available at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/scitotenv

Lead shot contribution to blood lead of First Nations people: The use of lead isotopes to identify the source of exposure

Leonard J.S. Tsuji[a,*], *Bruce C. Wainman*[b], *Ian D. Martin*[a], *Celine Sutherland*[c], *Jean-Philippe Weber*[d], *Pierre Dumas*[d], *Evert Nieboer*[b,e]

[a]*Department of Environment and Resource Studies, University of Waterloo, Waterloo, Ontario, N2L 3G1, Canada*
[b]*Faculty of Health Sciences, McMaster University, Hamilton, Ontario, L8N 3Z5, Canada*
[c]*Attawapiskat First Nation Health Services, Attawapiskat, Ontario, P0L 1A0, Canada*
[d]*Centre de toxicologie, Institut national de sante publique du Quebec, Quebec City, Quebec, G1V 5B3, Canada*
[e]*Institute of Community Medicine, University of Tromso, Tromso N-9037, Norway*

ARTICLE INFO

Article history:
Received 4 February 2008
Received in revised form
20 June 2008
Accepted 25 June 2008
Available online 3 August 2008

Keywords:
Lead shotshell
Subsistence hunting
Waterfowl
Lead isotope ratios
Blood lead
First Nations

ABSTRACT

Although lead isotope ratios have been used to identify lead ammunition (lead shotshell pellets and bullets) as a source of exposure for First Nations people of Canada, the actual source of lead exposure needs to be further clarified. Whole blood samples for First Nations people of Ontario, Canada, were collected from participants prior to the traditional spring harvest of water birds, as well as post-harvest. Blood-lead levels and stable lead isotope ratios prior to, and after the harvest were determined by ICP-MS. Data were analyzed by paired *t*-tests and Wilcoxon Signed-Ranks tests. All participants consumed water birds harvested with lead shotshell during the period of study. For the group excluding six males who were potentially exposed to other sources of lead (as revealed through a questionnaire), paired *t*-tests and Wilcoxon Signed-Ranks tests showed consistent results: significant ($p<0.05$) increases in blood-lead concentrations and blood levels of $^{206}Pb/^{204}Pb$ and $^{206}Pb/^{207}Pb$ towards the mean values we previously reported for lead shotshell pellets; and a significant decrease in $^{208}Pb/^{206}Pb$ values towards the mean for lead shotshell pellets. However, when we categorized the group further into a group that did not use firearms and did not eat any other traditional foods harvested with lead ammunition other than waterfowl, our predictions for $^{206}Pb/^{204}Pb$, $^{206}Pb/^{207}Pb$ and $^{208}Pb/^{206}Pb$ hold true, but there was not a significant increase in blood-lead level after the hunt. It appears that the activity of hunting (i.e., use of a shotgun) was also an important route of lead exposure. The banning of lead shotshell for all game hunting would eliminate a source of environmental lead for all people who use firearms and/or eat wild game.

1. Introduction

Lead is a toxic metal that exerts its effects on bodily systems even at low levels of exposure (ATSDR, 2005; CDC, 2005). The use of lead shotshell to harvest game birds has been suggested as a source of lead in humans (Johansen et al., 2006; Levesque et al., 2003; Tsuji and Nieboer, 1997) through the consumption of lead pellets and/or fragments that contaminate the meat (Scheuhammer et al., 1998; Tsuji et al., 1999). However, a recent blood-lead study of First Nations people in Canada revealed using lead isotope ratios that although the source of lead exposure for the First Nations people could be identified as lead ammunition, the isotope ratios for lead shotshell pellets and bullets were indistinguishable (Tsuji et al., 2008a). It was concluded that lead-contaminated meat from

* *Corresponding author*. Tel.: +1 519 888 4567x32762; fax: +1 519 746 0292.
E-mail address: ljtsuji@fes.uwaterloo.ca (L.J.S. Tsuji).

0048-9697/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.scitotenv.2008.06.048

game harvested with lead bullets may also be contributing to the lead body burden (Tsuji et al., 2008a).

