Lead levels in Canadian children: Do we have to review the standard?

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Research indicates that the blood lead levels that were once considered safe can adversely affect the neurodevelopment of children. The purpose of the present article is to review issues surrounding lead exposure in Canadian children, including sources, chronic low levels of exposure, and recommendations for prevention. Information was obtained through searches of MEDLINE and Web of Science using a combination of: "Canada" or "Canadian" plus "child" or "paediatrics" plus "lead" or "lead poisoning" or "blood lead". Centers for Disease Control and Prevention data and American peer-reviewed literature were also used. On-line Health Canada advisories (available since 1995), as well as relevant reports from nongovernmental organization and the media, were reviewed. The present review found that there has been limited surveillance of blood lead levels of Canadian children and, mainly, among high-risk groups. Harmful health effects may occur below the current standards and the threat of lead in consumer products remains. The current regulation seems to be inadequate to protect Canadian children.

Key Words: *Blood lead; Canada; Children; Lead; Lead poisoning*

Le taux de plomb chez les enfants canadiens : Devrions-nous réviser la norme?

D'après les recherches, les taux de plombémie qu'on estimait sécuritaires peuvent nuire au développement neurologique des enfants. Le présent article vise à analyser les enjeux entourant l'exposition au plomb chez les enfants canadiens, y compris les sources, l'exposition chronique à des taux faibles et les recommandations de prévention. L'information a été colligée à l'aide de recherches dans MEDLINE et dans *Web of Science*, à l'aide d'une combinaison des termes Canada ou *Canadian* (canadien) et *child* (enfant) ou *paediatrics* (pédiatrie) et *lead* (plomb) ou *lead poisoning* (intoxication par le plomb) ou *blood lead* (plombémie). On a également fait appel aux données des *Centers for Disease Control and Prevention* et à la documentation scientifique américaine révisée par des pairs. Les conseils électroniques de Santé Canada (depuis 1995), de même que des rapports pertinents d'organismes non gouvernementaux et des médias, ont été examinés. La présente analyse a permis d'établir le peu de surveillance des taux de plombémie chez les enfants canadiens, et surtout dans les groupes les plus vulnérables. Des effets délétères sur la santé peuvent se manifester sous les normes actuelles, et il existe toujours un danger que du plomb soit présent dans les produits de consommation. Le règlement actuel semble insuffisant pour protéger les enfants canadiens.

Recent reviews (1,2) in Canadian medical journals have highlighted the potential health effects of lead exposure in children. Cases of substantial lead poisoning in children, marked by gastrointestinal symptoms, anemia and encephalopathy, are, thankfully, exceedingly rare in Canada today. Public health efforts to protect children from lead exposure, such as the removal of lead from gasoline and paint and control of emissions from industrial sources, have been very successful in reducing the body burdens of lead in Canadian children. Although the threat of lead has faded, it is far from being abolished. A growing body of research suggests that there is no threshold for the adverse effects of lead on the developing central nervous system. New sources of lead exposure from consumer products, many of which are intended for child use, are increasingly being discovered on the commercial market, and the potential for lead exposure from 'old' sources, such as paint and industrial sites, still exists. It is imperative that Canadian physicians do not become complacent regarding lead exposure and its potential adverse effects on children.

ADVERSE EFFECTS OF LOW-LEVEL LEAD EXPOSURE

The United States' Centers for Disease Control and Prevention (CDC) has defined the 'threshold' blood lead level that should raise concern and trigger interventions (3). This level has declined progressively as new knowledge of the neurodevelopmental effects of lead has become available. In 1975, the blood lead threshold was 1.45 µmol/L, but in 1991, it was lowered to 0.48 µmol/L, where it currently stands. (For ease of comparison across studies, all blood lead concentration units have been converted to µmol/L. To convert µmol/L to µg/dL, multiply by 20.72; 0.483 µmol/L=10 µg/dL.) The CDC has acknowledged that new research since 1991 provides evidence of adverse effects at levels below 0.48 µmol/L (3). Recent prospective studies (4-8) that have controlled for confounders such as socioeconomic status and parental education have demonstrated a relationship between blood lead levels less than 0.48 µmol/L and decrements in cognitive performance, as measured by intelligence quotient (IQ), mathematical ability, reading, block design, digit span and colour knowledge. Even very low in utero lead exposure may affect neurodevelopment. In a recent study (9) of 79 women, maternal blood lead levels at six to seven months' gestation and delivery were all below 0.16 µmol/L, with a mean of 0.03 µmol/L. When their infants were assessed at seven months of age using the Fagan Test of Infant Intelligence, a task involving novelty preference, infants scoring in the upper 15th percentile had much lower maternal blood lead

