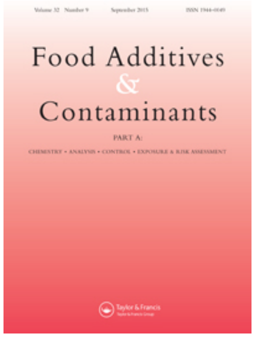

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Lead exposure through consumption of big game meat in Quebec, Canada: risk assessment and perception

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Game meat from animals killed by lead ammunition may expose consumers to lead. We assessed the risk related to lead intake from meat consumption of white-tailed deer and moose killed by lead ammunition and documented the perception of hunters and butchers regarding this potential contamination. Information on cervid meat consumption and risk perception were collected using a mailed self-administrated questionnaire which was addressed to a random sample of Quebec hunters. In parallel, 72 samples of white-tailed deer (n = 35) and moose (n = 37) meats were collected from voluntary hunters and analysed for lead content using inductively coupled plasma-mass spectrometry. A risk assessment for people consuming lead shot game meat was performed using Monte Carlo simulations. Mean lead levels in white-tailed deer and moose killed by lead ammunition were 0.28 and 0.17 mg kg^{-1} respectively. Risk assessment based on declared cervid meat consumption revealed that 1.7% of the surveyed hunters would exceed the dose associated with a 1 mmHg increase in systolic blood pressure (SBP). For consumers of moose meat once, twice or three times a week, simulations predicted that 0.5%, 0.9% and 1.5% of adults would be exposed to a dose associated with a 1 mmHg increase in SBP, whereas 0.9%, 1.9% and 3.3% of children would be exposed to a dose associated with 1 point intelligence quotient (IQ) decrease, respectively. For consumers of deer meat once, twice or three times a week, the proportions were 1.6%, 2.9% and 4% for adults and 2.9%, 5.8% and 7.7% for children, respectively. The consumption of meat from cervids killed with lead ammunition may increase lead exposure and its associated health risks. It would be important to inform the population, particularly hunters, about this potential risk and promote the use of lead-free ammunition.

Keywords: exposure assessment; risk assessment; lead; lead ammunition; game meat; risk perception; health effects

Introduction

Lead is a toxic metal that is widely used because it is easy to extract, highly malleable and resistant to corrosion (ATSDR 2007, Tokar et al. 2013). Inorganic lead compounds, most prominent in the environment are listed in group 2A by the IARC (2006) as probably carcinogenic to humans. In children, exposure is associated with neurological, neurobehavioral and developmental effects (Lanphear et al. 2005; Schnaas et al. 2006; ATSDR 2007; Chiodo et al. 2007; Nicolescu et al. 2010; Nigg et al. 2010; Braun et al. 2012; Liu et al. 2014). Lead exposure can induce cardiovascular (Navas-Acien et al. 2007; Bushnik et al. 2014), nephrotoxic, haematological, immunological, reproductive and skeletal effects (Carmouche et al. 2005; Iavicoli et al. 2006; ATSDR 2007; Vigeh et al. 2010). Today, the consensus is that no safe blood lead level can be determined for children (CDC 2014) and the previous provisional tolerable weekly intake (PTWI) of 25 μg kg^{-1} bw per week has been withdrawn by JECFA because it could no longer be considered health protective (JECFA 2011).

After the withdrawal of lead in gasoline and paint, food became the major source of exposure for the general population (EFSA 2012; Santé Canada 2013) with meats and meats products contributing 8% of total dietary exposure to lead (JECFA 2011). According to Health Canada (Santé Canada 2013), the estimated daily intake of lead from food for all ages of the general Canadian population is approximately 0.1 μg kg^{-1} bw.

Several research groups have reported the presence of high lead concentration and lead fragments in meat from lead-shot game animals (Falandysz et al. 2005; Dobrowolska & Melosik 2008; Hunt et al. 2009; Tsuji et al. 2009; Knott et al. 2010; Pain et al. 2010). Weekly consumption of game meat may be associated with significant exposure to lead (EFSA 2010; Morales et al. 2011; Lindboe et al. 2012). Indeed, several authors noted a relation between the consumption of small and big game meat and elevated blood lead levels (Levesque et al. 2003; Tsuji et al. 2008; Iqbal et al. 2009; Meltzer et al. 2013). No specific maximum lead level in game meat was established; however, a limit of 0.1 mg kg^{-1} was set

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by the European Commission (2006) for beef, lamb, pork and chicken.

