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Managing risks to children's health from lead in drinking water in British Columbia's daycares and schools

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Introduction & Scope

OBJECTIVES

- To identify the extent to which exposure to lead in the drinking water of British Columbia's daycares and schools adversely impacts the health of children.
- To assess the need for and options available to reduce lead in daycare and school drinking water.

RATIONALE

There is little information available regarding the effects of lead exposure for children residing in British Columbia (BC) (1). A 2014 report described lead levels in schools in a northern BC community above the 10 parts per billion (or 10 µg/L) threshold in the Canadian drinking water guidelines (2). An investigation by public health officials was triggered in response to the death of salmon eggs in a school classroom aquarium in that community (2). Officials subsequently found elevated levels of lead in the drinking water of several other schools in the same community. The chemistry of the community's water supply and the presence of lead pipes and/or fixtures was deemed the common factor leading to elevated levels of lead in the schools tested. This event highlighted concerns for the presence of lead in school and daycare drinking water.

This report aims to determine whether BC should consider Ontario's environmental regulations and regularly monitor and remediate lead in school and daycare drinking water (3).

BACKGROUND

In Canada the main routes of lead exposure are through ingestion of food, dust, lead-based paint, soil and drinking water (2,4). Blood lead levels (BLL) in Canadians have decreased markedly over the last 30 years to a current BLL average of 1.1 µg/dL in adults and 0.68 µg/dL in children aged 3-19 years (5). Less than 1% of Canadians now have BLL greater than 10 µg/dL (the current federal and provincial blood lead intervention level). This is mainly a result of restricted lead use in paint, gasoline, food cans and plumbing since the 1970s (1,5). However, despite the general decline of blood lead levels by 70% in Canada since 1978, elevated blood lead levels are still found in some BC residents (1).

Although the average daily consumption of lead from drinking water is low (7.2 µg in adults and 2.9 µg in children), some communities still experience higher levels of lead in drinking water (6). To date, plumbing systems in many areas across Canada still contain lead service lines or lead solder, which can contaminate household, residential and school water distribution systems (4). Therefore, despite lead being phased out from most environmental sources, it can still be present at low levels in tap water (7).

While blood lead levels have decreased over the past 20-30 years, the American Academy of Pediatrics (AAP) recently stated that blood lead levels below 5 µg/dL are strongly associated with adverse neurodevelopmental effects in terms of attention, problem behaviours, academic performance and intellectual deficits (7). Infants and young children are particularly susceptible to the presence of lead in their environment because of increased gastrointestinal absorption, hand-to-mouth behaviors, consumption of dust, and less effective renal excretion compared to adults (4,8). Further research is needed to investigate the sources and impacts of lead exposure in children and to better understand the most effective methods to control lead risks at the provincial, municipal and school district levels.

Blood lead levels in children

CANADA

Over the last few decades, blood lead levels in Canada have fallen dramatically due to regulations that greatly reduced lead levels in common environmental exposures such as paint, gasoline, and solder in food cans (1). According to the 2012/2013 Canadian Health Measures Survey (CHMS), the average concentration of blood lead in Canadians was 1.1 µg/dL (5). BLL were higher among males (1.2 µg/dL) than females (0.97 µg/dL). Importantly, BLL in youth tended to be lower than adults, with an average of 0.68 µg/dL among those aged 3-19 years compared to 1.2 µg/dL in those aged 20-79 years.

BRITISH COLUMBIA

There is little available information on lead exposure among residents of BC. The CHMS, although based on a cross-country sample, is only reported out on a country-wide basis. A 2014 report from the British Columbia Centre for Disease Control (BCCDC) gathered provincial data on blood lead analyses, associated hospitalisations, Drug and Poison Information Centre (DPIC) calls, as well as lead-related physician visits (1). Unlike the CHMS data, which is collected from the general population, blood lead analyses used for this provincial report were gathered from cases where lead exposure was a possible concern, and, as such, cannot be considered representative of the BC as a whole. Regardless, younger children (under age 5) were over-represented among those tested for blood lead. Approximately 96% of the 512 children tested in this age group demonstrated a blood lead concentration below 5 µg/dL (2009-10 data) (1). Older children (age 6-18) were found to have the lowest blood lead concentrations of all demographic groups, with 99.2% of the 946 children tested having a BLL below 5 µg/dL.