Owing to the seasonal nature of harvesting activities for aboriginal groups (Bjerregard et al., 2004; Johansen et al., 2006; Kosatsky, 1998; Tsuji and Nieboer, 1999), blood-lead levels should vary with the harvesting seasons. Blood-lead levels should be lowest prior to the bird-harvesting season and highest afterwards, if game birds harvested with lead shotshell are a major source of lead for subsistence harvesting groups (Bjerregard et al., 2004; Johansen et al., 2006; Kosatsky, 1998). In a study by Kosatsky (1998), it was shown that blood-lead concentrations increased two months following the goose hunting season in eastern James Bay Cree of northern Quebec, Canada. Similarly, in native Greenlanders (Inuit with some European genes; Bjerregard et al., 2004), Johansen et al. (2006) have reported a seasonal variation in blood-lead levels, which were highest when bird consumption peaked; however, some participants had relatively high blood-lead concentrations but low bird intakes. Johansen et al. (2006) suggested the use of stable lead isotope ratios as a way to distinguish between sources of lead.

Lead has four stable isotopes: three that are radiogenic (^{206}Pb is from the radioactive decay of ^{238}U; ^{207}Pb from ^{235}U; and ^{208}Pb from ^{232}Th), and one non-radiogenic isotope (^{204}Pb; Rabinowitz, 1995; Sangster et al., 2000). The relative abundance of stable isotopes can be used to distinguish between lead products, because there is variability for lead originating from different geological formations (i.e., ore bodies; Rabinowitz, 1995; Sangster et al., 2000). Stable lead isotope ratios have been successfully used in humans (Graziano et al., 1996; Gulson et al., 1998; Maddaloni et al., 1998) to differentiate between sources of environmental lead when sample size has been limited. In this paper, we examine blood-lead levels and stable lead isotope ratios prior to, and after the traditional spring harvest of water birds by First Nation Cree of the western James Bay region, northern Ontario, Canada, to determine whether such birds harvested with lead shotshell constitute a major source of lead for this subsistence harvesting group. The consumption of lead-contaminated food must be substantial to be seen as a change in blood-lead concentration and/or isotope ratio (Gulson et al., 1999). In the present study, we first predict that there should be an increase in blood-lead concentrations post-spring harvest. Second, since blood is a mixture of both contemporaneous sources of environmental lead and endogenous bone contribution (Gulson et al., 1995; Smith et al., 1996), we predict that blood-lead isotope ratios after the spring harvest should vary in the direction of the isotope ratios of lead shotshell pellets when compared to pre-spring harvest values. Indeed, 24-hour, human (n=6) dosing experiments by Graziano et al. (1996) and Maddaloni et al. (1998) have shown that ingested lead can impact pre-dosing blood-lead isotope ratios such that post-dosing, blood-lead isotope ratios varied towards the lead isotope ratio of the dosing agent.

2. Methods

2.1. Study sites

First Nation Cree that participated in the present study resided in the remote western James Bay area of northern Ontario, Canada. Sources of environmental lead were limited in this region. Both water and soil-lead concentrations have been reported as being low, with air levels below the Ontario Ambient Air Quality Criterion of 5 μg/m^3 (OMHE, 1989). Most dwellings were built after the lead content in paint had been reduced (Tsuji et al., 1999). Until the 1990s, most First Nations houses lacked indoor plumbing, and when indoor plumbing was installed, copper and plastic piping and fittings were used, as well as lead-free solder (Tsuji et al., 2000). Surface water in the region has been reported to contain a minimal amount of lead (McCrea and Fischer, 1986). Lastly, the use of white lead (89% $PbCO_3$, 11% linseed oil) for major repairs of wood and canvas boats was not of concern, as fibreglass boats have grown in popularity; while, people were aware of the toxicity of this type of lead and had taken proper precaution with respect to storage and use of this product (Fortin and Decou, 1995).