In Quebec, Canada, hunting is practised by 285 000 people (Ministère des forêts de la faune et des parcs 2013). In 2013, 545 938 hunting permits were delivered for all games (Ministère des forêts de la faune et des parcs 2014a) and, in 2011, the number of days dedicated to hunting by Quebecers was estimated at 4.35 million person-days (Ministère des forêts de la faune et des parcs 2013). By far, white-tailed deer and moose were the most important big game species hunted in 2013, with 61 067 and 28 141 specimen harvested respectively. Third were black bears with 3524 specimen, including 840 trapped animals. Therefore, the former species likely represent the most important source of lead exposure from big game meat consumption for the population. During the 2013 hunting season, 67% of the 61 067 white-tailed deer and 85% of the 28 141 moose were killed with rifles that can potentially use lead ammunition (Ministère des forêts de la faune et des parcs 2014b). Hunters and their family likely constitute the population most at risk from lead exposure through the consumption of game meats.

The present study had the following objectives: (1) to assess the consumption of white-tailed deer and moose meat by Quebec hunters; (2) to document the perception of hunters and butchers regarding the associated health risk; (3) to measure lead contamination in game meats in Quebec; and finally (4) to assess the health risks related to lead intake from consuming lead shot game meat in this particular population and in the general population.

Materials and methods

Data collection

Data collection was divided in three parts. First, we conducted a survey among Quebec hunters to document their consumption of moose and white-tailed deer meats and their perception of the risk pertaining to lead exposure from this source. A second survey was performed in a sample of Quebec butchers to verify how they handle moose and white-tailed deer meats. Finally, samples of moose and white-tailed deer meat harvested in Quebec were analysed to determine their lead content. The protocol of the study was approved by the ethical committee of Laval University.

Hunters survey

The population targeted for the first part of the study was composed of Quebec hunters who had killed a moose or a white-tailed deer in Quebec during the 2013 hunting period. Available data from the Norwegian Game and Lead study indicated that 37% of the surveyed population (hunters and non-hunters) consumed moose or deer meat once a week or more (NSCFS 2013). Based on these data, we calculated that a sample size of 559 hunters would be needed to estimate the same prevalence (37%) with a confidence level of 95% and a precision of 4%. Assuming on a response rate of 53% (Duchesne et al. 2004), 1055 hunters would need to be solicited. We mailed self-administered questionnaires to 1172 hunters who were randomly selected from the list of the Quebec's "Ministère des Forêts, de la faune et des parcs" (MFFP) of hunters who had killed a moose or a white-tailed deer in Quebec during the 2013 hunting period. Information was obtained on hunting behaviours, consumption of big game animals including white-tailed deer and moose, risk perception related to consuming lead shot game meat, and the treatment of the meat around the wound channel. The frequency of consumption was recorded as never, less than once a month, once a month, twice a month, three times a month, once a week, twice a week and three times or more a week. Consumption frequencies were mathematically transformed into numbers of game meal by year. The questionnaire was pretested with 10 hunters.

Butchers survey

For the second part of the study, 31 butchers from 10 of the 17 socio-administrative areas in Quebec (1–5 butchers per area), representing 60% of the Quebec population, were recruited by telephone. They answered a questionnaire by telephone documenting how they treated the meat around the entry and exit of the wound channel and their perception of the risk related to consuming this meat. The questionnaire was pretested by five butchers.

Meat sample collection

Pieces of meat (minced, n = 65; steak, n = 7) from white-tailed deer (n = 35) and moose (n = 37) were obtained from voluntary hunters in 11 of the 17 socio-administrative areas (61% of the Quebec population). Sixty samples were from lead shot game animals and 12 from game animals killed using lead-free methods (copper ammunition, crossbow).

Laboratory analysis

Meat samples were stored in plastic bags at −80°C and analysed at the Quebec Toxicology Centre (Institut national de santé publique du Québec (INSPQ)) for lead according to INSPQ's method M-589-C (INSPQ 2013). The samples were homogenised and digested in nitric acid at 120°C for 16 h in a hermetic Teflon bomb (Savillex, Eden Prairie, MN, USA). Lead concentration was determined in digested samples by inductively coupled plasma-mass spectrometry (ICP-MS) using an Elan DRCII instrument (Perkin Elmer, St. Waltham, MA, USA). We used an external calibration curve comprising four concentrations of lead dissolved in nitric acid 2% and hydrochloric acid 0.1%. The LOD was 0.001 mg kg^{-1} and the LOQ was 0.003 mg kg^{-1}. Within- and between-day precisions (coefficient of variation) were 0.7% at 4.83 μg g^{-1} (n = 10) and 12% at 0.063 μg g^{-1} (n = 46) respectively. The matrix effect was less than 8% for the analysis of different types of biological samples. The accuracy established with the certified reference materiel NIST SRM 1577c (bovine liver from the National Institute of Standard and Technology) was +4.5%. Each analytical sequence included two certified reference materials (NIST SRM 1577c and DOTLT-4) and a house control (FANI 1207).

Data analysis

Frequency distributions were computed for the different variables documented by questionnaires. Risk perception data were analysed in relation to age and hunting experience and proportions were compared using the χ^2 test. Statistical analyses were performed using SAS version 9.3 software. A $p \leq 0.05$ was considered to be statistically significant.

