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Lead exposure in Nunavik: from research to action

Ariane Couture[1,2]*, Benoît Levesque[3,2], Éric Dewailly[2], Gina Muckle[2], Serge Déry[4] and Jean-François Proulx[4]

[1]Department of Social and Preventive Medicine, Faculty of Medicine, Laval University, Québec, Canada; [2]Public Health Research Unit, CHUQ Research Center and Laval University, Québec, Canada; [3]Quebec National Institute of Public Health (INSPQ), Québec, Canada; [4]Nunavik Public Health Direction, Nunavik Regional Board of Health and Social Services, Kuujjuaq, Canada

Background. In 1999, the Government of Canada regulated the use of lead shot for hunting. Concurrently, the Nunavik Regional Board of Health and Social Services (NRBHSS) was informed of the results of an isotope study that pointed to lead ammunition as a likely source of lead exposure in Nunavik. Rapidly thereafter, a coalition for the banning of lead shot was implemented by the NRBHSS as well as by regional/local partners and by Inuit hunters in order to disseminate this information to the public.

Objectives. The purpose of this article is to describe the intervention conducted in the winter of 1999 by the NRBHSS and to assess the combined impact of national legislation and an awareness campaign on blood lead levels in Nunavik.

Study design. Impact assessment of the intervention for the banning of lead shot conducted in 1999 in Nunavik using blood lead levels data before and after the intervention.

Methods. Data on blood lead levels in Nunavik describing foetal exposure as well as during childhood and in adults published between 1992 and 2009 were compiled. Blood lead levels in Nunavik prior to and after the interventions were compared. To assess the current situation, the most recent blood lead levels were compared with those from surveys conducted during the same period in North America.

Results. Analysis of blood samples collected from umbilical cord and from adults show that blood lead levels in Nunavik significantly declined between 1992 and 2004. Nevertheless, lead exposure in Nunavik still remains higher in comparison to that observed in other North American surveys.

Conclusions. The current situation regarding lead exposure in Nunavik has significantly improved as a result of the implemented intervention. However, according to recent data, a gap still subsists relative to other North American populations.

Keywords: *lead*; *lead shot*; *environmental contaminants*; *hunting*; *Inuit*; *Nunavik*; *public health intervention*

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Elemental lead is a heavy metal naturally present in the earth's crust. It is also frequently found in a variety of commercial products and residues from industrial production (1,2). As it is absorbed by bones and tissues in place of calcium, lead can have harmful effects on virtually all body systems (2). The safe threshold of lead is still yet to be identified (3). Particularly in foetuses and children, lead exposure is harmful to the developing nervous system, causing both physical and neurological damage (2–6). In adults, blood lead levels in the range from 1.2 to 1.9 μmol/L have been associated with hypertension, subtle effects on the central nervous system and adverse effects on the reproductive system (3,7). In addition, toxic effects on cardiovascular and renal systems have also been reported in individuals chronically exposed to lead generating blood lead levels of less than 0.24 μmol/L (3).

Lead can be found in both urban and rural areas (7). Although a considerable distance from urban centres and seemingly free of sources of pollution, the Canadian Arctic is no exception. Exposure to environmental contaminants by Inuit of this region is well documented.

Several years ago, a number of studies had shown that Inuit populations were generally more prone to lead exposure than those of other Canadian regions (8–15). In 1992, Quebec Public Health authorities conducted a cross-sectional health survey in Nunavik. During this investigation, the authors found a mean blood lead level

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of 0.42 μmol/L in Inuit adults aged 18–74 years, 5 times higher than that observed in the United States for the same period (1991–1994) (14,16). Between 1993 and 1996, analysis of umbilical cord blood from a sample of 475 Inuit newborns from Nunavik showed that in 7% of cases, blood lead level was above the limit of 0.5 μmol/L (rounded from 0.48 mol/L, equal to 10 μg/dl) adopted by the Canadian authorities (15) and used as the detection threshold for reportable diseases (MADO) on lead exposure in Quebec (17). The study documented an average blood lead level of 0.20 μmol/L (18). In comparison, for the same period, Rhainds et al. observed a mean lead concentration of 0.076 μmol/L in newborns from southern Quebec, 2 times less than that observed among Inuit. In the latter study, only 0.16% of sampled blood lead levels exceeded the limit of 0.48 μmol/L (19). By comparing lead isotopes from cord blood of newborns from southern Quebec and Inuit newborns, it was revealed that the higher blood lead levels in the Nunavik population were likely attributable to the use of lead ammunition for hunting (16).