2.2. Sample collection

This study was approved by the McMaster University Research Ethics Board. All participants signed a consent form prior to the initial blood collection and then completed a questionnaire in an interview format (to collect personal data pertaining to demographics, lifestyle, and the level of consumption of traditional foods over the specific period of the study), after the second blood sample was collected. The hunting of waterfowl during the spring-harvest season (typically mid-April to the end of May) is a way of life for the Cree. Whole blood samples were collected from participants (females, n=10; males, n=14) prior to the spring harvest of 2000 (i.e., late March to early April) in lavender-top (with EDTA), 6-ml plastic Vacutainer tubes. Blood samples were mixed, allowed to cool to room temperature, then frozen, and stored at −20 °C. Also, whole-blood samples were collected from participants after the spring harvest and the threat of community flooding had subsided (i.e., early July of 2000; approximately one-and-a-half months after the end of the spring-waterfowl harvest). Post-harvest blood samples were collected from 6 of the original 10 females sampled and 11 of the original 14 males; these participants constitute our cohort. People who were not re-sampled were absent during the re-sampling period. One female participant who donated pre- and post-harvest blood samples was excluded from the study, because her blood-lead concentration was <10 μg/L (our detection limit based on three times the average standard deviation of noise); thus, isotope values could not be determined using our protocol. Blood samples were shipped frozen to the Centre de toxicologie, Institut national de sante publique du Quebec for lead and isotope determinations.

2.3. Blood-lead determination

Blood-lead determination was by electrothermal atomic absorption spectrometry (Perkin Elmer model ZL 4100). Samples were simply diluted and injected into the instrument (see Tsuji et al., 2008b for a detailed account). Accuracy and precision were checked using reference material from the Centre de toxicologie's administered interlaboratory comparison program; while, periodic evaluations were also performed

using external proficiency testing (e.g., US Centers for Disease Control and Prevention).

2.4. *Stable lead isotope determination*

Lead isotope ratios were determined by inductively coupled plasma mass spectrometry (ICP-MS; Perkin Elmer Sciex Elan 6000) and relative abundances were expressed as the ratios $^{206}Pb/^{204}Pb$, $^{206}Pb/^{207}Pb$ and $^{208}Pb/^{206}Pb$. Operating conditions and mass spectrometer settings were as follows: 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 was cross flow; interface cones were platinum; dwell time=25 ms; number of sweeps=500; and number of replicates=4 (Tsuji et al., 2008a). Analytical accuracy was assessed using the Pb standard NIST SRM-982 (n=20; % accuracy: 206/204=−0.27; 206/207=−0.25; 208/206=0.13); while, the blood material reference Quebec Multielement External Quality Assessment Scheme 99BO1 was employed to evaluate the analytical precision (n=22; %RSD: 206/204=0.32; 206/207=0.22; 208/206=0.21) during runs and the mass bias of the instrument.

Simply, blood-lead samples ≥80 μg/L were diluted 10 fold in 0.1% Triton-X100 and 0.5% ammonia solution. To avoid nebulisation problems, a minimum 10-fold dilution was required. For blood-lead samples <80 μg/L, treatments were needed to eliminate some parts of the matrix; acidic deproteinisation removed most of the organic material in order to eliminate clogging formation during the nebulising process.

2.5. *Statistical analyses*

The questionnaire revealed that some of the participants had been involved in hobbies/work (after the first blood collection, but prior to the second blood collection) known to be associated with lead exposure (e.g., boat repairs [the use of basic lead carbonate in oil; Fortin and Decou, 1995] and renovation of old buildings where leaded paint was used); these individuals (all males, n=6) were analyzed separately as a group, as lead exposure was potentially not just from the consumption of lead-contaminated meat. For this group of males, paired t-tests (two-tailed, as we make no predictions) were performed for blood-lead concentration and isotope ratios $^{206}Pb/^{204}Pb$, $^{206}Pb/^{207}Pb$ and $^{208}Pb/^{206}Pb$; also, data were analyzed by Wilcoxon Signed-Ranks tests (two-tailed). Data analyses were similar for the main group, except, tests were one-tailed. Power achieved for the effect size observed in paired t-tests was calculated according to Faul et al. (2007).