Lead Exposure

LEAD SOURCES

While clinical presentations of lead toxicity are now rare due to the reductions in environmental exposures, current blood lead levels remain well above those of the pre-industrial era (9,10). The American Academy of Pediatrics (AAP) recently published a policy statement identifying the most common sources of lead exposure among U.S. children (7). These included house, toy and furniture paint from before 1978, as well as modern toys manufactured and painted overseas, lead bullets, fishing sinkers, plumbing & faucets, contaminated soil, hobbies involving soldering, batteries, pewter pitchers, ceramic dinnerware and exposure via parental occupation.

In the United States, increasing blood lead levels have been associated with lower socioeconomic status (11,12). In British Columbia, similar risk factors for lead exposure in young children have been identified, including being a member of a lower income family, living near contaminated industrial emissions and living in older homes or those with lead in the plumbing systems (1). Being exposed to lead-based materials in ceramics, stained glass, weights and ammunition, as well as eating lead game shot, also contribute to the aggregate risk for high blood lead levels in children.

PROPORTION OF LEAD EXPOSURE BY SOURCE

The degree to which each of these sources contribute to overall lead exposure varies depending on environmental and individual risk factors. Nonetheless, researchers have attempted to apportion the risk of major lead exposure sources.

Lead paint and dust have been identified as the leading contributor to blood lead levels in U.S. children, accounting for approximately 70% of childhood lead exposure (7,13–15). Drinking water was found to be the second largest exposure in the U.S. Children living in housing with water lead concentrations of greater than 5 parts per billion (> 5 µg/L) were found to have blood lead levels that were 20.4% (1.0 µg/dL) higher than children exposed to water lead levels below 5 parts per billion (5 µg/L). From 2007 to 2010, approximately 2.6% of preschool children in the United States were found to have a blood lead concentration greater or equal to 5 µg/dL (≥50 ppb), representing approximately 535 000 US children between 1 and 5 years of age (7,14). Lead was a common component of water distribution systems in Canada prior to the creation of the National Plumbing Code in 1970 (16), upon which most provincial and territorial regulations are based. Lead in pipes was subsequently banned in 1975, followed by solder in 1986. Based on a water lead concentration of 4.8 µg/L and a consumption rate of 0.6 L/day, Health Canada estimated drinking water constitutes approximately 10% of total lead *exposure* in children aged 2 years (17). However, in communities with lead service lines and inadequate corrosion control, the contribution of lead in drinking water can increase dramatically (2,7,17). This was documented in a community in northern BC in 2014, as well as in the ongoing Flint, Michigan water crisis. In a case study of lead in the water if a northern BC school, increased lead content in drinking water was estimated to contribute up to 60% of secondary school students' daily lead exposure (2). Another study from Quebec found a 10-fold increase in the lead concentration in drinking water resulted in a 23% increase in the blood lead levels of children (18).

The importance of lead in school drinking water necessitates consideration of several factors, not least the amount of water that children drink at school. The relative use of different drinking water sources is also important, as drinking fountains may be associated with higher water lead concentrations (19). This depends on the plumbing layout and composition as well as the other factors, such as water temperature, stagnation, pH and water hardness. Based on data gleaned from the National Health and Nutrition Examination Survey (2009-2012), research suggests that American children have a high prevalence of inadequate hydration at school, particularly among older boys from ethnic minorities (20). Among these children, 54.5% meet the criteria for inadequate hydration. In response to these findings, subsequent campaigns have attempted to increase water consumption in schools. Research indicates that water is the most commonly consumed beverage at schools in both the US & Canada, particularly for those between 2 and 5 years of age (21). Children in this age group typically consume around 325 mL per day, which is considerably less than in other countries (22). One study from Seattle (23) suggested that school drinking water does not appreciably affect children's BLLs; however, the BLLs were higher than those typically found in BC children. In contrast, a study undertaken in Montreal found strong correlation between tap water lead levels and blood lead levels in children aged 1-5; however, the study was undertaken in homes where water appeared to make up a greater proportion of children's daily fluid intake (24).

In summary, the correlation between drinking water lead levels and blood lead levels is strong; however, the correlation between *school* drinking water lead levels and children's blood lead levels is less robust. This may be due to the relative amount of water consumed at school compared to total daily fluid consumption. Other factors, such as nutritional status, may also contribute to this discrepancy, particularly with respect to iron and calcium, as these deficiencies can lead to increased absorption of ingested lead.