Risk assessment

Two separate risk assessments were performed. First, we assessed the health risk for hunters based on the frequency distribution of cervid meat consumption documented by the questionnaire. Second, we assessed the health risk for adults and children according to selected frequencies of game meat consumption (once a month, twice a month, once a week, twice a week and three times a week). Microsoft Excel 2007 and @Risk 6 (Palisade Corporation, New York, NY, USA) software were used to perform Monte Carlo simulations of lead exposure following different scenario (100 000 iterations per exposure scenario). The input data for each exposure scenario are presented in Table 1.

Assessing the distribution of individual exposure doses (IEXPD)

We calculated individual lead exposure dose (IEXPD) according to the following equation (Van der Voet & Slob 2007):

$$\text{IEXPD} = (\text{Cons}_1{}^*\text{Conc}_1{}^*F + \text{Cons}_2{}^*\text{Conc}_2{}^*F)/365$$

where IEXPD is lead intake (μg kg^{-1} bw day^{-1}); $Cons_1$ and $Cons_2$ are the consumptions of white-tailed deer and moose meats respectively (g game meat kg^{-1} bw $year^{-1}$); $Conc_1$ and $Conc_2$ are the concentrations of lead in uncooked white-tailed deer and moose meats respectively (mg kg^{-1}); and F is the processing factor for cooking game meat, which was set at 1.

We assumed that each individual consumed 2 g of game meat per body weight per serving (150 g of meat per serving for adults weighing 75 kg or 30 g of meat per serving for children weighing 15 kg) (Lindboe et al. 2012). We attributed a concentration equal to half the LOD (0.0005 mg kg^{-1}) to meat samples with concentrations below the LOD (0.001 mg kg^{-1}).

Assessing the distribution of the individual critical effect dose (ICED)

According to JECFA (2011), lead effects on neurodevelopment (children) and systolic blood pressure (adults) provided the appropriate basis for dose–response analyses. The critical

Table 1. Input data for health risk assessment related to lead exposure through game meat consumption.

Variable	Units	Symbol	Value, formula or distribution
Serving size of big game by meat	g kg^{-1} body weight		2
Number of serving for white-tailed deer	$year^{-1}$	N_1	Discrete distribution $(\{x_i\};\{p_i\})$[a]
Number of serving for moose	$year^{-1}$	N_2	Discrete distribution $(\{x_i\};\{p_i\})$[a]
Lead concentration in white-tailed deer meat	mg kg^{-1}	$Conc_1$	Lognormal distribution (0.38, 11.38)
Lead concentration in moose meat	mg kg^{-1}	$Conc_2$	Lognormal distribution (0.11, 2.33)
Intra-species variability factor		IF	Lognormal distribution (0, 0.68)
Amount intake for red deer	g kg^{-1} $year^{-1}$	$Cons_1$	$2*N_1$
Amount intake for moose	g kg^{-1} $year^{-1}$	$Cons_2$	$2*N_2$
Individual exposure dose	μg kg^{-1} day^{-1}	IEXP	$(Cons_1*Conc_1 + Cons_2*Conc_2)/365$
Individual critical effect dose related to systolic blood pressure (SBP)	μg kg^{-1}	$ICED_{BP}$	CED_{BP}/IF
Individual margin of exposure related to SBP		$IMoE_{BP}$	$ICED_{BP}$/IEXPD
Individual critical effect dose related to intelligence quotient (IQ)	μg kg^{-1}	$ICED_{IQ}$	CED_{IQ}/IF
Individual margin of exposure related to IQ		$IMoE_{IQ}$	$ICED_{IQ}$/IEXPD

Note: [a]Discrete distributions reflecting actual consumption data were used when performing risk assessment for hunters; specific consumption frequencies were used in different scenarios when conducting risk assessment for adults and children.

effect dose for systolic blood pressure (CED_{BP}) (1.2 µg kg^{-1} bw day^{-1}) is the long-term dietary exposure corresponding to an increase of 1 mmHg in systolic blood pressure for adults and the critical effect dose for intelligence quotient (IQ) (CED_{IQ}) (0.6 µg kg^{-1} bw day^{-1}) is the long-term dietary exposure corresponding to a decrease of 1 IQ point for children (JECFA 2011). We used the critical effect dose and the intra-human variability to define the ICED. We assumed the distribution of the intra-species factor to be log-normally distributed with a geometric mean of 1 and a geometric SD of 1.98 (lognormal distribution: mean = 0, SD = 0.68) (Slob & Pieters 1998; Van der Voet & Slob 2007).

Assessing the individual margin of exposure (IMoE)

The IMoE is the ratio of the individual critical effect dose (ICED) to the individual lead exposure dose (IEXPD): IMoE = ICED/IEXPD (Van der Voet & Slob 2007). We considered an IMoE value below 1 as indicative of a critical effect for an individual. The probability of critical effect (PoCE) was that of IMoE values below 1 in the population. For adults, we used the individual critical exposure dose for blood pressure ($ICED_{BP}$) and for children, the individual critical exposure dose for IQ ($ICED_{IQ}$).