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levels (mean of 0.021 µmol/L) than infants in the lower 15th percentile (mean of 0.045 µmol/L) (9).

Ten years ago, a meta-analysis (10) concluded that lead exposure was negatively associated with cognitive performance, without any evidence of a threshold level below which lead does not have an effect. An intriguing finding of this meta-analysis was that the slope of the association between blood lead and IQ was greater at lower levels of exposure, suggesting a logarithmic dose-response relationship (10). This has been confirmed in prospective studies of children whose blood lead concentration had never exceeded 0.48 µmol/L in numerous longitudinal assessments. For example, IQ declined by 7.4 points as lifetime average blood lead concentration increased from 0.048 µmol/L to 0.48 µmol/L, whereas the corresponding IQ decline for blood lead concentrations ranging from 0.48 µmol/L to 1.45 µmol/L was 2.5 points (4). A reanalysis of a prospective cohort study (7) also confirmed that the slope of the inverse relationship between blood lead and IQ was greater at lower blood lead levels than at higher blood lead levels. Although the true nature of the relationship between blood lead levels below 0.48 µmol/L and IQ requires further study, current evidence suggests that for a given increment in the blood lead level, the negative effect on IQ is greater at blood lead levels below 0.48 µmol/L than at levels above 0.48 µmol/L.

Although changes in IQ associated with lead exposure have been demonstrated, the impact of low-level lead exposure on specific clinical outcomes, such as developmental disabilities, is not completely understood (11). It has been emphasized that even though small IQ decrements may not be noticeable in an individual, the effects at a population level may be substantial. For example, a downward shift in the population IQ distribution curve by five points would result in a 50% increase in the number of individuals classified as mentally retarded (IQ lower than 70) and a comparable decrease in the number of gifted individuals (IQ higher than 130) (12). Developmental disabilities include a wide spectrum of diagnoses, from learning disabilities to attention deficit hyperactivity disorder and aggressive behaviour. The etiology of these conditions is multifactorial, including genetic, environmental and social factors, and what we have learned from studies of lead will help us in studying low-dose effects of other neurotoxicants as well (12,13).

With regard to school performance, a recent Taiwanese study (14) of 934 grade 3 children (mean blood lead concentration of 0.27 µmol/L) demonstrated that children with higher blood lead levels had lower class rankings in Chinese, history, mathematics and science, with blood lead level having a greater impact on language ability than on mathematics. An earlier longitudinal study (15) demonstrated an association between early childhood low-level lead exposure and subsequent high school failure and reading disabilities. Delinquent behaviour has also been linked to asymptomatic lead exposure (16). A group of male youths who had been arrested and adjudicated as delinquent had bone lead levels with an order of magnitude that was greater than that of control subjects. After controlling for several potential confounders, bone lead level was strongly associated with delinquency, and the strength of the association was exceeded only by the association between race and delinquency (16).

In addition to adverse chronic neurodevelopmental effects, low-level lead exposure may affect the endocrine system. A recent cross-sectional study (17) that controlled for numerous potential confounders demonstrated that girls with blood lead levels as low as 0.14 µmol/L had delayed pubertal development and decreased height compared with girls with a blood lead level of 0.0483 µmol/L or lower.

