Chapter 3

Toxicology, Societal Costs of Lead Exposure, Sources and Routes of Lead Exposure

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Introduction

There are multiple sources of lead in the environment that threaten the developing minds and capacities of young children. The effects of lead depend on both the level and the duration of exposure. Children may be more vulnerable to lead exposure at certain ages. The primary source of exposure for adults is in the workplace. For children, the primary exposure is from dust formed from deteriorated lead-based paint (LBP) or varnish. The lead dust makes its way into the body through normal hand-to-mouth activities of very young children.

This chapter provides information on the history of lead as a toxin, how the body metabolizes lead, the adverse effects of lead on young children, societal costs of lead exposure and the most common sources and routes of lead exposure.

Lead Exposure in Human History

Lead is ubiquitous in modern industrialized societies, and evidence of the negative effects of lead on humans has been noted for centuries. Historical researchers have taken an in-depth look at the history of the uses of lead, its toxicity, and the role of the lead paint industry in the research and promotion of lead (Markowitz and Rosner 2002, 2013).

Lead in the Human Body

Just as the sources of lead exposure in children differ from adults, so does the way a child's body metabolizes and is affected by lead. Figure 3.1 shows the path lead takes in a child’s body from exposure (usually through hand-to-mouth activity) to elimination. A more detailed discussion of the most common sources of lead and routes of exposure are discussed in the last section of this chapter.

Figure 3.1
Lead Sources and Routes of Exposure

Exposure and Absorption of Lead in Children’s Bodies

The primary route of exposure to lead in children is through the gastrointestinal tract. Ingestion of lead contaminated dust through normal hand-to-mouth activity is the primary manner in which children introduce lead into their bodies. Children’s blood lead levels peak around 15 to 24 months of age coinciding with increased hand-to-mouth behavior and increased mobility in
children at these ages. Children’s blood lead levels also tend to be higher in the summer months. This seasonal trend reflects the fact that (a) children play outdoors more in summer and thus have more contact with exterior paint in summer time and (b) dwelling exteriors typically have more lead paint than interior surfaces. Exposure to exterior leaded paint may come from a variety of activities. Children may play on lead-painted porches and stairs or next to exterior walls, or play in yards or alleys where deteriorated paint has fallen to the ground. In climates such as Wisconsin, windows are opened in the summer months, allowing deteriorated exterior paint on windows or walls to enter the home environment and become accessible.

Children absorb up to 50 percent of the lead they ingest, about five times as much as adults. Gastrointestinal absorption of lead is enhanced by a fasting state, iron or calcium deficiency, and high fat diets.

Children who play outdoors near lead contaminated soil are at risk of exposure if they contaminate their hands and then either put their hands in their mouth or eat without washing their hands. Studies of lead in soil find that smaller particles of soil contain a higher percentage of lead. This trend is true especially as particle size decreases below the visible range. (Clark et al, 2006)

Children who ingest lead particles absorb more lead from smaller particle sizes. These ingested particles may come from paint or from historical leaded gasoline emissions.

Lead is absorbed rapidly through the lungs when inhaled. Smaller particles are more efficiently absorbed. Up to 95 percent of inhaled lead is absorbed, if particle size is less than 1 micron. The primary source of inhaled lead had been emissions of small particles of lead oxide from automobiles using leaded gasoline. Since the phase-out of lead from gasoline, the amount of lead inhaled by children is typically far smaller than the amount ingested.

Absorption of inorganic lead through the skin is minimal. By contrast, organic lead compounds such as leaded gasoline are easily skin absorbed. Lead poisoning in children through dermal exposure is rare, primarily because leaded gasoline has been mostly phased out and children’s contact with these materials is limited.

**Distribution of Lead in Children’s Bodies**

Once absorbed into the child’s system, lead is distributed in three body systems: blood, soft tissue, and bone. The concentration and mobility of lead within each system varies (see Table 3.1).