Uncertainty analysis (hunters only)

To evaluate the uncertainty for individual exposure dose (IEXPD), 1000 iterations with 10 Monte Carlo simulations with different seeds were performed to characterise the confidence interval at 95%. The arithmetic mean was used to describe the average of IEXPD and PoCE. Moreover, we made a sensitivity analysis using the Spearman rank correlation to identify the significant variables correlated to the $IMoE_{BP}$.

Results

Participation rate, selected hunting practice

Among the 1172 hunters contacted, 429 (37%) returned the questionnaire and 333 (28%) provided valid answers to the question regarding their game meat consumption. Table 2 shows selected variables in relation to hunting practices of the participants. A large proportion of them (83%) had at least 10 years' hunting experience, and 74% used lead ammunition (Table 2). The majority of hunters (80%) answered that game animals were handled by butchers.

Table 2. Selected hunting variables documented in hunters from Quebec, Canada, 2013.

Variable	%
Hunting experience (n = 429)	
Less than 5 years	7
5 to 10 years	10
More than 10 years	83
Hunting methods (n = 429)	
Crossbow	42
Rifle	94
Gun	7
Black powder	15
Use of lead ammunition (n = 419)	
Yes	74
No	12
Don't know	14
Butchering cervid carcass (n = 425)	
Hunter	8
Butcher	80
Hunter and butcher	12

Consumption of white-tailed deer and moose meats by hunters

Few hunters (2.4%) consumed only white-tailed deer meat, but a higher proportion (35%) ate moose meat only. The majority of hunters consumed both meats (62%). white-tailed deer and moose meat were consumed once or more per week by 26% and 49% of the respondents respectively. The mean of the yearly moose meat consumption was about twofold greater than that of white-tailed deer meat (Table 3). When assessing the risk for hunters, we used a discrete distribution for the frequencies of consumption (Table 1).

Risk perception and handling of the meat around the wound channel

A majority of participating hunters (71%) assumed that the consumption of white-tailed deer and moose killed with lead ammunition was safe (41%) or very safe (30%). We did not find a statistically significant difference in risk perception by hunter's age (p = 0.29) or hunting experience (p = 0.62). Most hunters (60%) indicated that the meat around the wound was removed if damaged. A smaller proportion (39%) removed the meat damaged or

Table 3. Consumption of white-tailed deer and moose meats per year (kg $year^{-1}$) by Quebec hunters in 2013.

	Mean	SD	P25	P50	P75	P95
Consumption of white-tailed deer meat ($Cons_1$)	4.53	6.33	0	1.96	7.33	19.38
Consumption of moose meat ($Cons_2$)	8.94	7.44	3.49	6.85	11.82	24.87

Note: P25 = 25th percentile; P50 = 50th percentile; P75 = 75th percentile; P95 = 95th percentile.

not up to different radial distances from the wound channel. Respectively, 54%, 39% and 7% of these hunters declared that the meat was removed at a radial distance between 0 and 10 cm, between 10 and 20 cm, and more than 20 cm from the wound channel.

The consumption of the meat around the wound channel was believed to be dangerous or very dangerous for health by 74% of butchers interviewed. Among those, 61% declared trimming only the damaged meat, while 39% declared discarding all meat, damaged or not, located within a mean radial distance of 5 cm (range = 2–12 cm) from the wound channel.

Contamination data

Lead was detected in 90% of the 30 samples of white-tailed deer meat and in 70% of the 30 moose meat samples from animals killed by lead ammunition. Lead levels in lead shot meat samples were greater than 0.1 mg kg^{-1} in 37% of the white-tailed deer samples and in 13% of the moose samples (Table 4). Mean and median (P50) lead concentrations were respectively 0.28 and 0.004 mg kg^{-1} for white-tailed deer and 0.17 and 0.003 mg kg^{-1} for moose killed by lead ammunition (Table 5). The lead levels in steak samples from animals killed by lead ammunition were below the LOD for the three samples of white-tailed deer. For the three moose samples, these levels were respectively below the LOD, from LOD to LOQ (0.002 mg kg^{-1}), and from LOQ to 0.1 mg kg^{-1} (0.0049 mg kg^{-1}).

In 12 samples obtained from animals killed by copper ammunition or crossbow, lead was detected in three of the five samples of white-tailed deer meat and in three of the seven samples of moose meat (Table 4). The maximum concentration (0.034 mg kg^{-1}) of lead in these meat samples was much lower than the 0.1 mg kg^{-1} reference limit established by the European Commission (2006).

Table 4. Type of meat samples provided by voluntary hunters stratified per lead concentrations intervals.