Although evidence supporting a relationship between low-level lead exposure and adverse health effects in childhood is mounting, there is very little evidence with which to gauge the potential long-term impact of these exposures into adulthood. Follow-up studies of severely lead poisoned children (with symptoms suggestive of blood lead levels that were greater than 3.0 µmol/L) have demonstrated that these children have increased mortality from all causes (especially cardiovascular disease [18]), and are more likely to have hypertension and lower hemoglobin values than matched controls (19). In a study (20) of adults surveyed from 1976 to 1980 (median blood lead level of 0.63 µmol/L) and followed until the end of 1992, those with blood lead levels of 0.97 µmol/L to 1.40 µmol/L had significantly elevated mortality from all causes, including circulatory disease and cancer, compared with those with blood lead levels of less than 0.48 µmol/L. To date, there have been no long-term follow-up studies of children with only mild to moderate lead exposure, and, as a result, the potential long-term health impacts of such exposures, if any, are not known.

Currently, there is little evidence to support active treatment of mildly elevated blood lead levels. The United States Agency for Toxic Substances and Disease Registry has noted that chelation therapy is not indicated for individuals with blood lead concentrations below 2.2 µmol/L (21). For example, a recent randomized, double-blind, placebo-controlled trial (22) of chelation therapy in children aged 12 to 33 months with blood lead levels between 1.0 µmol/L and 2.1 µmol/L did not demonstrate any differences between the chelation and placebo groups in blood lead levels at one year follow-up or neuropsychological test results at three years follow-up. Environmental lead abatement strategies, such as soil remediation and house dust control, are also of limited effectiveness in reducing blood lead levels to less than 1.2 µmol/L (23). In 1994, the Canadian Task Force on the Periodic Health Examination concluded that there was "insufficient evidence to recommend for or against chelation therapy or residential deleading...for children with blood lead levels 10-49 µg/dL [0.48-2.4 µmol/L]" (24). Nevertheless, as discussed below, remediation of lead-containing soil can be of benefit in residential areas that have been contaminated with lead. If a child is discovered to have mildly elevated blood lead, the sensible approach is to seek out the source of lead and then protect the child from further exposure. Unfortunately, the main source of lead exposure may be difficult to find in such cases, and, therefore, the only truly effective 'treatment' option is the primary prevention of lead exposure (2,25,26).

LEAD LEVELS IN CANADIAN CHILDREN

Unfortunately, a representative nationwide picture of current blood lead levels in Canadian children is not available. A rough approximation can be derived from previous population studies, surveys of children exposed to point sources of lead pollution and data from national screening in the United States.

Several recent studies have measured lead concentrations in umbilical cord blood to assess prenatal lead exposure. Studies from Toronto, Montreal, Quebec City and several administrative regions in Quebec demonstrated mean umbilical cord blood lead concentrations of 0.076 µmol/L to 0.094 µmol/L, with up to 0.9% of infants having levels above 0.48 µmol/L (27-30). Aboriginal infants tended to have greater prenatal exposure. A sample of 79 infants from Moosonee and Moose Factory in northern Ontario revealed a mean umbilical cord blood lead concentration of 0.10 µmol/L, with 3% of the cord blood samples showing levels above 0.48 µmol/L (31). In Nunavik, Quebec, 475 Inuit newborns had a mean umbilical blood lead concentration of 0.19 µmol/L; 6.9% of infants had levels above 0.48 µmol/L, with some measuring above 0.72 µmol/L (32).

