**AGENCY FOR TOXIC SUBSTANCES AND DISEASE REGISTRY**

## *CASE STUDIES IN ENVIRONMENTAL MEDICINE (CSEM)*

# Lead Toxicity

**Course: WB2832**

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| **Key Concepts** | • Lead poisoning is a completely preventable disease.<br>• No safe blood lead level (BLL) threshold for children has been identified.<br>• Blood lead levels once considered safe are now demonstrated to be hazardous.<br>• Children of all races and ethnic origins are at risk of lead toxicity throughout the United States.<br>• Lead may cause irreversible neurological damage as well as renal disease, cardiovascular effects, and reproductive toxicity.<br>• Lead is one of the most commonly found hazards at Superfund sites.<br>• This case study is focused on lead exposure in the United States; exposures globally may vary.<br>• Primary prevention of lead exposure is the most important and significant strategy to protect children and adults from lead exposures.<br>• Families, service providers, advocates, and public officials need to be educated on primary prevention of lead exposure in homes and other facilities occupied by children so that lead hazards are eliminated before exposure occurs. |
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# Table of Contents

## How to Use This Course

| | |
|---|---|
| **Introduction** | The goal of the ATSDR *Case Studies in Environmental Medicine* (CSEM) series is to increase the primary health care provider's knowledge of hazardous substances in the environment and to promote medical practices that aid in the prevention, evaluation and care of potentially exposed patients. This CSEM focuses on lead toxicity. |
| **Availability** | Two versions of the Lead Toxicity CSEM are available.<br>• The HTML version https://www.atsdr.cdc.gov/csem/csem.asp?csem=34&po=0 provides content through the Internet.<br>• The downloadable PDF version https://www.atsdr.cdc.gov/csem/lead/docs/csem-lead_toxicity_508.pdf provides content in an electronic, printable format, especially for those who may lack adequate Internet service.<br>• The HTML version offers interactive exercises and prescriptive feedback to the user. |
| **Instructions** | To make the most effective use of this course,<br>• Take the Initial Check to assess your current knowledge about lead toxicity.<br>• Read the title, learning objectives, text, and key points in each section. |

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| | • Complete the progress check exercises at the end of each section and check your answers.<br>• Complete and submit your assessment and posttest response online if you wish to obtain continuing education credit. Continuing education certificates can be printed immediately upon completion. There is no charge for continuing education credits. |
| **Instructional Format** | This course is designed to help you learn efficiently. Topics are clearly labeled so that you can skip sections or quickly scan sections you are already familiar with. This labeling will also allow you to use this training material as a handy reference. To help you identify and absorb important content quickly, each section is structured as follows: |

| **Section Element** | **Purpose** |
|---|---|
| Title | Serves as a "focus question" that you should be able to answer after completing the section. |
| Learning Objectives | Describes specific content addressed in each section and focuses your attention on important points. |
| Text | Provides the information you need to answer the progress check question(s) and achieve the learning objectives. |
| Key Points | Highlights important issues and helps you review. |
| Progress Check exercises | Enables you to test yourself to determine whether you have mastered the learning objectives. |
| Progress Check Answers | Provide feedback to ensure you understand the content and can locate information in the text. |

**Learning Objectives** Upon completion of the Lead Toxicity CSEM, you will be able to:

| **Section Title** | **Learning Objectives** |
|---|---|
| What Is Lead? | • Explain what lead is. |
| Where Is Lead | • Describe potential sources of lead exposure in the |

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| Found? | United States today. |
| What Are Routes of Exposure to Lead? | • Identify the most common routes of exposure to lead in the United States today. |
| Who Is at Risk of Lead Exposure? | • Identify the populations most heavily exposed to lead. |
| What Are U.S. Standards for Lead Levels? | • Describe the Centers for Disease Control and Prevention's (CDC) reference value for lead in children's blood,<br>• Describe the U.S. Occupational Safety and Health Administration's (OSHA) Permissible Exposure Limit (PEL) for lead in workplace air,<br>• Describe the U.S. Environmental Protection Agency's (EPA) drinking water regulation for lead, and<br>• Describe the Consumer Product Safety Commission's (CPSC) regulatory limit value for lead in paint. |
| What Is the Biological Fate of Lead in the Body? | • Describe how lead is absorbed,<br>• Describe how lead is distributed in the body, and<br>• Identify the half-life of lead in the blood. |
| What are Possible Health Effects from Lead Exposure? | • Describe how lead affects adults and children,<br>• Describe what is the most sensitive organ system for lead exposure in children, and<br>• Specify that there is no identified threshold or safe level of lead in blood. |
| Clinical Assessment – Exposure History | • Describe how to take a screening exposure history for lead exposure, and<br>• Identify lead exposure-related questions to ask during a child visit. |
| Clinical Assessment – Signs and Symptoms | • Name typical signs and symptoms consistent with lead toxicity,<br>• Describe how lead exposure dose and symptoms can vary, and |

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| | • Describe key features of the physical examination for patients exposed to lead. |
| Clinical Assessment – Diagnostic Tests and Imaging | • Describe guidelines for blood lead screening and confirmatory diagnostic testing on patients at risk of recent or ongoing lead exposure, and<br>• Describe imaging and other clinical modalities that may assist in the diagnosis of current or past lead exposed patients. |
| How Should Patients Exposed to Lead Be Treated and Managed? | • Describe a management strategy for children whose blood lead levels are equal to or greater than the current CDC reference value of 5µg/dL. |
| What Instructions Should Be Given to Patients? | • Describe instructions to parents and patients to prevent or reduce lead exposure,<br>• Describe instructions for patients exposed to lead, and<br>• Describe communication strategies that health care providers can use to best deliver clinical information to their lead exposed or potentially exposed patients. |

## Initial Check

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| **Instructions** | This Initial Check will help you assess your current knowledge about lead toxicity. To take the Initial Check, read the case below, and then answer the questions that follow. |

**Case Study**

A father brings his 2-year-old boy into a pediatrician's office for a routine well-child visit. The boys lives with his parents and an older sister in a rented apartment.

The pediatrician examines the boy and finds no abnormalities. The boy's growth and development indicators are within normal limits for his age.

Three years later, concerned that her child is hyperactive, the mother brings the same child, now 5 years old, to your office (his previous pediatrician recently retired).

At a parent-teacher conference last week, the kindergarten teacher said that the boy seems impulsive and has trouble concentrating. They recommended evaluation by a physician as well as by the school psychologist. The mother states that her son has always seemed restless and easily distracted, but that these first 6 months in kindergarten have been especially difficult.

He has also complained recently of frequent intermittent abdominal pains and constipation. The mother gave him acetaminophen for stomach pains with little change. She has also been giving him a fiber laxative, which has reduced the frequency and severity of constipation. She wonders if the change to attending kindergarten has played a role in his increased complaints.

Family history reveals that the boy's parents are divorced. He lives with his older sister, mother, and maternal grandparents in an older suburb of your community. The parents divorced when the boy was three years old. The father works in retail at a local shopping center. The child visits with his father one weekend a month, which is working out fine. However, he seems to be fighting more with his sister, who has been diagnosed with attention deficit hyperactivity disorder (ADHD) and is repeating first grade. Since the mother moved in with her parents after her divorce 2 years ago, she has worked with the grandfather in an automobile radiator repair shop, where her children often come to play after school. She has recently been

laid off and has expressed worry about increasing financial dependence on her parents as the children grow older. She also worries that the grandfather, who has gout and complains increasingly of abdominal pain, may become even more irritable when he learns that she is pregnant from the father of her son. Her third child is due in 6½ months. The father has no lead exposure risk factors.

When you inquire about the home, she explains that it was built in the 1960s. Her father bought it 30 years ago at a good price, as it is on a busy street close to the center of town. She has no idea of the type of pipes they have or the source of drinking water. They don't use any kind of water filtration system. The yard is bare. She doesn't see her father doing any improvements to the house due to his economic situation.

You ask about smoking habits and learn that the mother smokes up to a pack of cigarettes a day, sometimes in front of the children at home. The grandfather also smokes, but seldom in front of the children.

On chart review, you see that the previous pediatrician examined the boy for his preschool physical 1 year ago. A note describes a very active 4 year old who could dress himself without help but could not correctly name the primary colors. His vision was normal, but hearing acuity was below normal according to a hearing test administered for his preschool physical. The previous doctor noted that the boy's speech and language abilities were slightly delayed. Immunizations are up to date.

Further history on last year's visit indicated adequate diet, with no pica behavior. Hemoglobin 10 g/dL and low ferritin. Hematocrit was diminished at 30%. Peripheral blood smear showed hypochromia and microcytosis. There was no evidence of blood loss, and stool examination was negative for occult blood. The diagnosis was "mild iron deficiency anemia," and elemental iron 5 milligrams/kilograms (mg/kg) per 24 hours (divided 3 times daily without food) was prescribed. The family failed to keep several follow-up

appointments, but the child did apparently complete the prescribed 3-month course of iron supplements. He received no medications and had no known allergies. No psychological studies, learning, speech or behavioral evaluations were performed.

On physical examination today, you note that the boy is in the bottom 10th percentile for height and weight. The previous year he was plotted at the 20th percentile. His attention span is very short, making him appear restless. He has difficulty following simple instructions. Except for hearing acuity below normal, slightly delayed language, and social skills, the boy has reached most important developmental milestones.

**Initial Check**

1. What information (if taken at his age 2 well child visit) would have assisted with prevention and early identification of lead exposure risks?

   A. Smoking status of parents.
   B. Age and condition of boy's primary residence.
   C. Occupations of family members.
   D. Drinking water source and delivery system.
   E. B and D.
   F. All of the above.

2. What should be included in this boy's problem list?

   A. Delayed language ability, slightly impaired hearing.
   B. Short stature, history of hypochromic, microcytic anemia (treated with iron supplementation), abdominal pain, constipation.
   C. Possible attention deficit hyperactivity disorder, school and family stressors, lead exposure risk.
   D. A and C.
   E. All of the above.

3. What test would you order to confirm or rule out your diagnosis?

   A. Capillary blood lead level (finger stick).
   B. Abdominal radiograph.
   C. Venous blood lead level (BLL).

D. Erythrocyte protoporphyrin (EP)/zinc protoporphyrin (ZPP) level.

4. Which other family member is most vulnerable for effects of lead exposure at this time?

A. The mother.
B. The older sister.
C. The unborn baby.
D. The grandfather.

**Initial Check Answers**

1. What information (if taken at his age 2 well child visit) would have assisted with prevention and early identification of exposure risks?

The best choice is Answer F. All of the above.

Two of the obvious sources of lead suggested in the case study are leaded paint at home (paint flakes, household dust, and soil) and fumes and dust from solder at the radiator repair shop. However, smoke from cigarettes is also a source of lead that can be an important exposure (first, second or third-hand) to children. He or she could have explained the need to quit smoking not only in front of the children, but in the home, as tobacco and its toxins adhere to the furniture, clothing and walls (third hand smoking). Other information that would have assisted with prevention and early identification of lead exposure risks is the drinking water source and delivery system, as well as the occupations of the mother and father.

You can ask questions about the age of the family's house, when it was most recently painted, and the condition of the paint to get a preliminary sense of the potential extent of this exposure pathway. If the house was built before 1978, the child may be exposed to higher lead content paint chips, lead-contaminated soil, or lead in dust in the home.

Additionally, you should determine if the boy ever had pica (a compulsive eating of non-food items, to be distinguished from normal hand-to-mouth

behavior of children). Pica is more common in children ages 2 to 5, so it is likely that this is a present behavior. You can also ask about the length, type, and precise location of the boy's play at the radiator shop.

*More information for this answer can be found in the "Clinical Assessment – Exposure History" section.*

2. What should be included in this boy's problem list?

   The best choice is Answer E: All of the above.

   History suggests

   - Delayed language ability,
   - Slightly impaired hearing,
   - Short stature,
   - Possible attention deficit disorder,
   - Anemia, and
   - Abdominal pain.

   The child is also experiencing passive exposure to his mother's cigarette smoke and family disruption and possible stress related to his parents' divorce, or possibly to attending kindergarten.

   *More information for this answer can be found in the "Clinical Assessment – Signs and Symptoms" section.*

3. What test would you order to confirm or rule out your diagnosis?

   The best choice is Answer B. Venous blood lead level (BLL).

   To confirm lead poisoning, the best test is a venous BLL. Capillary blood draws (finger-sticks) are not considered reliable for diagnosis purposes. A venous or a screening capillary BLL is usually the first test drawn, instead of the EP/ZPP. Erythrocyte protoporphyrin (EP), commonly assayed as zinc

protoporphyrin (ZPP), is not sufficiently sensitive at lower BLLs and therefore is not as useful a screening test for lead exposure in children.

If the BLL is below 25 µg/dL, then a serum ferritin level and other iron studies can be used to determine if iron deficiency anemia exists.

*More information for this answer can be found in the "Clinical Assessment – Diagnostic Tests and Imaging" section.*

4. Which other family member is most vulnerable for effects of lead exposure at this time?

The best choice is Answer C. The unborn baby.