	White-tailed deer n (%)	Moose n (%)
All samples	35	37
Minced meat	31	34
Steak	4	3
Lead shot meat samples		
Number	30	30
Minced meat	27 (90)	27 (90)
Steak	3 (10)	3 (10)
Below the LOD[a]	3 (10)	9 (30)
LOD–LOQ[b]	9 (30)	6 (20)
LOQ–0.1	7 (23)	11 (37)
Lead level ≥ 0.1	11 (37)	4 (13)
Lead-free meat samples		
Number	5	7
Minced meat	4	7
Steak	1	0
Less than LOD	2	4
LOD–LOQ	2	3
LOQ–0.1	1	0
Lead level ≥ 0.1	0	0

Notes: [a]LOD = 0.001 mg kg^{-1}.
[b]LOQ = 0.003 mg kg^{-1}.

Table 5. Distribution of lead concentration in white-tailed deer and moose meats killed by lead ammunition.

	Lead concentration (mg kg^{-1})						
Game	Mean	GM	P25	P50	P75	P95	Maximum level
White-tailed deer	0.283	0.015	0.001	0.004	0.200	0.880	4.20
Moose	0.170	0.005	0.001	0.003	0.010	1.40	2.00

Note: GM, geometric mean; P25 = 25th percentile; P50 = 50th percentile; P75 = 75th percentile; P95 = 95th percentile

Risk assessment for hunters

Lead exposure doses predicted for hunters through the consumption of white-tailed deer and moose meats and results from the uncertainty analysis are listed in Table 6. The predicted weekly exposure dose from eating lead-shot cervid meat represented at mean and 95th percentile of 3.3% and 8.5% of the previous PTWI respectively for our surveyed hunters. The effect of seed has been tested with the appropriate number of iterations. Globally, the narrow ranges included in the uncertainty intervals indicated a good precision of our dose predicted. The probability of critical exposure (PoCE), which is related to a 1 mmHg systolic blood pressure increase, was 1.7%. Based on the uncertainty analysis, the mean estimate of the predicted PoCE was 1.74% with a 95% confidence interval that

Table 6. Individual exposure dose (IEXPD), uncertainty intervals of IEXPD and individual weekly exposure of hunters to lead through consumption of white-tailed deer and moose meats.

	Individual exposure dose (µg kg^{-1} bw day^{-1})	Uncertainty intervals of IEXPD (µg kg^{-1} bw day^{-1})	Individual weekly dose (µg kg^{-1} bw $week^{-1}$)
Mean	0.118	0.134 (0.094–0.175)	0.828
P50	0.007	0.0073 (0.0069–0.0076)	0.050
P75	0.032	0.0323 (0.0309–0.0338)	0.224
P95	0.305	0.301 (0.2846–0.3168)	2.13

Note: P50 = 50th percentile; P75 = 75th percentile; P95 = 95th percentile.

ranged from 1.48% to 2%. The sensitivity analysis showed that the most significant variables correlated to the $IMoE_{BP}$ were lead concentrations in white-tailed deer ($R = 0.59$) and moose ($R = 0.49$). Moreover, a low correlation was found between $IMoE_{BP}$ and with the intra-species variability factor ($R = 0.28$), the number of serving white-tailed deer meat per year ($R = 0.26$) and the number of serving moose meat per year ($R = 0.18$)

Risk assessment for adults and children according to specific scenarios

Individual daily lead exposure doses and probabilities of critical exposure to lead, according to the frequency of consumption of meat from white-tailed deer and moose killed with lead ammunition, are presented in Table 7. For consumption scenarios of white-tailed deer meats once, twice or three times a week, the predicted PoCE were respectively 1.6%, 2.9% and 4% for adults and 2.9%, 5.8% and 7.7% for children. For consumers of moose meats once, twice or three times a week, the predicted PoCE were respectively 0.5%, 0.9% and 1.5% for adult and 0.9%, 1.9% and 3.3% for children.

Discussion and conclusions

We documented a consumption of at least one meal a week for 26% and 49% of respondents respectively for white-tailed deer and moose. The mean and median lead levels in meat were respectively 0.28 and 0.004 mg kg^{-1} for white-tailed deer and 0.17 and 0.003 mg kg^{-1} for moose shot with lead ammunition, reflecting that the distribution does not follow a normal distribution. In fact, respectively 40% and 50% of white-tailed deer and moose samples were under the LOQ. Nevertheless, respectively 37% and 13% of white-tailed deer and moose samples had lead levels higher than 0.1 mg kg^{-1}. Following simulations, the individual exposure dose of the population of hunters who participated in our study averaged 0.118 μg kg^{-1} day^{-1} and the 95th percentile was 0.305 μg kg^{-1} day^{-1}. Given the assumptions, the model predicted that 1.7% of our surveyed hunters would exceed the dose associated with a 1 mmHg increase in SBP. Our study suggests that eating at least one meal a week of venison shot with lead ammunition may exposed a small proportion of children (white-tailed deer: once a week = 2.9%; three times a week = 7.7%; moose: once a week = 0.9%; three times a week = 3.3%) or adults (white-tailed deer: once a week = 1.6%; three times a week = 4%; moose: once a week = 0.5%; three times a week = 1.5%) to doses exceeding the level associated with a 1 point IQ decrease or a 1 mmHg increase in SBP respectively (Table 7). The majority (71%) of hunters who participated in this study claimed that white-tailed deer meat consumption or moose shot with lead ammunition is safe. In addition, around 60% of the hunters indicated that only the damage meat around the wound channel was withdrawn. The proportion was similar for butchers (61%).