As children grow older and interact with their environment, blood lead concentrations rise, usually peaking at around one to three years of age and then declining thereafter (33-35). Neri and Tessier (36) reported the results of several population studies that were conducted in the 1970s. Examples of results from children not exposed to point sources of lead pollution were surveys conducted in Halifax and Ottawa (36), which revealed that 4% and 8% of children, respectively, had blood lead concentrations greater than 1.45 µmol/L. To date, there has been only a single Canada-wide survey of blood lead levels, performed as part of the Canada Health Survey of 1978 to 1979 (37). Blood lead levels were generally higher in males; 10% of males less than five years of age had blood lead levels that were greater than 0.48 µmol/L. For both sexes combined, the proportion of children aged three to 10 years from each region with blood lead values greater than 0.48 µmol/L was 24.6% for the Atlantic region, 22.6% for Quebec, 9.7% for Ontario, 17.5% for the prairies and 6.6% for British Columbia (36). In a 1984 Ontario survey (33) of 1269 urban, suburban and rural children aged six years and younger, more than 50% had a blood lead level greater than 0.48 µmol/L (37.2% had levels ranging from 0.48 µmol/L to 0.68 µmol/L, 10.4% had levels ranging from 0.72 µmol/L to 0.92 µmol/L, 4.2% had levels that were 0.97 µmol/L or greater). Geometric mean blood levels in this sample ranged from 0.43 µmol/L in rural areas to 0.58 µmol/L in urban areas. Lead levels were lower in a population sample of two- to three-year-old Vancouver children who were surveyed in 1989; the mean blood lead level was 0.29 µmol/L and only 8.1% had a level of 0.48 µmol/L or greater (35). More recent studies (38,39) that have examined Aboriginal children living in northern Ontario and Quebec have revealed that 4% and 2.7% of children, respectively, had blood lead levels that exceeded 0.48 µmol/L.

The majority of Canadian paediatric blood lead surveys have been performed to evaluate the impact of point sources of lead pollution, such as smelters and metal reclamation plants (40). Serial surveys have been conducted on children in South Riverdale, Toronto (36,41); Trail, British Columbia (36,42-44); and Rouyn-Noranda, Quebec (45,46); and single surveys have also been performed (34,47). In general, markedly elevated blood lead levels of children living near industrial sources have declined over time. In South Riverdale, Toronto, the mean blood lead level declined from 0.68 µmol/L in 1984 to 0.19 µmol/L in 1992 (41). In Trail, British Columbia, a mean blood lead level of just over 1.00 µmol/L in the 1970s declined to 0.29 µmol/L by 1999 (36,44). This reduction has been partially attributed to industrial emission controls and soil remediation (44-46), but the greatest influence has been the overall reduction of lead in the environment, such as the removal of lead from gasoline (48), and from solder and paint used in consumer products (1,2,49).

In the United States, the evaluation of children's blood lead levels is far more comprehensive than in Canada. Each year, more than one million children (2.4 million in 2001) under five years of age are screened for blood lead and the data are compiled at the national level by the CDC. The proportion of children with blood lead concentrations greater than 0.48 µmol/L has declined with subsequent surveys, from 8.6% during the period from 1988 to 1991 to 2.2% during the period from 1999 to 2000 (3). It was estimated that 434,000 American children had blood lead concentrations above 0.48 µmol/L during the period from 1999 to 2000 (3). In comparison, a federal-provincial committee estimated in 1994 that more than 66,000 Canadian children might have blood lead levels greater than 0.48 µmol/L (50). This value is comparable with the American figure after taking into account the population difference between the two countries.

Overall, blood lead concentrations in North American children have decreased over time. However, a sizable number of children still have blood lead concentrations that exceed 0.48 µmol/L, the CDC's current intervention level. In addition, because the adverse effects of lead on neurodevelopment can occur at blood lead concentrations below 0.48 µmol/L, as discussed above, identifying only those children with blood lead levels above this level underestimates the size of the affected population. Population blood lead levels will likely continue to decline over time secondary to the control of major environmental sources of lead pollution, such as lead in gasoline, which was completely banned in Canada by January 1990 (50).

SOURCES OF LEAD EXPOSURE

The reduction of lead in the general environment is partially offset by the presence of lead in consumer products. In recent years, a growing number of consumer products, many of which are marketed toward children, have been discovered to be potential lead exposure sources. These products include crayons (51); imported folk remedies, candies (52) and raisins (53); polyvinyl chloride miniblinds (54); candles (55); stainless steel rum flasks (56); children's jewellery (57,58); artificial Christmas trees (59); and the electrical cords of holiday lights (60). New exposure situations have also been described, such as the transfer of lead oxide dust (contained in dental

radiograph film boxes) from a dental hygienist's fingers into a patient's mouth (61). Other sources of lead in the home environment that are more commonly known (eg, chipping paint in older homes or parental hobbies such as stained glass making) have also been described (21).

