Chapter 2
Routes of Lead Exposure, Toxicology, and Societal Costs of Lead Exposure

Contents

Introduction

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

There are multiple sources of lead in the environment that threaten the developing minds and abilities of young children. The effects of lead poisoning depend on both the level and the duration of exposure. Children may be more vulnerable to lead exposure at certain ages. The primary exposure for children is 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. Other sources of exposure for children include lead in soil, water, and consumer products. The primary source of exposure for adults is from the workplace.

Adverse effects of lead exposure

The Centers for Disease Control and Prevention (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 cognitive, cardiovascular, immunological, renal, endocrine, 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.

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 or ethnic groups, and social or economic class.

Prenatal lead exposure has been associated with increased risk of pre-term delivery, reduced birth weight, and reduced performance on neurological testing (ATSDR, 2020). 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 improved by environmental enrichment.

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. Wright et al. (2008) 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 µg/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.

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, depression, panic attacks, and cognitive deficits such as memory loss and Alzheimer's disease.

Table 2.1 Expectations of learner and impact of lead exposure on the learner

Phase of learning	Expectations in a learning setting	Outcomes of lead exposure
Preschool	• Sit quietly for short periods of time. • Listen and follow directions. • Share supplies, activities, and attention. • Relate and adapt to a new set of peers and adult caregivers. • Develop listening, attention, and memory skills in the context of learning.	• Inability to sit still • Decreased hearing function and ability to differentiate sounds • Immature social skills • Short attention span • Difficulty in memorizing new concepts
Early elementary	• Adjust to a longer and more structured school day. • Develop the ability to understand and complete assignments and homework. • Face more objective rewards and consequences for their behavior. • Develop broader social networks and cooperative working skills. • Acquire basic academic skills such as reading words and short stories for meaning, performing arithmetic operations, and answering questions.	• Less likely to reach proficiency in reading, arithmetic, science, and social studies • More likely to be suspended from school
Upper elementary	• Become more independent in the face of increased physical, social, and academic demands. • Use basic skills to acquire information and solve problems. • Expand social networks (may experience isolation and bullying). • Participate in competitive and team sports. • Accept one's own and peers' skills and limitations.	• Impaired by poor language skills and attention deficits • More likely to experience difficulty making the transition from "learning to read" to "reading to learn" to learn new material • Less likely to participate in sports due to unstable coordination and other neuromuscular skills
Middle school	• Adapt to a more formal and impersonal academic structure with a number of teachers with different teaching styles and expectations. • Mature in independence to develop and utilize higher order cognitive and organizational skills. • Master several unrelated classes and assignments.	• Less likely to attain higher order cognitive and organizational skills • More likely to drop out of school, become pregnant, and commit violent crime

Phase of learning	Expectations in a learning setting	Outcomes of lead exposure
	• Experience mounting social pressures and need for peer acceptance.	
High school	• Adapt to a greater number of students and teachers and a more rigorous academic and disciplinary environment. • Establish new peer networks and achieve greater independence from family. • Balance school and part-time employment. • Withstand pressure to experiment with alcohol, drugs, and sexual activities. • Develop a more assertive, focused, and efficient learning style and apply good study and organizational skills. • Make decisions regarding vocation and further education beyond high school.	• Less likely to attain higher order cognitive and organizational skills • More likely to drop out of school, become pregnant, and commit violent crime

The evidence from this table comes from "Low Level Lead Exposure, Intelligence and Academic Achievement: A Long-Term Follow-Up Study" by Bellinger et al.

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. To learn more visit Childhood Lead Poisoning: Conservative Estimates of the Social and Economic Benefits of Lead Hazard Control - PMC (nih.gov).

Exposure and absorption in children's bodies

Just as the sources of lead exposure in children differ from adults, so does the way a child's body is affected by and metabolizes lead.

Ingestion

The primary route of exposure in children is ingestion of lead-contaminated dust through normal hand-to-mouth activity. Children absorb up to 50 percent of the lead they ingest, about five times as much as adults. Gastrointestinal absorption of lead is enhanced with iron or calcium deficiency, a high fat diet, or while in a fasting state (ATSDR, 2020).

Children's blood lead levels (BLLs) peak around 15 to 24 months of age, coinciding with increased hand-to-mouth behavior and increased

mobility at these ages. Children's BLLs also tend to be higher in the summer months. This seasonal trend reflects the fact that:

- Children play outdoors more in summer and thus have more contact with exterior paint in summertime.
- 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. Paint on interior windows can also cause lead dust to accumulate with the friction of opening and closing the windows.

Children who play outdoors near lead-contaminated soil are at risk of exposure if they contaminate their hands and then 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.

Inhalation

Lead is absorbed rapidly through the lungs when inhaled. Smaller particles are more efficiently absorbed. If the particle size of inhaled lead is less than 1 micron in size, up to 95 percent is absorbed (ATSDR, 2020). The primary source of inhaled lead had been emissions from automobiles using leaded gasoline. Since the phase-out of lead in gasoline for automobiles, the amount of lead inhaled by children is typically far smaller than the amount ingested. However, leaded aviation fuel is still available for private aircrafts and lead dust can be made airborne during renovation activities.

Absorption through skin

Absorption of inorganic lead through the skin is minimal. By contrast, organic lead compounds such as leaded gasoline are easily absorbed through the skin. Lead poisoning in children through dermal exposure is rare, primarily because leaded gasoline has been 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. (Table 2.2)

Table 2.2 Distribution of lead

	Blood	Soft tissue	Bone
Half-life	30 days	40 days	Spongy (pelvis, ribs, skull): 3–5 years Cortical (midtibia, midfemur): 30 years
% Total body burden	Up to 10%	10–20%	70% in children 90% in adults

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

Exposure is most commonly assessed by measuring the amount of lead in blood, although it only represents 5 to 10 percent of the total body lead burden. Once in the blood, up to 99 percent of lead may be bound with red blood cells and the remaining 1 percent resides in the blood plasma. It is this pool that is capable of crossing cell membranes and therefore can become biologically active. The blood plasma may also alter a capillary blood lead sample if the finger is squeezed too hard, resulting in higher plasma and a falsely low BLL.

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 tissues is related directly to the amount and duration of exposure; high blood lead levels and/or prolonged exposure can cause more severe effects.

Chelation Therapy is a treatment that removes build up of metals from the body. Metals like lead, mercury, iron, and arsenic can be toxic and chelation medicine binds to metals in the blood and are eliminated in urine.

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 achieves 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 BLL. Bone-to-blood migration may also occur during pregnancy and lactation in women with high bone lead levels. This can be a concern to the unborn child because lead crosses the placental barrier and readily binds to fetal hemoglobin. Bone-to-blood migration can also happen following bone fractures.

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.

Exposure during pregnancy and lactation

In November 2010, CDC issued guidelines for the identification and management of lead exposure in pregnant and lactating women. View the document for information including effects of lead on reproductive health, pregnancy and lactation, and the fetus and newborn. Health actions, and initial and follow-up testing schedules for pregnant and lactating women are also included.

Sources of lead exposure

Lead-based paint and varnish are the primary sources of lead poisoning among children in Wisconsin and nationwide. View the Sources of Lead Exposure handout for information on different sources of lead and prevention information.