The blood lead level (BLL) is the most common measurement of lead exposure, although it represents only 5 to 10 percent of the total body lead burden. Once in the blood, up to 99 percent of lead may be bound to erythrocytes and cannot diffuse across cell membranes. Approximately 1-10 percent is bound to microligands in the plasma. It is this pool that is capable of crossing cell membranes and therefore can become biologically active. Because lead is found primarily in the red blood cell rather than plasma, there are implications when collecting capillary blood lead samples. If the finger is squeezed too hard, a blood sample may be obtained that is higher in plasma, resulting in a BLL that is falsely low. Lead readily binds to fetal hemoglobin. (For more information, see Chapter 8: Medical Management.)
Table 3.1  Distribution of Lead in the Body

<table>
<thead>
<tr>
<th></th>
<th>Blood</th>
<th>Soft Tissue</th>
<th>Bone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Half-life</td>
<td>30 days</td>
<td>40 days</td>
<td>Spongy (pelvis, ribs, skull): 3-5 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cortical (midtibia, midfemur): 30 years</td>
</tr>
<tr>
<td>% Total body burden</td>
<td>up to 10%</td>
<td>10-20%</td>
<td>70% in children</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>90% in adults</td>
</tr>
</tbody>
</table>

Source: Lead Poisoning in Childhood, S. Pueschel, J. Linakis, A. Anderson

Up to 20 percent of lead retained in the body is stored in soft tissues such as kidney, liver, bone marrow, and brain. It is in these sites where lead has the most toxic effects. The extent of damage to soft tissues is related directly to the amount and duration of exposure; higher exposures and persistent exposures cause more severe effects.

The remainder of lead retained by the body is stored in the bones. The half-life of lead in bone can be up to 30 years, and throughout that time it seeks to create a steady-state with blood lead. As the BLL drops due to chelation and/or decreased exposure, lead migrates from the bone to blood, and may be the cause of a prolonged elevated blood lead level. Bone-to-blood migration may also occur during pregnancy and lactation in women with high bone lead levels, which may have developed in early childhood or following fractures (see Chapter 11 Reproductive).

Elimination of Lead from Children’s Bodies

An estimated 60 percent of absorbed lead is eliminated from the body. The primary route of elimination is through the kidney, followed by feces, hair and nail growth, and sweat loss. In animal studies comparing lead metabolism in infant and adult rats, lead was cleared from the blood much more slowly in infant rats, and localized in the brain to a greater degree.

Adverse Effects of Lead Exposure

The CDC identifies lead as the number one environmental health threat to young children. Lead toxicity can have an adverse effect on virtually every system in the body. The result of lead toxicity can be seen in the peripheral nervous, hematopoietic, renal, and gastrointestinal systems. It affects the regulation of vitamin D, and the growth, hearing, and cognitive development of a young child. Most importantly, it can cause irreversible damage to the central nervous system. At very high levels, lead exposure can cause seizures, coma, and death.

Continued research on lead toxicity in children has caused a rapid decrease in the blood lead levels of concern for children. As recently as the early 1960s, the level of concern for children was 60 mcg/dL. In 1985, that level was lowered to 25 mcg/dL; in 1991, the level was lowered to 10 mcg/dL. That decrease was prompted by an acceptance of widespread research that showed damage from lead at BLLs as low as 10 mcg/dL to the central nervous system of young children, causing developmental delays, lower IQ, hyperactivity, learning disabilities, behavioral problems, and school failure. Physical effects noted at this level include impaired hearing, slowed growth, and nephropathy. In May 2012, CDC concurred with its advisory committee’s recommendation to acknowledge negative health effects in young children with BLLs as low as 5 mcg/dL and to change the terminology from “level of concern” to “reference level.” The recommendation was made due to the overwhelming evidence that lead exposure at levels below 10 mcg/dL causes damage to the cognitive, cardiovascular, endocrine, and immune systems.
The recommendation of the ACCLPP arises from several considerations. In the first research that specifically looked at a large number of children with BLLs known to be <10 mcg/dL, deficits in cognition and academic abilities associated with lead exposure have been noted. Adjusting for factors known to have an impact on these outcomes, children with BLLs >3 mcg/dL demonstrated impairment in cognitive, memory and visual-spatial skills. The adverse effects of lead on reading and other language-based abilities were significant, as these are potent predictors of academic achievement and anti-social behavior. This study further supports the research that has indicated no minimal threshold for lead toxicity.