To limit potential lead exposure from sources such as consumer products, regulations that limit lead content and/or restrict the sale of such products are required. Unfortunately, Canada has a poor record of developing and enforcing regulations that limit the use of lead in commercial products. (A detailed discussion of the history of Canada's regulatory response with regard to lead can be found in reference 50.) Currently, imported products intended for child use that are sold on store shelves are not tested for lead content and may only be tested after a problem has been detected (50). For example, it was only after a Calgary child was discovered to have lead poisoning from sucking on a pendant that other children's jewellery products were tested by Health Canada. Of the 95 pieces of children's jewellery that were tested, more than two-thirds contained greater than 50% lead, which prompted the release of an advisory (57). This was the limit of what could be done. Health Canada has no power to recall hazardous products from store shelves and, therefore, only public advisories and warnings can be issued (50,62). In response to the jewellery incident, Charles Ethier, the Director General of Health Canada's Product Safety Program, was quoted by the Canadian Broadcasting Corporation's *Marketplace* as saying, "there is nothing preventing the sales of those particular items at the retail level. Those products are not regulated and there is nothing preventing their sale" (62).

However, even for well-recognized lead hazards, such as lead in paint, existing regulations may not be totally protective. Under the Hazardous Products Act, paint containing greater than 0.5% lead is prohibited for use on indoor residential surfaces, furniture, toys, carriages, strollers, cribs and cradles (50). However, according to the Hazardous Products Act, paint containing greater than 0.5% lead may be used on interior or exterior surfaces, furniture or any other premises not "ordinarily used or frequented or likely to be used or frequented by children" (63). There is no upper limit to the lead content of paint that is used in these situations. As noted by Cooper et al (50), there is no guarantee that building occupancy and use will not change over time. As well, although the use of lead-based paint in consumer products is prohibited, playground equipment is not considered a consumer product (64). In 1994, a five-year-old Montreal boy who occasionally ate paint chips from metal playground structures was found to have a blood lead level of 2.00 µmol/L, more than four times the CDC intervention level of 0.48 µmol/L (64). Subsequent paint chip testing of various playground structures revealed lead contents that ranged from 0.0068% to 10.0% (64). Fortunately, most paint suppliers have elected to not sell leaded paint even for industrial uses as part of their corporate policy (based on discussions with several industrial paint suppliers in the Edmonton area in January 2004).

Recognizing that children may continue to be at risk from lead in consumer products, Health Canada is currently developing a lead risk reduction strategy aimed at reducing the lead content of several categories of consumer products to which children are likely to be exposed (65). To date, two new regulatory proposals have been prepublished and may be modified after Health Canada has reviewed all the feedback. The proposed Children's Jewellery Regulations and Candles Regulations are amendments to the Hazardous Products Act that would limit the lead content of children's jewellery and candles, respectively (66). These amendments are the first regulatory steps of Health Canada's lead risk reduction strategy, and it is expected that further regulations will follow. Nevertheless, the sheer number and diversity of products on the market makes the task of identifying and regulating those that contain lead daunting.

Old industrial sites create another possible pathway for lead exposure in children. 'Brownfield' is the term given to a contaminated former industrial site, and the federal government has recently encouraged the development of such sites to sustain expanding residential growth (67). If not properly remediated, lead contamination of soil can persist for a long period of time, and residential communities that have been built over old industrial sites may have soil lead levels that exceed environmental guidelines. Recently, a Calgary community was faced with such a situation (68,69). Indoor dust lead content can be influenced by outside sources such as soil, as demonstrated in an analysis of soil and house dust lead in Sydney, Nova Scotia (70). Lead in house dust has been shown to be a major source of lead exposure in children (71), and children may also be acutely exposed by the direct consumption of contaminated soil (70).