FACTORS AFFECTING LEAD LEVELS IN DRINKING WATER

Many factors contribute to the total level of lead found in drinking water. As noted above, the sources of lead in drinking water are primarily related to various components of plumbing systems, mainly lead service lines, lead solder, brass fittings and faucets (7,8). Drinking water leaving treatment facilities has generally contains low levels of lead. In Canada, water leaving municipal treated facilities have average lead concentrations of less than 1 µg/L (25). Water delivery systems then carry drinking water from treatment facilities through municipal and private service lines. Those systems which pre-date modern lead regulations (pre-1990) have a greater probability of higher lead content and impose an increased risk to those consumers in terms of total lead ingestion from tap water (8,9).

Properties of water flowing through plumbing systems can exacerbate the leaching of lead from pipes and other lead containing infrastructure. Increased temperature, acidity or softness can facilitate lead leaching and result in elevated water lead levels. The solubility of lead containing corrosion by-products is inversely proportional to the pH of the water, leading to lower levels of lead at the tap for higher pH levels (26). Water low in dissolved metals, such as calcium and magnesium (i.e. soft), tends to be more corrosive than water with higher metal concentrations (8). In addition, the solubility of lead is reduced at relatively low alkalinity (30–50 mg/L as calcium carbonate) (26).

The flow of water can also affect lead levels, increasing under high-flow or stagnant conditions (17,27). In addition, turbulent, as opposed to laminar, flow of water through pipes has been shown to increase lead content, likely due to the dislodging of lead particles (28).

Other characteristics of plumbing systems, such as the presence of lead solder joins between copper pipes, can also influence lead leaching. Research has demonstrated that, under stagnant conditions, corrosive microenvironments can form around the interfaces of lead solder and copper pipes, leading to increased concentrations of soluble lead (29).

The use of disinfectants in water treatment systems has also been shown to have an effect on lead levels. Edwards *et al.* (30) noted that a change of disinfectant in Washington, D.C. from chlorine to chloramine resulted in an increase in lead leaching and subsequently elevated blood lead levels in children. The effect of chloramine on lead leaching was also documented in North Carolina, with the greatest increases in BLL seen in children who resided in residences with older plumbing systems (31).

Assessing the impacts of lead exposure

The harmful effects of high blood lead levels have been extensively documented. While regulation has markedly reduced high level exposure to lead, exposure at levels formerly considered not to be hazardous continues to be a concern. This is supported by evidence of subclinical health impacts from low-level lead exposure, suggesting that lead is a no-threshold toxin (7,32). Identifying populations at the greatest risk of lead exposure and related health impacts will help establish priorities for exposure reduction.

PHARMACOKINETICS AND PHARMACODYNAMICS OF LEAD

Lead exposure typically occurs via inhalation or ingestion of lead containing particles or substances (33). Absorption of lead via the inhalational route of exposure occurs predominantly in the lower respiratory tract, whereas ingested lead is absorbed in the duodenum. The rate of lead absorption is affected by many factors. Dietary intake of calcium, phosphorus, zinc and iron has been found to decrease the rate of lead absorption. An inverse relationship between ascorbic acid (vitamin C) intake and elevated blood lead levels has also been demonstrated (34). In contrast, fasting, as well as intake of saturated fats, can increase absorption of lead (8,33). The ability to absorb lead can also differ depending on age. Children can absorb up to 53% of ingested lead compared to 10% in adults (6).

Lead distributes widely to multiple tissues in the body, including blood, bone, liver, kidney, lungs and brain; however, bone represents the main repository. The distribution of lead in the body also differs depending on age. In adults, 90% of lead is found in bone, whereas in children, 70% of lead is found in bone with the rest circulating in the blood stream or accumulating in other tissues (33).

Elevated blood lead concentrations can also be caused by bone resorption. While bone resorption may be less of an issue among children exposed to lead at schools and daycares, it may influence blood lead levels for adult employees and visitors. Pregnancy can trigger increased bone resorption, more so in the 3rd trimester, which is a normal mechanism for meeting the increased calcium demands of the developing fetus. Similarly, increased bone resorption and remodeling is seen in menopause, hyperparathyroidism, prolonged bed rest and other age-related processes, thereby also causing increased blood lead concentrations (33).

HIGH-LEVEL VERSUS LOW-LEVEL LEAD EXPOSURES AND RELATED HEALTH EFFECTS

With an average of only 3 hospitalisations for lead per year in BC between 2001/02 and 2009/10, clinical lead poisoning has become rare as a result of previous public health efforts (1).