In 2003, Canfield et al. reported decrements in school age IQ among 213 children whose peak BLLs had never exceeded 10 mcg/dL. Similarly, Bellinger and Needleman (2003), in a reanalysis of data from 48 children from the Boston cohort study whose BLLs never exceeded 10 mcg/dL, reported a similar association. Since 2003, additional reports of associations between BLLs <10 mcg/dL in children with adverse cognitive, and increasingly with other physiological consequences, have been published. Additionally, data from earlier cross-sectional studies of IQ in older children, not considered central to the argument in 2003, have since been reinterpreted as highly relevant, based on re-analysis of prospective data focusing specifically on the time course of associations between blood lead and IQ.

ACCLPP reviewed these and other data, and stated in 2005 that these associations, more likely than not, were causal. There are now additional compelling studies in the scientific literature reporting associations between BLLs <10 mcg/dL and adverse effects in children that form a more substantive body of evidence than was available at the time of the 2005 CDC statement. Collectively, these new studies, and re-interpretation of past studies, have demonstrated that it is not possible to determine a threshold below which BLL is not inversely related to IQ. Healey et al., citing Lanphear et al. as the critical study in its toxicological assessment, asserted that there is a negative slope relating BLL and IQ down to concurrent BLLs of 1 mcg/dL. An increase in concurrent BLL from 1 to 4 mcg/dL is associated with a change in mean IQ of approximately -2.3 to -5.2 IQ points, with a best estimate of -3.7 IQ points. The German Human Biomonitoring Commission concluded that it is not possible to identify a threshold BLL below which there are no cognitive deficits.

Studies have also now extended the effects of low BLLs, and suggest the involvement of specific areas of cognitive dysfunction. These include measures of academic achievement such as reading and writing, as well as attention deficits, specifically impulsivity. For example, Chandramouli et al. reported that BLLs in the range of 5-10 mcg/dL in 30-month-old children were associated with reductions in reading and writing scores in 7- to 8-year-old children from the Avon Longitudinal Study. In a case-control study of children 6 to 17 years old, where the mean BLL was 0.73 and maximum BLL was 2.2 mcg/dL, higher BLLs were associated with parent-reported combined-type attention deficit hyperactivity disorder and hyperactivity-impulsivity after controlling for IQ and prenatal smoking.

**Lead and Learning**

Two recent UW-Madison studies (Amato et al., 2012, 2013) of Milwaukee 4th grade students found that those who were lead poisoned before the age of 3 were almost 3 times more likely to:

- be suspended from school
- fail 4th grade

School suspensions are associated with lower reading achievement, tobacco use, dropping out of school and violent behavior later in life.
The effects reported in children are supported by biological plausibility, i.e., experimental animal studies. Animal research on the effects of lead on brain structure and function demonstrate multiple cellular and synaptic disruptions caused by lead. These disruptions in cellular anatomy and neurotransmitter systems can be noted by the breakdown in their function of modulating emotional response, memory, learning and visual-spatial relationships. Studies have persistently shown a correlation between low-level lead exposure during early brain development and deficits in neurobehavioral-cognitive performance that manifest later in childhood. The effects demonstrated in several longitudinal studies have been consistent across cultures, racial/ethnic groups, and social/economic class.

Prenatal lead exposure has been associated with increased risk of pre-term delivery, reduced birth weight, and reduced performance on neurological testing. For children whose subsequent lead exposure is low and who receive developmentally appropriate stimulation, there is evidence that the damaging neurological effects associated with prenatal exposure may be partially ameliorated by environmental enrichment (see Chapter 10. Educational Assessment and Intervention).

Lead poisoning continues to predict negative outcomes for adults poisoned as children. Violent crimes committed by adults are strongly associated with prenatal and childhood lead poisoning; a 2008 study found that for each increase of 5 micrograms per deciliter of lead in blood as a child, an individual's risk of being arrested for a crime as an adult increases by 50 percent.

