 15, which inquires specifically about peeling or chipping paint in older buildings.

Environment

Risk in the surrounding environment is addressed by questions 1, 2, 3, 7, 9, 10, 21, 22, 23, 24, 25, 32, 34, 43, and 45, with the first four being CDC recommended questions. Thirty-one states ask question 2, whether the child has a sibling or playmate with lead exposure, and fifteen states ask question 10, whether any relatives or members of the same household have been exposed to lead. Nine states ask question 23, which asks whether the child has lived or traveled out of the United States.

Other Sources

Lastly, there are eight questions about other established lead sources; 4,5,16, 17, 18, 19, 41, and 44. Sixteen states ask about living near industries likely to release lead. Four states included a question about children playing in loose soil. The Tennessee Department of Health is the only state to ask a question about whether a home has lead pipes (n.d.).

Discussion/Recommendations

The CDC has established that there is no lead level of exposure to children that is without ill effects (2009). However, nine states still ask providers to report only over a certain level and two states have no mandatory reporting. Having access to all test results, regardless of negative or positive, is critical for producing accurate screening recommendations. Test results can be correlated with risk questionnaires to determine which questions predict true risk and which are unnecessary, finely tuning these instruments for providers. It allows each state to discover which current geographic areas are high risk, allowing for timely intervention to eliminate future exposure and accurate identification of children who should be screened. All of this information assists in developing accurate screening recommendations that increase the provider's ability to provide appropriate care. For these reasons, it is recommended by the author that all test results, whether positive or negative for lead exposures, should be reported and evaluated by every state. Costs to states will vary depending on available resources, testing materials, and testing procedures. Additional costs exist for those states that are not following current CDC guidelines, and also for states that need to evaluate their geographic risk. Cost to the provider would be minimal, especially if submission can be made electronically.

The CDC recommends that all states without a lead screening plan in place universally screen Medicaid-eligible children while acquiring data in order to assess risk in their communities (2009). Arkansas, Montana, Nevada, and South Dakota have no lead screening plan and none of them universally screen Medicaid-eligible children. Arkansas and Montana require providers to report lead results, though not universally, while Nevada and South Dakota do not require reporting. It is recommended by the author that all four states universally screen Medicaid-eligible children, in accordance with current CDC recommendation. Also, the author recommends that all lead results be reported to their state departments. This will increase each state's data about lead exposures in their state.

Since 2009, the CDC established there is no longer a disparity between lead risk in Medicaid-eligible and non-Medicaid-eligible children and suggested that each state decide whether to continue with targeted Medicaid screening or change to universal screening. At this time, thirty states screen Medicaid-eligible children, fifteen states screen universally, and four states (Delaware, Kansas, North Carolina, and Pennsylvania) screen both. If the twenty-six states that screen only Medicaid-eligible children have not considered changing to a universal approach they should assess their risks, as the CDC data implies they might be missing lead positive non-Medicaid-eligible children.

The population that includes children with increased risk and children with symptoms is only tested by nine states. This is a very reasonable group to inquire about. The children with symptoms consistent with lead exposure could easily be overlooked due to the lack of hallmark symptoms. More importantly, lead exposure requires early intervention in order to limit negative, irreversible outcomes. Consequently, it is recommended that all states should consider inclusion of this population.

The South Carolina Department of Health and Environmental Control defer determining lead risk to the health care provider's discretion (n.d.). They provide neither a risk assessment questionnaire nor any other recommendations for populations that should be tested. They do require that all results of lead tests be reported, which gives them information about risk in the state. Health care providers would benefit from the South Carolina Department of Health and

Environment using this data to suggest targeted screening populations in order to best intervene and help children residing there. It is recommended that the South Carolina Department of Health and Environment consider evaluating their lab results and work on creating more targeted screening for their state.

Of the children who live in high-risk areas, only three states have declared they update their high-risk areas yearly (Massachusetts, Missouri, Nebraska). While other states may be also updating their targeted areas, they have not made it clear to providers where to access this information. It is recommended that all states with data collection capabilities supply providers with a list of updated risk areas yearly. This will update providers to emerging areas of risk, which ensures testing, and stop unnecessary testing in areas that have eliminated lead in the environment. It should be clear to providers when this list will be updated and where to access it.

In the literature review, it was established that most lead exposures come from lead based paint, dust contaminated with lead, water which runs through lead pipes, traditional folk medicines, jewelry, toys, and exposures to caregivers who work with lead (CDC, 2013). All of these exposure types are mentioned in some way by a risk assessment question. However, no states asked questions about all of these sources. It is recommended that all states include a risk assessment question asking about all of these common sources in order to truly assess a child's risk.

Many states with risk questionnaires include questions about populations they have already asked providers to screen. For example, California, Delaware, and North Carolina ask all providers to test children who have recently immigrated and also ask, "Has your child recently immigrated?" on their risk assessment questionnaire. This redundancy makes sense, as it is one more trigger to remind the provider that a certain population is at increased risk. However, there were several states that don't take advantage of this reiteration. Nine other states ask the same question, ensuring that these children will be tested, but do not identify children who have immigrated as a population that needs to be screened. Florida requires that this population be tested but doesn't include a screening question on their risk assessment questionnaire. It is recommended that states ensure the populations they deem at risk be included in the risk questionnaire screening questions as an additional safeguard to ensure adequate lead screening.

There are several questions that address universal or widespread risk factors but are asked by a limited number of states. For example, question 34 asks whether a child participates in cultural practices that may use lead and is only asked by the Michigan Department of Community Health (2009). This question would be appropriate to use in any state, as cultural and recreational practices in our nation are varied. It also opens up a conversation between the parents and providers, allowing parents to discuss cultural practices and to consider lead risks they might not have thought about otherwise. It is recommended that each state review other lead risk assessment questionnaires and consider inclusion questions that pertain to their pediatric populations.

The Louisiana Department of Health is the only department to ask whether parents wash children's hands before they eat. This is an intriguing question, as it has been established that children are at higher risk for lead exposures secondary to handling things contaminated with lead, (such as soil), then putting their hands in their mouths. The CDC states that washing a child's hands before eating assists in preventing lead exposure (2013). It is recommended that states consider adding a question about hand washing into their questionnaires or ensure that information about decreasing lead risk through hand washing is available to providers and the general public.

Both the State of Alaska Department of Health and Human Services (2013) and the North Dakota Department of Health (n.d.) include a question about children eating wild game, as it has been established that wild game increases blood lead levels (Iqbal, 2008; Watson & Avery, 2009). This question assists parents in both recognizing that wild game poses a risk of lead exposure to their families and also allows them to acknowledge whether they hunt or not to the provider, so that their risk can be assessed. This would be a good question for any state with high subsistence rates or large quantities of hunters to include.

Five states ask whether the child has had a history of elevated blood lead levels in the past. This is a great question, especially for children joining a new practice, as it identifies children who have established sources of lead in their environment. This question also clues in providers to ask about whether the lead source was identified, if there are ongoing risks, whether the child has symptoms, and also whether any existing siblings have been tested or need testing. It is recommended that other states consider inclusion of this question.

Limitations/Future Research

The largest limitation to this study lies in the risk factor questionnaire section. Without knowing how strongly each question correlates with true lead exposure risk, it is difficult to make recommendations about which questions should be utilized by each state and which are not appropriate questions. Future research might be done to evaluate all questions asked in current risk questionnaires. Comparing data on actual sources of exposures against local and national risk questions to establish a risk correlation would greatly improve risk questionnaires in general. Additionally, continued and systematic collection of data on pediatric lead exposures would be of benefit.

Conclusion

Based upon the identification of weaknesses and unique approaches to pediatric lead screening currently being utilized in the United States, this study has given several recommendations with the aims of improving current practices. Utilizing the SEM framework, this project proposed change on many levels. This was done with the understanding that in order to create positive changes in the individual, there must be changes in the surrounding environment.

On a policy level, the states with screening protocols that are not compliant with CDC recommendations or which do not provide clear, evidence based screening strategies in a single document accessible to providers can improve upon current policies. On an organizational level, clinics and hospitals are encouraged to implement policies that support their providers by evaluating whether their state's recommendations are best practice. On an interpersonal level, nurse practitioners as well as other health care providers will be able to analyze information presented in this project and current recommendations from their state to determine how they will provide accurate screening approaches to their patients.

Recommendations made by this project can be considered for implementation by the nurse practitioner in order to supplement their own state's recommendations as they find necessary. This will assist the nurse practitioner and other health care providers in their ability to provide appropriate care for their pediatric patients. This multilevel approach to health care promotion can be an impetus to provide the best screening possible, ensuring healthier children in the United States.

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Appendix

Table 1

Screening Approaches in the Fifty States

Column 1: State	Column 2: Reporting Threshold for Providers (μg/dL)	Column 3: All children at defined ages	Column 4: All children not previously tested at defined ages	Column 5: Any child with symptoms of possible lead poisoning, unexplained illness, foreign substance ingestion, behavioral problems, or developmental delays	Column 6: Children with increased risk, positive answers on questionnaire, or with changes in risk status	Column 7: Children that participate in publicly supported programs at defined ages	Column 8: Children that participate in publicly supported programs and were not tested at defined ages	Column 9: Children that live in high risk areas at defined ages	Column 10: Children entering public school at defined ages	Column 11: All children whose parents have requested a screen or with provider suspicion	Column 12: All foreign adoptees, immigrants, refugees, children of migrant workers, or in foster care	Column 13: Use of risk assessment questionnaire?
Alabama	>10	X	X	X	X							X
Alaska	All				X							X
Arizona	<16: >10 >16: >25				X	X	X	X				X
Arkansas**	<6: >10 >6: none											
California	All				X	X	X			X	X	X
Colorado	All				X	X	X	X			X	
Connecticut	All	X	X	X	X							X
Delaware	All	X			X	X		X	X	X	X	X
Florida	All			X	X	X	X	X			X	X
Georgia	All				X	X	X	X				X
Hawaii	All				X	X	X					X
Idaho	≥ 10					X	X					
Illinois	All			X	X	X	X	X				X