While the mother may be at risk, the unborn baby has the highest risk of neurodevelopmental problems. The mother has recently been laid off, ending the ongoing occupational exposure for her and her unborn child. However, her lead body burden can continue to expose the unborn child because the bone lead from all sources is mobilized during pregnancy and passed to the fetus through the mother's blood. The unborn baby is also at risk if the mother currently smokes or has smoked in the past. In addition, the baby will be at risk to potential home-based sources when he or she begins to move around and mouth objects. Prenatal exposure and exposure at a very young age to lead can damage development of the brain.

Additional sources of exposure for the children include possibly playing at the radiator repair shop after school, and, since the grandfather still works there, take-home exposure if he brings contaminated clothes or shoes into the house. This is especially important for the pregnant mother, whose occupational exposure has ended but who may still be exposed by the take-home exposure from her father's clothes/shoes. The person

handling these clothes and doing the laundry may also be exposed.

The grandfather may be exposed, as he shows irritability and abdominal pain. If this source is removed (using “lead safe” practices or switching jobs) he should recover. You should, however, suggest that he should be tested and talk to his physician about it. The older sister might be at risk from exposure in the home or radiator repair shop, although because she is older she will probably ingest less lead through hand-to-mouth behavior at this time. However, her history also suggests she may have been exposed as a younger child as well.

*More information for this answer can be found in the “Who Is at Risk of Lead Exposure?” “What Are U.S. Standards for Lead Levels” and “What Are Possible Health Effects from Lead Exposure?” sections.*

## What Is Lead?

**Learning Objectives**

Upon completion of this section, you will be able to

- Explain what lead is.

**Introduction**

Lead is a soft, blue-gray metal, usually found as lead compounds, combined with other elements. Much of its presence in the environment stems from

- Its historic use in paint and gasoline in the United States,
- Recycling operations,
- Ongoing or historic mining/smelting,
- Commercial operations, and
- Lead contaminated consumer products.

**Forms of Lead**

**Elemental lead.**

The chemical symbol for lead is Pb (from the Latin name plumbum). Lead has an atomic number of 82 and

an atomic weight of 207.2. It is a bluish-grey metal that tarnishes easily in air to a dark grey. The density of lead is 11.34 g/cm3. It has a low melting point of 327.46 °C or 621.43 °F. Naturally occurring lead ores comprise 0.002% (15g/t) of the earth's crust.

**Inorganic lead.**

This is the form of lead found in higher lead content paint, soil, dust and various consumer products. The color varies, depending on the chemical form, and the most common forms are white lead (a lead carbonate compound), yellow lead (lead chromate, lead monoxide) or red lead (lead tetraoxide). Lead acetate has a sweetish taste.

**Organic lead.**

Tetraethyl and tetramethyl lead is the form of lead used in leaded gasoline to increase octane rating. The combustion of organic lead –when it is added to gasoline as a fuel additive– results in the release of lead into the atmosphere. However, their use was phased out in the United States starting in the early 1970's, and banned for use in gasoline for motor vehicles beginning January 1, 1996.

Organic forms of lead are extremely dangerous, as they are absorbed through the skin and are highly toxic to the brain and central nervous system, much more so than inorganic lead.

Exposure to organic lead is generally limited to an occupational context [EPA 1996]. Potential exposures to organic lead should be taken very seriously. The symptoms and treatment are different from those of inorganic lead.

The main focus of this course is on inorganic lead toxicity.

**Properties**

Lead is a

- Very soft,
- Dense, and
- Ductile (moldable) metal.

Lead is very stable and resistant to corrosion, although acidic water may leach lead out of

- Pipes,
- Fittings, and
- Solder (metal joints).

Lead is a poor conductor of electricity and an effective shield against radiation.

Because of these properties, and because it is relatively easy to mine and recycle, lead has been used for many purposes for thousands of years. Ancient Romans used lead for plumbing, among other uses. In modern times, lead was added to paint and gasoline to improve performance. In the United States, lead was phased out of gasoline starting in the late 1970's, and banned for use in gasoline for motor vehicles beginning January 1, 1996, due to health concerns. Current uses of lead are discussed further in the next section.

Lead accumulation in the body is the result of anthropogenic (human) use, which has concentrated lead throughout the environment. Because lead is spread so widely throughout the environment, it can be found in everyone's body today. The main exposure route is oral, especially in small children, as they have hand-to-mouth behaviors that increase their risks. The respiratory route allows exposure to lead-containing dust, especially in occupational settings and during home renovations. Some authors suggest that because environmental lead accumulation and levels found today, which can result in adverse health effects, many people are exposed to levels of lead that are “orders of magnitude” greater than that of pre-industrial levels [Jusko et al. 2008; Flegal and Smith 1995; Budd et al. 1998].

**Key Points**

- Lead is a naturally occurring, very soft, dense, and ductile (moldable) metal.
- Lead is still used in some commercial products made or imported into the United States.
- Lead is very stable and accumulates in the environment.
- Lead is resistant to corrosion, although acidic water may leach lead out of pipes, fittings, and solder (metal joints).
- The body absorbs organic lead (as was used in leaded gasoline for "on-road" vehicles in the past in the United States, and is used in some occupational settings today) faster than inorganic lead. And, unlike inorganic lead compounds, organic lead can be readily absorbed through the skin.
- Most lead encountered in the environment today is inorganic.

**Progress Check**

1. Which of the following statements regarding environmental lead is correct?

   A. Lead is a naturally occurring metal that is very soft, dense and ductile.
   B. Lead is very stable and accumulates in the environment.
   C. Lead can be found in some consumer products, old house paint, contaminated dust or drinking water.
   D. Most lead encountered in the environment today is inorganic.
   E. All of the above.

   *To review relevant content, see "Properties"* and *"Forms of Lead" in this section.*

## Where Is Lead Found?

**Learning Objectives**

Upon completion of this section, you will be able to

- Describe potential sources of lead exposure in the United States today.

**Introduction**

"An exposure pathway must, by definition, have five components:

1) a source of contamination (such as deteriorating lead-based paint on the walls, doors and windows of a home; used car batteries; open burning of waste);

2) an environmental medium and transport mechanism (such as lead contaminated dust on the floor of a home, lead smoke from open burning, or lead exhaust from leaded gasoline);

3) a point of exposure (such as children's hands, the floor, or children's toys);

4) a route of exposure (such as eating the dust through hand-to-mouth behavior); and

5) an exposed population (such as children in the home environment or pregnant women in polluted environments or workplaces).

When all five components are present, the exposure pathway is termed a complete exposure pathway" [WHO 2010].

The distribution of lead in the environment varies from place to place. Each of the following sources of lead is discussed further in this section.

- Lead-contaminated house dust is the major source of exposure for children in the United States, resulting from higher lead content paint that remains in older buildings.
- Lead occurs in drinking water through leaching from lead-containing pipes, faucets, and solder frequently found in the plumbing of older buildings.
- Lead in lead-glazed food containers may contaminate water, food, and beverages without being seen, tasted, or smelled.
- Lead may be found in and around workplaces where lead is used as well as in waste materials from production processes.

- Lead may still be found in

  - Some commercial products,
  - Some imported jewelry and candies,
  - Children's toys,
  - Cosmetics, and
  - Folk, traditional or home remedies.

- Lead concentrations in soil, air, and water can be especially high near the sites of historic or ongoing mining operations or smelters.
- Lead concentrations in inner city soil can be especially high from accumulation that occurred before the elimination of lead from gasoline in the United States (early phase down/phase out efforts starting in the late 1970s with continuation into the 1990s).
- Lead from exposure to cigarette smoke (including second and third hand tobacco smoke exposures [SHS & THS]) may contribute to increased blood lead levels (BLLs) in children.
- While BLLs over time are consistently declining in the United States, it is still a serious health problem for many people, particularly children in urban areas.

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| **Economic Costs of Childhood Lead Poisoning** | "Blood lead concentrations have decreased dramatically in U.S. children over the past 4 decades, but too many children still live in housing with deteriorated high content lead-based paint and are at risk for lead exposure with resulting lead-associated cognitive impairment and behavioral problems" [AAP 2016].<br><br>Landrigan et al. 2002a estimated that the U.S. economy incurs $43.4 billion annually in the costs of all pediatric environmental disease.<br><br>Childhood lead poisoning alone accounts for the vast majority of these costs, which includes<br><br>• Medical costs,<br>• Disability,<br>• Education, and<br>• Parental lost work time.<br><br>A more recent study described the loss of economic productivity resulting from reduced cognitive potential and from preventable childhood lead exposure to range from $44.8–$60.6 billion in 2008 [Trasande and Liu 2011].<br><br>Evidence continues to accrue that commonly encountered blood lead concentrations, even those below 5 µg/dL (50 ppb), impair cognition; there is no identified threshold or safe level of lead in blood [AAP 2016].<br><br>Evidence-based guidance is available for managing increased lead exposure in children, and reducing sources of lead in the environment, including lead in housing, soil, water, and consumer products, and has been shown to be cost-beneficial [AAP 2016]. Primary prevention should be the focus of policy on childhood lead toxicity. |
| **Lead-based Paint in Homes and Buildings** | Lead-contaminated household dust is considered the major high-dose source of lead for children in the United States today [AAP 2016; Lanphear et al. 2002]. Much of this is due to the degradation of interior paint, especially in housing built before 1978. |

In 1977 the Consumer Product Safety Commission (CPSC) limited the lead in most paints to 0.06% (600 ppm by dry weight) [CPSC 1977]. In 2009 CPSC further limited lead content in household paint and similar surface coatings in children's products, and some furniture, for adult and children, to a concentration of lead not greater than 0.009 percent (90 parts per million) [CPSC 2009]. “Many of the steel bridges in the highway system are still coated with paint that contains up to 50% lead by weight” [DOT 2016a].

Most literature refers to “Lead-based paint,” or “Lead Paint” to paint manufactured before 1978, which used to contain higher amounts of lead. Household paint manufactured today may still contain very small amounts of lead.

In addition to degradation of interior paint, lead may be tracked into homes in significant quantities from exterior soil contaminated by historical use of lead in

- Paint (exterior sources),
- Gasoline, or
- Industries (old smelters).

A secondary source of lead exposure for workers' families can take place if workers bring home lead-contaminated dust on their

- Skin,
- Hair,
- Clothes,
- Shoes, or
- Tools.
- Lead may be released through past or ongoing home renovation.
- Even though leaded paint may be covered with non-leaded paint, lead dust may still be released into the home environment by

    - Chalking,
    - Chipping,
    - Friction,
    - Impact, or

- Peeling.

Lead-based paint is present in one-third of the nation's dwellings [ACCLPP 2012].

- Between 83% and 86% of all homes built before 1978 in the United States have lead-based paint in them [CDC 1997a]. A high percentage of these homes are rental properties, a major risk factor for elevated BLLs [ACCLPP 2012]. Rental homes are likely to have less frequent improvements and poor maintenance, thus allowing older lead-containing paint to peel and flake.
- The older the house, the more likely it is to:
  - Contain lead-based paint,
  - Have a higher concentration of lead in the paint, and
  - Have paint that is deteriorated.
- Before 1955, a significant amount of white house paint sold and used was 50% lead and 50% linseed oil. In 1955, manufacturers adopted a voluntary house paint lead-content standard of 1%, but house paint with higher levels of lead continued to be manufactured [Rabin 1989 as cited in AAP 1993].
- The amount of lead allowable in paint was lowered by federal law to 1.0 % in 1971 and then to 0.06% in 1977.

The number of existing U.S. housing units built before 1950, when paint had high lead content, decreased from 27.5 million in 1990 to 25.8 million in 2000 [CDC 2003], and 23.2 million in 2006 [HUD 2011]. Despite the gradual decline in the number of houses containing higher lead content paint, however, it still poses a risk to the millions of children living in these homes.

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| **Lead in Drinking Water** | Lead occurs in drinking water through leaching from lead-containing pipes, faucets, and solder frequently found in the plumbing of older buildings.<br><br>• Homes built before 1986 are more likely to have lead pipes, fixtures, and solder, although newer homes may also be at risk if they are built in older neighborhoods (see below).<br>• "Lead service lines" (the water service pipes that connect the water main in the street or "public water main" to the household plumbing system can be made of lead) in the water supply systems of older neighborhoods can leach lead. Therefore, even if household pipes are replaced, there is still the possibility of receiving lead from "lead service lines".<br>• "Approximately 7 percent of the homes connected to community water systems [in the United States] have a lead service line." "There are about 15 to 22 million Americans nationally served by lead lines" [AWWA 2016].<br>• If "lead service lines" are replaced, but the household plumbing remains as galvanized iron pipes, there can still be ongoing lead exposure in drinking water.<br>• Corrosion build up on the inside of galvanized pipes can create the potential for lead to accumulate over time. Acidic water can contribute to the leaching of lead from pipes into the drinking water supply.<br>• Having a drinking water filtration system (filtered tap water/filtration pitchers) certified by an independent testing organization such as the National Sanitation Foundation (NSF) to remove lead can be a safe drinking water option when instructions on how to use, maintain, and/or replace filters are followed.<br>• Boiling water will not eliminate lead.<br><br>Other potential sources of lead contamination include [EPA 2016a; Mushak et al. 1989, as cited in AAP 1993]<br><br>• Brass fixtures (brass faucets or fittings),<br>• Copper pipes with lead solder for drinking water, and |

- Older drinking water coolers and coffee urns.