Lead in the body can negatively impact health throughout the lifespan. Childhood lead poisoning increases the risk of death from stroke and heart attack as adults. Studies have also shown that childhood lead exposure is linked to adult kidney disease, diabetes, depression, panic attacks and cognitive deficits such as memory loss and Alzheimer’s disease.

**Societal Costs of Lead Exposure In Children**

Societal costs of lead exposure include increased incidence of poor school performance, behavior disorders, and anti-social behavior among children who are lead poisoned. Difficulties achieving in school can lead to classroom disruption, increased costs for special education, and decreased earning potential for the affected child.

Many studies have documented that there is no safe level of lead in the body. Blood lead levels as low as 5 mcg/dL are linked to decreased school performance, behavioral problems, and other difficulties in learning.

In addition, Wright et al. found that lead-exposed children are more likely to be arrested for violent crimes as young adults. A prospective study that followed 250 children from before birth to early adulthood found that each increase in 5 mcg/dL of lead in blood observed at age 6 increased the probability of an arrest for violent crime as a young adult by 48 percent when controlling for other potentially confounding factors (Wright et al., 2008).
These damaging effects of lead poisoning result in heavy costs for the families of lead poisoned children and for the communities where children live. In 2011, Trasande and Liu calculated the annual cost of lead poisoning in the U.S. to be 76.6 billion. Wisconsin’s proportional share of these costs is $1.5 billion per year; note that this estimate excludes the costs of crime associated with lead exposure. Estimates that include the savings from crime prevention (such as Muennin and Bao) are higher, approximately $4 billion/year. In 2009, Gould calculated that each dollar spent on preventing lead poisoning results in a return on investment of $17 to $221 when the costs of lead poisoning, which include health care, education, lost earnings and crime, are calculated.

**Sources and Routes of Lead Exposure**

The following pages include brief descriptions of the commonly identified sources of lead exposure and the vehicles or routes by which they enter a child’s body. It is important to remember that LBP and varnish are the primary sources of lead poisoning among children in Wisconsin and nationwide.

1. **Source: LBP and varnish**

   Exposure to lead-based paint (LBP) is the major source of lead poisoning for children. When lead paint is intact, it is unlikely to cause exposure. The risk of exposure increases as the paint breaks down into smaller particles. The smaller the particles, the more easily they are dispersed, become accessible to children, and are absorbed by the body. If lead paint is allowed to deteriorate due to normal wear (moisture damage, temperature changes, friction, or impact), or when paint is deliberately disturbed by renovation activity, house dust and soil become contaminated. The resulting lead dust and chips can enter a child’s body through normal hand-to-mouth activity.

   **Routes of Exposure:**
   - Lead dust created by deteriorating LBP or renovation activities can stick to fingers, toys, soil, food, and other accessible surfaces. Young children are then likely to ingest the lead dust through normal hand-to-mouth activity. This is the most common route of exposure for children.
   - LBP is a hazard if it is peeling, chipping, chalking, or cracking. LBP that appears to be undisturbed can be a problem if it is on surfaces that rub together (friction surfaces) or surfaces that children chew, such as windows and window sills, doors and door frames, stairs, railings and banisters, porches, fences, and/or furniture.
   - Surfaces that have been covered with new paint or another covering can expose layers of LBP if they are consistently rubbed, or when they become cracked, chipped or deteriorated.
   - Lead in varnish is typically found on floors, stairs, doors, windows and wood trim and even old baby cribs.
• LBP that is intact, undisturbed, and inaccessible to young children may not pose a lead hazard and should be left alone.

2. **Source: Industrial Source/Occupational**
Industries that produce and/or use lead in manufacturing can create lead hazards. A list of industries identified with EBLLs among workers is listed in Table 3.2. Construction trade activity that disturbs old paint can cause exposure to LBP dust for workers through ingestion and inhalation; their families, from exposure to contaminated clothing and shoes; and dwelling occupants, from lead particles created by the work and left in the dwelling.