As outlined by the WHO, signs of acute lead intoxication include “dullness, restlessness, irritability, poor attention span, headaches, muscle tremor, abdominal cramps, kidney damage, hallucinations and memory loss” (35). Clinical emergencies often present in adults when blood lead levels exceed 100 µg/dL and in children when levels exceed 80 µg/dL. Such presentations can be associated with extensive vomiting, encephalopathy and even death (7). Children may also present acutely with “colic, constipation, fatigue, anemia” and a range of neurological symptoms ranging from “poor concentration to stupor” (36).

Individuals chronically exposed to lead over a period of several months to years may present with “tiredness, sleeplessness, irritability, headaches, joint pain, gastrointestinal symptoms, muscle weakness, mood disturbances and peripheral neuropathy” (35).

Higher levels of blood lead in children can increase the risk of impulsivity, aggressive behaviour, conduct disorder, delinquency, and criminal behaviours (4,7). BLLs greater than 20 µg/dL are associated with tremor, sensory nerve impairment, and neuro-motor impairment (8).

Although lead can affect various body systems, the neurological effects, including neuro-developmental and behavioural deficits, are often the most prominent (35). According to the AAP, blood lead levels below 10 µg/dL can cause cognitive impairment with no identifiable threshold for toxic effect (7). As cited by the AAP, the National Toxicology Program found sufficient evidence of neurological effects among children with BLLs below 5 µg/dL based on consistency of effect between cross-sectional and prospective studies (37). These effects can include “decreased academic achievement, lower IQ scores, attention related behaviour problems and antisocial behaviours” (7,38). The evidence of a relationship between low BLLs and a reduction in intelligence and attention is among the strongest associations for neurological deficits and lead (8). Ultimately, there is no safe blood level for lead, as even low levels of lead exposure are linked with intellectual deficits, hyperactivity and inattention in children (7).

There is a clear association between early lead exposure (BLLs 1-10 µg/dL) and developmental effects in children (3 to 18 years old), such as decreased academic achievement, reading skills, math skills, attention, auditory function and visual function (8). Deficiencies in memory, IQ, attention, fine motor coordination, behaviour regulation, and anxiety can persist past childhood into teenage years and beyond (8,33,35,38).

While no threshold has been found for the effects of lead on IQ, it is clear that lead adversely impacts neurodevelopment of children at levels well below those associated with clinical symptoms (33). Children are more susceptible to the effects of lead due to their rapid growth and development early in life. Lead interferes with the complex processes of brain development and may lead to irreversible deficits (36).

An internationally pooled analysis by Lanphear *et al.* (32) used data from seven prospective cohort studies from different countries across a large range of IQs and examined the blood lead concentration-IQ relationship. This study presented evidence that the relationship between BLL and IQ is steeper at lower blood lead concentrations (Figure 1).

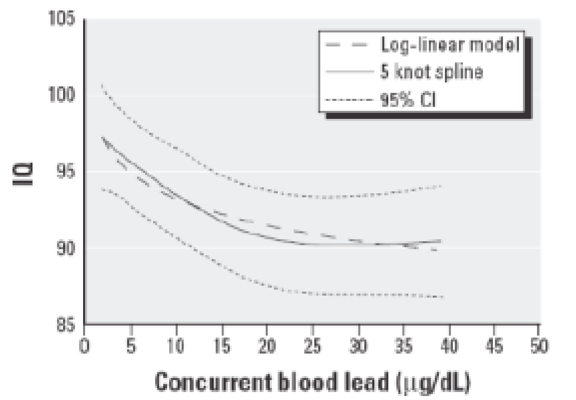

Figure 2. Concurrent blood lead concentration and IQ among 1,333 school aged children in an international pooled analysis (32).

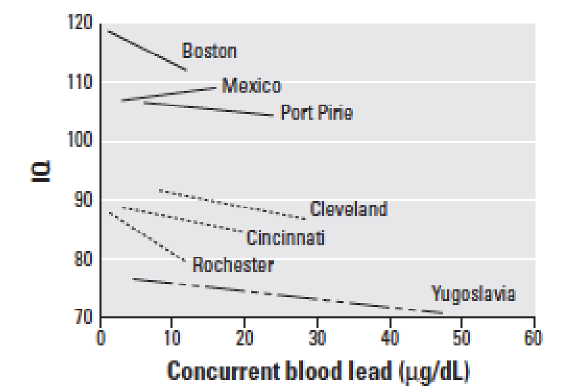

Figure 2. Individual Cohort BLL-IQ Relationships (32)

Despite the wide acceptance of Lanphear's 2005 paper (32) there are some potential limitations. The heterogeneity of the populations in the pooled sample may be considered both a strength and a limitation given the differential weighting caused by variations in sample sizes. Examination of Lanphear's individual cohorts suggests that the log-linear relationship, described as representing the association of BLL and IQ, could be a statistical anomaly brought about by amalgamation of widely varying individual cohorts (Figure 2); however, other studies have confirmed a log-linear relationship between blood lead levels (BLL) and IQ at blood lead levels less than 10 µg/dL (39).