Column 1: State	Column 2: Reporting Threshold for Providers (µg/dL)	Column 3: All children at defined ages	Column 4: All children not previously tested at defined ages	Column 5: Any child with symptoms of possible lead poisoning, unexplained illness, foreign substance ingestion, behavioral problems, or developmental delays	Column 6: Children with increased risk, positive answers on questionnaire, or with changes in risk status	Column 7: Children that participate in publicly supported programs at defined ages	Column 8: Children that participate in publicly supported programs and were not tested at defined ages	Column 9: Children that live in high risk areas at defined ages	Column 10: Children entering public school at defined ages	Column 11: All children whose parents have requested a screen or with provider suspicion	Column 12: All foreign adoptees, immigrants, refugees, children of migrant workers, or in foster care	Column 13: Use of risk assessment questionnaire ?
Indiana	All	X	X		X							X
Iowa	All	X	X		X				X			X
Kansas	All	X			X	X	X					X
Kentucky	All				X	X		X				X
Louisiana	All	X	X		X							X
Maine	All			X	X	X						X
Maryland	All				X	X	X	X	X			X
Massachusetts	All	X						X	X			X
Michigan	All				X	X	X	X				X
Minnesota	All				X	X	X	X		X		X
Mississippi	All			X	X	X	X					X
Missouri	All				X	X	X	X				X
Montana**	<13: ≥ 5 >13: none											
Nebraska	All				X	X	X	X				X
Nevada*												
New Hampshire	All				X	X	X	X				X

New Jersey	All	X	X		X							X
New Mexico	All				X	X	X			X		X
Column 1: State	Column 2: Reporting Threshold for Providers (µg/dL)	Column 3: All children at defined ages	Column 4: All children not previously tested at defined ages	Column 5: Any child with symptoms of possible lead poisoning, unexplained illness, foreign substance ingestion, behavioral problems, or developmental delays	Column 6: Children with increased risk, positive answers on questionnaire, or with changes in risk status	Column 7: Children that participate in publicly supported programs at defined ages	Column 8: Children that participate in publicly supported programs and were not tested at defined ages	Column 9: Children that live in high risk areas at defined ages	Column 10: Children entering public school at defined ages	Column 11: All children whose parents have requested a screen or with provider suspicion	Column 12: All foreign adoptees, immigrants, refugees, children of migrant workers, or in foster care	Column 13: Use of risk assessment questionnaire ?
New York	All	X			X							X
North Carolina	All	X	X		X	X		X			X	X
North Dakota	>10				X	X	X					X
Ohio	All				X	X		X				X
Oklahoma	All				X	X						X
Oregon	All			X	X							X
Pennsylvania	<16: ≥ 25 >16: none	X	X			X	X					
Rhode Island	All	X	X		X							X
South Carolina	All				X							
South Dakota*												
Tennessee	All	X	X		X					X		X
Texas	All				X	X	X	X		X		X
Utah	≥ 10				X			X		X		X
Vermont	All	X	X	X							X	
Virginia	<15: ≥ 10 >15: ≥ 25				X	X	X	X		X		
Washington	All			X	X					X	X	

West Virginia	All				X	X	X					
Wisconsin	All				X	X	X	X				X
Column 1: State	Column 2: Reporting Threshold for Providers (µg/dL)	Column 3: All children at defined ages	Column 4: All children not previously tested at defined ages	Column 5: Any child with symptoms of possible lead poisoning, unexplained illness, foreign substance ingestion, behavioral problems, or developmental delays	Column 6: Children with increased risk, positive answers on questionnaire, or with changes in risk status	Column 7: Children that participate in publicly supported programs at defined ages	Column 8: Children that participate in publicly supported programs and were not tested at defined ages	Column 9: Children that live in high risk areas at defined ages	Column 10: Children entering public school at defined ages	Column 11: All children whose parents have requested a screen or with provider suspicion	Column 12: All foreign adoptees, immigrants, refugees, children of migrant workers, or in foster care	Column 13: Use of risk assessment questionnaire ?
Wyoming	All				X	X	X					X

*State has no protocols for pediatric lead screening per their Department of Health

**State refers providers to the CDC's protocols, has no state protocol

Table 2

Questions Included in Risk Assessment Questionnaires by Participating States

		AL	AK	AZ	CA	CT	DE	FL	GA	HI	IL	IN	IA	KS	KY	LA	MA	MD	ME	MI	MN	MS	MO	NC	ND	NE	NH	NJ	NM	NY	OH	OK	OR	RI	TN	TX	UT	VA	WI	WY
1	Do you suspect that your child is at risk?	X			X		X																															X		X
2	Does your child have a sibling or friend who has been exposed to lead or diagnosed with lead poisoning?	X		X		X	X		X	X	X	X	X		X		X			X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
3	Had your child recently immigrated as an adoptee, immigrant, or refugee?	X	X		X		X				X	X								X				X		X							X			X		X		
4	Do any adults that routinely interact with your child come into contact with lead?	X	X	X		X	X	X	X	X	X	X	X	X	X	X		X	X	X		X	X		X	X	X	X	X	X	X	X	X	X	X	X		X		X
5	Does your household contain traditional, ethnic, folk remedies, or cosmetics?	X	X	X		X	X	X	X			X	X		X	X				X		X	X		X	X	X		X	X		X	X		X	X				X
6	Does your child routinely eat food known to have lead or was carried/ informally imported from another country?	X	X	X			X	X					X		X	X									X				X	X						X				X
7	Do you live in or frequently visit area deemed high-risk by the health department?						X				X									X			X								X	X								

		AL	AK	AZ	CA	CT	DE	FL	GA	HI	IL	IN	IA	KS	KY	LA	MA	MD	ME	MI	MN	MS	MO	NC	ND	NE	NH	NJ	NM	NY	OH	OK	OR	RI	TN	TX	UT	VA	WI	WY
8	Has your child had an elevated blood level in the past?									X											X						X	X												X
9	Does your child receive benefits from a publicly supported program (i.e. Medicaid, Head Start)?	X									X								X	X				X			X		X		X	X	X					X	X	X
10	Has anyone who lives in the same house or is related to your child had elevated blood lead levels?		X			X								X	X			X			X			X	X					X		X	X	X		X		X		X
11	Does your child live in or visit a home or building built before 1950/1960/1978?	X	X	X		X	X	X	X	X	X	X	X	X		X		X	X	X	X	X	X	X		X	X		X		X		X		X	X	X	X	X	X
12	Has your child ever lived in a home built before 1950?																																						X	
13	Does your child live in or visit a home or building that is or was undergoing renovation or remodeling?	X	X	X	X			X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
14	Has your child ever lived in a house undergoing remodeling?																																						X	

		AL	AK	AZ	CA	CT	DE	FL	GA	HI	IL	IN	IA	KS	KY	LA	MA	MD	ME	MI	MN	MS	MO	NC	ND	NE	NH	NJ	NM	NY	OH	OK	OR	RI	TN	TX	UT	VA	WI	WY
15	Have you noticed any peeling or chipping paint in or around the pre-1960/1978 house or building that your child has lived in or regularly visited?				X								X		X	X	X	X			X	X	X		X			X		X	X	X		X						
16	Does your child live near industries likely to release lead?	X		X			X	X	X		X		X	X									X				X		X	X				X	X			X		X
17	Does your child live by or play near a busy road?							X							X							X					X		X	X					X					
18	Does your child play in loose soil?			X				X								X							X																	
19	Does your child live near or play on tailings from mining or milling operations?																																				X			
20	Does your child eat or drink from imported pottery or imported ceramic cookware?		X	X				X		X				X	X	X											X		X	X		X	X		X	X				X
21	Is the child in foster care?							X												X						X														
22	Is your child a member of a minority group?											X																												
23	Has your child visited or lived in another country?		X	X				X			X		X														X			X			X							X
24	Are you requesting a lead exposure test?				X																																	X		
25	Have you had a change in circumstance has put your child at risk for lead exposure?				X																																			X

		AL	AK	AZ	CA	CT	DE	FL	GA	HI	IL	IN	IA	KS	KY	LA	MA	MD	ME	MI	MN	MS	MO	NC	ND	NE	NH	NJ	NM	NY	OH	OK	OR	RI	TN	TX	UT	VA	WI	WY
26	Does your child eat or chew on non-food substances?		X	X				X	X	X			X			X		X				X	X				X		X	X					X	X				
27	Does the child have a sibling with excessive mouthing behavior?																																							X
28	Does your child eat or drink from leaded crystal or pewter dishes?							X						X		X														X			X		X					
29	Are the child's hands washed before meals and snacks?															X																								
30	Does your child drink well water?																					X																		
31	Does your child eat wild game?		X																						X															
32	Have you recently moved?																										X													
33	Does your child chew on our mouth jewelry or toys from vending machines?																															X								
34	Do you participate in any cultural practices that may use lead?																			X																				
35	Does your child participate in hobbies that might expose them to lead?														X																									
36	Does your home or a building your child visits frequently have plastic or vinyl mini-blinds?							X								X						X		X	X				X			X			X					

		AL	AK	AZ	CA	CT	DE	FL	GA	HI	IL	IN	IA	KS	KY	LA	MA	MD	ME	MI	MN	MS	MO	NC	ND	NE	NH	NJ	NM	NY	OH	OK	OR	RI	TN	TX	UT	VA	WI	WY
37	Does your child live in a house/building built before 1978 that has water damage?																				X																			
38	Has your child had any symptoms consistent with lead poisoning?						X	X																																
39	Does your family have a catchment water system?									X																														
40	Do you use hot tap water for cooking or drinking?																										X													
41	Are painted materials or unusual materials ever burned in a household fireplace?															X																								
42	Do you have any concerns for or is there evidence of delayed development, behavioral disabilities, or learning disabilities?																																X							X
43	Have you ever been told your child has low iron or anemia?																										X								X					
44	Does your home have lead pipes or copper pipes with lead joints?																																		X					
45	Are the child's parents migrant farm workers?																																							X

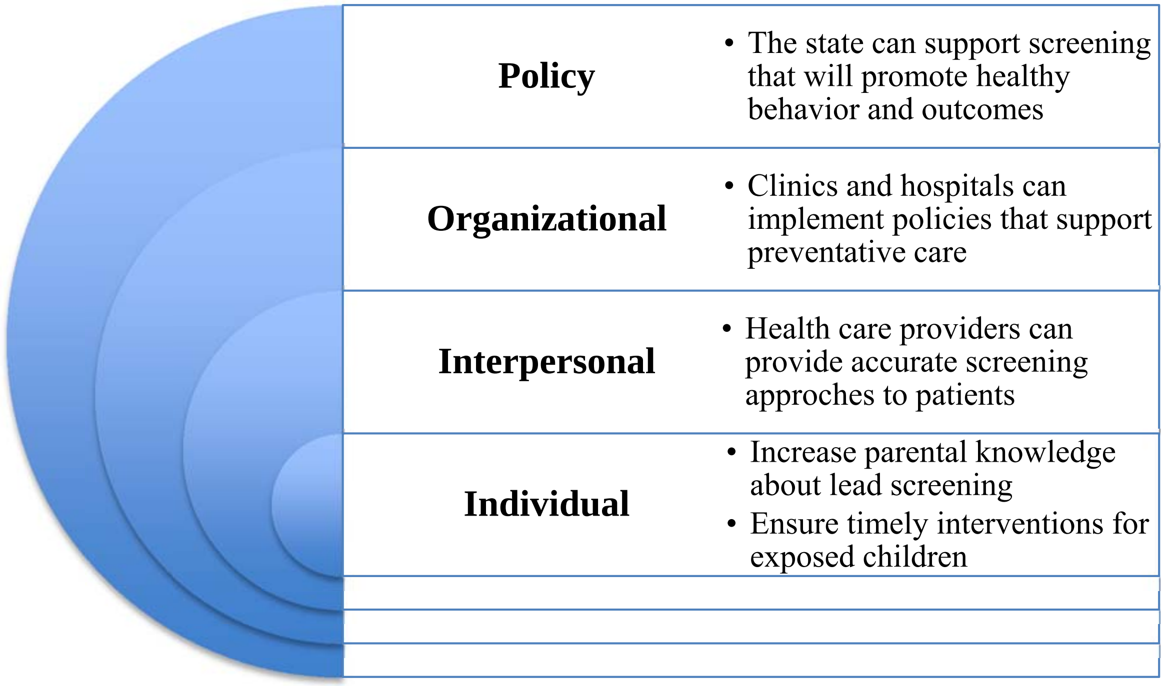

Figure 1. Framework for this project based upon the Social Ecological Model. It emphasizes that change happens to the individual when their surrounding environment also changes.