EPA recommends replacing lead service lines, galvanized pipes or pipes that were soldered using lead, brass faucets/fittings, and the use of filtration systems for tap water [EPA 2016a].

Lead in water has not been identified as the major problem with lead in the United States. However, some areas of the country may have a serious problem with lead contamination in the drinking water distribution system.

**Foods and Beverages Contaminated with Lead**

Even when lead is not intentionally used in a product, it may contaminate items such as food, water, or alcoholic drinks, such as moonshine whiskey [CDC 1992; Warren and Vaughan 1922]. Lead may contaminate food during

- Production,
- Processing,
- Packaging, and
- Storage.

*Production*

Production sources may include

- Leaf and root vegetable uptake of lead from soil,
- Deposits of atmospheric lead onto leafy vegetables [Levin et al. 2008; Mushak et al. 1989 as cited in AAP 1993], and
- Grinding or cutting equipment used during processing that may be contaminated with lead.

*Packaging*

Lead in packaging may contaminate food.

- Bright red and yellow paints and print on bread bags and candy food wrappers from other countries, particularly Mexico, have been found to contain lead [FDA 2014; Levin et al. 2008; Mushak et al. 1989 as cited in AAP 1993].

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| | • Although lead was phased out of cans containing food or drinks in the United States in the 1980's, some imported food or drink cans may still contain lead in the solder.<br><br>*Storage*<br><br>Food or beverages may be stored in lead-containing vessels that contaminate the product.<br><br>• Even "safe" pottery and ceramic-ware (especially imported) can become harmful if the protective glaze wears off and exposes people to the lead-containing pigments.<br>• Lead-glazed pottery, particularly if it is imported, is often overlooked as a potential source of lead exposure.<br>• Wine and homemade alcohol distilled and/or stored in leaded containers may become contaminated.<br>• Wine or other alcoholic drinks stored in leaded-crystal glassware may become contaminated.<br><br>*Other*<br><br>Other sources of food contamination include<br><br>• Certain “natural” calcium supplements.<br>• Food grown in lead contaminated soil from historic use of lead-containing pesticides in the United States (such as lead arsenate used as an insecticide or fungicide in orchards). |
| **Commercial Products** | While lead is prohibited from many products in the United States, imported or pre-regulation products may still pose a risk. Lead is still used in commercial products [CDC 2013b; CDC 2013d; CDC 2013e; Levin et al. 2008] and may be found in products such as<br><br>• Artificial turf,<br>• Artificial Christmas trees<br>• Automotive batteries,<br>• Bridge paint,<br>• Computers,<br>• Curtain weights, |

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| | • Fishing tackle,<br>• Jewelry,<br>• Pewter,<br>• Pool cue chalk,<br>• Some ceramic glazes,<br>• Toys (especially antique or imported),<br>• Leaded wick candles,<br>• Vinyl lunch boxes, and<br>• Vinyl miniblinds (made before 1997). |
| **"Traditional" or "Folk" Imported Home Remedies and Cosmetics** | Some people can be exposed to lead using certain imported home remedies or cosmetics [CDC 2013c]. Several examples are listed below.<br><br>The Mexican folk remedies *azarcon* and *greta* used to treat the colic-like illness "empacho" contain lead. These remedies are also known as<br><br>• Alarcon,<br>• Coral,<br>• Liga,<br>• Maria Luisa, and<br>• Rueda.<br><br>Lead-containing remedies used by some Asian communities include<br><br>• Ba-baw-san,<br>• Bali goli,<br>• Chuifong,<br>• Ghasard,<br>• Kandu, and<br>• Tokuwan.<br><br>Middle Eastern remedies and cosmetics that contain lead include<br><br>• Alkohl,<br>• Cebagin, and<br>• Saoott.<br><br>Saper et al. 2004 discussed heavy metal content of Ayurvedic herbal medicine products. |

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| | For more information on these products, see the Centers for Disease Control and Prevention's web site, especially Appendix 1 of the document "Managing Elevated Blood Lead Levels Among Young Children" [CDC 2002] at https://www.cdc.gov/nceh/lead/CaseManagement/caseManage_main.htm or<br><br>https://www.cdc.gov/nceh/lead/tips/folkmedicine.htm |
| **Environmental and Industrial Sources** | Lead is ubiquitous in the environment because of widespread human use. Environmental background levels vary depending on historic and ongoing uses in the area.<br><br>• Abandoned industrial lead sites, such as old mines or lead smelters, may continue to pose a potential public health hazard.<br>• Industrial sources range in size from large mines and hazardous waste sites (e.g., Superfund sites) to small auto repair facilities.<br>• Industries such as mining and lead smelting contribute to high levels of lead in the environment around such facilities.<br>• People living near hazardous waste sites, incinerators, landfills may be exposed to lead and chemicals that contain lead by breathing air, drinking water, eating foods, or swallowing dust or dirt that contains lead.<br>• Local community members may be exposed to lead from these sources through ingestion (or inhalation) of lead-contaminated dust or soils.<br>• Higher lead content paint may also contaminate soil, especially in areas immediately adjacent to houses built before 1978, and bridges.<br>• People may be exposed to lead in soils directly or by eating foods grown in lead-contaminated soils, and old orchards.<br><br>The past use of lead in gasoline has contaminated soils, especially along roadways. Tetraethyl lead (TEL) was phased out of gasoline for "on-road" use in the United States between 1973 and 1996. |

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| **Smoking and Second and Third-hand Smoke** | Active and passive smoking (second-hand smoke) is associated with increased BLLs in U.S. adults [Mannino et al. 2005] and children [CDC 2013a]. Third-hand smoke (surface residue from tobacco cigarette smoke) is a new health concern [Ferrante et al. 2013].<br><br>Second hand smoke (SHS) is generally considered passive or involuntary inhalation exposure to cigarette smoke by persons other than the intended "active" smoker. It may also be referred to as "Environmental Tobacco Smoke" (ETS). Sometimes ETS is broken down into "mainstream smoke" which is exhaled by the smoker and "side stream smoke" which comes from the end of a lit tobacco cigarette, cigar, or pipe. SHS may contribute to increased BLLs in U.S. children, independent of lead dust concentrations [CDC 2013a; USDA 2009 as cited in CDC 2013a; NHLBI 2007; PHS 2006]. There is no risk-free level of secondhand smoke exposure; even brief exposure can be harmful to health.<br><br>Lead dust concentrations, usually ingested during hand to mouth activity, do not appear to mediate this association, suggesting inhalation as a major pathway of exposure from SHS [Apostolou et al. 2012]<br><br>Second-hand smoke is associated with increased blood lead levels in U.S. children aged 4-16 years. A representative sample of 5,592 U.S. children, age 4–16 years, who participated in the Third National Health and Nutrition Examination Survey (1988–1994) showed that the geometric mean blood lead levels were 38% higher in children with high cotinine levels compared with children who had low cotinine levels. The logistic regression models showed that children with high cotinine levels were more likely to have blood lead levels ≥10 µg/dL than were children with low cotinine levels [Mannino 2003].<br><br>Third-hand smoke (THS) is the residue from tobacco smoke, which remains on just about every surface exposed to that smoke and may build up over time. This residue poses an additional exposure risk, especially in infants and children, that may impact BLLs. Children and infants have an increased exposure risk to tobacco THS |

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| | than adults because they typically spend more time indoors and have age-specific behaviors (such as mouthing). This increased exposure risk may increase their risk of potential health hazards from exposure to THS [Ferrante et al. 2013]. However, more studies are needed to support an association between third-hand smoke exposure and increased BLLs in children. |
| **Occupational Exposures** | The major exposure pathways for workers are inhalation and ingestion of lead-bearing dust and fumes.<br><br>Workers in the lead smelting, refining, and manufacturing industries experience the highest and most prolonged occupational exposures to lead [ATSDR 2010]. Increased risk for occupational lead exposure occurs among workers in<br><br>• Battery manufacturing,<br>• Automobile brake repair,<br>• Companies that work with lead solder,<br>• Bridge maintenance and repair,<br>• Construction, especially renovation/rehabilitation,<br>• Municipal waste incineration,<br>• Other manufacturing industries,<br>• Pottery/ceramics companies and studios,<br>• Radiator repair,<br>• Rubber products and plastics industries, and<br>• Steel welding/cutting operations.<br><br>Workers renovating highway overpasses and bridges are frequently exposed to higher lead content paint applied to these structures over many years [OSHA 2005]. |

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| **”Para-Occupational”, “Take Home”, or “Secondary” Exposure** | Para-occupational exposure is defined as exposure which occurs in households who live with an occupationally exposed worker, but who are not themselves occupationally exposed. It is important to note that occupational exposures can result in secondary exposure for workers' families if workers bring home lead-contaminated dust on their<br><br>• Skin,<br>• Hair,<br>• Clothes,<br>• Shoes, or<br>• Tools.<br><br>Children may also be exposed to occupational lead sources if parents work in these industries and allow their children to visit them at work, or if lead dust from workers’<br><br>• Clothing,<br>• Hair,<br>• Body,<br>• Shoes, or<br>• Tools<br><br>contaminates the interior of vehicles that children also ride in.<br><br>Many small businesses and cottage industries are actually located in the home. Some examples include<br><br>• Battery recycling,<br>• Jewelry making, and<br>• Production of leaded glass and pottery.<br><br>Household contamination can result in “bystander” exposure levels similar to those found in industrial settings.<br><br>Secondary exposures (also called domestic, take home, second hand, etc.) can be prevented by workers **showering and/or changing clothing and shoes before returning home** or after finishing their work that involves lead at home. |

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| **Historical Use of Leaded Gasoline** | The past use of lead in gasoline has contaminated soils, particularly in inner cities, and especially along roadways.<br><br>"The deadliness of tetraethyl lead was sadly confirmed in the summer of 1924, when workers engaged in producing the additive fell sick and died at several refineries in New Jersey and Ohio. Banner headlines greeted each new fatality until a total of 15 workers had lost their lives -and their minds" [EPA 1985].<br><br>Lead has been blended with gasoline, as an additive primarily to boost octane levels, since the early 1920s. In addition to increasing the octane of gasoline, leaded gasoline also protected exhaust valve seats (in vehicles designed to operate on leaded gasoline) from excessive wear. Both of these objectives are now accomplished without the use of leaded gasoline [EPA 1985].<br><br>The use of TEL in gasoline paved the way for the development of the high power, high-compression internal combustion engines that were to win WWII and dominate the U.S. automobile industry until the 1970s.<br><br>The first reduction standards for Tetraethyl lead (TEL) came out in the early 1970s. Effective January 1, 1996, the Clean Air Act banned the sale of leaded fuel for use in on-road vehicles. However, EPA allowed fuel containing TEL to continue to be sold for off-road uses, including aircraft, racing cars, farm equipment, and marine engines [EPA 1996]. As of January 2015, only Algeria, Yemen and Iraq continue to use leaded gasoline –in addition to unleaded gasoline [UNEP 2015]. |

**Historical Use of Lead Arsenate**

Lead arsenate (PbHAsO4) was first used in the U.S. apple orchards in 1892 as an insecticide spray. It was the most heavily used arsenical throughout the United States and worldwide [Schooley et al. 2008; Peryea 1998].

Lead arsenate was used in the United States as an insect growth regulator, insecticide, herbicide and fungicide [EPA 1986]. This insecticide was very popular among farmers because of its effectiveness, low cost, ease of use, and persistence. Over the next 60 years the frequency and amount of lead arsenate applications increased, leading to pesticide resistance. Growers eventually switched to more viable alternates –at the time- such as DDT.

Widespread use of lead arsenate and frequent applications at increasing rates over time contributed to lead and arsenic to accumulate in topsoil, contaminating thousands of acres across the United States" [Schooley et al. 2008; Peryea 1998].

**Lead Sources and Contamin-ated Media**

**Table 1. Where is Lead Found?**

| Lead Source | Contaminated Media |
|---|---|
| Gasoline (leaded)* | Soil |
| Lead solder/pipes | Drinking water |
| Mining and smelting | Outdoor air, dust, soil |
| Packaging or storage containers (including lead soldered cans) | Food, beverages |
| Paint (pre-1978)** | Household dust and soil |
| Production sources | Imported foods, remedies, consumer products including cosmetics, jewelry, toys, candy, glassware, table and cookware. |

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| | Tobacco | Cigarettes, cigars, and other tobacco products when smoked (and second-hand smoke). Clothes, furniture, draperies, walls, hair, skin (from third-hand smoke). | |
| | Workplaces that involve use of lead | Outdoor and indoor air, and dust | |

* Past use of TEL in the United States

** Leaded paint for residential use (higher than 0.06% Pb content) was banned in 1977 [CPSC 1977]. In 2008, the lead content in paint was lowered to 0.009% by CPSC [CPSC 2009]. Many of the steel bridges in the highway system are still coated with paint that contains up to 50% lead by weight [DOT 2016a].