**Table 3.2. Industries Linked to Elevated Blood Lead Levels**

<table>
<thead>
<tr>
<th>Industry</th>
<th>Products Used in Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary smelting/refining of nonferrous metals</td>
<td>Storage batteries (lead batteries)</td>
</tr>
<tr>
<td>Brass foundry</td>
<td>Valve and pipe fittings (except plumber’s brass goods)</td>
</tr>
<tr>
<td>Plumbing fixture fittings and trim (brass goods)</td>
<td>Glass products made with lead</td>
</tr>
<tr>
<td></td>
<td>Primary batteries, dry and wet</td>
</tr>
<tr>
<td>Motor vehicle parts/accessories</td>
<td>Chemicals and chemical preparations</td>
</tr>
<tr>
<td>Firing ranges</td>
<td>Industrial machinery and equipment</td>
</tr>
<tr>
<td>Pottery studios</td>
<td>Inorganic pigments</td>
</tr>
<tr>
<td>Bridge, tunnel, and elevated highway construction</td>
<td></td>
</tr>
<tr>
<td>Automotive repair shops</td>
<td></td>
</tr>
</tbody>
</table>

Source: Bader and Marion, 1990; Maizlish et al., 1990.

**Routes of Exposure:**
• Lead-emitting industries such as smelters and battery manufacturing plants can cause lead contamination of air, soil, and food grown in contaminated soil.
• Adults working in industries or other occupations involving exposure to lead may be directly exposed and/or may carry lead-contaminated dust home to their families on their hair, clothing, and shoes.

3. **Source: Hobbies**
Hobbies that involve lead or lead-containing materials (Table 3.3) can cause exposure if steps are not taken to contain the lead and keep it away from children.
Table 3.3. Hobbies Involving Lead Products

<table>
<thead>
<tr>
<th>Hobby</th>
<th>Products Used in Hobby</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casting</td>
<td>Ammunition, fishing weights, toy soldiers</td>
</tr>
<tr>
<td>Stained glass</td>
<td>Lead solder</td>
</tr>
<tr>
<td>Making pottery</td>
<td>Lead glazes</td>
</tr>
<tr>
<td>Furniture refinishing</td>
<td>Leaded paint or varnish</td>
</tr>
<tr>
<td>Art and painting</td>
<td>Paints, glazes or colored pencils</td>
</tr>
</tbody>
</table>

Source: Adapted from CDC Manual, 1991

Routes of Exposure:
- Eating, drinking, or smoking in the work area.
- Hands or clothes worn while working can become contaminated and expose children through contact. People involved in these hobbies are advised to avoid contact with children until they have showered and changed clothes.
- Lead contaminated dust from these hobbies can be spread to other areas of the home where children play or spend time.

4. Source: Toys, Children’s Products and Other Household Products
In 1978, regulation of the commercial manufacturing of toys and children’s products in the United States became more stringent for lead content. However, lead is periodically identified in products made in the United States or imported. There is concern about the lead content of toys imported from Southeast Asia, Central and South America, Eastern European countries, and Mexico.

Examples of widely used products that have been found to contain lead are candles with leaded wicks, vinyl mini and vertical blinds, and car keys. Any products built before 1978, such as toys, playground equipment and furniture, should be regarded as containing lead until tested.

Imported candies from Mexico, Thailand, and China have been tested and found to contain high levels of lead. The California Department of Health website includes a current list of candies tested for lead and a file with pictures of candies that have tested positive for lead.

For current information on other product recalls, contact CPSC directly at 800-638-2772 or visit a website where you can search a database for products that contain lead. EPA’s website also includes information on lead in products.

Routes of Exposure:
Mouthing, chewing, or ingesting dust or paint from products that contain lead.

5. Source: Traditional Home Remedies, Imported Candies and Cosmetics
In some cultures, families may use remedies or cosmetics that contain lead (see Table 3.4). Use of powder remedies containing lead for cosmetics or medical conditions is often...
steeped in traditions that may be unfamiliar to health care professionals in the U.S. It may take several interactions with the family to gain their trust and willingness to inform you of how, why, and which of these medicines or cosmetics they may use. In addition, use of herbal supplements has been linked to increased lead in blood among women. (Buettner C. et al., 2006) If possible, obtain a sample of the suspected medicine or cosmetic to be analyzed for lead at the Wisconsin State Laboratory of Hygiene.

