An Evaluation of the Biokinetics of Bone Lead Levels in Children Following Tap Water Exposure Using the All Ages Lead Model (AALM)

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Abstract:

Background and Purpose: Throughout the course of the early- to mid-1900s, human activity and industrialization resulted in the widespread adoption of lead use across the United States. As a result of its malleability and ability to increase product durability, lead was used in several ubiquitous products including paint, gasoline, and pipes (Dignam et al. 2019). As awareness of the detrimental health effects associated with lead have increased over time, corresponding efforts to reduce environmental lead exposure have increased as well. Nonetheless, due to its natural elemental occurrence and the high prevalence of its earlier use, lead remains ubiquitous in our environment today. When combined with aging infrastructural systems, the result is an urban lead burden that continues to persist across numerous cities in the United States such as Los Angeles, New York City, Detroit, and Pittsburgh (LARC 2024). Lead exposure can occur through a number of environmental pathways including soil, dust, water, air and diet. Children are particularly vulnerable to lead's detrimental health effects due to their state of continued development. While soil and house dust lead exposures have been widely studied in children, the impacts of lead exposure through tap water exposure have been evaluated to a lesser degree. Exposure to lead through tap water can occur if lead is leached from lead service lines (LSLs) and other lead-containing plumbing materials. Although the installation of LSLs is prohibited in the U.S. today, LSLs can still be found throughout America, particularly in high-poverty areas where aging infrastructure has not yet been updated. To date, blood lead levels (BLLs) are the most widely accepted biomarker for evaluating pediatric lead exposure, particularly when evaluating ongoing and recent exposures. Bone lead levels have also been evaluated as a possible diagnostic tool for assessing whether a child's lead exposures from several years prior may have resulted in a sustained, elevated lead body burden in later years. The results to date indicate that lead does not bioaccumulate in the bones of children, and it has been suggested that this may be due to the high degree of turnover that is known to occur between the bone and blood compartments while the child is growing (Nie et al. 2011, O'Flaherty 1995). Currently, there are limited data on bone lead exchange and turnover in children. Biokinetic models present an effective tool to estimate and model lead exposure, particularly when real-world data is limited. In this assessment, we used the All Ages Lead Model (AALM) developed by the U.S. Environmental Protection Agency (EPA) to demonstrate whether transient increases in bone lead levels in a hypothetical child will return to baseline in an age-dependent manner once elevated lead exposures from tap water cease.

Methods: The AALM allows for the assessment for intermittent exposures of one day or more, as well as chronic exposures, and can be applied to specific individuals or to groups of similarly exposed individuals. To model the impact of an acute increase in lead exposure from the tap water exposure pathway, inputs for soil, dust, diet, and air were held constant at defaults specified by the AALM manual while lead inputs for tap water were increased at levels above the Lead and Copper Rule (LCR) action level for lead of 15 parts per billion (ppb). Specifically, we used water lead levels (WLLs) of 5 and 15 ppb for durations of 3

months, 1 year, and 2 years to evaluate the resultant impacts of short-term elevated lead exposures on bone lead levels in a hypothetical child beginning at 3 years of age. In particular, we evaluated when bone lead levels returned to baseline following the initiation of elevated lead exposure through water. For the purposes of this analysis, a return to baseline is defined as the point in time at which bone lead levels, following exposures to elevated water lead levels, returned to alignment with bone lead levels from exposures to default water lead levels (continuous exposure to 0.9 ppb as defined by the AALM). The value of 5 ppb is the average of the median first draw WLLs in Flint, Michigan as reported for copper (2.4 ppb) and lead (7.6 ppb) service lines in Pieper et al. (2018) and 15 ppb is the action level for lead in drinking water as set by the EPA's lead and copper rule (LCR).

Results: In each model run, child bone lead levels consistently returned back to baseline levels after the elevated exposures ceased. For both male and female children in the lower bound exposure scenario who were exposed to WLLs of 5 ppb for three months, bone lead levels returned to baseline approximately 605 days (1.66 years) and 618 days (1.69 years) after exposure ceased, respectively. For male and female children in the upper bound exposure scenario who were exposed to WLLs at 15 ppb for 2 years, bone lead levels returned to baseline approximately 3,252 days (8.91 years) and 3,205 days (8.78 years) after exposure ceased, respectively. The results of this analysis indicate that lead does not bioaccumulate in the bones of children who experience episodic lead exposure and that elevated bone lead levels that exist during exposure do not persist into adulthood.

Conclusions: The findings of this modeling exercise confirm previous suggestions that lead does not accumulate in the bones of children and that brief but elevated childhood lead exposures do not result in elevated bone lead levels in adulthood.