3. Results

All participants consumed waterfowl harvested with lead shotshell (range: 8–72 portions; each portion=75 g) during the

Table 1 – Blood-lead levels and lead isotope ratios in First Nations people before and after the waterfowl hunting season

Exposure group	Sub-group	Subject ID	Sex	Blood Pb (μg/L)		Pb isotope 206/204		Pb isotope 206/207		Pb isotope 208/206	
				Before [a]	After [b]	Before [a]	After [b]	Before [a]	After [b]	Before [a]	After [b]
Group 1: lead shotshell exposure	a) non-hunter [c]	1008	Female	33	33	18.38	18.74	1.182	1.202	2.061	2.037
		1014	Female	25	19	18.27	18.54	1.179	1.186	2.065	2.057
		1529	Male	33	87	18.09	18.44	1.167	1.184	2.078	2.057
		6000	Male	73	137	18.52	18.90	1.183	1.216	2.054	2.029
	b) hunter [d]	1042	Female	33	46	18.56	18.82	1.200	1.207	2.046	2.035
		1043	Female	25	31	18.25	18.30	1.182	1.171	2.061	2.075
		1047	Female	41	70	18.93	19.09	1.215	1.216	2.020	2.020
		1504	Male	172	224	18.73	18.89	1.201	1.211	2.041	2.027
		1528	Male	41	41	18.41	18.64	1.187	1.201	2.057	2.040
		1550	Male	41	44	18.56	18.72	1.193	1.199	2.045	2.040
Group 2: lead shotshell exposure and additional lead exposure [e]		1501	Male	178	157	18.56	18.45	1.190	1.185	2.050	2.054
		1520	Male	66	54	17.95	18.06	1.157	1.155	2.091	2.091
		1547	Male	56	73	18.25	18.29	1.177	1.169	2.063	2.089
		1521	Male	64	309	18.78	18.77	1.203	1.197	2.032	2.040
		1548	Male	44	46	18.06	18.00	1.158	1.161	2.086	2.084
		6001	Male	35	54	18.18	18.18	1.175	1.165	2.067	2.088

[a] Samples were collected in late March and early April of 2000, prior to the start of the spring harvest of waterfowl. The spring harvest was from mid-April to the end of May.
[b] Samples were collected in early July of 2000, approximately one-and-a-half months after the spring harvest of waterfowl was finished.
[c] These participants consumed waterfowl harvested with lead shotshell (April–June, 2000), but did not consume any other game harvested with lead ammunition and did not participate in any other activity during the study period that would have exposed them to other sources of lead, including hunting.
[d] These participants consumed waterfowl harvested with lead shotshell and consumed other game harvested with lead ammunition, while participating in the activity of hunting. However, this group did not participate in other activities which would have exposed them to additional sources of lead.
[e] These participants consumed waterfowl harvested with lead shotshell and consumed other game harvested with lead ammunition, while participating in the activity of hunting and other activities which may have exposed them to additional sources of lead during the study period (e.g., boat repairs using basic lead carbonate in oil, renovation of old buildings where lead paint was used).

months of April, May, and June of 2000, except for subjects numbered 1008 and 1043 (they consumed waterfowl only in April and May). Large mammals were also consumed (8/16 people; range: 1–48 portions), as well as fish (6/16 participants; range: 1–36). Small mammals (2/16 individuals; range 1–2 portions) and upland game birds (only one person, 3 portions) were rarely eaten during this time period. Twelve of the 16 people in the study participated in the spring harvest; the four individuals (ID # 1008, 1014, 1529, 6000; Table 1) who did not participate in the spring hunt, also did not eat upland game birds, fish, large mammals and only one ate a small mammal (one portion; method of harvest was a snare), but did consume waterfowl harvested with lead shotshell.

Blood-lead concentrations and isotope ratios in participants (including the six males potentially exposed to other lead sources) before and after the spring harvest of waterfowl are given in Table 1. Paired *t*-tests (Table 2) and Wilcoxon Signed-Ranks tests (Table 2) showed consistent results: significant increases in blood-lead concentration, $^{206}Pb/^{204}Pb$, and $^{206}Pb/^{207}Pb$ in participants from the first to the second sample, which were accompanied by a significant decrease in $^{208}Pb/^{206}Pb$ values. By contrast, paired *t*-tests and Wilcoxon Signed-Ranks tests both showed no significant increases in blood-lead concentration, $^{206}Pb/^{204}Pb$, $^{206}Pb/^{207}Pb$ and $^{208}Pb/^{206}Pb$ values for the group of six males potentially exposed to other lead sources (Table 2).