### Table 3.4. Traditional Home Remedies/Cosmetics Containing Lead

<table>
<thead>
<tr>
<th>Culture/use of product</th>
<th>Name(s) of product</th>
<th>Description of product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latino: abdominal pain called “empacho”</td>
<td>Alarcon, azarcon, coral, greta, liga, rueda</td>
<td>Yellow or orange powders</td>
</tr>
<tr>
<td>Asian, Indian: intestinal disorders</td>
<td>Ghasard, Bali gol, Kandu</td>
<td>Brown powder, Flat black bean, Red powder</td>
</tr>
<tr>
<td>Hmong: fever or rash</td>
<td>Pay-loo-ah</td>
<td>Red powder</td>
</tr>
<tr>
<td>Asia and Mideastern countries: cosmetic, treatment for infections of the skin or umbilical stump, for ceremonial use or eye protection</td>
<td>Kohl or akohl, Surma, Ceruse, Kajal</td>
<td>Powder</td>
</tr>
</tbody>
</table>

**Route of Exposure:**
Direct ingestion, if taken as a medication, or hand-to-mouth, if topical application is involved, such as with a cosmetic.

6. **Source: Plumbing fixtures and pipes that contain lead**
The most common source of contamination of drinking water is lead in plumbing solder. Contamination from lead pipes, lead connectors, and lead service lines is less frequent. Brass or bronze plumbing and well parts that have lead added to increase the malleability may be disguised by a chrome coating. The small wire mesh screen at the spigot end of the faucet can trap lead solder particles and contaminate the water. Where lead is present in plumbing, contamination is increased by corrosive water (acidic or low mineral content, “soft” water), the length of time the water sits in the pipes, and hot water.

**Routes of Exposure:**
Water that passes through lead containing plumbing fixtures or pipes can become contaminated and become a hazard when used in drinking, cooking, or food and formula preparation.

7. **Source: Dishware**
The lead content of commercial dishware, pottery and crystal manufactured in the U.S. is regulated. However, if these items are imported from countries without such regulation they may contain dangerous amounts of lead in glaze or glass. On occasion, the Consumer Product Safety Commission (CPSC) has recalled products that contain unsafe amounts of lead, such as imported ceramics and dishware.
If you would like more information on product recalls, contact CPSC directly at 800-638-2772 or visit their web site, http://www.cpsc.gov. The Wisconsin Department of Agriculture, Trade and Consumer Protection (DATCP) also conducts product recalls and notices on unsafe products. You can contact DATCP at 608-224-4944 or visit http://datcp.wi.gov/Consumer/Product_Safety/Children_Recalls_and_Advice/index.aspx.

**Routes of Exposure:**
- Ingestion of contaminated foods stored in dishes with leaded glaze or paint or leaded crystal.
- Acidic foods and beverages, such as tomato sauce, coffee, juice or wine can exacerbate the leaching of lead when prepared or stored in leaded containers.

8. **Source: Lead-Based Solder in Cans**
The lead solder used to seal cans may contaminate the food it contains. In 1995, the U.S. banned the use of lead solder in food or soft drink cans, but it is still used in many other countries and may still be found in cans imported to the U.S.

**Routes of Exposure:**
Ingestion by children of food or beverages stored in cans with lead-soldering.

9. **Source: Leaded Gasoline**
Leaded gasoline contributes directly to air lead levels. Fallout from the air causes contamination of soil, dust, and crops. Lead in soil does not biodegrade. Annual emissions of lead from gasoline have fallen dramatically since the mid-1970s, when the lead content of gasoline was regulated. The decline of lead in gasoline has been accompanied by a decline in the mean BLLs of the United States (U.S.) population. However, leaded gasoline is still used in some airplanes and is available for racing cars in the U.S. Leaded gasoline is still used in other countries, and children who are adopted or immigrate from these countries should be tested for lead poisoning.

**Routes of Exposure:**
- Exhaust from leaded gasoline stays in several inches of topsoil.
- Children playing on or in the soil may be exposed.
- Food grown in contaminated soil may contain lead.
References


Chapter 3.12

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Muennin, P, Bao, P. (2009), The social costs of childhood lead exposure in New Jersey, New Jersey Department of the Public Advocate.