In 1994, approximately 80% of Inuit were engaged in hunting, fishing or trapping of wildlife (20). Among the latter, the hunting of migratory birds, notably geese, is particularly popular with residents of Nunavik. The geese are hunted with a shotgun using pellet cartridges, typically containing lead or steel. Before being killed by the hunter, the bird may already be contaminated with lead from its own ingestion of stray lead pellets in the environment (sediments, plants, etc.) or, in animals previously injured, by the presence of lead shot in the flesh (21). Moreover, it is now acknowledged that certain behaviours related to rifle shooting likely increase lead exposure: inhalation of lead dust when recharging the firearm, homemade fabrication of lead ammunition, ingestion or inhalation of lead powder, preparation of carcasses and especially consumption of lead shot contaminated meat (3).

After having removed the lead shot embedded in game meat and performed a visual inspection of the carcass, small fragments (<1 mm in diameter) of lead remain scattered in the flesh (22). Cooking a carcass containing lead shot can also contaminate other sections of the carcass that initially were not (22). Hence, by eating game meat from hunting, the Nunavik population was exposed to a weak but significant source of lead (23).

This observation was made in the late 1990s. Coincidently, albeit in a completely different context, the Canadian Wildlife Service had been interested in recent years by the problem of exposure of migratory birds to lead through ingestion of shot pellets. In 1997, a regulation prohibiting the possession and use of lead shot cartridges for hunting waterfowl and migratory birds within 200 m of a water basin came into effect in order to protect wildlife. On September 1st 1999, the Canadian Government amended the law by extending the ban across Canada, including dry land (24,25). This legal framework, while adopted for other reasons, nonetheless put in place legislation that was not only potentially beneficial for wildlife birds but also to human populations for which consumption of game meat from migratory bird hunting are a critical part of their diet. This would ultimately become the foundation for a program aimed at limiting exposure of the population to lead as a result of hunting activities. However, while it is all well to put regulations in place, it is still necessary for such regulation be adhered to. It is in this context that officials of the Nunavik Public Health Department and local collaborators undertook a campaign to raise awareness amongst hunters and ammunition suppliers. Following a description of the intervention performed, the aim of this article is to describe the combined impact of the regulation on migratory bird hunting and the joint intervention conducted by both researchers and the Nunavik Regional Board of Health and Human Social Services (NRBHSS) in the winter of 1999. This intervention was aimed at disseminating scientific knowledge to the community regarding alleged exposure to lead through hunting and its potential effects on population health.

Material and methods

Description of the intervention

The NRBHSS was informed in late 1998 by researchers from the Faculty of Medicine of Université Laval and from the Centre de Santé Publique de Québec of the results of an isotopic study designating lead ammunition as a likely source of lead exposure in Nunavik. Dr. Jean-Francois Proulx from the Nunavik Public Health Department of the NRBHSS then contacted the regional authorities of the Hunting, Fishing and Trapping Association (HFTA). All agreed to communicate these results prior to the start of the migratory bird hunting season at the Annual General Meeting (AGM) of the Association. The AGM brings together various organizations such as hunting representatives of 14 Nunavik municipalities, and representatives of the Makivik Corporation, the Hunter Support Program (HSG), the Kativik Regional Government (KRG), Fisheries and Oceans Canada (FOC) and the Ministère des Ressources Naturelles et de la Faune du Québec (MRNF). As part of this endeavour, the Public Health Department made its first presence at the AGM. Since then, officials of the Nunavik Public Health Department are present at each AGM, enabling scientific knowledge on animal life and human health to impact interventions on the ground. The results of the lead isotope ratios study (15) were presented at the AGM in March 1999, generating a lively debate between hunters present. A consensus ensued to the effect that it was unacceptable to continue to use lead shot ammunition

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because of the health dangers to Inuit children. The mobilization of all Nunavik hunters toward solving the problem of lead exposure has made possible a concerted action between various regional partners.