The identification of lead ammunition as a source of lead exposure in First Nations: The use of lead isotope ratios

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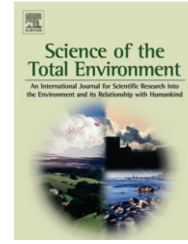

The identification of lead ammunition as a source of lead exposure in First Nations: The use of lead isotope ratios

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ABSTRACT

The use of lead shotshell to hunt water birds has been associated with lead-contamination in game meat. However, evidence illustrating that lead shotshell is a source of lead exposure in subsistence hunting groups cannot be deemed definitive. This study seeks to determine whether lead shotshell constitutes a source of lead exposure using lead isotope ratios. We examined stable lead isotope ratios for lichens, lead shotshell and bullets, and blood from residents of Fort Albany and Kashechewan First Nations, and the City of Hamilton, Ontario, Canada. Data were analyzed using ANOVA and regression analyses. ANOVA of isotope ratios for blood revealed significant differences with respect to location, but not sex. Hamilton differed from both Kashechewan and Fort Albany; however, the First Nations did not differ from each other. ANOVA of the isotope ratios for lead ammunition and lichens revealed no significant differences between lichen groups (north and south) and for the lead ammunition sources (pellets and bullets). A plot of $^{206}Pb/^{204}Pb$ and $^{206}Pb/^{207}Pb$ values illustrated that lichens and lead ammunition were distinct groupings and only the 95% confidence ellipse of the First Nations group overlapped that of lead ammunition. In addition, partial correlations between blood-lead levels (adjusted for age) and isotope ratios revealed significant ($p<0.05$) positive correlations for $^{206}Pb/^{204}Pb$ and $^{206}Pb/^{207}Pb$, and a significant negative correlation for $^{208}Pb/^{206}Pb$, as predicted if leaded ammunition were the source of lead exposure. In conclusion, lead ammunition was identified as a source of lead exposure for First Nations people; however, the isotope ratios for lead shotshell pellets and bullets were indistinguishable. Thus, lead-contaminated meat from game harvested with lead bullets may also be contributing to the lead body burden.

1. Introduction

Lead is a non-essential element that has detrimental effects on most bodily systems even at low levels of exposure (ATSDR, 2005; CDC, 2005). Four major changes during the last three decades in North America (excluding Mexico) have reduced the amount of environmental lead: the elimination of leaded gas, the move towards 'lead-free' paint, the use of lead-free solder in the canning and plumbing sectors, and the use of copper and non-lead piping and fittings (Royal Society of Canada, 1986; Fleming, 1994; ATSDR, 2005; CDC, 2005). Although these major environmental sources of lead have been dealt with through

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legislation, there are still other important sources of anthropogenic lead, such as, lead shotshell used for hunting and sporting activities. Several countries, such as, Denmark and the Netherlands have banned all uses of lead shotshell (Thomas, 1997); while, lead shotshell has only been banned for waterfowl hunting in the US (USFWS, 1988) and for most migratory bird hunting in Canada (Environment Canada, 2000). Thus, lead shotshell can still be legally purchased and used to hunt upland game birds and small mammals, as well as used in sporting activities (e.g., skeet shooting) in the US and Canada (Thomas, 1997).

Human health concerns have been raised with respect to the consumption of wild game harvested with lead shotshell. In a review of the literature, Balch and Silver (1971) found that foreign bodies were rarely found in the human appendix; however, lead pellets were the second most common item found in this organ which they attributed to the consumption of wild game harvested with lead shotshell. Moreover, in subsistence harvesting groups, the radiographic presence of lead pellets/fragments in the gastro-intestinal system (including the appendix) has been reported to be common (Carey, 1977; Reddy, 1985). For example, approximately 15% of randomly selected radiographs for First Nation Cree of the western James Bay region, northern Ontario, Canada, showed radiographic evidence of lead pellets and/or fragments in the gastro-intestinal tract, intraluminally and/or in the appendix. There are medical reports for Canadian Aboriginal people (First Nations, Inuit, Metis) where hundreds of lead pellets (>500) have been removed in an appendectomy (Carey, 1977; Reddy, 1985); the consumption of wild game harvested with lead shotshell was the assumed source of the pellets in all cases. Two studies (Scheuhammer et al., 1998; Tsuji et al., 1999) demonstrated through radiography and spectrometry that approximately 10% of game birds harvested with lead shotshell became contaminated with lead pellets/fragments whereby edible bird tissue exceeded the Canadian consumption guideline for lead in fish protein (0.5 μg/g wet weight [ww]; no guidelines exist for game birds; Health Canada, 1991) — lead levels reached 19,900 μg/g ww (Tsuji et al., 1999). It should be stressed that lead pellets located in the gastro-intestinal tract are not inert and become a source of chronic lead exposure, as it has been shown by Madsen et al. (1988) that patients with lead pellets in the gastro-intestinal tract (showed radiographically) exhibit significantly higher blood-lead levels than controls. Durlach et al. (1986) report on a case of acute lead poisoning (674 μg/L plasma lead) where 29 lead pellets were removed from the colon and appendix of a farmer who regularly ate wild game killed with lead shotshell. Even a single pellet located in the gastro-intestinal tract has been suspected of causing acute lead poisoning (550 μg/L blood-lead level) as reported for a 45-year consumer of wild game (Gustavsson and Gerhardson, 2005). Indeed, elevated tissue-lead levels have been reported for indigenous people, who are exposed to limited sources of environmental lead, and who subsist on wild game harvested with lead shotshell (Tsuji et al., 1997, 2001; Odland et al., 1999; Hanning et al., 2003; Levesque et al., 2003; Johansen et al., 2006).

Lead is unique among the metals in that there is variability associated with the abundance of its four stable isotopes, namely, ^{206}Pb (the product of the radioactive decay of ^{238}U); ^{207}Pb (derived from ^{235}U); ^{208}Pb (from the decay of ^{232}Th); and the non-radiogenic isotope, ^{204}Pb (Rabinowitz, 1995; Sangster et al., 2000). Their relative abundance depends on the age of the ore body the lead originates from (Rabinowitz, 1995; Sangster et al., 2000). Isotopic ratios of stable isotopes (e.g., ^{206}Pb/^{207}Pb) can be used as markers that can discern the environmental source of lead. Background isotopes ratios, such as in human blood, respond to exposure to lead sources with a different isotopic ratio (Rabinowitz, 1995). The determination of stable lead isotope ratios in human (Graziano et al., 1996; Gulson et al., 1998, 1999; Maddaloni et al., 1998) and animal (Scheuhammer and Templeton, 1998; Scheuhammer et al., 2003) tissues have been used to distinguish between different lead sources.

More specifically, the use of stable lead isotope ratios has recently been used in an attempt to identify lead shotshell as a major source of lead for a Canadian Inuit population, but results were not definitive (Levesque et al., 2003); ^{206}Pb/^{207}Pb for cord blood was significantly different between Inuit (n=60, $\bar{x}$=1.195, range: 1.166–1.230) and southern Quebecers (n=89, $\bar{x}$=1.166, range: 1.126–1.230), but both ranges of cord blood overlapped with the range of isotope ratios determined for four brands of lead shotshell pellets (n=10; range: 1.125–1.233; Levesque et al., 2003). It is not surprising that Inuit and southern Canadian cord-blood isotope ratios showed a large range of values in that cord blood is a reflection of maternal blood, which is a mixture of both recent lead exposure and endogenous bone contributions (Gulson et al., 1995; Smith et al., 1996); as much as, 40–70% of lead-in-blood may be remobilized lead from tissue stores including bone (Gulson et al., 1995, 1997; Smith et al., 1996). In this paper, we test the hypothesis that lead shotshell is a source of lead exposure for subsistence harvesting groups.

2. Methods

2.1. Study sites

Fort Albany First Nation is located (52°15′N, 81°35′W) in the remote western James Bay region of northern Ontario, Canada, and is populated by approximately 850 First Nation Cree (Tsuji et al., 2006). Kashechewan First Nation is located 20 km north of Fort Albany and is populated by 1400 Cree (Tsuji et al., 2006). Hunting of game birds and mammals is a way of life for these people (Tsuji and Nieboer, 1997). Current sources of environmental lead are limited in this region: water-and soil-lead concentrations have been reported as low with air levels below the Ontario Ambient Air Quality Criterion of 5 ug/m^3 (OMHE, 1989); most houses were built after the use of lead-reduced paint or were panelled (Tsuji et al., 1999); most First Nations houses were not equipped with indoor plumbing until the 1990s when copper and plastic piping and fittings (as well as lead-free solder) were used (Tsuji et al., 2000); surface water in the region contains minimal lead (McCrea and Fischer, 1986); historically, schools of the region were lead-piped and soldered (Murray, 1989; St. Pierre, 1992), but since the 1980s bottled water or distilled water has been used in the old schools (Tsuji et al., 1999) and new schools with non-leaded plumbing have been erected; and white lead (89% $PbCO_3$, 11% linseed oil) incorporated in major repairs of boats made of wood and canvas has been in limited use as fibreglass boats have grown in popularity, while, most people are aware of the toxicity of white lead and have taken proper precaution in the storage and use of this product (Fortin and Decou, 1995). The comparison community is the City of Hamilton which is populated by approximately 714,000 non-Native people; this industrial city is located in the Great Lakes region of southern Ontario, Canada (Tsuji et al., 2006).