The mean lead concentration documented in this study for white-tailed deer killed by lead ammunition is consistent with the data presented by Morales et al. (2011) (Table 8) who noted a mean lead level at 0.33 mg kg^{-1} (maximum at 4.6 mg kg^{-1}) in red deer (61 samples of steak meat) and by Falandysz et al. (2005) who reported a mean lead level at 0.22 mg kg^{-1} also in

Table 7. Individual daily lead exposure doses and probabilities of critical exposure (PoCE) in adults and children according to different consumption frequencies of cervid meats.

		Once a month	Twice a month	Once a week	Twice a week	Three times a week
White-tailed deer	Individual exposure dose (μg kg^{-1} bw day^{-1})					
	Mean	0.024	0.050	0.107	0.212	0.319
	P50	0.001	0.002	0.004	0.007	0.011
	P75	0.005	0.010	0.021	0.042	0.062
	P95	0.061	0.122	0.263	0.525	0.790
	PoCE – adults (%)	0.4	0.7	1.6	2.9	4
	PoCE – children (%)	0.7	1.7	2.9	5.8	7.7
Moose	Individual exposure dose (μg kg^{-1} bw day^{-1})					
	Mean	0.007	0.014	0.031	0.062	0.092
	P50	0.0003	0.0007	0.001	0.003	0.004
	P75	0.002	0.004	0.008	0.016	0.023
	P95	0.020	0.040	0.086	0.172	0.258
	PoCE – adults (%)	0.1	0.2	0.5	0.9	1.5
	PoCE – children (%)	0.2	0.4	0.9	1.9	3.3

P50: 50th percentile; P75: 75th percentile; P95: 95th percentile

Table 8: Lead level in game meat documented in other studies.

Source	Sample		Lead level (mg kg^{-1})				
	Game animals	*N*	Median	Mean	P95	Minimum	Maximum
Quebec, Canada (present study)	White-tailed deer	30	0.004	0.28	0.88	0.005	4.2
	Moose	30	0.003	0.17	1.40	0.005	2
Ontario, Canada[a]	Caribou	7	–	–	–	1	5726
	White-tailed deer	4	–	–	–	0.3	867.4
EFSA (2012)	Wild boar	966	–	1.143	0.67	–	–
	Roe deer	733	–	0.048	0.124	–	–
	Moose	47	–	0.015	0.046	–	–
	Reindeer	490	–	0.061	0.15	–	–
Spain[b]	Red deer	61	–	0.326	0.915	0.016	4.6
	Wild boar	64	–	1.29	6.1	0.05	10.4
Norway[c]	Minced moose	52	0.3	5.6	79	–	110
Poland[d]	Red deer	82	–	0.22	–	0.01	1.5
Sweden[e]	Minced moose	54	0.027	0.9	–	–	31

Sources: [a]Tsuji et al. (2009); [b]Morales et al. (2011); [c]Lindboe et al. (2012); [d]Falandysz et al. (2005); [e]Swedish National Food Agency (2012).

red deer (82 samples of steak meat) (Table 8). However, the mean level of lead in our study was higher than the mean concentration of 0.048 mg kg^{-1} documented by EFSA (2012) for roe deer (n = 733) (Table 8).

Concerning moose killed by lead ammunition, the mean lead concentration (0.17 mg kg^{-1} with a maximum level at 2 mg kg^{-1}) in our study was higher than the concentration of 0.015 mg kg^{-1} documented by EFSA (2012) (n = 47), but it was lower than the level described by the Swedish National Food Agency (2012) (54 samples of minced meat) in Sweden (mean = 0.9 mg kg^{-1}; maximum = 31 mg kg^{-1}) and Lindboe et al. (2012) in Norway (mean = 5.6 mg kg^{-1}; maximum = 110 mg kg^{-1}; on 52 samples of minced meat). The difference between the mean levels documented in our study and those described by EFSA (2012) can probably be explained by the exclusion of a high value of lead concentration classified as an outlier in this latter study. Moreover, the meat samples (roe deer: n = 733; moose: n = 47) were analysed in 21 countries without identification of the type of ammunition used (with or without lead). In Lindboe et al. (2012) and Swedish National Food Agency (2012), the maximum lead levels documented were much higher than in the present study (4.2 mg kg^{-1} for white-tailed deer and 2 mg kg^{-1} for moose). Obviously, these values had a great influence on the arithmetic means.