The Regional Coalition for the Banning of Lead Shot in Nunavik was borne of a regrouping of the NRBHSS (DSP), the Hunting, Fishing and Trapping Association, the Makivik Corporation and the Kativik Regional Government in 1999, after holding of the AGM. All of the participants signed a resolution to the effect that the use of lead shot should be banned in Nunavik. An awareness campaign was then initiated on the issue of lead exposure from hunting, including the introduction of new regulations on migratory bird hunting. Once the agreement ratified, the Regional Public Health Department contacted the major regional ammunition retailers, namely the Fédération des Coopératives du Nouveau-Québec (FCNQ), the North West Company (Northern Store) and the Hunter Support Program (HSG). The hunting associations also conveyed the information on the ban of lead shot in Nunavik to merchants and municipal officials. The information was well received by businesses. Most merchants immediately removed lead shot ammunition from their shelves.

In addition, information was broadcasted on the radio throughout the Nunavik territory under the form of pre-recorded public service announcements destined to the general population. Dr. Serge Déry, Director of the Nunavik Public Health Department, and his team participated in an open line radio program which was broadcasted during primetime throughout all of the Nunavik communities. Posters and brochures were produced. Written information was conveyed in all 3 official languages, Inuktitut, French and English. The documents were distributed in public areas. Lastly, several articles appeared in various periodicals; among others, information was disseminated in the Makivik Magazine distributed free in the 3 official languages in each of the households in Nunavik, in Le Fil des évènements from Université Laval, in the Bulletin d'Information en Santé Environnementale of the Institut National de Santé Publique du Québec (INSPQ), as well as articles and scientific papers generated by the isotope ratios study.

Assessment of the impact of the intervention

Sources and comparison of data

To assess the effects of interventions conducted in 1999–2000 on blood lead levels in Nunavik, we compiled all blood lead levels from 1992 to 2007 from umbilical cord blood samples collected at birth (prenatal exposure), as well as from blood samples collected from children aged 4 to 13 years (exposure during childhood) and blood samples from adults. Prenatal exposure was documented for the villages of Puvirnituq, Inukjuak and Kuujjuaraapik located on the Hudson coast, at 2 different periods: 1993–1996 (18) and 1995–2001 (6). Exposure during childhood was depicted by the follow-up of children at 5 and 11 years of age from samples collected between 1993–1996 and 1995–2001 (5,4). Finally, adult exposure was documented from 2 population surveys conducted in 14 Nunavik villages, 1 in 1992 (14) and the other in 2004 (13).

For prenatal exposure, analysis of temporal fluctuations of lead exposure in 3 villages, Puvirnituq, Inukjuak and Kuujjuaraapik had already been carried out by Dallaire et al. (23). This analysis is described and the most recent data were compared with blood lead levels of 1,109 newborns in 10 hospitals over 10 administrative regions located in southern Quebec for the 1993–1995 period (19). For exposure during childhood, for which comparable data in North America is more recent, blood lead levels were compared with those from the National Health and Nutrition Survey (NHANES) for 1999–2008 in the United States (26). For adults, the NHANES blood lead levels were also used, as well as preliminary data on blood lead levels of the Canadian Health Measures Survey (CHMS) for the period 2007–2008 (27), and the results of blood lead levels from the recent survey conducted in Quebec by the Institut national de santé publique du Québec (INSPQ) and Héma-Québec obtained from 3,490 blood donors aged 18 and older in 2006–2007 (28). While comparisons may be somewhat imperfect due to varying age groups and time periods, these comparisons were conducted on the basis of a descriptive approach. The geometric mean was used as a measure of central tendency and 95% confidence intervals were used to verify the statistical significance of comparisons.