**Likely Global Sources of Lead**

Countries with different regulations, standards and practices than the United States, may have lead exposure from

- Backyard smelters,
- Candles (leaded wick),
- Candy (and packaging/wrappers because of the ink used to print the labels),
- Canned products,
- Cottage industries,
- Jewelry,
- Leaded glassware,
- Stained glass paintings and supplies,
- Moonshine alcohol (may be a risk in some countries),
- Poor quality lead glazes,
- Toys,
- Traditional or folk remedies, etc.

**Key Points**

- Prior to the 1950s, higher lead content paint was widely used.
- Residential use of higher lead content paint was banned in 1978 in the United States, with the establishment of a 0.06% allowable lead content in house paint in 1977.

- The allowable 1977 amount was further reduced in 2008 to 0.009% lead content.
- In the United States higher lead content paint is a primary source of environmental exposure to lead. Lead may be released from higher lead content paint in home environments if the paint is

  - Disturbed (e.g., during renovation),
  - Deteriorated (peeling, chipping, and chalking), or,
  - Subject to friction or impact (doors, windows, porches, etc.).

- The past use of lead in gasoline and higher lead content in paint can result in high lead levels in soil and house dust.
- Some commercial products still contain lead (and some imported products that aren't regulated as they would be if made in the United States).
- Contaminated

  - Drinking water,
  - Food,
  - Alcohol, and
  - Home remedies are some sources of environmental exposure to lead.

- Workers in many industries (with potential for secondary exposure to their families) can have occupational exposure to lead.
- Historic or ongoing lead-related industries (including mining and smelting) can result in high lead levels in surrounding soil.
- Tobacco smoking is associated with increased BLLs in adults.
- Second-hand smoke can increase BLLs in children.
- Third-hand smoke is a more recent health concern. More studies are needed to support an association between third-hand smoke exposure and increased BLLs in children.

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| **Progress Check** | 2. In the United States today, all of the following are potential exposure sources for lead, **EXCEPT**:<br><br>A. Gasoline for on-road vehicles.<br>B. House paint (produced pre 1978).<br>C. Lead or galvanized home water pipes.<br>D. Imported food storage containers, home remedies, and cosmetics.<br>E. Tobacco smoking and second-hand smoke.<br><br>*To review relevant content, see "Lead-Based Paint in Homes and Buildings", Foods and Beverages Contaminated with Lead", "Traditional or 'Folk' Imported Home Remedies and Cosmetics", "Smoking and Second and Third hand Smoke", "Historical use of Leaded Gasoline", and "Likely Global Sources of Lead" in this section.* |

## What Are Routes of Exposure to Lead?

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| **Learning Objectives** | Upon completion of this section, you will be able to<br><br>• Identify the most common routes of exposure to lead in the United States today. |

## Introduction

Today almost everyone is exposed to environmental lead. Exposure to lead and lead chemicals can occur through inhalation, ingestion, dermal absorption, absorption from retained or embedded leaded foreign body, and trans-placental (endogenous) routes.

- Most human exposure to lead occurs through ingestion or inhalation.
- In the United States, the public is not as likely to encounter lead that readily enters the human body through the skin (dermal exposure), especially now that leaded gasoline is banned for on-road vehicles.
- Retained shrapnel, bullets or other embedded leaded foreign bodies can be a source of ongoing lead exposure.
- Inhalation may be the major contributor for workers in lead-related occupations and "do-it-yourself" home renovators and persons with hobbies (stained glass making/soldering, etc.).

Lead exposure is a global issue. Lead mining and lead smelting are common in many countries, where children and adults can receive substantial lead exposure from often unregulated sources at high levels that are uncommon today in the United States [Kaul et al. 1999; Litvak et al. 1999; Wasserman et al. 1997; López-Carrillo et al. 1996; Rothenberg et al. 1994]. Most countries have discontinued or are in the process of phasing out the use of leaded gasoline for all uses [UNEP 2011].

## Ingestion

Lead exposure in the general population (including children) occurs primarily through ingestion, making it the route that most commonly leads to elevated BLLs. This includes swallowing a foreign body containing lead (i.e., jewelry, etc.).

From 20% to 70% of ingested lead is absorbed into the body, (with children generally absorbing a higher percentage than adults) [ATSDR 2010] (see the *"What are Possible Health Effects from Lead Exposure?"* section).

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| | • Lead paint is the major source of higher lead level exposures in children in the United States [ATSDR 2010; AAP 1993]. As higher lead content paint<br><br>o Deteriorates,<br>o Peels,<br>o Chips,<br>o Is removed (e.g., during renovation),<br>o Or crumbles due to friction (e.g., in windowsills, steps, and doors),<br><br>house dust and surrounding soil may become contaminated. Lead then enters the body through normal hand-to-mouth activity [Sayre et al. 1974, as cited in AAP 1993].<br><br>• Ingestion of contaminated<br><br>o Food,<br>o Water, or<br>o Alcohol may be significant for some populations. In addition, ingesting certain traditional, folk or home remedy medicines may expose people to lead or lead compounds (see the *"Where is Lead Found?"* section).<br><br>• When fine particulate lead is inhaled, it can be absorbed directly through the lungs or could also be carried by the mucociliary tree to the throat where it can be swallowed and absorbed via the GI system. |
| **Inhalation** | Inhalation is the second major pathway of exposure for the general population in the United States. The amount absorbed from the respiratory system depends on particle size, respiratory volume, amount of deposition, and the mucociliary clearance of the inhaled lead.<br><br>• Almost all inhaled lead is absorbed into the body (with children generally absorbing a higher percentage than adults, as they have a higher respiratory frequency) [ATSDR 2010] (see the *"What are Possible Health Effects from Lead Exposure?"* section). |

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| | • Since leaded gasoline additives were phased out beginning in the 1970s and control measures were implemented in industries to reduce air emissions, inhalation from these sources is no longer the major exposure pathway to lead for the general population in the United States.<br>• Leaded gasoline is still used in only a handful of countries, but the resulting emissions pose a major public health threat.<br>• Inhalation may be the primary route of exposure for some workers in industries that involve lead.<br>• Inhalation may be the primary route of exposure for adults involved in home renovation activities, and hobbies like lead glass making, stained glass making/soldering.<br>• Lead is a component of tobacco and tobacco smoke, and smokers have higher blood lead levels (BLLs) than do nonsmokers [Mannino et al. 2005; Mannino et al. 2003].<br>• Second hand smoke may contribute to increased BLLs in U.S. children. Lead dust concentrations, usually ingested during hand to mouth activity, do not appear to mediate this association, suggesting inhalation of second hand smoke is a major pathway of exposure [Apostolou et al. 2012].<br>• Eliminating second hand smoke exposure may reduce lead exposure in children [Apostolou et al. 2012]. |
| **Dermal** | Dermal exposure plays a role for exposure to organic lead among workers, but is not considered a significant pathway for the general population.<br><br>• Organic lead may be absorbed directly through the skin.<br>• Organic lead (tetraethyl lead) is more likely to be absorbed through the skin than inorganic lead.<br>• Dermal exposure is most likely among people who work with lead or materials that contain lead. |
| **Endogenous Exposure** | Endogenous exposure to lead may contribute significantly to an individual's current BLL. Numerous reports document lead poisoning resulting from retained bullet or shrapnel fragments; thus, a history of military |

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| | or other penetrating trauma may be important [Kathuria 2014]. If in a pregnant woman, this poses a particular risk to the developing fetus (See the *"What are Possible Health Effects from Lead Exposure?"* section). Trans-placental exposure to the unborn child can happen if the mother is exposed to lead.<br><br>• Once absorbed into the body, lead may be stored for long periods in mineralizing tissue (*e.g.,* teeth and bones).<br>• The stored lead may be released again into the bloodstream, especially in times of calcium stress (*e.g.*, pregnancy, lactation, osteoporosis) or calcium deficiency. |
| **Key Points** | • Ingestion is the most common route of exposure to lead for children, and the route that most commonly leads to elevated BLLs.<br>• Inhalation can be a significant exposure pathway, particularly for workers in lead industries, "do-it-yourself" home renovators, persons with hobbies (stained glass making/soldering), smokers and children exposed to second hand smoke.<br>• Embedded or retained leaded foreign bodies can be a source of ongoing lead exposure.<br>• Trans-placental exposure to the unborn child can happen if the mother is exposed to lead. |
| **Progress Check** | 3. The two primary routes of exposure to lead in U.S. children are<br><br>A. Ingestion and inhalation.<br>B. Inhalation and dermal.<br>C. Dermal and endogenous.<br>D. Endogenous and inhalation.<br><br>*To review relevant content, see "Ingestion" in this section.* |

## Who Is at Risk of Lead Exposure?

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| **Learning Objectives** | Upon completion of this section, you will be able to |

- Identify the populations most heavily exposed to lead.

**Introduction**

"In the late 1700s, Ben Franklin described various environmental and occupational effects which he attributed to lead, affecting trades, such as printers, plumbers, and painters. In the early 1900s, detailed information on the hazards began to appear. First, a study in Britain linked exposures to lead with high rates of infertility, stillbirths, and first year infant deaths. About the same time, an Australian study observed lead poisoning among children and identified household dust and paint as the sources of the lead. Childhood activities, such as nail-biting, thumb-sucking, and eating with fingers contaminated with lead are the ways lead was introduced into the body" [DOT 2016b].

Both children and adults are susceptible to health effects from lead exposure, although the typical exposure pathways and effects can be somewhat different.

- Children who reside in pre-1978 housing (and especially those in inner cities, where a large number of older rental homes exist, or homes built before 1950) are at greatest risk for exposure, because older housing may contain paint with higher lead content.
- "Childhood lead exposure has a significant and persistent impact on brain reorganization associated with language function" [Yuan et al. 2006].
- Adults who work in jobs involving lead are occupationally exposed.
- Developing fetuses are also at risk for adverse health outcomes (less than 1% of the mothers have levels greater than or equal to 5 micrograms per deciliter, or µg/dL), as levels that present risk to the fetus may not present risk to the mother.
- Smokers and their relatives (if exposed to second-hand smoke) are at a high risk for exposure due to the lead in tobacco smoke.

**Children**

While children's blood lead levels (BLLs) have steadily declined in recent decades, there are still an estimated 535,000 U.S. children ages 1-5 years with BLLs at or above the upper reference source range value of 5 µg/dL [CDC 2013g]. This was calculated using the 2007-2010 National Health and Nutrition Examination Survey [NHANES] cycle that showed 2.6% of children in this age group, with levels above 5 mcg/dL, based on the U.S. Census Bureau 2010 count [CDC 2013g].

- In particular, children who live in older housing are more likely to have elevated BLLs than U.S. children as a whole.
- No economic or racial/ethnic subgroup of children is free from the risk of adverse health effects due to high BLLs.
- Of the 434,000 children reported with confirmed elevated BLLs (≥10 µg/dL) between 1997 and 2001 (2.2% of children aged 1-5 years), approximately

  - 17% were non-Hispanic whites,
  - 60% were non-Hispanic African-Americans,
  - 16% were Hispanic, and
  - 7% were of other races or ethnicities [CDC 2003].

- The children affected are more likely to be poor and from racial/ethnic minority groups living in substandard housing. African-American children remain at increased risk for higher blood lead concentration after adjusting for environmental lead exposures and dietary intake [Lanphear et al. 2002].

Because of their behavior and physiology, children are more affected by exposure to lead than adults.

- Children absorb more ingested lead than do adults.
- Children generally ingest lead-contaminated soil and house dust at higher rates than adults because of mouthing and hand-to-mouth behaviors.
- Children who exhibit pica, a compulsive hand-to-mouth behavior and repeated eating of non-food

items –not considered pathologic in infants and toddlers up to 2 years of age-, are at greatest risk.

- Children have a higher breathing rate than adults, breathing in a greater volume of air per pound.
- Being shorter than adults, children are more likely to breathe lead-contaminated dust and soil as well as lead-containing fumes close to the ground.
- The percent of lead absorbed in the gut, especially in an empty stomach, is estimated to be as much as 5 to 10 times greater in infants and young children than in adults [Ziegler et al. 1978 as cited in ATSDR 1999; James et al. 1985; Chamberlain et al. 1978; Alexander et al. 1974].
- Gastrointestinal absorption of lead in children is increased by deficiencies in

    - Ascorbate,
    - Calcium,
    - Iron, and
    - Zinc [Mahaffey 1990, as cited in AAP 1993].

Lead in dust and water can contribute up to 35% and 20% respectively to lead exposure in children's Blood Lead Levels (Figure 1).