4. Discussion

Blood-lead concentration results were consistent with the hypothesis that lead-contaminated game bird meat is a significant source of exposure for First Nation Cree of the western James Bay region, a conclusion supported by the significant increase in blood-lead concentrations of our main study group after the spring harvest of water birds, as predicted; while, that of males potentially exposed to other sources of lead did not increase significantly. Similarly, Kosatsky (1998) reported increases in blood-lead levels two months following the spring and fall harvests of waterfowl in eastern James Bay Cree for all age groups (0–5 years, 6–11, 12–19, 20–49, 50+) after test year and sex adjustments. Johansen et al. (2006) have also reported

Table 2 – Tests of difference in blood-lead levels and lead isotope ratios in First Nations people before and after the waterfowl hunting season

Exposure group	Variable (before–after hunt[a])	Paired *t*-test					Wilcoxon Signed-Ranks Test
		Mean difference	*t*-statistic	*df*	*p*-value	Observed power[b]	*p*-value
Group 1: lead shotshell exposure[c]	Blood Pb (μg/L)	−21.500	−2.594	9	**0.01452**	0.77246	**0.01489**
(1-tailed test)	Pb isotope ratio 206/204	−0.238	−7.043	9	**0.00003**	0.99999	**0.00248**
	Pb isotope ratio 206/207	−0.010	−2.792	9	**0.01049**	0.82232	**0.01416**
	Pb isotope ratio 208/206	0.011	2.920	9	**0.00852**	0.85208	**0.01641**
Group 1a: non-hunter[d]	Blood Pb (μg/L)	−28.000	−1.551	3	0.10937	0.33200	0.14253
(1-tailed test)	Pb isotope ratio 206/204	−0.340	−14.077	3	**0.00039**	1.00000	**0.03395**
	Pb isotope ratio 206/207	−0.019	−3.591	3	**0.01849**	0.85502	**0.03395**
	Pb isotope ratio 208/206	0.020	4.966	3	**0.00784**	0.97564	**0.03395**
Group 1b: hunter[e]	Blood Pb (μg/L)	−17.167	−2.107	5	**0.04446**	0.56747	**0.02156**
(1-tailed test)	Pb isotope ratio 206/204	−0.170	−5.731	5	**0.00113**	0.99922	**0.01301**
	Pb isotope ratio 206/207	−0.005	−1.262	5	0.13132	0.29228	0.12443
	Pb isotope ratio 208/206	0.006	1.186	5	0.14451	0.26765	0.13926
Group 2: lead shotshell exposure and additional lead exposure[f]	Blood Pb (μg/L)	−41.667	−1.012	5	0.35794	0.13194	0.46307
(2-tailed test)	Pb isotope ratio 206/204	0.005	0.160	5	0.87925	0.05200	0.78646
	Pb isotope ratio 206/207	0.005	2.467	5	0.05673	0.52347	0.07474
	Pb isotope ratio 208/206	−0.010	−2.026	5	0.09859	0.37518	0.07962

The bolded values are significant ($p<0.05$).

[a] Samples were collected in late March and early April of 2000 (before the start of the spring harvest of waterfowl) and in early July of 2000, approximately one-and-a-half months after the spring harvest of waterfowl was finished. The spring harvest was from mid-April to the end of May.

[b] Power achieved for the effect size observed in paired t-tests was calculated according to Faul et al. (2007).

[c] These participants consumed waterfowl harvested with lead shotshell (April–June, 2000).

[d] These participants consumed waterfowl harvested with lead shotshell, but did not consume any other game harvested with lead ammunition and did not participate in any other activity during the study period that would have exposed them to other sources of lead, including hunting.

[e] These participants consumed waterfowl harvested with lead shotshell and consumed other game harvested with lead ammunition, while participating in the activity of hunting. However, this group did not participate in other activities which would have exposed them to additional sources of lead.

[f] These participants consumed waterfowl harvested with lead shotshell and consumed other game harvested with lead ammunition, while participating in the activity of hunting and other activities which may have exposed them to additional sources of lead during the study period (e.g., boat repairs using basic lead carbonate in oil, renovation of old buildings where lead paint was used).

a seasonal variation in blood-lead levels where levels were highest when bird consumption was at its highest. The consumption of lead in the diet must be substantial to be seen as a change in blood-lead concentration and/or isotope ratio because of low absorption and the clearance rate of lead from blood (Gulson et al., 1999).