2.2. Sample collection

2.2.1. Blood samples

After a consent form was signed (the form and study were approved by the McMaster University Research Ethics Board), subjects completed a questionnaire in interview format to collect information pertaining to demographics, lifestyle and consumption of wild meats. Only adults (≥18 years of age) were recruited from the communities of Fort Albany (female, $n=49$; male, $n=48$), Kashechewan (females, $n=48$; males, $n=51$), and Hamilton (females, $n=27$; males, $n=25$). Each participant donated blood into a 6-ml plastic Vacutainer tube containing EDTA. Blood samples were gently mixed with the anticoagulant in the vacutainer, allowed to cool at room temperature, frozen, and then stored at −20 °C. Samples were collected during the time period 1999 to 2000. Vacutainers were shipped frozen to the Centre de toxicologie, Institut national de sante publique du Quebec for lead isotope determination.

2.2.2. Lichen samples

Epiphytic lichens have no root system and collect moisture and nutrients exclusively from the air through ion exchange, particle entrapment and the direct uptake of gases; thus, lichens are effective biomonitors and represent atmospheric lead (Carignan and Gariepy, 1995). Lichens were collected from the bark or tips of tree branches (Carignan and Gariepy, 1995; Watmough and Hutchinson, 2004) from the mainland portion of the Fort Albany community, as well as from forested areas in the Hamilton region. Lichens were placed in paper brown bags and allowed to dry overnight before being stored in plastic Ziploc® bags. In the laboratory, samples were cleaned with distilled deionized water, dried and ground with liquid nitrogen into a fine powder. The powder was stored in plastic Ziploc® bags.

2.2.3. Lead ammunition samples

Scheuhammer and Templeton (1998) examined lead shotshells from 22 brands and report limited within-cartridge and within box variability in $^{206}Pb/^{207}Pb$ (CV<0.3%); thus, we sampled 12 gauge shotshells ($n=9$) given to us from First Nation hunters, from different boxes for the major manufacturers of lead shotshell in the western James Bay region (i.e., Federal and Winchester). Lead pellets were removed from shotshells using stainless-steel surgical instruments and stored in plastic, Ziploc® bags. Similarly, First Nation hunters donated rounds of .22, 30.30, 30-06 and 12 gauge lead slugs from different boxes of Federal and Winchester ammunition. Lead tips of bullets and slugs were removed with stainless-steel surgical instruments and stored in plastic, Ziploc® bags.

2.3. Blood-lead determination

A detailed account is given in Tsuji et al. (2008). Briefly, blood samples were diluted and injected into an electrothermal atomic absorption spectrometer (Perkin Elmer model ZL 4100). The detection limit for lead was 10 μg/L.

2.4. Stable lead isotope determination

Although isotope dilution thermal ionization mass spectrometry was once the standard in lead isotope analysis, it has now been shown that inductively coupled plasma mass spectrometry (ICP-MS) is sufficiently accurate and precise to be used in environmental studies (Delves and Campbell, 1988; Ting and Janghorbani, 1988; Adgate et al., 1998). Sangster et al. (2000) advise that all four isotopes should be measured to decrease the likelihood of a false match.

The isotopic ratios were determined by ICP-MS (Perkin Elmer Sciex Elan 6000). Masses were monitored according to

Table 1 – Blood Pb isotope ratios for three communities: descriptive statistics

Isotope ratio	Community	Sex	n	Mean	Std. Deviation	Minimum	Maximum
Ratio 206/204	Ft. Albany	F	37	18.34	0.44	17.54	19.20
		M	40	18.29	0.38	17.34	19.06
	Kashechewan	F	33	18.31	0.40	17.66	19.41
		M	49	18.26	0.35	17.57	19.15
	Hamilton	F	18	17.91	0.28	17.12	18.26
		M	13	17.84	0.25	17.48	18.32
Ratio 206/207	Ft. Albany	F	37	1.177	0.024	1.129	1.223
		M	40	1.177	0.020	1.122	1.216
	Kashechewan	F	33	1.178	0.023	1.136	1.237
		M	49	1.174	0.020	1.136	1.213
	Hamilton	F	18	1.156	0.016	1.106	1.180
		M	13	1.151	0.016	1.125	1.176
Ratio 208/206	Ft. Albany	F	37	2.063	0.029	2.010	2.124
		M	40	2.064	0.026	2.015	2.128
	Kashechewan	F	33	2.067	0.026	2.002	2.114
		M	49	2.067	0.024	2.017	2.115
	Hamilton	F	18	2.097	0.018	2.070	2.153
		M	13	2.099	0.017	2.067	2.124

Table 2 – Pb isotope ratios for leaded ammunition and lichens

Isotope ratio	Sample type	n	Mean	Std. Deviation	Minimum	Maximum
Ratio 206/204	Northern lichen	20	18.19	0.11	18.00	18.36
	Southern lichen	6	18.20	0.26	17.93	18.58
	Lead shotshells	9	19.19	0.26	18.69	19.49
	Lead bullets	8	19.30	0.10	19.17	19.42
Ratio 206/207	Northern lichen	20	1.172	0.002	1.168	1.178
	Southern lichen	6	1.169	0.015	1.150	1.186
	Lead shotshells	9	1.223	0.014	1.199	1.239
	Lead bullets	8	1.228	0.005	1.222	1.234
Ratio 208/206	Northern lichen	20	2.081	0.005	2.070	2.091
	Southern lichen	6	2.079	0.017	2.052	2.100
	Lead shotshells	9	2.011	0.017	1.991	2.041
	Lead bullets	8	2.008	0.007	1.997	2.020

specific operating conditions and mass spectrometer settings (RF power, 1000 W; nebuliser gas flow rate, 1.0 l/min; auxilliary gas flow rate, 1.0 l/min; plasma gas flow rate, 15 l/min; nebuliser type, cross flow; interface cones, platinum; dwell time, 25 ms; number of sweeps, 500; and number of replicates, 4). Results were expressed as relative abundances of $^{206}Pb/^{204}Pb$, $^{206}Pb/^{207}Pb$, and $^{208}Pb/^{206}Pb$. The lead standard NIST SRM-982 was used to validate the analytical accuracy ($n=20$; % accuracy: $^{206}Pb/^{204}Pb=-0.27$; $^{206}Pb/^{207}Pb=-0.25$; $^{208}Pb/^{206}Pb=0.13$). The blood material reference QMEQAS 99BO1 was used to evaluate the analytical precision ($n=22$; % RSD: $^{206}Pb/^{204}Pb=0.32$; $^{206}Pb/^{207}Pb=0.22$; $^{208}Pb/^{206}Pb=0.21$) during runs and the mass bias of the instrument.

Blood-lead samples with concentrations ≥80 μg/L were simply diluted 10 fold in 0.1% Triton-X100 and 0.5% ammonia solution. A minimum 10-fold dilution was required in order to avoid nebulisation problems. For lead concentrations <80 μg/L, treatments were needed to eliminate some parts of the matrix. Acidic deproteinisation removed most of the organic material to eliminate possible clogging formation during the nebulising process, especially for dilutions of 1:1 to 1:4 v/v. Determination of isotopic ratios on blood samples <10 μg/L was not possible. Lichen and lead ammunition samples were digested in pressurized Teflon vessels overnight, at 120 °C, using ultra-pure concentrated nitric acid.

2.5. *Statistical analyses*

Stable lead isotope ratio data ($^{206}Pb/^{204}Pb$, $^{206}Pb/^{207}Pb$, and $^{208}Pb/^{206}Pb$) for blood were considered in an ANOVA of location and sex, with appropriate post-hoc tests. Plots of means and confidence intervals for lead isotope ratios in blood for each sex and location illustrate similarities and differences found by ANOVA. Isotope ratio variates ($^{206}Pb/^{204}Pb$, $^{206}Pb/^{207}Pb$, and $^{208}Pb/^{206}Pb$) for lead ammunition (and lichens) were used in an ANOVA of ammunition type (and location) with post-hoc tests. Means and confidence intervals are presented for lead isotope ratios in lead ammunition by type, and lichens for location, to demonstrate similarities and differences found by ANOVA.

In addition, we carried out partial correlation analysis between blood-lead levels and the three lead isotope ratios, adjusting for age which is a known correlate of blood-lead concentrations in these First Nations subjects (Tsuji et al., 2008). If lead ammunition is a significant source of lead for these First Nations subjects, we would predict positive partial correlations between blood-lead level and the isotope ratios $^{206}Pb/^{204}Pb$ and $^{206}Pb/^{207}Pb$, and a negative partial correlation with isotope ratio $^{208}Pb/^{206}Pb$. Therefore, a 1-tailed test is appropriate to the null hypothesis of no positive correlation in these first two instances, and no negative correlation with the latter ratio.

3. Results

Descriptive statistics are presented for isotope ratios in blood (Table 1), lead ammunition and lichens (Table 2). ANOVA of isotope ratios for blood revealed significant differences (Wilks λ) with respect to location ($p \leq 0.0000004$), but not sex ($p \geq 0.38$). No significant effects were seen for the LOCATION×SEX interactions ($p \geq 0.80$). ANOVA, followed by post-hoc multiple comparison tests (Levene's Test, $p \geq 0.15$; thus, results were Bonferroni protected) showed significant differences between locations ($^{206}Pb/^{207}Pb$, and $^{208}Pb/^{206}Pb$; $p \leq 0.000003$; Figs. 1 and 2; the plot of $^{206}Pb/^{204}Pb$ is not shown as it is similar to $^{206}Pb/^{207}Pb$). Notable

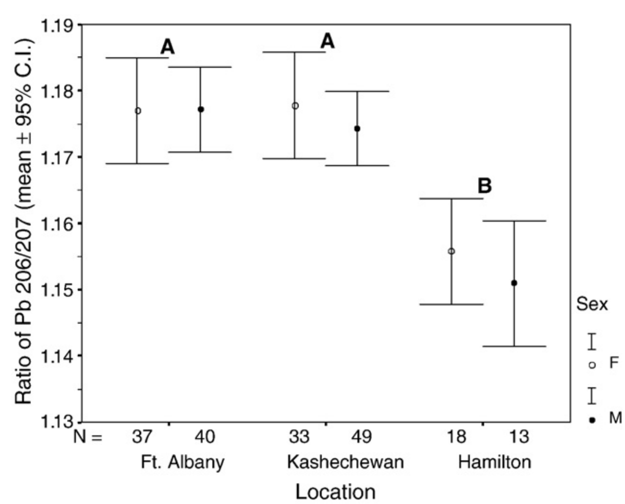

Fig. 1 – Means (±95% confidence intervals) of isotope ratio $^{206}Pb/^{207}Pb$ for blood lead collected from three different locations: Fort Albany First Nation, Kashechewan First Nation, and Hamilton, Ontario, Canada. There were no significant ($p>0.05$) sex differences within localities. Locations with different letters were significantly different ($p<0.05$).