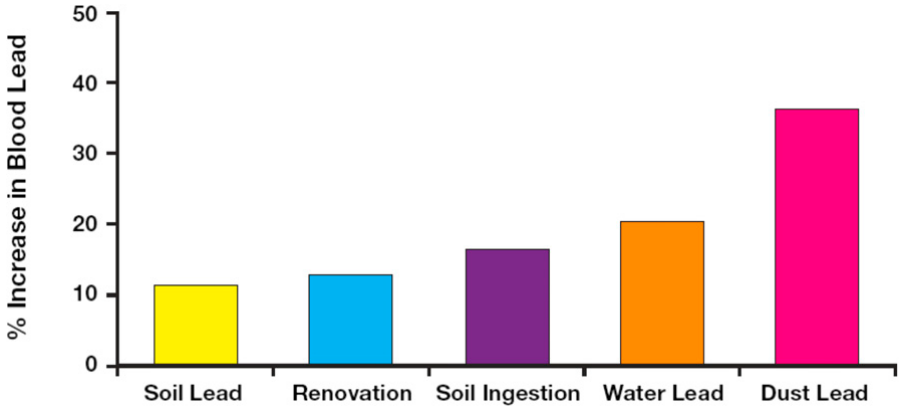


**Figure 1. Sources of Contribution of Lead Exposure to Children's Blood Lead Concentrations** [AAP 2016, adapted from Lanphear et al. 2012, and Spanier et al. 2013]

Children are more sensitive than adults to elevated BLLs. Children's developing brains, nervous system, and other organ systems are very sensitive to lead.

Differences between the adult blood brain barrier and that of fetuses and very young children, increases the risk of lead's entry into the developing central nervous system of the latter two. This can result in prolonged or permanent neurobehavioral disorders.

- Childhood lead exposure is inversely associated with
    - Brain reorganization associated with language function [Yuan et al. 2006],
    - Intellectual abilities [Lanphear et al. 2005],
    - Academic achievement,
    - Psychomotor development [Lanphear et al. 2005],
    - High school attendance,
    - Reaction times,
    - Class rank,
    - Hand and-eye coordination, and
    - Vocabulary and grammatical reasoning scores [AAP 1993].

- ”Blood lead concentrations <5 µg/dL are associated with intellectual deficits (lower IQ score), academic disabilities, attention-related behaviors, and problem behaviors” [Landrigan and Etzel 2014].
- Lanphear et al. [2005] report a deficit of approximately 2 IQ points for the Blood Lead variable of 10-20 µg/dL. The decrements in IQ associated with lead were found to be proportionately greater at the lowest blood lead levels [Landrigan and Etzel 2014; Bellinger 2008]. “At lower concentrations of lead in the blood – below 10 µg/dL - children tested for IQ at ages three and five, showed a greater decline in IQ for a rise in blood lead from 1 to 10 µg/dL, than those whose blood lead level went from 10 to 20 µg/dL” [Canfield et al. 2003].
- “The blood lead concentration was inversely and significantly associated with IQ. In the linear model, each increase of 10 µg per deciliter in the lifetime average blood lead concentration was associated with a 4.6-point decrease in IQ (P=0.004), whereas for the subsample of 101 children whose maximal

lead concentrations remained below 10 µg per deciliter, the change in IQ associated with a given change in lead concentration was greater. When estimated in a nonlinear model with the full sample, IQ declined by 7.4 points as lifetime average blood lead concentrations increased from 1 to 10 µg per deciliter" [Canfield et al. 2003].

- "Early childhood lead exposure is associated with poorer achievement on standardized reading and math tests in the third grade, even at very low B-Pbs" [Evens et al. 2015].
- "Children with moderate lead poisoning in early childhood performed significantly lower on all components of elementary school end-of-grade examinations compared with unexposed children" [Magzamen et al. 2013].
- Even low-level lead exposure can negatively impact a wide range of cognitive functions, such as attention, language, memory, cognitive flexibility, and visual-motor integration based on various types of neuropsychological and neurobehavioral testing [Canfield et al. 2004; Canfield et al. 2003].
- "For every 1 µg/dL increase in blood lead concentration, there was a 0.7-point decrement in mean arithmetic scores, an approximately 1-point decrement in mean reading scores, a 0.1-point decrement in mean scores on a measure of nonverbal reasoning, and a 0.5-point decrement in mean scores on a measure of short-term memory. An inverse relationship between blood lead concentration and arithmetic and reading scores was observed for children with blood lead concentrations lower than 5.0 µg/dL" [Lanphear et al. 2000].
- Children's renal, endocrine, and hematological systems may also be adversely affected by lead exposure.

Children are also exposed to lead through second-hand tobacco smoke [Apostolou et al. 2012; Mannino et al. 2005; Mannino et al. 2003].

There is no known threshold exposure level (as indicated by BLL) for many of these effects. No blood

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| | lead threshold for adverse health effects has been identified in children, however, more severe effects occur at higher levels and more subtle effects, some not clinically recognizable, at very low levels.<br><br>Preventing lead exposure in early childhood is critical to improving school performance [Evens et al. 2015; Lanphear et al. 2005].<br><br>“The consequences of exposure to many other chemicals or mixtures of chemicals, such as insecticides —chemicals oftentimes specifically designed to be toxic— are largely unknown. Many of these chemicals or their metabolites are routinely found in the blood and body fluids of pregnant women and children” [Lanphear et al. 2005]. |
| **Adults** | Although children are at greater risk from lead exposure, adult exposures can also result in harmful health effects.<br><br>• Most adult exposures are occupational and occur in lead-related industries such as [CDC 2016]<br><br>o Manufacturing,<br>o Construction,<br>o Services, and<br>o Mining.<br><br>• One frequent source of lead exposure to adults is home renovation that involves<br><br>o Scraping,<br>o Remodeling, or<br>o Otherwise disturbing lead-based paint.<br><br>Renovation involving lead based paint should only be undertaken after proper training, or with the use of certified personnel (see EPA’s Safe Renovation brochure at http://www2.epa.gov/lead/lead-safe-certified-guide-renovate-right. |

- Adults can also be exposed during certain hobbies and activities where lead is used [CDC 2011a]. Some of the more common examples include

  - Artistic painting,
  - Car repair,
  - Electronics soldering,
  - Glazed pottery making,
  - Metal soldering,
  - Molding of bullets, slugs, or fishing sinkers,
  - Stained-glass making, and
  - Shooting firearms.

- Tobacco smoke is a source of lead [Apostolou et al. 2012; Mannino et al. 2005; Mannino et al. 2003].
- Mine workers may inhale lead dust and lead oxide fumes if they

  - Eat,
  - Drink, and
  - Smoke in or near contaminated areas, thereby increasing their probability of lead ingestion.

- If showers and changes of clothing are not provided, workers can contaminate their homes and/or vehicles with lead dust on their

  - Hair,
  - Skin,
  - Shoes,
  - Clothing, and
  - Tools

  thus inadvertently exposing family members.

- People who use the following items also increase their lead exposure risk:

  - Paints, pigments,
  - Facial makeup, or
  - Hair coloring with lead or lead acetate.

- Cosmetics containing lead include

- Surma,
- Sindhoor and
- Kohl,

popular in certain Asian countries.

- Other than the developmental effects unique to young children, the health effects experienced by adults from adult exposures are similar to those experienced by children, although the thresholds are generally higher.

| **Table 2. Populations at Risk of Exposure to Lead in the Workplace** | |
|---|---|
| • Auto repairers | • Lead refining workers |
| • Battery manufacturers and recycling | • Lead smelter workers |
| • Bridge reconstruction workers | • Plastic manufacturers |
| • Construction workers | • Plumbers, pipe fitters |
| • Firing range instructors | • Police officers |
| • Glass manufacturers | • Printers |
| • Lead manufacturing industry employees | • Rubber product manufacturers |
| • Lead mining workers | • Shipbuilders |
| • Workers in recycling plants for electronics, computers, etc. | • Steel welders or cutters |

**Pregnant Women, Lactating Women and Developing Fetuses**

The mother's BLL is an important indication of risk to the fetus and neurological problems in newborns. In addition, mothers who had exposure to lead in the past may store lead in their bones. Lead may be released from bones during times of calcium stress such as pregnancy and lactation. Pregnant women with elevated BLLs may have an increased chance of

- Preterm labor,
- Miscarriage,
- Neurological effects and intrauterine growth restriction (IUGR),
- Spontaneous abortion or stillbirth, and/or
- Low birth weight.

See the *"What are Possible Health Effects from Lead Exposure?"* section for more information.

**Table 3. Risk Factors for Lead Exposure in Pregnant and Lactating Women** [CDC 2012]

- Recent immigration from or residency in areas where ambient lead contamination is high, e.g., from countries where leaded gasoline is still being used (or was recently phased out), or where industrial emissions are not well-controlled.
- Living near a source of lead, such as lead mines, smelters, or battery recycling plants (even if the establishment is closed).
- Working with lead or living with someone who does (take-home exposures).
- Cooking, storing, or serving food in lead-glazed ceramic pottery made in a traditional process and usually imported by individuals outside the normal regulatory commercial channels.
- Eating or mouthing non-food items (pica) that may be contaminated with lead (such as soil, clay, or lead-glazed ceramic pottery).
- Using alternative or complementary medicines, herbs, or therapies for home remedies or certain traditional herbs that may be contaminated with lead.

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| | • Using imported cosmetics, such as kohl or surma, or certain imported foods or spices that may be contaminated with lead.<br>• Engaging in certain high-risk hobbies or recreational activities, like leaded glass, hunting, or jewelry making (if using leaded products), and those who have family members who do.<br>• Renovating or remodeling older homes without using safe lead work practices.<br>• Disturbing higher lead content paint and/or creating lead dust, or spending time in such a home environment.<br>• Consuming lead-contaminated drinking water from homes with leaded pipes or source lines with lead.<br>• Having a history of previous lead exposure or evidence of elevated body burden of lead from past exposures, particularly with a deficiency in certain key nutrients (e.g., calcium, iron).<br>• Living with someone identified with an elevated BLL.<br>• Having exposures in common with a child, close friend, or other relative living in the same environment. |
| **Key Points** | • Today, children who live in pre-1978 housing are the population generally at greatest risk for lead poisoning.<br>• Adults who work with lead or have hobbies involving lead may also be significantly exposed.<br>• Developing fetuses exposed to lead are also at risk for adverse health outcomes.<br>• Children may also be exposed to lead through second-hand tobacco smoke. |
| **Progress Check** | 4. Which population group is likely to be the most heavily exposed to lead in the United States?<br><br>A. Pregnant women living near industrial sites.<br>B. Children who live in older housing, especially those in inner cities.<br>C. African-American teenagers of single households with no high school completion. |

D. Older adults in nursing homes that were built before 1978.

*To review relevant content, see "Introduction" and Children" in this section.*

5. In general, all of the following occupations entail significant exposure to lead **EXCEPT**

   A. Automobile mechanics.
   B. Construction workers.
   C. Plumbers.
   D. Electricians.

   *To review relevant content, see "Adults" in this section.*

## What Are U.S. Standards for Lead Levels?

**Learning Objectives**

Upon completion of this section, you will be able to

- Describe the Centers for Disease Control and Prevention's (CDC) reference value for lead in children's blood,
- Describe the U.S. Occupational Safety and Health Administration's (OSHA) Permissible Exposure Limit (PEL) for lead in workplace air,
- Describe the U.S. Environmental Protection Agency's (EPA) drinking water regulation for lead, and
- Describe the Consumer Product Safety Commission's (CPSC) regulatory limit value for lead in paint.

**Introduction**

Because lead causes significant public health problems, a number of federal agencies have issued advisory standards or enforceable regulations that set lead levels in different media. Table 4: Standards and Regulations for Lead, below summarizes these standards and regulations [ACCLPP 2012]; see subsequent sections for further explanation.

Although reductions in lead exposure for the U.S. population have resulted in lower blood lead levels (BLLs) over time, epidemiological studies continue to provide evidence of health effects at increasingly lower BLLs [AAP 2016, NTP 2012].

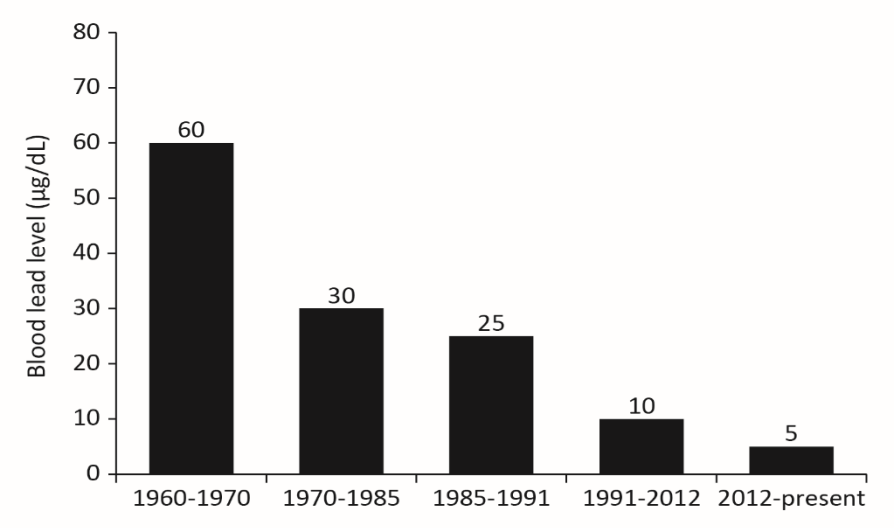


**Figure 2. Lowering of BLLs Considered Elevated by CDC Over Time**

The National Toxicology Program [2012] concludes that there is sufficient evidence for adverse health effects in children and adults at BLL <5 µg/dL [CDC 2012].