Isotope ratios $^{206}Pb/^{204}Pb$, $^{206}Pb/^{207}Pb$ and $^{208}Pb/^{206}Pb$ showed no significant trends for the special group of six males who were potentially exposed to alternative sources of lead (group 2, Table 2). However, isotope ratios for our main study groups behaved in the way we predicted in that $^{206}Pb/^{204}Pb$ and $^{206}Pb/^{207}Pb$ values increased significantly after the spring harvest. Values of these isotope ratios varied towards the mean values we have reported for lead shotshell pellets used in the region ($^{206}Pb/^{204}Pb = 19.19$; $^{206}Pb/^{207}Pb = 1.223$) and away from the mean levels we have found for atmospheric lead of the region ($^{206}Pb/^{204}Pb = 18.19$; $^{206}Pb/^{207}Pb = 1.172$; Tsuji et al., 2008a); while, $^{208}Pb/^{206}Pb$ values significantly decreased post-harvest towards the mean level found for lead shotshell pellets ($^{208}Pb/^{206}Pb = 2.011$) and away from the mean level we have reported for atmospheric lead of the western James Bay region ($^{208}Pb/^{206}Pb = 2.081$; Tsuji et al., 2008a). Likewise, in a 24-hour dosing experiment by Graziano et al. (1996) of six healthy adults (2 males, 4 females; 23–28 years of age) with lead in the form of sherry stored in lead crystal decanters ($^{206}Pb/^{207}Pb$ of the lead crystal decanter = 1.078), $^{206}Pb/^{207}Pb$ values decreased significantly from a mean of 1.202 to 1.137. Maddaloni et al. (1998) have also reported for six healthy adults (2 males and 4 females; 24–33 years of age) who were dosed (24-hour experiment) with 250 μg Pb/70 kg body weight (lead was in a soil matrix delivered in a gelatin capsule; $^{206}Pb/^{207}Pb = 1.1083 \pm 0.0002$) that average $^{206}Pb/^{207}Pb$ values dropped from 1.195 to 1.167; when the subjects had been fed, the change was in the direction of the $^{206}Pb/^{207}Pb$ value of lead-in-soil, but the trend was not as dramatic.

Testing of paired (before versus after spring harvest) observations offers maximum statistical power in a dataset with relatively small sample sizes. Nevertheless, observed power of the *t*-tests for blood lead in Group 1 and Group 1b was below 0.80. This casts some doubt on the significant differences found in comparison of paired individuals before and after the hunt; however, the confirmatory significant result for the Wilcoxon test supports the rejection of the null hypothesis of no difference in blood lead before and after the hunt for these groups of individuals.

Although all our predictions were shown to be correct, the issue of confounders must also be addressed. There are three confounders of interest: 1. Fumes from lead bullets and primers have been recognized as a source of lead exposure for people handling firearms (Anderson et al., 1997; Bonanno et al., 2002; Valway et al., 1989). 2. Hand-to-mouth activities have also been cited as a source of concern (Bonanno et al., 2002; Valway et al., 1989). 3. The collinearity between waterfowl and other game consumption makes it difficult to tease out effects (Kosatsky et al., 2001) or in other words, people who eat a lot of one type of traditional food, typically eat a lot of other types of traditional food (Bjerregard et al., 2004). In the present study, all participants ate waterfowl during the study period and many ate other types of traditional foods; nevertheless, there were four individuals (ID # 1008, 1014, 1529, 6000; Table 1) who did not use firearms, did not stay at the spring camps, did not eat any other traditional foods harvested with leaded ammunition other than waterfowl, and did not participate in any known activity associated with increased lead exposure. For these individuals as a group (1a), our predictions for $^{206}Pb/^{204}Pb$, $^{206}Pb/^{207}Pb$ and $^{208}Pb/^{206}Pb$ hold true (Table 2), but there was not a significant increase in blood-lead level after the hunt, as the two female blood-lead concentrations either stayed the same or decreased in contrast to the two males whose blood-lead concentrations almost doubled. This apparent gender difference needs to be explored further. In contrast, results for group 1b suggests that hunting activity (i.e., use of a firearm) may expose people to an isotopically different source of lead than that of lead pellets (and lead bullets which have been shown to be isotopically indistinct with respect to lead pellets; Tsuji et al., 2008a) as $^{206}Pb/^{207}Pb$ and $^{208}Pb/^{206}Pb$ values before and after the hunt for this group were not significantly different (Table 2, cf. group 1a). However, blood-lead levels were significantly greater after the hunt (Table 2, cf. group 1a) and $^{206}Pb/^{204}Pb$ values increased significantly. Perhaps the ammunition primer, lead styphnate, was the source of lead exposure (Anderson et al., 1997; Bonanno et al., 2002; Valway et al., 1989). People who hunted (group 1b) would be exposed to this source of lead; while, the people who did not hunt (group 1a) would not be exposed to the primer.