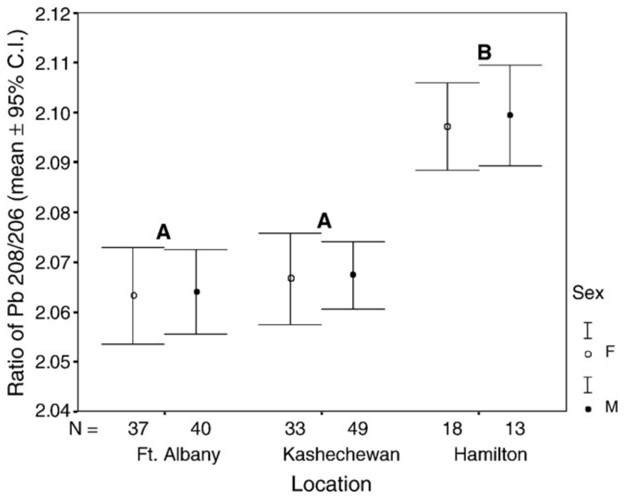

Fig. 2 – Means (±95% confidence intervals) of isotope ratio $^{208}Pb/^{206}Pb$ for blood lead collected from three different locations: Fort Albany First Nation, Kashechewan First Nation, and Hamilton, Ontario, Canada. There were no significant ($p>0.05$) sex differences within localities. Locations with different letters were significantly different ($p<0.05$).

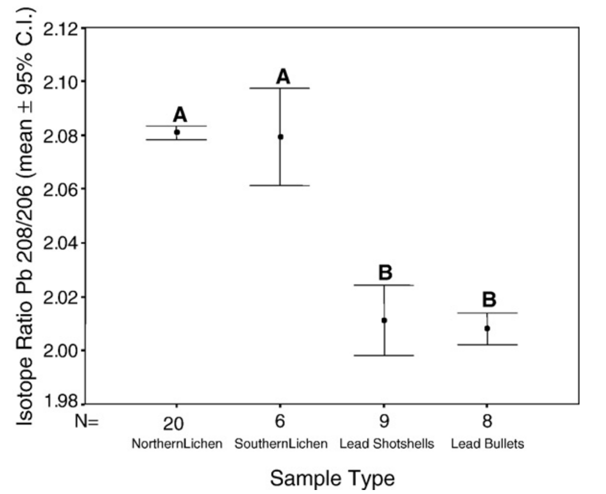

Fig. 4 – Means (±95% confidence intervals) of isotope ratio $^{208}Pb/^{206}Pb$ for lichens collected from northern and southern Ontario, Canada, and lead shotshells and bullets. Variables with different letters were significantly different ($p<0.05$).

significant differences occurred for $^{206}Pb/^{204}Pb$, $^{206}Pb/^{207}Pb$, and $^{208}Pb/^{206}Pb$ where Hamilton differed from both Kashechewan and Fort Albany ($p\leq0.000003$); however, Fort Albany and Kashehchewan did not differ significantly ($p=1$; Figs. 1 and 2). ANOVA of isotope ratios for lead ammunition and lichens revealed significant differences ($^{206}Pb/^{204}Pb$, $^{206}Pb/^{207}Pb$, and $^{208}Pb/^{206}Pb$; $p<0.00001$; Figs. 3 and 4; $^{206}Pb/^{204}Pb$ is not shown). Post-hoc multiple comparison tests (Levene's Test, $p\leq0.008$; thus, Tamhanes T2 for heterogenous variances was used) showed no significant differences within lichens ($^{206}Pb/^{204}Pb$, $^{206}Pb/^{207}Pb$, and $^{208}Pb/^{206}Pb$; $p\geq0.99$) and within lead ammunition ($^{206}Pb/^{204}Pb$, $^{206}Pb/^{207}Pb$, and $^{208}Pb/^{206}Pb$; $p\geq0.89$), but significant differences between lichens and lead ammunition ($^{206}Pb/^{207}Pb$, and $^{208}Pb/^{206}Pb$; $p\leq0.00047$; Figs. 3 and 4; $^{206}Pb/^{204}Pb$ is not shown).

A plot of $^{206}Pb/^{204}Pb$ and $^{206}Pb/^{207}Pb$ values with 95% confidence ellipses illustrates that lichens and lead ammunition are distinct groupings (Fig. 5). Only the 95% confidence ellipse of the First Nations group overlaps that of lead ammunition; however, the First Nations' ellipse also envelops the lichen and Hamilton groupings. The Hamilton 95% confidence ellipse overlaps both the lichen grouping and the less radiogenic portion of the First Nations' ellipse. Specifically, three out of 31 subjects from Hamilton lie outside the 95% confidence ellipse for the Hamilton data. By contrast, 63 subjects from First Nations communities, or 39.7% of the 159 individuals, lie outside the confidence ellipse for Hamilton subjects. All but 6 of these 63 First

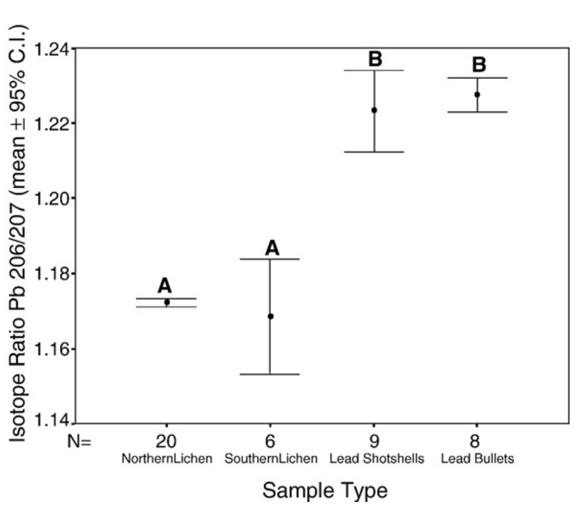

Fig. 3 – Means (±95% confidence intervals) of isotope ratio $^{206}Pb/^{207}Pb$ for lichens collected from northern and southern Ontario, Canada, and lead shotshells and bullets. Variables with different letters were significantly different ($p<0.05$).

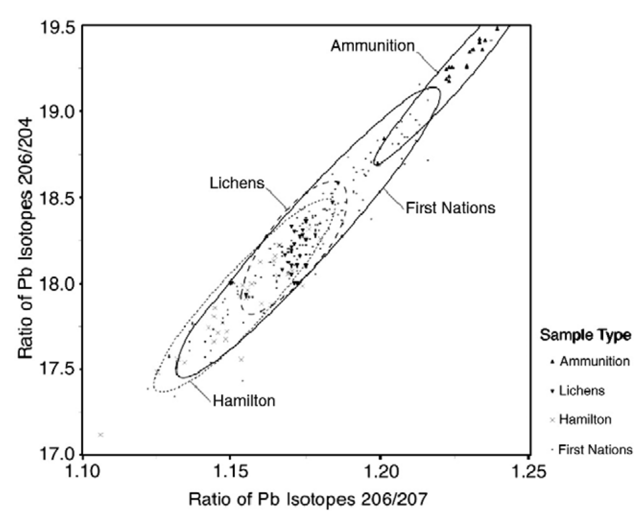

Fig. 5 – Discrimination between sources of lead for people from Fort Albany First Nation, Kashechewan First Nation, and Hamilton, Ontario, Canada, using $^{206}Pb/^{204}Pb$ and $^{206}Pb/^{207}Pb$ isotope ratios.

Nations subjects have Pb isotope values more similar to the signature for lead ammunition than to the Hamilton or lichen lead isotope signature. It is clear that the lead isotope ratios of First Nations subjects are skewed towards that of leaded ammunition.

Partial correlations, adjusting for the effect of age, between blood-lead level and isotope ratios, showed significant positive correlation for $^{206}Pb/^{204}Pb$ (r=0.2234, p=0.002), and for $^{206}Pb/^{207}Pb$ (r=0.1761, p=0.013). In the case of $^{208}Pb/^{206}Pb$, the partial correlation with blood-lead level was significantly negative (r=−0.1374, p=0.041).

4. Discussion

The significant differences in lead isotope ratio values between First Nations (Fort Albany and Kashechewan) people relative to non-Native, Hamilton residents was not unexpected, as these two First Nation communities are remote, located in close proximity to each other, have similar lifestyles and consume similar traditional diets as compared to the residents of the industrial city of Hamilton (Tsuji et al., 2006). The $^{206}Pb/^{207}Pb$ values found in the present study for Hamilton residents (males, $\bar{x}$=1.151; females, $\bar{x}$=1.156) are similar to what has been reported in eastern Canada for automobile leaded gas ($\bar{x}$=1.15; Sturges and Barrie, 1987). This observation suggests that the isotopic pattern of the current background lead exposure is similar to that of petrol additives or that endogenous stores of lead-in-bone are contributing substantially to the blood-lead compartment of the Hamilton residents as leaded gas has not been used in Canada or the US for decades (Royal Society of Canada, 1986; Fleming, 1994; ATSDR, 2005; CDC, 2005). The background isotope ratio values for lichens collected from the Hamilton area ($^{206}Pb/^{204}Pb$, $\bar{x}$=18.20; $^{206}Pb/^{207}Pb$, $\bar{x}$=1.169) were not only comparable to those reported by Flegal et al. (1989) for surface waters of Lake Ontario near Hamilton ($^{206}Pb/^{204}Pb$, $\bar{x}$=18.21; $^{206}Pb/^{207}Pb$, $\bar{x}$=1.1681), but no significant differences in isotope ratios between lichens sampled from the northern (i.e., the First Nations) and southern (i.e., Hamilton) Ontario sites were found. This suggests that the atmospheric lead source is similar in these two areas. However, it should be stressed that although 60% of First Nations subjects overlap the 95% confidence ellipse for Hamilton subjects, nearly all the remaining 40% (63 individuals) show skewness towards higher positive values for isotope ratios $^{206}Pb/^{204}Pb$ and $^{206}Pb/^{207}Pb$, towards the leaded ammunitions isotopic signature.