Results

Prenatal exposure

Dallaire et al. (23) conducted an analysis of temporal fluctuations of prenatal exposure to lead for the period 1994–2001 in the villages of Puvirnituq, Inukjuak and Kuujjuaraapik. The results, stratified by year of birth, are presented in Fig. 1, and constitute an adaptation of the figure presented in the original article. The authors noted a significant decrease in mean blood lead levels of about 8% annually, with a greater drop observed in 1999, immediately after the introduction of measures to reduce lead exposure resulting from hunting. Mean blood lead levels in cord blood of children born before and after the introduction of the campaign to eliminate the use of lead shot significantly decreased from 0.20 to 0.12 μmol/L ($p < 0.0001$) along with a mean blood lead level in 2000 (0.11 μmol/L (95% CI = 0.071–0.164)) which was significantly different from that recorded in 1994 (0.23 μmol/L (95% CI = 0.197–0.270)) (23). Prior to April 1999, 10.8% (23/214) of newborns had blood lead levels above 0.48 μmol/L. This proportion decreased to 3.6%

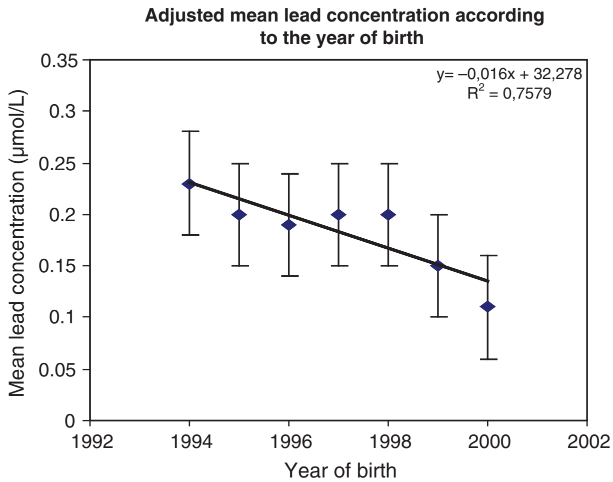

Fig. 1. Adjusted mean lead concentration according to the year of birth. Adapted from Dallaire et al. (23). The solid line represents slope estimates. Results of years 2000 and 2001 were merged because of the small number of recorded values in 2001.

(1/28) after April 1999 (Ariane Couture, Public Health Research Unit, Laval University Medical Center (CHUL-CHUQ), and Laval University, Québec, Canada. E-mails, Frederick Dallaire, Researcher, Public Health Research Unit, Laval University Medical Center (CHUL-CHUQ), and Laval University, Québec, Canada. 2010-03-04). However, while these averages are not statistically different, the fact remains that the most recent results of the Dallaire et al. study (23) (2000: Geo. Mean 0.11 μmol/L (95% CI = 0.071–0.164)) are higher than those obtained in 1,109 newborns from southern Quebec between 1993 and 1995 for which a geometric mean of 0.076 μmol/L (95% CI = 0.074–0.079) was documented (19).

Exposure during childhood

Blood lead levels in children were derived from a first group of children aged 4–6 years and a second group in whom ages ranged from 10 to 13 years, yielding a total of 110 children for the 2000–2002 period and 198 children for the 2005–2007 period for the first and second group, respectively. In 2000–2002, mean blood lead determinations documented in 4–6 year-old children was 0.20 μmol/L (5). Between 2005 and 2007, mean blood lead levels of children aged 10–13 years was 0.13 μmol/L (4). Table I highlights the above results in relation to results obtained in the US NHANES survey for age groups 1–5 and 6–11 years respectively for the periods 2001–2002 and 2005–2006 (29). The Nunavik data were collected after the intervention of 1999 and show a significant difference in concentrations between 4–6 and 11–13 years. While the US data also show a significant difference in concentrations between age groups of 1–5 and 6–11 years, Nunavik blood lead levels were significantly higher however, with more than twice the levels documented in the United States for both age groups.