In response to concerns regarding the validity of Lanphear's analysis, Crump *et al.* undertook an independent reanalysis of the pooled data and modified the approach to controlling for non-lead variables, the measures of IQ/lead exposure and the types of transformations/models used to fit the data (40). While this reanalysis identified several potential errors and questionable assumptions from Lanphear's study, the researchers confirmed the non-linear relationship between lead exposure and IQ.

Jusko *et al.* also studied the effect of low blood lead levels on children's IQ (41). They found that blood lead concentrations in children aged 6 years of 5.0 – 9.9 µg/dL were associated with a significantly lower IQ (IQ 4.9 points) compared to levels of less than 5.0 µg/dL when adjusted for child's sex, birth weight, and transferrin saturation; however, when the adjusted IQ of children with blood lead levels 5.0 -9.9 µg/dL was compared with blood lead concentrations greater than 10 µg/dL there were no significant differences. This further supports the argument posited by Lanphear that the blood lead–IQ relationship is steeper across the lower range of blood lead levels.

Eliminating or controlling lead risks

EFFECTIVENESS OF LEAD REMOVAL OR REDUCTION

Minimization of lead exposure is of utmost importance for children, whom the evidence base has identified as most vulnerable to the adverse and irreversible effects of lead exposure on neurodevelopment, intellectual abilities, academic achievement and problem behaviours (7).

Reducing or eliminating the sources of childhood lead exposure is considered a cost-beneficial approach to mitigating lead toxicity (7). A 2011 analysis calculated the cost of lost economic productivity due to reduced cognitive potential from preventable childhood lead exposure in the United States to be approximately $51 Billion (42). An earlier 2009 cost-benefit analysis by Gould focused on the effect of lead paint on children under age 6 and concluded that every $1 spent on lead reduction would result in an estimated benefit valued between $17 and $221 (43). Benefits of blood lead reduction were measured in terms of avoided health care costs, special education, ADHD, crime, potential lifetime earnings and tax revenues gained; however, these estimates were based on the distribution of BLL among US children under the age of 6 sampled between 2003-2006, as reported in the CDC's NHANES study. The most recent data from the CHMS would suggest that current BLLs in Canada are notably lower in comparison to the 2003-2006 NHANES data, averaging 0.68 µg/dL among those aged 3-19 years (5). In contrast, the Gould cost-benefit estimates were based on the effect of reduction of lead exposure on BLL greater than 2 µg/dL. The majority of children in BC would be expected to be below such a level, and therefore the putative cost-benefit of the Gould study cannot be reliably applied to this population; however, the research in the US by Gould indicates that controlling blood lead levels compares favourably with vaccination against common childhood diseases, with return on investment ranging from $17-$221 compared for every dollar invested compared to $5.30-$16.50 for vaccination programs. The same paper also notes that there would be a tangible decrease in violent crime, rapes, robberies and murders, although how this analysis would translate into a Canadian context is not clear given the lower blood lead levels compared to the study population. The crime reduction is accounted for in the cost-benefit analysis but there are clearly non-monetary costs associated with such crimes that would be avoided.

The cost benefit analysis of only school drinking water remediation in BC has not been formerly undertaken, but, given the high cost of infrastructure remediation and relatively small contribution of daycare and school drinking water to blood lead levels in children, it might be a salient exercise to consider whether other programs aimed at improving children's' IQ, such as maternal smoking cessation programs and home environment improvement, might be more cost effective. As noted above, the blood lead levels among Canadian children are much lower than those in whom this research was undertaken; however, where elevated school drinking water lead levels may contribute to elevated children's blood lead levels, given the lack of a threshold for the adverse effects of lead on multiple body systems, it would be reasonable to view intervention favourably from a cost-benefit analysis approach on the basis of what evidence currently exists.