**Biologic Guidelines**

As new information has emerged about the

- Neurological,
- Reproductive, and
- Possible hypertensive toxicity of lead,

and as parameters that are more sensitive are developed, BLLs previously thought to be "safe" have been demonstrated to cause adverse health outcomes.

Five micrograms per deciliter (µg/dL) was adopted by CDC in 2012 as the upper reference range value for BLLs in children as an advisory level for environmental and educational intervention [ACCLPP 2012].

- Primary prevention strategies should be designed to keep children's BLLs below 5 µg/dL [ACCLPP 2012].
- Children receiving Medicaid are required to be screened.
- No blood lead threshold for adverse health effects has been identified in children, and no BLL above zero is free of all risk.
- At lower concentrations of lead in the blood – below 10 µg/dL - children tested for IQ at ages three and five, showed a greater decline in IQ for a rise in blood lead from 1 to 10 µg/dL, than those whose blood lead level went from 10 to 20 µg/dL [Canfield et al. 2003].

Experts now use an upper reference level value of 97.5% of the population distribution for children's blood lead, based on the National Health and Nutrition Examination Survey (NHANES) estimate of the distribution of BLLs in children ages 1-5 years. In 2012-2015, the value to identify children with blood lead levels that are much higher than most children have, is 5 micrograms per deciliter (5 µg/dL) [ACCLPP 2012].

The National Toxicology Program [2012] concludes that there is sufficient evidence for adverse health effects in children and adults at BLL <5 µg/dL [CDC 2012].

The American Conference of Industrial Hygienists (ACGIH) develops Biological Exposure Indices (BEI) as

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| | guidance values for assessing biological monitoring results in occupational settings by individuals trained in the discipline of industrial hygiene to assist in the control of potential workplace health hazards and for no other use. These values are not fine lines between safe and dangerous concentrations and should not be used by individuals without training in the discipline of industrial hygiene. |
| **Physician Reporting Require-ments** | Most states ask or require primary care physicians and/or laboratories to report all BLLs to the appropriate health agency. This is to ensure<br>• Abatement (removal) of the lead source,<br>• Education of the patient, parent/family,<br>• Remediation (corrective) steps are taken, and<br>• Targeting public health activities to areas with highest risk.<br><br>Physicians should strongly consider consulting a health agency, such as the local health department, or poison control center, in cases of lead toxicity. |
| **Workplace Air** | The OSHA Lead Standard applies to all workers in general industries, shipyards, and in construction industries where an employee may be occupationally exposed to lead [OSHA 2012a OSHA 2012b OSHA 2012c].<br><br>Action level means employee exposure, without regard to the use of respirators, to an airborne concentration of lead of 30 micrograms per cubic meter of air (30 µg/$m^3$) calculated as an 8-hour time-weighted average (TWA).<br><br>• OSHA set a Permissible Exposure Limit (PEL) for lead in workplace air of 50 µg/$m^3$ (8-hour time weighted average).<br>• OSHA mandates periodic determination of BLL for those exposed to air concentrations at or above the action level of 30 µg/$m^3$ for more than 30 days per year.<br>• The worker must be notified in writing within 15 days after the receipt of the results or any monitoring performed, and provided with a medical |

examination if a BLL is found to be greater than 40 µg/dL.

- The employer is obligated to remove the employee from excessive exposure, with maintenance of seniority and pay, until the employee's BLL falls below 40 µg/dL if a worker's one-time BLL reaches 60 µg/dL (or averages 50 µg/dL or more on three or more tests) in general industries or shipyards, or 50 µg/dL in construction.

The current Code of Federal Regulations standards for lead may be accessed at: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10030.

https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10641.

https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10318. States can have more protective standards than federal OSHA, e.g., California.

The National Institute of Occupational Safety and Health (NIOSH) at CDC has set a Recommended Exposure Limit (REL) of 50 µg/$m^3$ for a Time Weighted Average (TWA) of 8 hours to be maintained so that worker blood lead remains <60 µg/dL of whole blood. The REL can be accessed at: https://www.cdc.gov/niosh/npg/npgd0368.html.

ACGIH has set a threshold limit value for a time-weighted average (TLV/TWA) of 50 µg/$m^3$ for lead in workplace air (except for lead arsenate). This can be accessed at: http://www.acgih.org/

ACGIH has set a Biological Exposure Indices (BEI) for blood lead at 30 µg/dL.

As previously mentioned, ACGIH's BEI and TLV values are intended for use in the practice of industrial hygiene as guidelines or recommendations to assist in the control of potential workplace health hazards and for no other use. These values are not fine lines between safe and dangerous concentrations and should not be used by

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| | individuals without training in the discipline of industrial hygiene.<br><br>CDC [2010] recommends a precautionary approach, noting that a BLL ≥5 µg/dL in a pregnant woman indicates that she has or has had exposure to lead well above that for most women of child bearing age in the United States. For occupationally exposed pregnant women, the recommendation is to keep BLLs as low as possible and to remove pregnant women from lead-exposed work areas if BLLs are ≥10 µg/dL [CDC 2010].<br><br>CDC/NIOSH reference BLL for adults is 5 µg/dL [CDC 2013h]. |
| **Soil** | Lead-contaminated soil can pose a risk through direct ingestion, uptake in vegetable gardens, or tracking into homes.<br><br>• Soil contains lead concentrations less than 50 parts per million (ppm), but soil lead levels in many urban areas exceed 200 ppm [AAP 1993].<br>• The EPA's standard for lead in bare soil in play areas is 400 ppm by weight and 1200 ppm for non-play areas [EPA 2000a]. This regulation applies to cleanup projects using federal funds.<br><br>The soil screening level (SSL) for lead represents a conservative estimate for a level that would be protective of public health in residential soils based on an analysis of the direct ingestion pathway for children. This value is for guidance only and is not enforceable. |

**Drinking Water**

The Lead and Copper Rule (also referred to as the LCR) is an EPA regulation to control lead and copper in drinking water. Lead and copper enter drinking water primarily through plumbing materials. Exposure to lead and copper may cause health problems ranging from stomach distress to brain damage.

The LCR was established in 1991, and has undergone various revisions. It has four basic requirements:

1) Require water suppliers to optimize their treatment system to control corrosion in customer's plumbing;
2) Determine tap water levels of lead and copper for customers who have lead service lines or lead-based solder in their plumbing system;
3) Rule out the source water as a source of significant lead levels; and,
4) If lead action levels are exceeded, require the suppliers to educate their customers about lead and suggest actions they can take to reduce their exposure to lead through public notices and public education programs.

The EPA Lead and Copper Rule has set drinking water standards with two levels of protection [EPA 1991; EPA 2000b].

- Action levels for lead of 15 ppb and copper of 1.3 ppm in more than 10% of customer taps sampled. An action level is the level for enforcement.
- The maximum contaminant level goal (MCLG) is zero. This is the level determined to be safe according to toxicological and biomedical considerations, independent of feasibility.

"If a water system, after installing and optimizing corrosion control treatment, continues to fail to meet the lead action level, it must begin replacing the lead service lines under its ownership" [EPA 2007].

Exceeding the action level alone is not a violation of the regulation. Public water systems are assigned a violation when they fail to perform actions required by the

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| | regulations. This happens after the action level is exceeded [EPA 2000b; EPA 2016b].<br><br>The use of lead solder and other lead-containing materials in connecting household plumbing to public water supplies was banned by EPA in June of 1988.<br><br>• Many older structures, however, still have lead pipe or lead-soldered plumbing internally, which may substantially increase the lead content of water at the tap.<br>• Regulations controlling the lead content of drinking water coolers in schools went into effect in 1989.<br><br>Residents can buy inexpensive drinking water lead screening kits or hire professionals to test their water. For further information, call the EPA Safe Drinking Water Hotline toll-free at 1-800-426-4791 or visit https://www.epa.gov/safewater/.<br><br>The U.S. Food and Drug Administration (FDA) level for bottled water is 5 ppb [FDA 2009]. |
| **Food** | The FDA has set a number of action levels (enforceable) and levels of concern for lead in various food items. These levels are based on FDA calculations of the amount of lead a person can consume without ill affect [FDA 2014, 1995, and 1994].<br><br>For example, FDA has set an action level of 0.5 µg/dL for lead in in food products intended for use by infants and children and has banned the use of lead-soldered food cans [FDA 1994]. |
| **Paint** | White house paint contained up to 50% lead before 1955. Federal law lowered the amount of lead allowable in paint to 1% in 1971. In 1977, the Consumer Products Safety Commission limited the lead in most paints to 0.06% (600 ppm by dry weight). Since 2009, the lead allowable in most paints is now 0.009%. Paint for bridges and marine use may contain greater amounts of lead. |

| **Table 4: Standards and Regulations for Lead** [ACCLPP 2012] | | | | |
|---|---|---|---|---|
| **Agency** | **Media** | | | **Level** |
| ACGIH | Air (workplace) | 150 µg/$m^3$<br>50 µg/$m^3$ | TLV/TWA guideline for lead arsenate<br>TLV/TWA guideline for other forms of lead | |
| ACGIH | Blood | 30 µg/dL | Advisory; indicates exposure at TLV* | |
| CDC | Blood | 5 µg/dL | Reference range upper value for children's BLL and reference BLL for adults (NIOSH). | |
| CPSC | Paint | 90 ppm (0.009%) | Regulation; by dry weight. New standard for lead in household paint and similar surface coatings in children's products, and some furniture, for adult and children, children's toys, jewelry, etc. | |
| EPA | Air (ambient) | 0.15 µg/$m^3$ | Regulation; NAAQS; 3-month average | |
| EPA | Soil (residential) | 400 ppm (play areas)<br>1200 ppm (non-play areas) | Soil screening guidance level; requirement for federally funded projects only (40 CFR Part 745, 2001] | |
| EPA | Water (drinking) | 15 µg/L<br>0 µg/L | Action level for public supplies<br>Non-enforceable goal; MCLG | |
| FDA | Food | Various | Action levels for various foods; example: lead-soldered food cans now banned | |
| FDA | Drinking water | 5 ppb | Bottled water | |

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| NIOSH | Air (workplace) | 50 µg/$m^3$ | REL (non-enforceable) |
| OSHA | Air (workplace) | 50 µg/$m^3$<br><br>30 µg/$m^3$ | Regulation; PEL (8-hour time weighted average) (general industry)<br>Action level (averaged over an 8-hour period) |
| OSHA | Blood | 40 µg/dL<br><br>50 µg/dL and 60 µg/dL | Regulation; cause for written notification and medical exam, and return to work after removal<br>Regulation; cause for medical removal from exposure |

ACGIH – American Council of Government and Industrial Hygienists
CDC – Centers for Disease Control and Prevention
CPSC – Consumer Products Safety Commission
EPA – Environmental Protection Agency
NIOSH – National Institute of Occupational Safety and Health
OSHA – Occupational Safety and Health Administration
BLL – Blood Lead Levels
MCLG – Maximum Contaminant Level Goal
NAAQS – National Ambient Air Quality Standards
PEL – Permissible Exposure Level
ppm – parts per million
REL – Recommended Exposure Limit
TLV/TWA – Threshold Limit Value/Time Weighted Average
µg/dL – micrograms per deciliter

* Note: BEI and TLV values are intended for use in the practice of industrial hygiene as guidelines or recommendations to assist in the control of potential workplace health hazards and for no other use. These values are not fine lines between safe and dangerous concentrations and should not be used by anyone untrained in the discipline of industrial hygiene.

**Key Points**

- In 2012, CDC established a reference range upper value of 5 µg/dL for children's BLLs based on the NHANES estimate of 97.5% of the distribution.
- Most states have reporting systems for BLLs.
- OSHA has set required standards for an action level at 30 µg/$m^3$ averaged over an 8-hour workday.
- EPA has set a standard for lead in the ambient air of 0.15 µg/$m^3$ averaged over a calendar quarter.
- EPA has established 400 ppm for lead in bare soils in play areas and 1,200 ppm for non-play areas for federally funded projects.
- EPA's action level for lead in water delivered to users of public drinking water systems is 15 µg/L.
- FDA has set various action levels regarding lead in food items, cosmetics and bottled water.
- Use of lead-soldered food cans is now banned in the U.S
- CPSC has limited the lead content in paint intended for residential use and similar surface coatings in children's products, toys and jewelry to 0.009%.

**Progress Check**

6. The CDC's reference range upper value of 5 µg/dL for children's blood is

   A. The BLL below which no effects have been found.
   B. Also used by OSHA as a level of concern in workers.
   C. An advisory level for environmental and educational intervention.
   D. A regulatory level at which children must be immediately removed from any pre-1978 residences.

   *To review relevant content, see "Biologic Guidelines" in this section.*

7. What is EPA's action level for lead in water delivered to users of public drinking water systems in the United States?

   A. 0 µg/L.

B. 5 µg/L.
C. 10 µg/L.
D. 15 µg/L.

*To review relevant content, see "Biologic Guidelines", "Workplace Air", "Drinking Water", "Food", and "Paint" in this section.*

8. What are the OSHA Standards for Lead Levels?

A. Permissible exposure limit (PEL) of lead in the workplace.
B. The frequency and extent of medical monitoring triggered by the action level.
C. Other responsibilities of the employer.
D. All of the above.