Adults

With regard to adults, the 1992 survey included 492 participants representing the adult population of Nunavik, while the 2004 survey was conducted among a sample of 917 participants. Participant characteristics as well as the protocol used in both surveys were similar, and results of both studies were comparable. There was a statistically significant decrease (55%; $p < 0.001$) in lead exposure between 1992 and 2004. This decrease was observed in both sexes for all age groups and for both areas of residence (Hudson Bay and Ungava Bay). Blood lead levels significantly decreased by half among adults in Nunavik between 1992 and 2004 (10,13). In addition, in 1992, a proportion of 26% of women aged 18–44 years had blood lead levels greater than 0.5 μmol/L (14), whereas in 2004, only 2% of women aged 18–39 years exceeded the limit of 0.48 μmol/L (10,13).

Table II presents the results obtained for blood lead levels among adults aged 18 and over in Nunavik in 1992 and 2004; also included are data from the NHANES study for the years 2003–2008 (29), preliminary data from the CHMS Survey of Canada 2007–2008 (27) in those aged 20 years and over, as well as the results of the Quebec INSPQ study among blood donors (28). Overall, and as observed above, there was a significant decrease in concentrations in Nunavik between 1992 and 2004,

Table I. Mean blood lead levels in children from Nunavik and the USA

	Nunavik[a,b]		NHANES[c]	
Age group	4–6[a]	10–13[b]	1–5	6–11
Period	2000–2002	2005–2007	2001–2002	2005–2006
n	110	198	898	934
Geometric mean (μmol/L)	0.197	0.13	0.082	0.049
95% CI	0.173–0.225	0.113–0.143	0.077–0.091	0.043–0.053

[a]Després et al. (5) and personal communication (Ariane Couture, Public Health Research Unit, Laval University Medical Center (CHUL-CHUQ), and Laval University, Québec. Person-to-person communication, Gina Muckle, Researcher, Department of Social and Preventive Medicine, Laval University and Public Health Research Unit, CHUQ Research Center (CHUL), Beauport, Canada. 2010-01-25).
[b]Boucher et al. (4).
[c]National Health and Nutrition Examination Survey (NHANES), CDC, USA.

Table II. Mean blood lead levels in adult populations from Nunavik, Canada, USA and Quebec

	Nunavik[a]		CHMS[b]	NHANES[c]		INSPQ[d]
Age group	18–74		20–79	20 and +		18 and +
Period	1992	2004	2007–2008	2003–2004	2007–2008	2006–2007
n	493	917	1810	4525	5364	3490
Geometric mean (μmol/L)	0.42	0.19	0.07	0.073	0.066	0.082
95% CI	0.40–0.44	0.18–0.20*	0.06–0.08	0.067–0.077	0.062–0.072	0.081–0.084

[a]Inuit Health Survey (1992–2004), Quebec, Canada.
[b]Canadian Health Measures Surveys (CHMS), Statistics Canada, Canada.
[c]National Health and Nutrition Examination Survey (NHANES), CDC, United States of America.
[d]Étude de la prévalence de la plombémie chez les donneurs de sang, INSPQ, Québec, Canada.
*Significant variation between Nunavik health survey 1992 and 2004, $p < 0.001$, documented in Fontaine et al. (10) and Dewailly et al. (13).

although the geometric mean documented in 2004 was significantly higher than that documented elsewhere in Canada and the United States as well as in blood donors in Quebec.

Discussion

The data documented in the context of the present study show that blood lead levels in newborns from the east coast of Hudson Bay decreased significantly from 1994 to 2000, with the decrease occurring primarily in 1999–2000 (23), namely the period corresponding to the intervention by Nunavik organizations relative to the banning of lead shot in hunting activities. There was also a very significant decrease of over 50% in mean blood lead levels documented for all Nunavik adults between 1992 and 2004 (10,13). These data would suggest a successful intervention orchestrated by Nunavik authorities. However, recent changes in dietary habits and lifestyle of the Inuit may also partially explain these results through a reduction in the consumption of game meat from hunting and an increased consumption of store-purchased food (30,31).