Under certain circumstances, the contribution of lead in school drinking water in BC has been modelled to demonstrate that it could importantly contribute to raised BLLs (2). A recent model proposed by Triantafyllidou *et al.* allows for the estimation of reduction in elevated blood lead levels (>5µg/dL) among children attending schools that remediated lead levels in school drinking water through the use of flushing, water filters, and removal of lead plumbing (44). This model was based on drinking water lead levels measured both pre- and post-remediation within school districts in Seattle and Los Angeles. Estimated reductions in elevated BLLs were demonstrated following the use of water filters and removal of lead plumbing (Seattle), as well as the use of flushing practices (Los Angeles). It is reasonable that such a model could be adapted for school-based populations in BC in an effort to estimate expected reductions in elevated BLLs resulting from various intervention options aimed at reducing lead in BC school and daycare drinking water where water lead levels exceed the federal guideline value.

POTENTIAL IMPACT DRINKING WATER LEAD INTERVENTIONS ON CHILDREN

As stated above, Canadian blood lead levels have fallen over the last several decades such that 70% of Canadians now have blood lead concentrations in the lower range of 1–5 µg/dL (5). The average blood lead levels among children in Canada is even lower with an average of 0.68 µg/dL among those aged 3-19 years. Given the reduction to currently low average blood lead levels among Canadian children, it is important to consider whether interventions at schools and daycares would have a measureable effect on health outcomes.

The relationship between blood levels and IQ per unit of blood lead at blood lead levels less than 5 µg/dL may be more marked than at higher blood lead levels for children. For example, a change in BLL from 5 to 4 µg/dL would be expected to produce a greater IQ benefit than a shift from 10 to 9 µg/dL. The population level effect on IQ of reducing blood lead concentrations will likely therefore be greater at these low levels; however, given the extensive distribution of low levels of lead in infrastructure and the environment, lead reduction at these lower levels may also be costlier.

There is conflicting evidence regarding the impact of interventions focused on reducing lead in school and daycare drinking water. While some research suggests that contamination of tap water with lead can affect blood lead levels in children (24), other research suggests that, at low-moderate water lead levels, exposure to lead at the tap may not meaningfully increase children's blood lead levels (19), particularly when at school water consumption comprises only 30% of daily water intake. The limited effect of tap water on children’s blood lead levels is likely due to the small contribution of water to overall lead intake, as most exposure involves dust, paint and food. Therefore, sustained intake of water with high lead concentrations would be expected to make a small difference to blood lead levels, while low lead level water intake would not make an appreciable difference.

Nonetheless, remediation of lead in school drinking water has been modelled to reduce the risk of elevated BLLs using a BLL threshold of 5 µg/dL (44). Although Deshommes *et al.* found no meaningful association between low-moderate water lead levels in school drinking water and BLLs in children, they did demonstrate exposure to extreme levels of lead at schools or daycares was associated with a high probability of children exceeding a BLL of 5 µg/dL (19).

Therefore, interventions aimed at reducing lead in drinking water may be particularly effective for those schools and daycares where the water lead levels are found to be markedly elevated.

OPTIONS TO REDUCE LEAD LEVELS IN DRINKING WATER

Provincial

In 2007, provincial regulations were introduced in Ontario for the required testing of school drinking water for lead content (45). Initially, testing was mandated annually for all schools and daycares; however, that has since been reduced to once every three years at schools and daycares where lead levels have been consistently documented as below 10 µg/L (3). Requirements were also set in place for the flushing of pipes, the frequency of which is dependent on the age of the plumbing system and whether recent lead testing has been above or below the 10 µg/L standard. There are currently proposed updates to the Ontario regulations which would further strengthen the protection of children from drinking water lead exposure, with a priority on children under the age of 6 years (46). These proposals include the expansion of sampling to include all taps and fountains in a facility and the option to mitigate lead levels with filters as opposed to flushing. Updates to flushing practices also aim to streamline this mitigation measure based on risk and in the interest of water conservation. The strength of the monitoring program is that the level of intervention is based upon regular and objective measures of risk, allowing for primary prevention of lead exposure. The intended result is the targeting of interventions at those facilities posing the greatest risk. However, the threshold for intervention needs consideration to balance feasibility of workload and efficacy of the intervention.

The U.S. CDC supports blood lead screening in children as an important identifier of those at-risk of lead toxicity; such a program also has the benefit of generating data to target primary prevention strategies (47). The highest priority for screening should be placed on children with the highest probability of excess lead exposure.