For white-tailed deer as for moose, the mean lead levels documented in the present study exceeded the maximum limits (0.1 mg kg^{-1}) established by the European Commission (2006) for beef, lamb, pork and chicken. A proportion of 37% of the lead-shot white-tailed deer samples and 13% of the moose samples were higher than this maximum limit level. In the literature, the proportions of deer meat samples exceeding this maximum limit range from 9% in red deer to 29% in roe deer (Lazarus et al. 2014). Lindboe et al. (2012) documented a proportion of 60% of moose minced meat samples exceeding this value.

As documented by EFSA (2012), our results showed a tendency for lead levels in deer killed by lead ammunition to be higher than the levels in moose, but the difference was not statistically significant (p = 0.19). It is plausible that the higher body mass of moose in comparison with white-tailed deer influences the lead levels found. Furthermore, as expected, in the 12 samples of moose or white-tailed deer meats killed with other means than lead ammunition, lead was detected at a quantifiable level only in one sample of white-tailed deer and the concentration was low. Even if the number of analysed animals is small, these results suggest that the baseline lead levels in white-tailed deer and moose in Quebec is low. Taken as a whole, our data indicate that lead exposure from consuming white-tailed deer or moose meats is the result of the use of lead ammunition.

Considering the data from the hunters' survey, the estimated weekly exposure dose from eating lead shot cervid meat represented at mean and 95th percentile, 3.3% and 8.5% of the previous PTWI respectively. Given the assumptions, the model predicted that 1.7% of them would exceed the dose associated with a 1 mmHg increase in SBP. Moreover, weekly consumers of meat from white-tailed deer or moose shot with lead ammunition would be exposed to lead doses exceeding the level associated with a 1 point IQ decrease for children and a 1 mmHg increase for SBP for adults. In Spain, Morales et al. (2011) documented a mean exposure dose at 3.89 µg kg^{-1} bw $week^{-1}$, a dose of 0.89 µg kg^{-1} bw $week^{-1}$ at 95th percentile and a maximum exposure dose at 56 µg kg^{-1} bw $week^{-1}$ representing respectively 4%, 16% and 224% of the previous PTWI for hunters following the consumption of red deer and wild boar. Lindboe et al. (2012) documented in Norway that the consumption of meat from moose shot with lead ammunition contribute significantly to the total human exposure and some regular consumers could be exposed to dose exceeding the previous PTWI.

The majority (71%) of hunters assumed that the consumption of white-tailed deer and moose killed by lead ammunition is safe (41%) or very safe (30%) for health in concordance with the Food Standards Agency (2012b) which documented that 61% of consumers strongly agreed and 21% slightly agreed that lead-shot wild game meat was the healthiest meat. This finding suggested that hunters were not aware about the health risks related to lead-killed game meat, suggesting that it would be important to inform the population, particularly hunters, about this potential health problem.

A proportion of 60% of hunters declared that the meat around the wound was removed if damaged, but, according to the remaining 39%, the meat, damaged or not, was discarded respectively between 0 and 10 cm, between 10 and 20 cm, and more than 20 cm of a radial distance from the wound channel for 54%, 39% and 7% of them. A study conducted in Norway with 23 hunting team leaders documented that the meat around the wound was removed between 0 and 10 cm, between 10 and 20 cm, and more than 20 cm respectively by 35%, 43% and 22% (NSCFS 2013), representing a higher proportion for this last category. In Poland, Dobrowolska and Melosik (2008) documented in 10 red deer killed by lead ammunition high lead levels around the entry (minimum = 135 mg kg^{-1}; maximum = 476 mg kg^{-1}) and the exit of wounds (minimum = 59.9 mg kg^{-1}; maximum = 123.7 mg kg^{-1}). These lead levels decreased from around the wounds but remained high at 15 cm (minimum = 2.6 mg kg^{-1}; maximum = 16.9 mg kg^{-1}) and at 25 cm (minimum = 0.1 mg kg^{-1}; maximum = 5.8 mg kg^{-1}). Nevertheless, the removing of only damaged meat around the wound is not sufficient to prevent the contamination of the game meat. Following a recent study, the Swedish National Food Agency (2014) recommended removing any meat that is visibly affected by the bullet and an additional 10 cm of meat visibly unaffected by the bullet.

