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

MICHAEL J. KOSNETT

University of Colorado, Denver, c/o 1630 Welton, Suite 300, Denver, CO 80202, USA.
E-mail: Michael.Kosnett@ucdenver.edu

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.*

KOSNETT, M. J. 2009. 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. *In* R. T. Watson, M. Fuller, M. Pokras, and W. G. Hunt (Eds.). Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans. The Peregrine Fund, Boise, Idaho, USA. DOI 10.4080/ilsa.2009.0103

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).

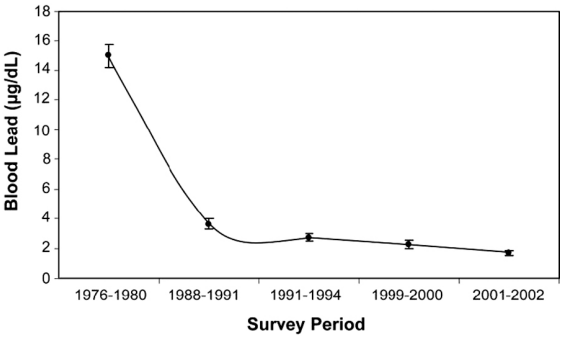

Figure 1. Blood lead concentration in U.S. Children. From: EPA, 2006 (Figure 4-3).

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).

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

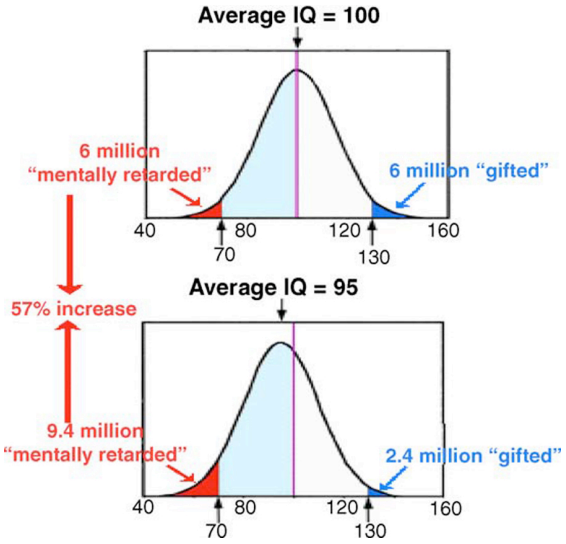

Figure 2. Changes in the number of children with IQ <70 and >130 per 100 million population based on a drop in the mean IQ of five points. Reprinted with permission, from Gilbert and Weiss, 2006.

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)

ACKNOWLEDGEMENTS

The assistance of Estelle N. Shiroma, D. Env, and Ms Kun Zhao, of ENVIRON, Emeryville, CA with the LeadSpread blood lead modeling is gratefully acknowledged.

LITERATURE CITED

ATSDR. Agency for Toxic Substances and Disease Registry. 2007. Toxicological Profile for Lead. ATSDR, Atlanta, Georgia, USA.

BARLTROP, D., AND F. MEEK. 1979. Effect of particle size on lead absorption from the gut. Archives of Environmental Health 34:280 – 285.

BIHRLE, C. 2008. An evolving perspective on lead in venison. Pages 30-35 in North Dakota Outdoors Magazine. August-September 2008. North Dakota Game and Fish Department, Bismarck, North Dakota, USA.

BORJA-ABURTO, V. H., I. HERTZ-PICCIOTTO, M. R. LOPEZ, P. FARIAS, C. RIOS, AND J. BLANCO. 1999. Blood lead levels measured prospectively and risk of spontaneous abortion. American Journal of Epidemiology 150:590-597.

CDC. CENTERS FOR DISEASE CONTROL AND PREVENTION. 1991. Preventing Lead Poisoning in Young Children. CDC, Atlanta, Georgia, USA.

CDC. CENTERS FOR DISEASE CONTROL AND PREVENTION. 2005a. Third National Report on Human Exposure to Environmental Chemicals. NCEH Pub. No. 05-0570, Lead CAS No. 7439-92-1. CDC, Atlanta, Georgia, USA.

CDC. CENTERS FOR DISEASE CONTROL AND PREVENTION. 2005b. Preventing Lead Poisoning in Young Children. CDC, Atlanta, Georgia, USA.

CHAI, S. S., AND R. C. WEBB. 1988. Effects of lead on vascular reactivity. Environmental Health Perspectives 78:85-89.

DIETRICH, K. N., M. D. RIS, P. A. SUCCOP, O. G. BERGER, AND R. L. BORNSCHEIN. 2001. Early exposure to lead and juvenile delinquency. Neurotoxicology and Teratology 23:511-518.