It should be emphasized that no significant differences were noted within lead ammunition type for isotope ratios. Thus, we cannot distinguish between lead shotshell and lead bullets as the source of lead exposure, we can only comment on lead ammunition as a source. Nevertheless, significant differences between lichens and lead ammunition were noted for $^{206}Pb/^{204}Pb$, $^{206}Pb/^{207}Pb$, and $^{208}Pb/^{206}Pb$ allowing for source discrimination with respect to atmospheric lead and lead ammunition. In addition, the probability of correctly identifying lead source was aided by the finding that relatively little variation existed in the range of our values for $^{206}Pb/^{207}Pb$ for lead shotshell (1.199–1.239) compared to what has been reported in the literature by Scheuhammer and Templeton (1998; range: 1.07–1.27) and Levesque et al. (2003; range: 1.125–1.233). Variation in $^{206}Pb/^{207}Pb$ values as reported by Levesque et al. (2003) made it impossible to definitively identify lead shotshell as the source of exposure in Inuit cord blood (range: 1.166–1.230) as the control community's values (range: 1.126–1.230), also overlapped that of lead shotshell.

In the plot of $^{206}Pb/^{204}Pb$ and $^{206}Pb/^{207}Pb$ values with 95% confidence ellipses, lead from lead ammunition had the highest values (Fig. 5). The 95% confidence ellipse of the First Nations group overlaps that of lead ammunition illustrating that lead ammunition is a source of lead exposure in this group. Nevertheless, the First Nations' ellipse also envelops the lichen group suggesting that exposure is also from atmospheric lead. In addition, the confidence ellipse for the First Nations group extends outside the confidence ellipse for lichens, towards the origin of the graph, suggesting that a source other than atmospheric lead must contribute. For the Hamilton group, a major source of lead exposure is that from atmospheric lead since the Hamilton 95% confidence ellipse almost totally envelops that for lichens. Nevertheless, the confidence ellipse encompassing the lower range of values for the Hamilton grouping falls outside the ellipse for lichens also suggesting yet another lead source for these people. It appears that this lead source is common to both the First Nation and Hamilton people. Studies of half-lives of lead-in-bone (e.g., Brito et al., 2001, 2005) and its mobilization from tissue stores in individuals not occupationally exposed (Gulson et al., 1995, 1997; Smith et al., 1996) suggests that a substantial contribution of blood lead may derive from long-term tissue stores. Historic exposures may explain the additional lead source, since the release of lead from bone appears to be approximately 7 years for low body lead burdens (Brito et al., 2005).

The use of a firearm has been reported to be a source of lead exposure from lead fumes generated from the primer and the lead projectile as it passes down the barrel (Anderson et al., 1997; Valway et al., 1989; Bonanno et al., 2002), but no sex differences in isotope ratios were found in the present study even though James Bay Cree men typically do the hunting (Tsuji et al., 2008). Although the amount of wild game (harvested with lead ammunition) consumed would be a logical variable to investigate with respect to impacts on lead isotope ratios, there is one major issue associated with this type of endeavour. It is extremely difficult to quantify the amount of lead exposure through the consumption of lead-contaminated meat harvested with lead shotshell because the lead fragments from the lead ammunition are not homogeneously distributed in the meat (Frank, 1986; Scheuhammer et al., 1998; Johansen et al., 2001; Johansen et al., 2004; Rodrigue et al., 2005; Kreager et al., 2008). For example, Scheuhammer et al. (1998) report large differences between right and left matched pectoral muscle (five species of waterfowl had <1 μg/g dry weight [dw] in the left and 112–3910 μg/g dw in the right) of game birds harvested with lead shotshell and within a breast (sub-samples/duplicates, e.g., surf scoter, *Melanitta perspicillata*, original=43.4 μg/g dw, duplicate <1 μg/g dw). Indeed, only 12% of the variation in age-adjusted, blood-lead levels for the same individuals examined in the present study was attributable to variation in diet even though a significant (p<0.05) positive relationship between blood-lead levels and the diet variable representing wild game (i.e., Principal Component Axis-1) was noted (Tsuji et al., 2008). Perhaps heterogeneity in the distribution of lead shotshell fragments in wild meat would also explain why some individuals have been reported to have relatively high blood-lead concentrations but low consumption of game birds harvested with lead shotshell (Johansen et al., 2006). Nevertheless, partial correlations between blood-lead levels (age-adjusted) and isotope ratios support that lead ammunition was a definite source of lead exposure.

Another consideration is that Gulson et al. (1999) have demonstrated in female subjects, that major spikes in diet (lead concentration and $^{206}Pb/^{204}Pb$) results in small changes in isotope ratio and blood-lead concentrations with some exceptions. Relatively small spikes in dietary lead concentration and/or isotopic composition may be virtually undetectable due to low absorption and the relatively rapid clearance rate of lead from blood (approximately 30 days; Gulson et al., 1999). Thus, consumption of lead in the diet must be substantial to be seen as a change in isotope ratio. However, Graziano et al. (1996) have shown through a 24-hour dosing experiment of 6 healthy adults (2 males, 4 females; 23–28 years of age) that lead in the form of decanter stored sherry ($^{206}Pb/^{207}Pb$ of lead crystal decanter = 1.078) resulted in the mean isotope ratio ($^{206}Pb/^{207}Pb$) falling from 1.202 to 1.137 ($p < 0.05$). Similarly, in the Maddaloni et al. (1998) 24-hour dosing experiment of 6 healthy adults (2 males and 4 females; 24–33 years) a drop in the average $^{206}Pb/^{207}Pb$ value from 1.195 to 1.167 was shown, after participants were dosed with 250 μg Pb/70 kg body weight; lead was in a soil matrix with an isotope ratio ($^{206}Pb/^{207}Pb$) of $\bar{x} = 1.1083$ and delivered in a gelatin capsule to fasting participants. When subjects were in a non-fasting state, $^{206}Pb/^{207}Pb$ values decreased towards that of the lead-in-soil, but the change was not as dramatic (Maddaloni et al., 1998). Indeed, absorption of lead like other metals is strongly dependent on its chemical form (Drexler and Brattin, 2007), on the fasting state, and on the diet composition (Lonnerdal and Sandstrom, 1995).

In conclusion, it was shown that lead ammunition was a definite source of lead exposure for First Nations of the western James Bay region; however, the isotope ratios for lead shotshell and lead bullets were indistinguishable. Thus, past studies that suggested that lead shotshell was the main source of lead in subsistence harvesting groups must also recognize that lead-contaminated meat from game harvested with lead bullets may also be contributing to lead body burden in these groups.

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HUMAN EXPOSURE TO LEAD FROM AMMUNITION IN THE CIRCUMPOLAR NORTH

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ABSTRACT.—Circumpolar subsistence cultures use firearms, including shotguns and rifles, for hunting game for consumption. Lead shot is still used for waterfowl and seabird hunting in many subsistence areas (despite lead shot bans) because it is inexpensive, readily available, and more familiar than non-toxic or steel shot, which shoot differently. Here we review published literature on lead concentrations and lead isotope patterns from subsistence users in the circumpolar North, indicating that elevated lead exposure is associated with use of lead ammunition. Mechanisms of exposure include ingestion of lead dust, ammunition fragments, and shot pellets in harvested meat, and inhalation of lead dust during ammunition reloading. In Alaska, ammunition-related lead exposures have also been attributed to the use of certain indoor firing ranges, and the melting and casting of lead to make bullets. Since there is no safe lead exposure limit, especially for children, use of lead shot and bullets in subsistence cultures results in unnecessary and potentially harmful lead exposure. In order for lead ammunition to be feasibly phased out, alternatives must be affordable and readily available to subsistence hunters. Community outreach, including describing the harmful effects of even small amounts of lead, especially in children and women of child-bearing age, and training on the different shot patterns, velocities, and distances inherent in using shot and bullet materials other than lead, will also be necessary to promote acceptance of alternatives to lead ammunition.

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Key words: Alaska, ammunition, arctic, game, human, hunters, lead, subsistence, waterfowl.

HUMANS IN THE NORTH have been exposed to lead from many of the same sources as in temperate regions. In the 20th century, the greatest exposure was inhalation of atmospherically transported lead produced from leaded gasoline. Other atmospheric sources included combustion of other fossil fuels, particularly coal, non-ferrous metal production (mining, smelting), and waste incineration (AMAP

[3] The findings and conclusions in this document are those of the author(s) and do not necessarily represent the views of the US Fish and Wildlife Service.

2004, AMAP 2002). Lead leachate from lead solder used in food cans may have poisoned the crews of *Erebus* and *Terror*, the ships of the 1850s Franklin expedition to the North Pole (Bayliss 2002). Interestingly, lead solder for canning wasn't banned in the United States until 1995 (Federal Register 60(123): 33106-9), and may still be used elsewhere. Ingestion of lead-based paint chips by children remains an issue worldwide, although in abatement with regulation of leaded paint.

With control of these lead sources, however, blood lead levels in humans have dropped over the past few decades. A phase-out of leaded gas beginning in the 1980s, for example, resulted in a substantial decline in lead levels in humans in North America (Pirkle et al. 1994) and Greenland (Hansen et al. 1991), as well as in snow from Greenland (Robinson 1981) and in the Arctic ice pack. The prevalence of blood lead levels ≥10 μg/dL dropped from over 80% before 1980 to less than 10% in the 1990s (Pirkle et al.1998).

Still, some northern populations, especially indigenous peoples dependent upon subsistence foods, continue to have elevated blood lead levels. A primary source is thought to be lead from ammunition, by ingestion of lead fragments in game shot with lead, inhalation of fumes from home production of shot or sinkers (as in rural areas in Russia; AMAP 2004), and inhalation of dust or particles during prolonged shooting. In fact, the Arctic Monitoring and Assessment Programme stated:

Lead levels in Arctic indigenous peoples have declined since the implementation of controls on lead emissions. Concentrations of lead in blood currently reported are below a level of concern, however, continued monitoring is warranted because of the potent effects of lead on neurological development in the fetus and children (AMAP 1998).

This is still valid. In addition, recent data have shown that lead shot can be a significant source of human exposure (AMAP 2003).

Lead is exceptionally dense, making it ideal for projectiles. It is also relatively soft, which allows it to be formed, even in home environments, into a variety of bullet and shot gauges. This malleability also results in fracturing of the shot and bullets. The latter can leave macro- and microscopic traces of lead on average 15 cm from bullet pathways in meat (Hunt et al. 2006) and spread over an average of 24 cm and up to 45 cm apart (Hunt et al. 2009). Therefore, even if game is carefully cleaned and damaged meat discarded, embedded and invisible fragments of lead may still contaminate the meat (Stroud and Hunt 2009, Hunt et al. 2009).