Moreover, although caution must be exercised with regard to comparisons between different populations with slightly less than desired comparability in terms of age groups and study periods, the data nevertheless reveal an even higher exposure level in Nunavik than in other North American surveys. Both in children along the Hudson Bay coast whose blood lead levels were tested at birth, at 4–6 and 10–13 years as well as among a representative sample of the adult population throughout Nunavik, geometric averages were higher than in other reported studies. For instance, the geometric mean of cord blood lead levels in Puvirnituq, Inukjuak and Kuujjuaraapik in 2000–2001 was 1.4 times higher than that documented for newborns in southern Quebec in 1993–1995 (19). The same children in whom blood lead levels were verified at 4–6 years and at 10–13 years, after the intervention relative to lead shot, displayed a geometric mean which remained twice as high as that of American children for both age groups tested (Table I). A similar pattern was also observed in adults, when comparing data from Nunavik obtained in 2004 with recently obtained data on large samples in the United States, Canada and Quebec (Table II).

The overall result is that while the situation relative to lead exposure in Nunavik has significantly improved, a gap still subsists. Indeed, blood lead levels in adults have fallen by half over the last 18 years while the proportion of women of childbearing age with blood lead levels above the threshold of 0.48 μmol/L has decreased significantly. Nevertheless, in 2004, approximately 10% of individuals and 2% of women of childbearing age still presented blood lead levels above this threshold (13). Numerous studies have confirmed the deleterious effects of lead exposure during childhood as well as an array of documented health effects, notably on childhood development and behaviour (32,33). Furthermore, many recent studies confirm the presence of effects at exposure levels below the threshold of 0.48 μmol/L (4,5), which is the reference limit established by Health Canada. Moreover, the scientific community recommends that the threshold for acceptable exposure be lowered to reflect the results of recent epidemiological studies in children (4,32–38).

Conclusion

The institution of legislation at the national level as well as a local ban on the use of lead shot ammunition in 1999–2000 was associated with a decrease in lead exposure in Nunavik. Shortly after the establishment of public health interventions, accumulated evidences demonstrated the success of the process. "In addition to documented blood lead data showing a significant reduction in exposure in 2002, a survey conducted by telephone revealed that lead shot ammunition was available in only 6 of the 40 stores of the region (39,41)." While reassuring as such, these data nevertheless indicated that lead-containing ammunition was still available in Nunavik (39).

Yet, in 2004 and 2005, in Inukjuak, a survey of hunters on the use of lead shot ammunition revealed that only

31% of respondents were aware that the use of lead ammunition was banned in the community (40). Hence, according to Serge Déry of the NRBHSS: "Since very few assessment studies have focused on this subject, we cannot be certain that the message conveyed through previous communication strategies were well received and understood. It is therefore necessary to better document the involvement of hunters themselves in the removal of lead ammunition by merchants as well as in overall awareness of other hunters. Such involvement would represent a key element of efficient action in public health" (41).

As demonstrated by the recent data on blood lead in Nunavik, particularly among adults, exposure, while having decreased significantly, remains well above that reported in other surveys in North America. In environmental health, lead exposure remains one of the most important problems in terms of prevalence of exposure and impact on public health (42). The potential determinants of blood lead levels in Nunavik should be investigated further in order to identify current sources of lead and factors that modulate the effectiveness of health interventions on this issue. While part of the problem still remains, the success of the intervention of 1999 is evidence that concerted action, involving the various players at all levels, produces results. The key agencies continue to work closely towards resolving this problem.

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***Ariane Couture**
Maîtrise en santé communautaire (candidate)
Département de médecine sociale et préventive
Faculté de médecine
2180 Chemin Sainte-Foy
Pavillon de l'Est
Bureau 1108
Université Laval
Québec G1K 7P4
Canada
Email: ariane.couture.1@ulaval.ca