*To review relevant content, see "Workplace Air" in this section.*

9. Which of the following is true regarding U.S. standards and regulations of lead levels?

A. CDC adopted a reference value for lead in children's blood.
B. OSHA set Permissible Exposure Limit (PEL) for lead in workplace air.
C. EPA established drinking water regulation for lead.
D. CPSC set a regulatory limit value for lead in paint.
E. All of the above.
F. None of the above.

*To review relevant content, see "Biologic Guidelines", "Workplace Air", "Drinking Water", and "Paint" in this section.*

## What Is the Biological Fate of Lead in the Body?

**Learning Objectives**

Upon completion of this section, you will be able to

- Describe how lead is absorbed,
- Describe how lead is distributed in the body, and

- Identify the half-life of lead in the blood.

**Introduction**

The absorption and biological fate of lead once it enters the human body depends on a variety of factors.

The blood carries only a small fraction of total lead body burden, and serves as the initial receptacle of absorbed lead, distributing it throughout the body, making it available to other tissues.

Absorbed lead that is not excreted is exchanged primarily among three compartments:

1. Blood,
2. Mineralizing tissues (bones and teeth), which typically contain the vast majority of the lead body burden, and
3. Soft tissue (liver, kidneys, lungs, brain, spleen, muscles, and heart).

These compartments, and the dynamics of the exchange between them, are discussed below.

**Lead Absorption**

Lead absorption depends on a variety of factors, including particulate size, route of exposure, nutritional status, health, and age of the individual.

- Lead absorption can be impacted by route of exposure and is inversely proportional to the exposure particle size. For example, exposure to lead dust (respiratory route) may result in higher absorption than exposure to the equivalent amount of lead from chips (digestive route) of higher lead content paint.
- Adults typically absorb up to 20% of ingested inorganic lead after a meal and up to 60-80% on an empty stomach [ATSDR 2010].
- Children absorb about 50% of ingested lead after a meal [ATSDR 2010] and up to 100% on an empty stomach.
- Most inhaled lead in the lower respiratory tract is absorbed.

- Most of the lead that enters the body is excreted in urine or through biliary clearance (ultimately, in the feces).

The chemical form of lead or lead compounds entering the body is also a factor for the absorption and biological fate of lead.

- Inorganic lead, the most common form of lead, is not metabolized in the liver.
- Nearly all organic lead that is ingested is absorbed.
- Organic lead compounds (those found in leaded gasoline and additives sold in the United States in the past) are metabolized in the liver.

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| **Lead in the Blood** | Although the blood generally carries only a small fraction of total lead body burden, it does serve as the initial receptacle of absorbed lead and distributes lead throughout the body, making it available to other tissues (or for excretion).<br><br>• The half-life of lead in adult human blood has been estimated as 28 days [Griffin et al. 1975, as cited in ATSDR 2010] to 36 days [Rabinowitz et al. 1976, as cited in ATSDR 2010].<br>• Approximately 99% of the lead in blood is associated with red blood cells; the remaining 1% resides in blood plasma [Everson and Patterson 1980 as cited in ATSDR 1999; EPA 1986b; DeSilva 1981].<br>• The higher the lead concentration in the blood, the higher the percentage partitioned to plasma. This relationship is curvilinear — as blood lead levels (BLLs) increase, the high-end plasma level increases more.<br>• On average, it requires slightly more than 1 year for children enrolled in case management with BLLs ≥10 micrograms per deciliter (µg/dL) to decline to <10 µg/dL [Dignam et al. 2008].<br><br>The Blood Lead Level is the most widely used measure of lead exposure.<br><br>These tests, however, do not measure total body burden of lead—they tend to be more reflective of recent or ongoing exposures (see "*Clinical Assessment–Diagnostic Tests and Imaging"* section). |
| **Lead in Mineralizing Tissues (Bones and Teeth)** | The bones and teeth of adults contain about 94% of their total lead body burden; in children, that figure is approximately 73% [Barry 1975, as cited in ATSDR 2010].<br><br>• Lead in mineralizing tissues is not uniformly distributed. It tends to accumulate in bone regions undergoing the most active calcification at the time of exposure. |

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| | • Known calcification rates of bones in childhood and adulthood suggest that lead accumulation will occur predominately in trabecular bone during childhood, and in both cortical and trabecular bone in adulthood [Auf der Heide and Wittmets 1992 as cited in ATSDR 2010].<br><br>Two physiological compartments appear to exist for lead in cortical and trabecular bone [ATSDR 2010]:<br><br>• Inert component stores lead for decades, and<br>• Labile component readily exchanges bone lead with the blood.<br><br>Under certain circumstances, however, this apparently inert lead will leave the bones and reenter the blood and soft tissue organs.<br><br>• Bone-to-blood lead mobilization increases during periods of<br><br>o Advanced age,<br>o Broken bones,<br>o Chronic disease,<br>o Hyperthyroidism,<br>o Immobilization (bedridden, etc.),<br>o Kidney disease,<br>o Lactation [Landrigan et al. 2002b],<br>o Menopause,<br>o Physiologic stress, and<br>o Pregnancy.<br><br>Calcium deficiency exacerbates, or worsens, bone-to-blood lead mobilization in all of the above instances.<br><br>• Consequently, the normally inert pool poses a special risk because it is a potential endogenous source of lead that can maintain BLLs long after exposure has ended. |
| **Implications of Biological Fate** | Symptoms or health effects can also appear in the absence of significant current exposure because lead |

from past exposures can accumulate in the bones (endogenous source).

- In most cases, toxic BLLs reflect a mixture of current exposure to lead and endogenous contribution from previous exposure.
- An acute high exposure to lead can lead to high short-term BLLs and cause symptoms of acute lead poisoning.

It is important that primary care physicians:

- Evaluate a patient with potential lead poisoning,
- Examine potential current and past lead exposures,
- Look for other factors that affect the biokinetics of lead (such as pregnancy or poor nutrition), and
- Rule out lead poisoning in cases of unexplained seizures or coma.

**Key Points**

- Children absorb a higher percentage of ingested lead than adults.
- Once in the bloodstream, lead is primarily distributed among three compartments —blood, mineralizing tissue, and soft tissues. The bones and teeth of adults contain more than 95% of total lead in the body.
- In times of stress (particularly pregnancy and lactation), the body can mobilize lead stores, thereby increasing the level of lead in the blood.
- The half-life of lead in adult human blood has been estimated as 28 days.
- The body accumulates lead over a lifetime and normally releases it very slowly.
- Both past and current elevated exposures to lead increase patient risks for adverse health effects from lead.

**Progress Check**

10. Lead absorption depends on a variety of factors, including:

    A. Particulate size, route of exposure, and income and age of the parents.
    B. Nutritional and health status, educational level, and age of the individual.

C. Place of residence, educational level, and income the parents.
D. Particulate size, route of exposure, nutritional status, health, and age of the individual.

*To review relevant content, see "Lead in the Blood" in this section.*

11. Which of the following answer choices best describes where lead is distributed once it enters the body?

    A. Blood, sweat, and tears.
    B. Soft tissues and bones only.
    C. Blood, mineralizing tissue, and soft tissues.
    D. Teeth and long bones only.

    *To review relevant content, see "Introduction" "Lead in the Blood"* and *"Lead in Mineralizing Tissue (Bones and Teeth)" in this section.*

12. What is the approximate half-life of lead in the blood of an adult?

    A. Seven days.
    B. Twenty-eight days.
    C. Three to six months.
    D. One year.

    *To review relevant content, see "Lead in the Blood" in this section.*

## What Are Possible Health Effects from Lead Exposure?

**Learning Objectives**

Upon completion of this section, you will be able to

- Describe how lead affects adults and children,
- Describe what is the most sensitive organ system for lead exposure in children, and
- Specify that there is no identified threshold or safe level of lead in blood.

## Introduction

Blood lead concentrations have decreased dramatically in U.S. children over the past 4 decades. However, too many children still live in housing with deteriorated lead-based paint and are at risk for lead exposure with resulting lead-associated cognitive impairment and behavioral problems [AAP 2016; ACCLPP 2012].

### The Exposure-Disease Model

No matter how toxic, no chemical can harm a person (child, adult, or both) unless *exposure* occurs. After a sufficient level of exposure (dose) to the chemical, biologic uptake, target organ contact, and biologic change can occur, all of which can lead to disease or other effects [ATSDR 2012; ATSDR 2013].

Steps that must occur for an environmental toxicant to cause disease.

- Environmental contamination (potential exposure): the exposure source and how the contaminant disperses in the environment.
- Exposure: For a toxicant to cause disease, exposure must occur. Exposure occurs through an *exposure pathway* between the contaminant in the physical environment and the exposed person.
- Biologic uptake: the process by which the transfer of substances from the environment to plants, animals, and humans occurs.
- Absorbed dose: how much of a toxicant is absorbed after an exposure occurs.
- Biologic changes: the chemical changes causing damage to tissues following a toxic exposure and an absorbed dose.
- Target organ: the organ or organs affected by an exposure to the toxicant. The "critical organ" is the most sensitive organ.
- Clinical disease: physical signs and symptoms resulting from a sufficiently absorbed toxicant dose.

### Exposure Pathway

For a toxicant to cause disease, exposure must occur. Exposure occurs through an *exposure pathway* between

the contaminant in the physical environment and the exposed person.

An exposure pathway has five parts.

1. A source of contamination, such as an abandoned mine or industrial emissions.
2. An environmental medium and transport mechanism, such as water or movement through a groundwater aquifer.
3. A point of exposure, such as a private well.
4. A route of exposure, such as
    - eating,
    - drinking,
    - breathing,
    - touching,
    - transplacental exposure, and/or
    - intravenous exposure.
5. A receptor population, such as people potentially or actually exposed.

When all five parts are present, the exposure pathway is termed "a completed exposure pathway" [ATSDR 2005].

Lead serves no useful purpose in the human body. Its presence in the body can lead to toxic effects, regardless of age, gender, or exposure pathway.

The nervous system is the most sensitive organ system for lead exposure in children.

- Lead toxicity can affect every organ system.
- On a molecular level, proposed mechanisms for toxicity involve fundamental biochemical processes. These include lead's ability to inhibit or mimic the actions of calcium (which can affect calcium-dependent or related processes) and to interact with proteins (including those with sulfhydryl, amine, phosphate, and carboxyl groups) [ATSDR 2010].
- Lead’s high affinity for sulfhydryl groups makes it particularly toxic to multiple enzyme systems including heme biosynthesis.
- The National Toxicology Program [NTP 2012], and the American Academy of Pediatrics [AAP 2016]

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| | have concluded that there is sufficient evidence for adverse health effects in children and adults at blood lead levels (BLLs) <5 micrograms per deciliter (µg/dL).<br>• "There is no identified threshold or safe level of lead in blood" [AAP 2016].<br>• It is important to control or eliminate all sources of lead in children's environments to prevent exposure.<br><br>The sections below describe specific health effects for population groups and major organ systems and functions. Some of the information in the population group is repeated in the organ system specific sections. |
| **Children** | From 2007 to 2010, approximately 2.6% of preschool children in the United States had a blood lead concentration 5 µg/dL (≥ 50 ppb), which represents about 535,000 U.S. children 1 to 5 years of age [AAP 2016].<br><br>• In children, there is no identified threshold or "safe" blood lead level below which no risk of poor developmental or intellectual function is expected.<br><br>Data from the NTP [2012] showed that the effect of concurrent BLLs on IQ may be greater than currently believed.<br><br>Lead inhibits the bodies of growing children from absorbing iron, zinc and calcium, minerals essential to proper brain and nerve development.<br><br>• Children often show no signs of lead toxicity until they are in school, even as late as middle school, as expectations for academic achievement increase.<br>• The practicing health care provider can distinguish overt clinical symptoms and health effects that come with high exposure levels on an individual basis.<br>• However, lack of overt symptoms does not mean "no adverse impact."<br>• Lower levels of exposure have been shown to have many subtle adverse health effects. |

- Medical research has established a connection between early childhood lead exposure and future criminal activity, especially of a violent nature [Wright et al. 2008; Needleman et al. 2002; Needleman et al. 1996]. Numerous studies link elevated bone or blood lead levels with aggression, destructive and delinquent behavior, attention deficit hyperactivity disorder and criminal behavior [Wright et al. 2008; Braun et al. 2006; Needleman et al. 2004; Needleman et al. 2002; Nevin 2000; Bellinger et al. 1994].
- Acute exposure to very high levels of lead may produce encephalopathy in children.

While the immediate health effect of concern in children is typically neurological, it is important to remember that childhood lead poisoning can lead to health effects later in life, including

- ADHD, delayed learning, and lower IQ (which will impact school performance),
- Developmental problems with their offspring,
- Hypertension,
- Renal effects, and
- Reproductive problems.

Adverse health effects occur in children at BLLs <5 µg/dL [AAP 2016; NTP 2012]. The most common include

- Attention-related behavioral problems,
- Decreased cognitive performance, and
- Greater incidence of problem behaviors.