In this paper we review data on lead concentrations in people living in the circumpolar north and evaluate lead from ammunition as an important source for current lead exposure. We conclude that exposure to lead from ammunition is unnecessary and potentially harmful to Arctic indigenous populations.

REVIEW OF LEAD TOXICOLOGY

Absorption.—Lead can enter the human body through three main routes of exposure: eating, breathing, or being shot. The third route has obvious health consequences and will not be discussed further.

People can ingest lead that is present in their immediate environment, such as dust, or that is in food or water. Leachate from lead solder use in canned foods has already been discussed. Wild game that has been shot with lead ammunition can contain lead fragments, particles or dust that is consumed along with the meat. Lead can also be ingested if people handle lead products such as fishing sinkers, and then fail to wash their hands before eating food. Children often ingest lead when they mouth lead-containing toys or objects, or suck their fingers after touching lead objects or lead-containing dust or soil.

In humans, the percentage of lead that is absorbed into the bloodstream after oral ingestion is influenced by several factors, including age. Gastrointestinal absorption of water-soluble lead appears to be higher in children than in adults (ATSDR 2007). Estimates derived from dietary balance studies indicate that children (ages two weeks to eight years) absorb approximately 40–50% of ingested water-soluble lead, while non-fasting adults absorb only 3–10% of ingested water-soluble lead (ATSDR

2007). Nutritional status also affects gastrointestinal absorption of lead; fasting status increases lead absorption. The presence of food in the gastrointestinal tract lowers lead absorption, especially if calcium or phosphate is present in the meal. Children who have calcium or iron deficiencies have a higher absorption of lead from the gastrointestinal tract (ATSDR 2007).

Exposure to lead through inhalation can occur in a variety of ways. When lead is melted to make fishing sinkers, ammunition or other products, especially in a home environment, dangerous levels of lead fumes can be produced and inhaled. Lead can also be inhaled on dust particles, contaminated soils, or via occupational exposure in manufacturing and mining. When leaded gasoline is combusted, tetraalkyl lead is an inhalable byproduct.

Amounts and patterns of deposition of particulate aerosols in the respiratory tract are affected by the size of the inhaled particles, age-related factors that determine breathing patterns (e.g., nose vs. mouth breathing), airway geometry, and airstream velocity within the respiratory tract (ATSDR 2007). Absorption of deposited lead is influenced by particle size and solubility. Larger particles (>2.5 microns) that are deposited in the upper airways can be transferred by mucociliary transport into the esophagus and swallowed. Smaller particles (<1 micron) can be deposited deeper into the lungs including the alveolar region, where intimate contact with the bloodstream enhances absorption (ATSDR 2007).

Distribution and Excretion.—The excretory half-life of lead in blood is approximately 30 days for adult humans (ATSDR 2007). Lead that is retained by the body is mostly stored in bone, where it is assimilated due to its chemical similarity to calcium (AMAP 2002). Lead can be mobilized from bone and released into the bloodstream during the process of bone resorption. Mobilization of bone lead can occur during pregnancy and lactation, and after menopause due to osteoporosis (ATSDR 2007). Lead in a pregnant mother's blood is effectively transferred to the fetus, and maternal lead can also be transferred to infants during breastfeeding (ATSDR 2007).

Toxicity.—Lead poses a greater risk to children than to adults for several reasons. Lead is more toxic to children than to adults because the nervous system of children is still developing. Also, children absorb a greater percentage of the lead they are exposed to (ATSDR 2007), and children are often exposed to more lead than adults. Children play outdoors and sometimes engage in hand-to-mouth behaviors that increase their exposure potential. The crawling and mouthing behaviors of older infants and young toddlers place them at particular risk for exposure; blood lead levels (BLLs) in children typically peak at the age of two years for this reason (American Academy of Pediatrics 2005). Children are shorter than are adults; this means they breathe dust, soil, and vapors close to the ground. A child's lower body weight and higher intake rate results in a greater dose of hazardous substance per unit of body weight. If toxic exposure levels are high enough during critical growth stages, the developing body systems of children can sustain permanent damage. Children's brains are developing rapidly during the first six years of life, which is why exposure to a chemical like lead that targets the brain is most devastating at that critical time.

Lead can delay or impair brain development in children and adversely affect IQ, and impair a child's ability to learn. Lead can also cause anemia and impaired metabolism of vitamin D. The Centers for Disease Control and Prevention (1997) recognized BLLs of ≥10 µg/dL in children aged ≤6 years as levels of concern, and based on studies since then, the CDC now recognizes that 10 µg/dL does not define a lower threshold for the harmful effects of lead (Brown 2007). Multiple studies have shown that as blood lead concentrations increase, IQ decreases, for example, by 7.4 points as blood lead increased from 1 to 10 µg/dL in children up to five years old (Canfield et al. 2003), and with significantly higher rates of intellectual decrement in children with maximal BLL <7.5 µg/dL than ≥7.5 µg/dL (Lanphear et al. 2005). Thus, BLLs less than 10 µg/dL are clearly harmful, and there is growing consensus that there is no "safe" level of lead exposure. Other adverse health effects associated with relatively low BLLs in children include delayed sexual maturation, increased blood pressure, depressed renal glomerular filtration rate, and inhibition of pathways in heme synthesis (ATSDR 2007).

As BLLs rise in children, the harmful health effects of lead become more severe. A child exposed to a large amount of lead may develop anemia, kidney damage, colic, muscle weakness, and brain damage, which can ultimately kill the child (ATSDR 2007). Such symptoms of clinical lead poisoning are commonly observed in children with BLLs of 45 µg/dL or higher; children with BLLs of 70 µg/dL or higher should be hospitalized immediately for treatment (Centers for Disease Control and Prevention 2002).

Studies have reported adverse health effects in adults with blood lead levels between 25–40 µg/dL, including hypertension, subtle or sub-clinical central nervous system deficits, and adverse reproductive outcomes (Centers for Disease Control and Prevention 2002). Lead exposure is clearly related to elevated blood pressure, and may also cause negative clinical cardiovascular outcomes and impaired performance on cardiovascular function tests (Navas-Acien et al. 2007). Cardiovascular and renal effects have been seen in adults chronically exposed to lead at levels <5 µg/dL in blood, and no lower threshold has been established for any lead-cardiovascular association (Navas-Acien et al. 2007).

At high levels of lead exposure, the brain and kidney in adults or children can be severely damaged, and death can result. High levels of lead exposure may also cause miscarriage in pregnant women, and affect testicular hormones in men. Other symptoms of lead poisoning in adults include colic, anemia, and muscle weakness. Clinical symptoms of lead poisoning can occur in adults with BLLs above 40 µg/dL (ATSDR 2007).

HUMAN EXPOSURE TO LEAD IN THE ARCTIC

Research on human lead exposure in the Arctic in the last decade has linked elevated lead exposure to use of lead shot or bullets for hunting. Other lead exposures of prior importance have largely been controlled, such as lead-based paints, lead in drinking water, and lead from gasoline. Leaded gasoline was phased out from North American use in the 1980s, with subsequent declines in environmental levels, including blood lead in humans (AMAP 1998, AMAP 2003, Van Oostdam et al. 2003). The exception may be in northern Russia, where industrial contamination from mining and smelting of lead ores, and use of lead-containing gasoline, continues (AMAP 2003). However, populations in Russia who practice subsistence hunting, such as people on the Kola Peninsula, are probably also exposed to lead from ammunition (AMAP 2003, Odland et al. 1999).

Specific studies of lead exposure from lead shot began decades ago with documentation of residual (embedded or ingested) lead in waterfowl. Embedded lead shot were found in 18–45% of waterfowl, depending upon the species, tested in the USA, Canada, and Western Europe in the 1950s (Elder 1955). In Canada in the 1980s, 15% of 227 pooled breast muscle samples from waterfowl harvested with lead shot had lead concentrations >0.5 mg/kg (Canadian Wildlife Service unpublished data, cited in Scheuhammer and Norris 1995), and Frank (1986) found lead concentrations, some >100 µg/kg, in tissues of waterfowl harvested with lead shot. These fragments, confirmed by radiographs and ranging in size from dust to 1–2 mm, resulted from collision of shot with bone. In the mid-1990s, Hicklin and Barrow (2004) used fluoroscopy on live Canada Geese (*Branta canadensis*), American Black Ducks (*Anas rubripes*), Mallards (*A. platyrhynchos*) and Common Eiders (*Somateria millissima*) from eastern Canada. Twenty-five percent of 1,624 birds had embedded shot, most of which was assumed to be lead. From 15–29%, depending upon age, of over 700 Common Eiders collected in western Greenland after colliding with boats or drowning in fishing nets had embedded lead shot in them (Merkel et al. 2006). It is clear that both micro- and macroscopic lead particles remain in avian meat that has been shot with lead pellets (Scheuhammer et al. 1998) and in large mammals shot with lead-based rifle bullets (Hunt et al. 2006). Therefore, lead from ammunition is a potential public health concern for indigenous peoples (Tsuji et al. 1999) and others who depend on wild game for food.

In a study specifically designed to examine the link between lead shot use for subsistence hunting of birds and potential human exposure, Johansen et al. (2001) x-rayed 50 Thick-billed Murre (*Uria lomvia*) carcasses bought from hunters in Greenland. The birds had been harvested with lead shot, and had an average of 3.7 lead pellets per carcass (range 0–12). There was no correlation between the number of pellets and the lead concentration in meat, which ranged from 0.0074–1.63 ppm wet weight, although most lead found in the breast meat was from pellets that had gone through the meat and left fragments. The authors concluded that even after pellets were removed, lead shot fragmented to fine dust upon collision with bone, resulting in substantially greater (although variable) lead concentrations in murres shot with lead compared to those shot with steel. They estimated a potential dose of 50 µg of lead from eating one bird. An estimated 200,000 murres are harvested annually in Greenland, in addition to other seabirds and waterfowl. The authors concluded that using lead shot to hunt birds could be a significant public health concern (Johansen et al. 2001).

A variety of raptor species have been exposed to or poisoned by lead from predating or scavenging lead-shot game (Hunt et al. 2006) and waterfowl (Pattee and Hennes 1983, Elliott et al. 1992, Pain et al. 1993, Kendall et al. 1996, Miller et al. 1998, Mateo et al. 1999, Samour and Naldo 2002, Pain et al. 2009). Therefore, it is not surprising that people who consume game shot with lead can also have elevated blood lead levels. Numerous studies at both the population and individual levels have implicated and linked lead ammunition to elevated blood lead levels and clinical symptoms in northern peoples.