RECOMMENDATIONS

The challenge for physicians lies in identifying children with elevated blood lead levels so that potential sources of exposure can be identified and controlled. Universal screening for blood lead has been recommended in the United States, but compliance has been poor (3,23). Although universal blood lead screening of children has never been supported in Canada (24,49,72), targeted screening of high-risk children (eg, those who live near local pollution sources or have parents who work with lead) has been endorsed (24,72). The American Academy of Pediatrics has developed screening questions for parents to identify children who may be at risk for lead exposure, and these have also been recommended for use in Canada (1,2). They include the following:

- Does your child live in or regularly visit a house or child care facility built before 1950?
- Does your child live in or regularly visit a house or child care facility built before 1978 that is being or has been renovated or remodelled within the past six months?
- Does your child have a sibling or playmate with a history of lead poisoning? and
- Have you seen your child eat paint chips?

Based on the above discussion, the limitations of such questions with regard to assessing potential lead exposure

from consumer products and local environmental sources are obvious, and one should also not forget the exposures specific to immigrant children. Often, it is a concerned parent who raises the issue of potential lead exposure, such as the father of the Calgary child who sucked on jewellery (62) or the mother of the Montreal boy who ate playground paint chips (64).

A prudent approach is to educate all parents regarding the adverse health effects of low-level lead exposure and potential sources of exposure. Health Canada provides a detailed Web site that can assist in this regard (73). Physicians should have a high index of suspicion when assessing children with developmental problems, and it has been suggested that physicians should consider screening for lead exposure in children who present with growth failure; behavioural disorders; hearing loss; speech, language or attention deficits; developmental delay; microcytic anemia; or sleep problems (2). A blood lead test is an easy addition to a routine workup. Follow-up of children with elevated blood lead is essential, including a neurodevelopmental assessment, and it is imperative that any children who are found to have elevated blood lead levels (ie, higher than 0.48 µmol/L) be reported to the local public health department, which some evidence suggests is rarely done even in cases of moderate to severe lead poisoning (74).

Once alerted to a child with an elevated blood lead level, the public health department would be responsible for identifying the source of lead exposure and tracing other exposed children. At present, exposed children are not reported to Public Health. Making lead toxicity officially reportable would identify it as a public health hazard. However, the current challenge is how to proceed in modifying current threshold levels in light of recent evidence suggesting that neurodevelopmental damage can occur below the current standards (4).

Identification of children at risk from point sources of lead is mandatory, especially since intervention has been demonstrated as being effective (43). Lowering of regulatory limits will allow us to identify children at risk, the first step to mitigating neurodevelopmental damage.

ROLE OF THE PAEDIATRICIAN

After reviewing the literature, the authors suggest that paediatricians adopt a clinical, educational, research and advocacy role in caring for children potentially exposed to lead, and suggest that the Canadian Paediatric Society promote the following actions:

- Identification of children affected by or exposed to lead in chronic low doses, and initiation of appropriate laboratory investigations, neurodevelopmental assessment and interventions (40,43);
- Education of parents and caregivers to identify potential sources of chronic low dose exposure for children and their harmful health effects using available resources (73);
- Advocacy for a comprehensive lead survey in Canadian children;
- Generation of evidence for lowering regulatory limits below those currently in place (ie, higher than 0.48 µmol/L);
- Classification of lead exposure or effects as a notifiable condition; and
- Advocacy for legislation to limit the lead content of products to which children are exposed.

SUMMARY

Public health initiatives to remove environmental sources of lead have been very effective in minimizing childhood exposure to this toxic heavy metal. Unfortunately, the trend in lead research is the documentation of biological effects at lower and lower levels of lead exposure, with recurrent downward adjustments of 'safe' thresholds. These exposures are so ubiquitous that their effects may not be easily recognized, and our understanding of the role that low-level lead exposure may play in neurodevelopmental disorders is still in its infancy. Lead persists in the environment and will continue to be found in consumer products for years to come. For these reasons, it is important that the potential for lead exposure in Canadian children not be overlooked; the adverse health effects of lead are easily preventable, as long as potential exposure sources are recognized and controlled.

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