The use of lead shotshell for the hunting of waterfowl was banned in 1991, in the US (USFWS, 1988) and for migratory bird hunting in Canada, in 1999 (Environment Canada, 2000). Nevertheless, lead shotshell can still be used legally for the harvesting of upland game birds and small mammals in North America. In Canada, there are no federal laws restricting the use of lead shotshell in this capacity because upland game falls under the jurisdiction of the provincial governments (see for e.g., Ontario Provincial Offences, 1999); only migratory game birds are regulated by the federal "non-toxic" shot policy (Environment Canada, 2000). A similar situation exists in the US with the separation of power between federal and state governments (Thomas, 1997). Moreover, it has been shown that if lead shotshell is still legally available for upland game hunting, lead shotshell will also be used for waterfowl hunting in remote areas (Balogh, 1999). Clearly, any game harvested with lead shotshell may become contaminated to the point where the meat is unsuitable for human consumption. There is also the issue of additional lead exposure through the use firearms. The banning of lead shotshell for all game hunting would eliminate a significant source of environmental lead, especially for subsistence hunting groups.

Acknowledgements

We thank all the participants and Chief and Councils. We also acknowledge funding from the Toxic Substances Research Initiative (Health Canada).

REFERENCES

Anderson KE, Fischbein A, Kestenbaum D, Sassa S, Alvares AP, Kappas A. Plumbism from airborne lead in a firing range. Am J Med 1997;63:306–12.