For example, blood lead levels were monitored in 50 male hunters in Greenland before, during, and after the bird-hunting season in order to establish the association between bird consumption and blood lead concentrations (Johansen et al. 2006). Frequency of reported bird consumption was strongly associated with measured BLLs in the hunters, and eider meals were more important than murre meals as a lead source in the blood. Mean BLLs (12.8 µg/dL) were more than eight times higher in the group reporting more than 30 bird meals per month than in the group reporting no bird consumption (1.5 µg/dL).

At the population level, the Dene/Métis and bird-hunting Inuit in Canada averaged from 3.1–5.0 µg/dL of lead in maternal blood, compared to 1.9–2.2 µg/dL among Caucasians and other Inuit (Van Oostdam et al. 2003). However, 3.4% and 2.2% of the blood samples from the Inuit and Dene/Métis women, respectively, exceeded the 10.0 µg/dL Canadian Action Level (Walker et al. 2001). In Greenland, blood lead levels in Inuit mothers averaged 3.1–5.0 µg/dL, similar to the Canadian Inuit and Dene/Métis (AMAP 2003). In Siberia, indigenous women had average blood lead levels of 2.1–3.2 µg/dL, while non-indigenous women, who presumably obtained a smaller proportion, if any, of their food from hunting, averaged 0.02–0.04 µg/dL (AMAP 2003). In Nunavik (Arctic Quebec), adult Inuit blood lead levels were elevated and were related to age, smoking and, in particular, daily consumption of waterfowl (Dewailly et al. 2001). Blood lead, adjusted for age and sex, was associated with seabird consumption in Greenland (Bjerregaard et al. 2004). In that study, Greenlanders who reported consuming sea birds several times a week had a blood lead level >50% higher than those who reported eating sea birds only a few times a month or less.

Lead shot exposure and effects have also been documented at the individual level in northern humans. For example, Madsen et al. (1988) noted that lead shot in the appendix were often seen in lower abdominal x-rays in Denmark, and those with lead in the appendix had greater blood lead concentrations. Of 132 randomly selected radiographic charts from a hospital serving six native Cree communities in Northern Ontario (1990–1995), 15% showed lead shot in the gastrointestinal system (Tsuji and Nieboer 1997). Sixty-two patients in one Newfoundland hospital had from 1–200 lead shot in their appendices (Reddy 1985), and Hillman (1967), Greensher et al. (1974), Durlach et al. (1986), and Gustavsson and Gerhardsson (2005) all documented clinical symptoms resulting from lead shot in human appendices. In the USA in 2005, Cox and Pesola (2005) published a radiograph from an Alaska Native elder with an appendix full of shot, and stated “buckshot is commonly seen in Alaskan natives.”

Using lead isotopes to identify the source of lead when blood lead is elevated combines population and individual assessments. This method was used by Tsuji et al. (2008) to definitively document lead from ammunition—both shot and bullets—as a source of lead in First Nations Cree in northern Ontario. Lead isotope signatures of southern Ontario urban dwellers were different from those of northern First Nations people, who depended upon subsistence foods. Lead from ammunition had a separate signature from that found on lichens and, significantly, isotope signatures of First Nations people overlapped with that of lead from ammunition. Levesque et al. (2003) used a similar approach to identify the source of lead in cord blood of Nunavik Inuit infants born from 1993–96. Although mobilization of maternal bone lead resulted in less definite signatures than those documented by Tsuji et al. (2008), there was still a strong suggestion that the source of elevated cord blood lead, found in approximately 7% of Inuit newborns, was lead from ammunition. There were also signature differences between Inuit infants from Nunavik in northern Quebec, and Caucasian infants from southern Quebec. In Alaska, recent lead isotope data from blood of Alaska Natives from Bethel on the Yukon-Kuskokwim Delta and Barrow on the North Slope, regions where subsistence waterfowl hunts occur, showed signatures that overlapped with those of shot (Alaska Native Tribal Health Consortium, unpubl. data).

Blood Lead Surveillance in Alaska.—Alaska regulations require laboratories and health care providers to report all blood lead test results ≥10 µg/dL to the Alaska Division of Public Health, Section of Epidemiology; however, most laboratories report all BLL results (Section of Epidemiology 2008b). The Section of Epidemiology maintains a blood lead surveillance database of all reported blood lead levels from Alaskans (>26,000 records as of August 2008), and conducts individual case follow-up activities for all elevated BLLs.

In Alaska, the majority of adults with BLLs ≥25 µg/dL were males who worked in the metal ore mining industry (State of Alaska 2008a). Across all age groups, the majority (81%) of known non-occupational elevated lead exposures involved people exposed on indoor firing ranges, followed by children who were born or adopted from abroad (10%), and people casting lead as a hobby (3.4%) (State of Alaska 2008b).

Major lead sources for children aged <6 years in the contiguous United States are lead-contaminated dust and soil and deteriorated lead-based paint (Brown 2007), but these exposure sources are not frequently encountered in Alaska. The majority of Alaska children aged <6 years with elevated BLLs obtained their lead exposures abroad (State of Alaska 2008b). Many of the other sources of non-occupational lead exposure in Alaskans reflect the hunting and fishing, outdoor lifestyle of Alaska. Lead ammunition or lead fishing sinkers are commonly implicated as the primary exposure source of elevated BLLs in Alaska.

Elevated BLLs have been attributed to use of indoor firing ranges in Alaska (Lynn et al. 2005, Verbrugge 2007). Students shooting on high school rifle teams that used the problematic indoor shooting ranges were among the persons with elevated BLLs. Inadequate ventilation systems and improper maintenance practices at indoor firing ranges were documented at several ranges with lead exposure problems. The cleaning practice of dry sweeping is particularly hazardous, and should never be performed in indoor ranges. Elevated lead exposures have also occurred among Alaskans who hand reload ammunition, and among sportsmen who melt lead to cast their own bullets (State of Alaska 2008b). In June 2001 an adult Alaskan male suffered acute lead poisoning as a result of inhaling lead dust and fumes while melting and casting lead to make fishing sinkers (State of Alaska 2001). The patient had a BLL of 133 µg/dL and exhibited symptoms of fatigue, stomach pain with gastric upset for several months, and a fever of 102ºF for 10 days. The patient was hospitalized and received chelation therapy, and his BLL subsequently declined. The State of Alaska has not yet investigated whether consumption of game shot with lead may also be causing elevated lead exposures in Alaska, although this has recently been added to the list of potential risk factors under consideration during follow-ups for elevated BLLs.

REDUCING LEAD EXPOSURE IN CIRCUMPOLAR PEOPLE

In the circumpolar north, many indigenous peoples and other rural inhabitants depend on wild game for subsistence. In Alaska and elsewhere, scientists have documented the nutritional value of traditional foods such as fish, marine and terrestrial mammals, wild birds, and plants (Egeland et al. 1998, Nobmann et al. 1992). In many rural northern communities, wage-paying jobs are limited and market food is not available or is expensive. Further, wild foods are often nutritionally superior to market foods, which have high levels of processed sugars and fats. Subsistence food gathering is essential if people are to have enough healthy food. Traditional foods represent not just a critical food source, but also an integral part of Native culture and a way of life that has existed for many generations. Risk reduction strategies for lead exposure from ammunition must account for the need for inexpensive shot that is easy to use for subsistence hunting—a niche that is still being filled by purchased and reloaded lead shot in much of the North.

Risk reduction strategies that have been suggested for reducing lead exposure from use of lead shot include culture-specific outreach (see Tsuji 1998) to lead shot users and sellers, with the goal of voluntary behavior changes; capacity-building, which trains community members in outreach regarding lead shot risks and non-lead shot shooting techniques; and regulation, both from within and outside of subsistence communities (Tsuji 1999, AMAP 2003). Some are more successful than others; for example, regulation is often most effective if it is community-generated. Enforcement from outside the community, especially with the large distances and relatively low human population densities in Arctic regions, can be inefficient on broad scales.

After Inuit from Nunavik were found to have high cord blood lead levels, lead shot bans (Dallaire et al. 2003) and public health intervention (Levesque et al. 2003) resulted in “marked” and “significant” decreases in cord blood lead concentrations, from an average of 0.20 µmol/L before the ban in 1999 to 0.12 µmol/L after the ban (Dallaire et al. 2003). In the Mushkegowuk Territory of northern Ontario, collaborative health education outreach with direct community involvement was essential to changing attitudes about the safety of lead shot and inspiring behavioral change (Tsuji et al. 1999). In Alaska, outreach to food preparers, school-age children, and hunters about the risk of lead exposure from lead shot to human and bird health, resulted in two community-generated injunctions on the use of lead shot in areas covering 83 million acres (2.4 million ha) and numerous subsistence communities on the North Slope and Yukon-Kuskokwim Delta.

Reducing lead exposure from other sources, which may not be as widespread as the use of lead ammunition, could respond well to targeted outreach and regulation. For example, as the Alaskan examples illustrate, lead should not be melted and formed into shot or sinkers in home environments. In indoor shooting ranges, ventilation systems must be built correctly and correctly maintained, dry sweeping should be prohibited, and blood lead testing for regular users such as rifle teams should be performed at the beginning and end of each shooting season.

CONCLUSION

Since bans on lead in gasoline, instituted primarily in the 1980s and 1990s, lead levels in northern hemisphere humans have generally declined. A notable exception is the blood lead levels of Arctic indigenous peoples who rely on subsistence foods. In many cases, elevated blood lead levels in the Arctic have been associated with ingestion of lead from spent ammunition, primarily shot, although lead from fragmented bullets in big game may have been overlooked as a source until recently (Hunt et al. 2006, Tsuji et al. 2008, Hunt et al. 2009, Titus et al. 2009). Other cases of harmful lead exposure have resulted indirectly from use of lead in ammunition or for fishing (indoor firing ranges, home melting and manufacture of lead sinkers, shot, or bullets, and home reloading). Because subsistence populations by definition hunt much of their food, and because this food is important economically, nutritionally, and socially (Titus et al. 2009), an inexpensive source of ammunition is required. Lead is relatively inexpensive, but use of lead in ammunition comes with risks to humans, especially children, which do not occur with non-lead substitutes. Many approaches to reducing lead exposure have been proposed or implemented. For example, human health agencies can work with ammunition manufacturers and sellers to reduce the availability of lead ammunition, facilitate the availability of inexpensive non-toxic alternatives, and offer training on the different shot patterns, velocities, and distances inherent in using materials other than lead. The most effective means of reducing lead exposure have included community-based outreach and education on the dangers of lead from ammunition to both humans and the environment. These approaches have achieved positive behavioral changes, and may result in subsistence hunters and their families choosing to use non-toxic shot and bullets for their subsistence needs.

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