Given the scientific consensus of the subclinical and irreversible effect of low-level lead on the neurodevelopment of young children and infants, a provincial blood lead screening program, should be considered. As an alternative, mandated reporting of BLL results and follow up of at-risk children (e.g. BLL greater than 10 µg/dL) might also allow identification of at risk areas where many untested children may also be at risk.

Municipal

The total lead in water delivered to school and daycare taps is a function of both the lead leached from the school or daycare’s plumbing system, as well as the lead content in the water delivered by the municipality. As reported by Health Canada, the majority of water leaving treatment facilities across the country contained lead concentrations averaging less than 0.6 µg/L (8); however, in areas where municipal water delivery system components still contain lead, the concentration of lead may be elevated. This is influenced by multiple factors, including temperature, turbulent flow, pH, alkalinity and the age and condition of the service lines. Municipalities can reduce lead concentrations by controlling pH, alkalinity (or buffering capacity) and "hardness" or mineral load, as well as through the addition of anticorrosive agents (17). The replacement of dated service lines should also be considered when identified as a source of significant lead contribution due to either dissolved or particulate metal. Such action would reduce the concentration of lead in water in daycares, schools and, perhaps most importantly, residences.

Schools and Daycares

Testing for lead concentrations may be accomplished according to several different protocols that share characteristics (Appendix A), such as timing of sample collection, sample volume and a visual inspection of the plumbing system (48–50).

Studies have demonstrated considerable variability in water lead levels, depending on the source. The primary factor influencing water lead levels appears to be the length of the lead supply line, with secondary factors such as water quality, faucet type and temperature having less overall influence (49). Peak concentrations encountered during normal daily use appear to be better represented by samples at one-minute flow and thirty-minute stagnation time. Random daytime samples have also been shown to be highly variable but might be useful to indicate the need for more rigorous testing and is used as part of European regulatory protocols (50). Five minutes of flushing is enough to acquire a lead release generated only by the passage of fresh water through the plumbing system. This signature release from the lead supply lines (LSL) during flow is the major contributor to lead concentration in first-litre samples, even if contact time with lead is limited to about 30 seconds. Other issues include release of lead flecks from joints given non-turbulent flow, as well as lead release through electrochemical currents at lead-copper joints. Variability in lead levels can be marked even for standard sampling protocols, depending on the type of plumbing. Dezincification of lead containing materials primarily contributes to this observed variability (51). In summary, sampling protocols should be chosen with care and results interpreted with caution.

Lead leaching within school and daycare water systems can be influenced by similar factors as those discussed for municipal systems (i.e. temperature, turbulent flow, pH, hardness and the age and condition of service lines). Stagnation of water is also an important risk factor for elevated lead levels, as a lack of flow can result in increased leaching time (such as overnight or over the weekends) (17).

Several actions may be taken to reduce lead water content at schools and daycares. These include the inspection and possible replacement of plumbing components containing lead. Despite the high cost of replacing the entirety of a building’s plumbing infrastructure, such action represents the ideal approach to removing source lead from the system. Caution should be exercised before engaging in partial replacement, as it has been shown in some cases to paradoxically increase lead levels for up to several months following replacement (27,52).

Drinking water fountains have been identified as a potential source of lead leaching due to increased water stagnation time, narrow piping (leading to turbulent flow), and the propensity of fountains to contain multiple brass fixtures (17). Older brass, which predates current regulations, typically contains higher lead content and can increase the risk of lead leaching into drinking water (7,53). Drinking fountains identified to contain high-lead content components or fountains which have been confirmed to consistently deliver drinking water with lead levels above the federal standard of 10 µg/L should be removed or replaced.

Water filters can be fitted at point-of-use to reduce lead content in drinking water. Their use has been demonstrated through modelling to reduce the risk of lead exposure to elementary students in the United States (44). Filters require proper installation and maintenance in order to ensure their effectiveness, as well as limit the risk of trapping bacteria (9,17).

Flushing is commonly-used to mitigate lead exposure from drinking water. The intention is to purge stagnant water from the system which has had sufficient time to leach lead from lead-containing plumbing systems. In addition to being time-consuming and wasteful of water, there is little agreement on the duration of flushing required to ensure sufficiently-lowered lead levels (17). Furthermore, in systems containing lead service lines, flushing practices have even been shown to *increase* lead concentration in drinking water and should only be considered as a mitigation measure for interim use (7,54), albeit one that can be instituted immediately and with ease.