DOBROWOLSKA, A., AND M. MELOSIK. 2008. Bullet-derived lead in tissues of the Wild Boar (*Sus scrofa*) and Red Deer (*Cervus elaphus*). European Journal of Wildlife Research 54:231-235.

DTSC. DEPARTMENT OF TOXIC SUBSTANCES CONTROL. 2007. LeadSpread 7. DTSC, Sacramento, California, USA.

DURLACH, V., F. LISOVOSKI, A. GROSS, G. OSTERMANN, M. LEUTENEGGER. 1986. Appendectomy

in an unusual case of lead poisoning. Lancet 1(8482):687-688

EPA. ENVIRONMENTAL PROTECTION AGENCY. 1997. Exposure Factors Handbook. U.S. Environmental Protection Agency, National Center for Environmental Assessment, Washington, DC, USA.

EPA. ENVIRONMENTAL PROTECTION AGENCY. 2006. Air Quality Criteria for Lead (Final). U.S. Environmental Protection Agency, National Center for Environmental Assessment, Washington, DC, USA.

FINE, B. P., T. VETRANO, J. SKURNICK, AND A. TY. 1988. Blood pressure elevation in young dogs during low-level lead poisoning. Toxicology and Applied Pharmacology 93:388-393.

GILBERT, S. G., AND B. WEISS. 2006. A rationale for lowering the blood lead action level from 10 to 2 microg/dL. Neurotoxicology 27:693-701.

GUSTAVSSON, P., AND L. GERHARDSSON. 2005. Intoxication from an accidentally ingested lead shot retained in the gastrointestinal tract. Environmental Health Perspectives 113:491-493

HILMAN, F. E. 1967. A rare case of chronic lead poisoning: polyneuropathy traced to lead shot in the appendix. Industrial Medicine and Surgery 36:488-492

HOGBIN, M., A. SHAW, AND R. S. ANAND. 1999. Food portions and servings. How do they differ. Nutrition Insights, Volume 11, March 1999. USDA Center for Nutrition Policy and Promotion, Washington, DC, USA.

HU, H., A. ARO, M. PAYTON, S. KORRICK, D. SPARROW, WEISS S. T., AND A. ROTNITZKY. 1996. The relationship of bone and blood lead to hypertension. Journal of the American Medical Association 275:1171-1176.

IQBAL, S. 2008. Epi-Aid Trip Report:Assessment of human health risk from consumption of wild game meat with possible lead contamination among the residents of the State of North Dakota. National Center for Environmental Health, Centers for Disease Control and Prevention, Atlanta, Georgia, USA.

JOHANSEN, P., G. ASMUND, AND F. RIGET. 2004. High human exposure to lead through consumption of birds hunted with lead shot. Environmental Pollution 127:125-129.

JOHANSEN, P., H. S. PEDERSEN, G. ASMUND, AND F. RIGET. 2006. Lead shot from hunting as a source of lead in human blood. Environmental Pollution 142:93-97.

KOSNETT, M. J., R. P. WEDEEN, S. J. ROTHENBERG, K. L. HIPKINS, B. L. MATERNA, B. S. SCHWARTZ, H. HU, AND A. WOOLF. 2007. Recommendations for medical management of adult lead exposure. Environmental Health Perspectives 115:463-471.

LANPHEAR, B. P., R. HORNUNG, J. KHOURY, K. YOLTON , P. BAGHURST, D. BELLINGER, R. L. CANFIELD, K. N. DIETRICH, R. BORNSCHEIN, T. GREENE, S. J. ROTHENBERG, H. L. NEEDLEMAN, L. SCHNAAS, G. WASSERMAN, J. GRAZIANO, AND R. ROBERTS. 2005. Low-level lead exposure and children's intellectual function: An international pooled analysis. Environmental Health Perspectives 113:894-899.

MATEO, R., M. RODRIGUEZ-DE LA CRUZ, D. VIDAL, M. REGLERO, AND P. CAMARERO. 2007. Transfer of lead from shot pellets to game meat during cooking. Science of the Total Environment. 372:480-485.

MUNTNER P., S. VUPPUTURI, J. CORESH, AND V. BATUMAN. 2003. Blood lead and chronic kidney disease in the general United States population: Results from NHANES III. Kidney International 63:104-150.

NAVAS-ACIEN A., E. GUALLAR, E. K. SILBERGELD, AND S. J. ROTHENBERG. 2007. Lead exposure and cardiovascular disease – a systematic review. Environmental Health Perspectives 115:472-482.