Even if we sampled few pieces of steak compared with minced meat, the lead concentration in white-tailed deer documented in this study is consistent with the levels documented in steak meat samples by Morales et al. (2011) and Falandysz et al. (2005), thus reinforcing the realism of our results. Moreover, additional risk analyses were performed using the same scenarios but excluding the steak samples, and in all cases the impact on the predicted PoCE was less than 1%. Nevertheless, it is possible that minced meat is more contaminated because some pieces can potentially be of lower quality (e.g. close to the wound channel; Swedish National Food Agency 2014) and contained lead fragments with a secondary transfer to all the minced meat during the process in the grinder-mincer. In concordance with Iqbal et al. (2009) in North Dakota, we believe that it would be advisable to review the butchering practices concerning the meat potentially contaminated, particularly around the wound channel. Therefore, the butchers who prepare game meat should be made aware about this potential health problem.

The response rate in our study was 37% (28% for meat consumption). This casts some doubt on the representativity of our sample compared to the population of hunters who killed a moose or a white-tailed deer in Quebec during the 2013 hunting season. Nevertheless, as already stated, 71% of our respondents considered that the consumption of game meat killed with lead ammunition was safe. Therefore, we do not think that there was an important selection bias caused by the fact that participants would be more aware of the lead exposure in relation to hunting than non-participants. Even with this participation rate, our study is a major one on this topic, considering the large number of participants, the evaluation of their risk perception and the use of an integrated probabilistic approach to assess the risk related to the consumption of meats from two popular big game killed with lead ammunition. Moreover, the survey pertaining to the evaluation of the butchering practices around the wound channel and the risk perception of butchers was a valuable addition.

In addition of the representativeness of the analysed samples already discussed, our study may suffer other uncertainties. We used a food frequency questionnaire, which is subjected to recall bias, to assess the consumption of game meat by hunters and we had no information about weighted meat portions intake. However, we believe that if there is a bias, it is probably non-differential, affecting high and low consumers in the same way. Concerning the portions of meat consumed, we used 2 g kg^{-1} body weight as did Lindboe et al. (2012), which we believe is a good compromise in the absence of portion weights. As children and pregnant women are more vulnerable than the general population, the intra-species variability factor should be different. However, the use of a lognormal distribution (Slob & Pieters 1998; Van der Voet & Slob 2007) should reduce this bias.

In Norway, to reduce lead exposure from cervid meat consumption, NSCFS (2013) suggested the removal of meat around the wound channel and the use of lead-based ammunition with low fragmentation or ammunition without lead. In Germany, BfR (2011) documented that cutting out large sections of meat around the wound channel is not always enough to guarantee that the meat is not contaminated. The authors concluded that weekly consumers of wild game meat face an increased risk, and they recommended children, pregnant women and women planning to have children to avoid eating wild game that was killed by hunters. In the UK, the Food Standards Agency (2012a) advised people, including vulnerable groups (toddlers and children, pregnant women or women trying to be pregnant), that eating lead-shot game on a frequent basis can expose them to harmful levels of lead. They recommended that frequent consumers should eat less of this type of meat.

Our study suggests that hunters were not aware about health risks related to consuming meat from cervids killed with lead ammunition. It would be important to inform the population, particularly hunters, about this potential health problem and the effectiveness of lead-free ammunition. There are now good alternatives to lead ammunition, such as copper ammunition (Caudell et al. 2012; Thomas 2013; Gremse et al. 2014). Moreover, as particularly demonstrated in Poland (Dobrowolska & Melosik 2008), there is a health concern about the contamination of the meat around wounds and it would be important to inform butchers about this fact. To prevent contamination, it is difficult to suggest a precise radial distance from the wound channel. In concordance with the Swedish National Food Agency (2014), it would be advisable to withdraw at least any meat deteriorated by the bullet and an additional 10 cm (radial distance) of meat unaffected by the projectile. However, according to the data of Dobrowolska and Melosik (2008), the meat was contaminated across 25 cm of radial distance from the wound channel. Considering all the variables implicated (type of lead ammunition, mushrooming index, velocity on impact, animal age, bone impact etc.), more research about this topic is needed.

In conclusion, as regards a public health perspective, hunting is an activity associated with an increase of physical activity and an improvement of the quality of life for many people. Big game meat is also a good source of nutrients, which can be altered by lead contamination when using lead ammunition. This exposure can probably be prevented in large part by good butchering practices concerning the wound channel. However, there remain many uncertainties regarding the extent of the contamination (Dobrowolska & Melosik 2008; BfR 2011). Moreover, in real-life conditions, many consumers are not aware about the type and characteristics of the lead ammunition used or the quality of the work made by the butcher. In this context, it should be suggested to vulnerable people (toddlers and young children, pregnant women, women planning to have children) that they consume meats from cervids killed with alternatives to lead ammunition and to avoid meat from animals killed with lead ammunition. It should also be advisable for hunters consuming cervid meat on a weekly basis to use alternatives to lead ammunition. Finally, on a more global basis, considering the environmental impact of contamination by lead-based ammunition, notably on wildlife (Legagneux et al. 2014), a trans-sectorial partnership promoting lead-free ammunition based on a stepwise withdrawal of lead ammunition should be considered.

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