Other potential interim mitigation measures include using low temperature water, or to use alternative drinking water sources when lead levels in the school or daycare system are deemed unsafe. Temperature has been demonstrated to increase lead leaching from plumbing systems. It is generally accepted that elevated lead levels in drinking water are expected during warmer seasons (18). One proposed interim measure to mitigate lead levels in drinking water is to limit or reduce the temperature of water or to allow only the use of cold water from the drinking water system of schools or daycares (17). Alternatively, when lead levels in a school or daycare system exceed a set standard, the use of alternative drinking water sources, such as bottled or cooler water, may be considered (17).

Conclusion

- The detrimental effect of incremental increases in blood lead level on IQ is likely to be most marked at low BLLs. On this basis, despite the low BLLs in Canadian children by historical standards, further reduction of BLLs in BC's children is likely to maximize their neuro-developmental potential.
- School and daycare water lead levels may contribute to elevated BLLs in children in BC.
- Given that drinking water lead levels are influenced by many factors, including infrastructure and water characteristics, multiple possible points of intervention are available.
- Although the general quality of drinking water in BC is excellent, some communities may benefit from a targeted intervention where the school and daycare water quality exceeds water lead levels specified in Health Canada’s Drinking Water Guideline.

RECOMMENDATIONS

As such, the current available evidence justifies the following recommendations in order to minimize children's BLLs in BC:

1. Implement a province-wide program to annually sample school and daycare drinking water from multiple sources within each facility between May and September when ambient temperatures are highest. Ensure standardized lead testing to confirm that lead levels in school and daycare drinking water remain below the national drinking water guideline of 10 µg/L. Prioritization should be placed on monitoring the lead in drinking water accessed by infants and younger children [up to the age of 7 years], as they are the most susceptible to irreversible neurodevelopment effects at low-level lead exposure.
2. When the drinking water of school and daycare facilities exceeds the lead standard of 10 µg/L, ensure timely investigation to identify and mitigate the source of lead in drinking water. This should include a thorough plumbing system inspection and, when indicated, replacement of lead-containing plumbing components is recommended. Despite the high cost of total plumbing system replacement, such action is the ideal approach to removing source lead from the system.
3. School and daycare facilities, which have drinking water samples consistently exceeding the standard, should be subject to an increased frequency of review. In such circumstances, testing of municipal sources within the district should also be considered.
4. School drinking fountains that contain high-lead content components or consistently deliver drinking water with lead levels exceeding the national drinking water guideline of 10 µg/L should be removed or replaced.
5. As an interim measure to reduce drinking water lead content, certified water filters can be fitted at point-of-use. Filters require proper installation and regular maintenance in order to ensure their effectiveness and to limit bacterial build-up. Alternatively, bottled water can be supplied to schools where water lead levels exceed the maximum acceptable concentration until remedial factors have been undertaken and tested.
6. Flushing may be considered an interim measure to mitigate lead buildup following periods of water stagnation.
7. Municipalities can best ensure that lead concentrations remain low with adequate and consistent pH & alkalinity control, as well as through the addition of anticorrosive agents to drinking water. These mitigation measures should be reviewed in communities where high lead levels in schools and daycares are identified as being sourced from the municipal system.
8. Replacement of dated municipal service lines is recommended when these components are identified as a source of significant lead contribution as either dissolved or particulate metal. Post-replacement testing of drinking water lead is required as levels can be transiently raised.
9. Blood lead surveillance of young children, either through directed sampling in specific communities, or through the assessment of clinical lead analyses, would allow

prioritization of areas not otherwise protected by the primary prevention strategies outlined in the prior recommendations.

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Appendix A

Table 1. Shared characteristics of tap water sampling protocols for lead content analysis (48–50)

Protocol Characteristic	Details
Sampling Time	Should be representative of what students drink
	Sampling during weekends and vacations is not encouraged
	Stagnation time of at least 30 minutes but preferably 6-8 hours or overnight to determine first draw samples
	Flush for five minutes, then stagnate for 30 minutes, followed by sample collection at 1 and 5 minutes
	US EPA guidance advocates a two-step sampling process: Step 1 tests a sample after stagnation for 8-18 hours to identify sampling points with elevated lead levels; Step 2 takes samples after a 30 sec period of flushing but before the facility outlet has been used to quantify lead levels from water in plumbing behind the wall
	Attention during sample collection to not induce turbulent flow rates ensures sediment is not stirred up or films on pipes is not sloughed so sampling is representative of typical water use patterns
Sample Volume	250 to 1000 ml
Visual Inspection of Plumbing System	May identify high-risk plumbing work