NAWROT, T. S., L. THIJS, E. M. DEN HOND, H. A. ROELS, AND J. A. STAESSEN. 2002. An epidemiological re-appraisal of the association between blood pressure and blood lead: a meta-analysis. Journal of Human Hypertension 16:123-131.

NCHS. NATIONAL CENTER FOR HEALTH STATISTICS. 1984. Blood lead levels for persons ages 6 months to 74 years. United States, 1976-1980. Vital and Health Statistics. Series 11, No. 233. Pub. No. (PHS) 84-1683. National Center for Health Statistics, Washington, DC, USA.

NDDH. NORTH DAKOTA DEPARTMENT OF HEALTH. 2008. News release: State Health Department Announces Preliminary Findings in Blood Lead Level Study. November 5, 2008. North Dakota Department of Health, Bismarck, North Dakota, USA.

PIRKLE, J. L., J. SCHWARTZ., J. R. LANDIS., AND W. R. HARLAN. 1985. The relationship between blood lead levels and blood pressure and its cardiovascular risk implications. American Journal of Epidemiology 121:246-258.

SCHNAAS, L., S. J. ROTHENBERG, M. F. FLORES, S. MARTINEZ, C. HERNANDEZ, E. OSORIO, S. R. VELASCO, AND E. PERRONI. 2006. Reduced intellectual development in children with prenatal lead exposure. Environmental Health Perspectives 111:791-797.

SCHOBER, S. E., B. MIRAL, B. I. GRAUDBARD, D. J. BRODY, AND K. M. FLEGAL. 2006. Blood lead levels and death from all causes, cardiovascular disease, and cancer: Results from the NHANES III mortality study. Environmental Health Perspectives 114:1538- 1541.

SCHWARTZ, J. 1988. The relationship between blood lead and blood pressure in the NHANES II survey. Environmental Health Perspectives 78:15-22.

SCHWARTZ, J. 1995. Lead, blood pressure, and cardiovascular disease in men. Archives of Environmental Health 50:31-37.

SHIH, R. A., T. A. GLASS, K. BANDEEN-ROCHE, M. C. CARLSON, K. I. BOLLA, A. C. TODD, AND B. S. SCHWARTZ. 2006. Environmental lead exposure and cognitive function in community-dwelling older adults. Neurology 67:1556-1562.

STAESSEN, J. A., R. R. LAUWERYS, J. P. BUCHET, C. J. BULPITT, D. RONDIA, Y. VANRENTERGHEM, AND A. AMERY. 1992. Impairment of renal function with increasing blood lead concentrations in the general population. The Cadmibel Study Group. New England Journal of Medicine 327:151-156.

TSAIH. S. W., S. KORRICK, J. SCHWARTZ, C. AMARASIRIWARDENA, A. ARO, D. SPARROW, AND H. HU. 2004. Lead, diabetes, hypertension, and renal function: The normative aging study. Environmental Health Perspectives 112:1178-1182.

TSUJI, L. J. S., B. C. WAINMAN, I. D. MARTIN, J. P. WEBER, C. SUTHERLAND, E. N. LIBERDA, AND E. NIEBOER. 2008a. Elevated blood-lead levels in First Nation people of northern Ontario Canada: Policy implications. Bulletin of Environmental Contamination and Toxicology 80:14-18.

TSUJI, L.J.S., B. C. WAINMAN, I. D. MARTIN, C. SUTHERLAND, J. P. WEBER, P. DUMAS, AND E. NIEBOER. 2008b. The identification of lead ammunition as a source of lead exposure in First Nations: The use of lead isotope ratios. Science of the Total Environment 393:291-298.

VAZIRI, N. D., AND M. KHAN. 2007. Interplay of reactive oxygen species and nitric oxide in the pathogenesis of experimental lead-induced hypertension. Clinical and Experimental Pharmacology and Physiology 34:920-925.

WASSERMAN, G. A., X. LIU, D. POPOVAC, P. FACTOR-LITVAK, J. KLINE, C. WATERNAUX, N. LOIACONO, AND J. H. GRAZIANO. 2000. The Yugoslavia prospective lead study: contributions of prenatal and postnatal lead exposure to early intelligence. Neurotoxicology and Teratology 22:811-818.

WEISSKOPF, M. G., S. P. PROCTOR, R. O. WRIGHT, J. SCHWARTZ, A. SPIRO, D. SPARROW, H. NIE, AND H. HU. 2007. Cumulative lead exposure and cognitive performance among elderly men. Epidemiology 18:59-66.