ATSDR. *Toxicological profile for lead* (draft) US Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry, US. http://www.atsdr.cdc.gov/toxprofiles/tp2.html2005 [accessed 27 February 2007].
Balogh G. Lead and the spectacled eider. Endanger Species Bull 1999;24:6.
Bjerregard P, Johansen P, Mulvad G, Pederson HS, Hansen JC. Lead sources in human diet in Greenland. Environ Health Perspect 2004;112:1496–8.
Bonanno J, Robson MG, Buckley B, Modica M. Lead exposure at a covered outdoor firing range. Bull Environ Contam Toxicol 2002;68:315–23.
CDC. Preventing lead poisoning in young children. Atlanta, GA: US Centers for Disease Control and Prevention; 2005.
Environment Canada. Migratory bird regulations. Ottawa, Canada: Government of Canada; 2000.
Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behavior Res Methods 2007;39:175–91.
Fortin BM, Decou ML. White lead: reducing exposure to a lead source in the James Bay communities. Public Health and Epidemiology Report Ontario, vol. 6. ; 1995. p. 145–8.
Graziano JH, Blum CB, Lolacono NJ, Slavkovich V, Manton WI, Pond S, et al. A human *in vivo* model for the determination of lead bioavailability using stable isotope dilution. Environ Health Perspect 1996;104:176–9.
Gulson BL, Mahaffey KR, Mizon KJ, Korsch MJ, Cameron MA, Vimpani G. Contribution of tissue lead to blood lead in adult female subjects based on stable lead isotope methods. J Lab Clin Med 1995;125:703–12.
Gulson BL, Jameson CW, Mahaffey KR, Mizon K, Patison N, Law AJ, et al. Relationships of lead in breast milk to lead in blood, urine, and diet of the infant mother. Environ Health Perspect 1998;106:667–74.
Gulson BL, Mahaffey KR, Jameson CW, Patison N, Law AJ, Mizon KJ, et al. Impact of diet on lead in blood and urine in female adults and relevance to mobilization of lead from bone stores. Environ Health Perspect 1999;107:257–63.
Johansen P, Pedersen HS, Asmund G, Riget F. Lead shot from hunting as a source of lead in human blood. Environ Pollut 2006;142:93–7.
Kosatsky T. Human health risk associated with environmental lead exposure. In: Money S, editor. Hunting with lead shot—wildlife and human health concerns. Hull, Canada: Canadian Wildlife Service; 1998. p. 88–98.
Kosatsky T, Przybysz R, Weber JP, Kearney J. Puzzling elevation of blood lead levels among consumers of freshwater sport fish. Arch Environ Health 2001;56:111–6.
Levesque B, Duchesne JF, Gariepy C, Rhainds M, Dumas P, Scheuhammer AM, et al. Monitoring of umbilical cord blood lead levels and sources assessment among the Inuit. Occup Environ Med 2003;60:693–5.
Maddaloni M, Lolacono N, Manton W, Blum C, Drexler J, Graziano J. Bioavailability of soilborne lead in adults by stable isotope dilution. Environ Health Perspect 1998;106:1589–94.
McCrea RC, Fischer JD. Heavy metal and organochlorine contaminants in the five major Ontario rivers in the Hudson Bay Lowland. Water Pollut Res J Can 1986;21:225–34.
OMHE. Blood lead concentrations and associated risk factors in a sample of northern children, 1987. Ottawa, Ontario: Ontario Ministries of Health and the Environment; 1989.
Ontario Provincial Offences. Justice of the Peace/1999 Edition. Ontario, Canada: Government of Ontario; 1999.
Rabinowitz MB. Stable isotopes of lead for source identification. Clin Toxicol 1995;33:649–55.
Sangster DF, Outridge PM, Davis WJ. Stable lead isotope characteristics of lead ore deposits of environmental significance. Environ Rev 2000;8:115–47.
Scheuhammer AM, Perrault JA, Routhier E, Braune BM, Campbell GD. Elevated lead concentrations in edible portions of game birds harvested with lead shot. Environ Pollut 1998;102:251–7.
Smith DR, Osterloh JD, Flegal AR. Use of endogenous, stable lead isotopes to determine release of lead from the skeleton. Environ Health Perspect 1996;104:60–6.
Thomas VG. The environmental and ethical implications of lead shot contamination of rural lands in North America. J Agric Environ Ethics 1997;10:41–54.
Tsuji LJS, Nieboer E. Lead pellet ingestion in First Nation Cree of the western James Bay region of northern Ontario, Canada: implications for a nontoxic shot alternative. Ecosyst Health 1997;3:54–61.
Tsuji LJS, Nieboer E. Allowing Native children to reach their full cognitive potential: questioning the use of lead shotshell for the harvesting of all game. Can J Native Stud 1999;19:37–50.
Tsuji LJS, Nieboer E, Karagatzides JD, Hanning RM, Katapatuk B. Lead shot contamination in edible portions of game birds and its dietary implications. Ecosyst Health 1999;5:183–92.
Tsuji LJS, Iannucci G, Iannucci A. Improving community housing, an important determinant of health, through mechanical and electrical training programs. Can J Native Stud 2000;24:158–68.
Tsuji LJS, Wainman BC, Martin ID, Sutherland C, Weber JP, Dumas P, et al. The identification of lead ammunition as a source of lead exposure in First Nations: the use of lead isotope ratios. Sci Total Environ 2008a. doi:10.1016/jscitotenv.2008.01.022.
Tsuji LJS, Wainman BC, Martin ID, Weber JP, Sutherland C, Liberda EN, et al. Elevated blood-lead levels in First Nations people of northern Ontario Canada : policy implications. Bull Environ Contam Toxicol 2008b;80:14–8.
USFWS. Final supplemental environmental impact statement: issuance of annual regulations permitting the sport hunting of migratory birds. Washington, D.C.: U.S. Fish and Wildlife Service; 1988
Valway S, Martyny JW, Miller JR, Cook M, Mangione EJ. Am J Public Health 1989;79:1029–32.