In pregnant women, there is sufficient evidence that maternal BLLs <5 µg/dL are associated with reduced fetal growth or lower birth weight. BLLs <10 µg/dL are associated with decreased postnatal growth, and concurrent BLLs <10 µg/dL in children are associated with

- Reduced head circumference,
- Height, or

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| | • Other indicators of growth and delayed puberty [NTP 2012].<br><br>There is inadequate evidence for an association between BLLs <10 µg/dL and cardiovascular effects in children of any age, or renal function in children <12 years of age [NTP 2012]. BLLs in this range may not predict poor outcomes for individual children, but are important predictors at the population level.<br><br>It must be emphasized that **there is no known blood lead level for children** without some level of risk for some of the adverse neurological effects of lead in children. |
| **Adults** | The neurological effects in an adult exposed to lead as an adult can be neuropathy, and may be different from those of an adult exposed to lead as a child when the brain was developing (more information for adults in following sections).<br><br>• Childhood neurological effects, including attention deficit hyperactivity disorder (ADHD), may persist into adulthood.<br>• Lead-exposed adults may also experience many of the neurological symptoms experienced by children, but shown at higher blood lead levels.<br><br>Other effects are reduced sperm count and hypertension [NTP 2012]. However, sufficient evidence shows that BLLs <5 µg/dL are associated with decreased renal function and that BLLs <10 µg/dL are associated with increased blood pressure and hypertension [NTP 2012]. |

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| **Pregnant Women** | Sufficient evidence shows that maternal BLLs <5 µg/dL are associated with reduced fetal growth or lower birth weight [NTP 2012].<br><br>Pregnant women who were lead-exposed as adults may also experience many of the neurological symptoms experienced by children, although at higher blood lead levels.<br><br>Some women may develop eclampsia and pre-eclampsia with pregnancy. Maternal blood lead levels may be important predictors of the risk of developing eclampsia and pre-eclampsia [NTP 2012]. There is sufficient evidence showing that BLLs <5 µg/dL are associated with decreased renal function and that BLLs <10 µg/dL are associated with increased blood pressure and hypertension [NTP 2012]. |

**Neurological Effects**

Lead exposure has been linked with various types of brain damage. These include

- Problems with thinking (cognition);
- Difficulties with organizing actions, decisions, and behaviors (executive functions);
- Abnormal social behavior (including aggression); and
- Difficulties in coordinating fine movements, such as picking up small objects (fine motor control) [Cecil et al. 2008].

Sufficient evidence in children shows that BLLs <5 µg/dL are associated with increased diagnosis of attention-related behavioral problems, greater incidence of problem behaviors, and decreased cognitive performance. This is indicated by

- Decreased IQ,
- Lower academic achievement, and
- Reductions in specific cognitive measures [NTP 2012].

Lead causes activation of protein kinase C (PKC) and binds to PKC more avidly than calcium (its physiologic activator). This creates problems with neurotransmitter release. Alteration of PKC function also affects second-messenger systems within the cell which may lead to future changes in gene expression and protein synthesis.

A large body of evidence associates a reduction in IQ performance and other neuropsychological defects with BLLs <10 µg/dL, including reduced hearing [Landrigan and Etzel 2014; NTP 2012; ATSDR 2010; Lanphear et al. 2005].

- Neurological adverse effects of lead in children have been documented at exposure levels once thought to cause no harmful effects, including those <10 µg/dL [Canfield 2003; CDC 1997a] and <5 µg/dL [NTP 2012; Lanphear et al. 2005].
- Low doses of lead can cause a broad range of functional problems such as loss of self-control, shortened attention span and a host of learning

disorders that often cause lead-exposed children to perform poorly in school and ultimately to drop out [Bellinger 2008a; Bellinger 2008b; Chen et al. 2007; Wilson et al. 2006; Lanphear et al. 2005].
- Because otherwise asymptomatic individuals may experience neurological effects from lead exposure, clinicians should have a high index of suspicion for lead exposure, especially in the case of children with developmental delays.

Children suffer neurological effects from lead at much lower blood lead levels than adults.

- Subclinical neurological effects may occur at lower BLLs — at or below the regulatory standard of 10 µg/dL, in some cases — and it may not be possible to detect them on clinical examination at the time of the exposure or peak BLLs. Children often show no signs of lead toxicity until they are in school, even as late as middle school, when expectations for academic achievement increase.
- Some studies have found, for example, that for every 10 µg/dL increase in BLLs, children's IQ was found to be lowered by 4 to 7 points [Winneke et al. 1990 as cited in AAP 1993; Fulton et al. 1987; Landsdown et al. 1986; Hawk et al. 1986; Schroeder et al. 1985; Yule et al. 1981].
- Evidence shows that ADHD and hearing impairment in children increase with increasing BLLs, and that lead exposure may disrupt balance and impair peripheral nerve function [ATSDR 2010].

In children, acute exposures leading to very high blood lead levels (> 70 µg/dL), may produce encephalopathy and other accompanying signs of

- Ataxia,
- Coma,
- Convulsions,
- Death,
- Hyperirritability, and
- Stupor.

The BLLs associated with encephalopathy in children vary from study to study, but BLLs of 70-80 µg/dL or greater appear to indicate a serious risk. Even without encephalopathy symptoms, these levels are associated with increased incidences of lasting neurological and behavioral damage [ATSDR 2010].

In adults, lead encephalopathy may occur at extremely high BLLs, *e.g.*, 460 µg/dL [Kehoe 1961 as cited in ATSDR 2010].

- Precursors of encephalopathy may occur at lower BLLs, such as

    - Dullness,
    - Irritability,
    - Loss of memory,
    - Muscular tremor, and
    - Poor attention span.

Less severe neurological and behavioral effects have been documented in lead-exposed workers with BLLs ranging from 40 to 120 µg/dL [ATSDR 2010]. These effects include

- Decreased libido,
- Depression/mood changes,
- Diminished cognitive performance,
- Diminished hand dexterity,
- Diminished reaction time,
- Diminished visual motor performance,
- Dizziness,
- Fatigue,
- Forgetfulness,
- Headache,
- Impaired concentration,
- Impotence,
- Increased nervousness,
- Irritability,
- Lethargy,
- Malaise,
- Paresthesia,
- Reduced IQ scores, and

- Weakness.

Late signs of lead intoxication such as slowed nerve conduction and forearm extensor weakness (wrist drop) are more typical signs in workers chronically exposed to high lead levels.

Childhood lead exposure is associated with region-specific reductions in adult gray matter volume. Affected regions include the portions of the prefrontal cortex and anterior cingulate cortex (ACC) responsible for executive functions, mood regulation, and decision-making [Cecil et al. 2008]. These neuroanatomical findings were more pronounced for males, suggesting that lead-related atrophic changes have a disparate impact across sexes. This analysis suggests that adverse cognitive and behavioral outcomes may be related to lead's effect on brain development producing persistent alterations in structure. Using a simple model, Cecil et al. [2008] found that blood lead concentration mediates brain volume and fine motor function. As shown in Figure 3 (model uses composite data to represent areas of significant volume loss overlaid with mean childhood blood lead concentrations), lead exposure appears to have a larger effect on brain volume loss in men than in women, which might help to explain the higher incidence of antisocial behaviors among men than women. Overall, these findings may explain why children and adults who have a history of lead exposure have behavioral and other problems, and support ongoing efforts to reduce childhood lead exposure in the United States and other countries. More research is needed to support and expand upon these findings.

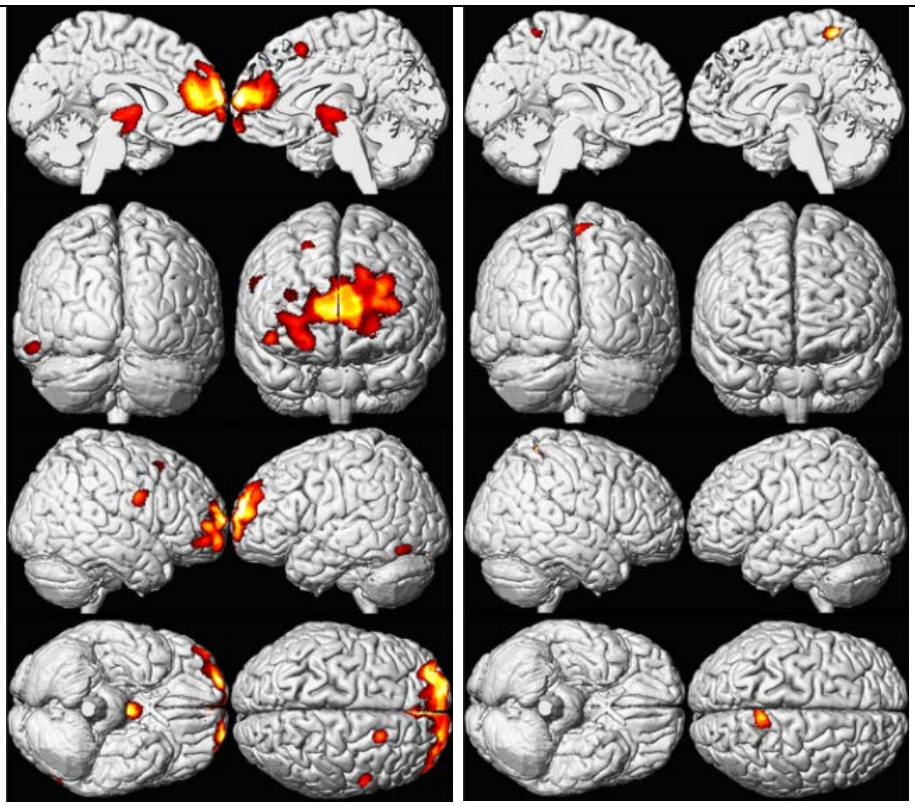

**Figure 3. Sex Influences Brain Volume Loss Associated with Lead Exposure (Males left and Females right)** [Cecil et al 2008].

A composite representation of regions with significant volume loss for Cincinnati Lead Study (CLS) participants associated with mean childhood blood lead concentrations is shown in red and yellow overlaid upon a standard brain template for males (n=83) and females (n=74). The model is adjusted for age at time of scanning and birth weight, using a cluster threshold of 700 voxels and unadjusted; $\underline{<}$0.001 [Cecil et al 2008].

**Renal Effects**

The lowest blood lead level at which lead has an adverse effect on the kidney remains unknown.

Many studies show a strong association between lead exposure and renal effects [NTP 2012; ATSDR 2010]. Latent effects of childhood lead exposure include chronic advanced renal disease or a reduction in renal function in adulthood.

Impaired renal function and kidney disease are reported at high levels of lead exposure, as estimated mainly through concentrations of serum creatinine (SCr) and rates of creatinine clearance from the body. However, a change in the serum creatinine is not sensitive for an early diagnosis of acute kidney injury [Han et al. 2008].

Urinary levels of matrix metalloproteinase-9 (MMP-9), *N*-acetyl-β-D-glucosaminidase (NAG), and kidney injury molecule-1 (KIM-1) have been used as biomarkers for the detection of acute kidney injury [Han et al. 2008].

- "Combining all three biomarkers achieved a perfect score diagnosing acute kidney injury" [Han et al 2008].
- Urinary biomarkers allow diagnosis of acute kidney injury earlier than a rise in serum creatinine.

BLLs of 1.5 µg/dL due to chronic low-level lead exposure reduces kidney function in adolescents. Doubling the blood lead level was associated with significant reduction in the glomerular filtration rate. "Chronic, low-level lead exposure is an important risk factor for chronic renal failure" [Landrigan and Etzel 2014].

Some population-based studies show accelerated increases in serum creatinine or reductions in creatinine clearance at BLLs below 60 µg/dL [Tsaih et al. 2004; Kim et al. 1996; Hu et al. 1994; Staessen et al. 1992].

- There is sufficient evidence that blood BLLs <5 µg/dL are associated with adverse effects on kidney function in adults (increased risk of chronic kidney disease, and decreases in the estimated glomerular filtration rate and creatinine clearance, markers of kidney function) [NTP 2012].
- At <10 µg/dL there is increased blood pressure and increased risk of hypertension in adults [NTP 2012]. However, continued or repetitive exposures can cause toxic stress on the kidney that, if unrelieved, may develop into chronic and often irreversible lead nephropathy (*e.g.*, chronic interstitial nephritis).
- Lead nephrotoxicity is characterized by

- Proximal tubular nephropathy,
- Glomerular sclerosis, and
- Interstitial fibrosis [Zalups and Diamond 2004; Goyer 1985; Loghman-Adham 1997].

- Most documented renal effects for occupational workers have been observed in acute high-dose exposures and high-to-moderate chronic exposures (BLL >60 µg/dL).

Some patients show Fanconi-like syndrome [Landrigan and Etzel 2014] (Fanconi syndrome consists of multiple defects in renal proximal tubular reabsorption, causing glucosuria, phosphaturia, generalized aminoaciduria, and bicarbonate wasting).

This nephropathy is most commonly reported in children, and even though it is reversible, should be treated to prevent further kidney damage. Treatment of acute lead nephropathy in children appears to prevent the progression to chronic interstitial nephritis [Weeden et al. 1986].

It should be noted that lead-induced end-stage renal disease is a relatively rare occurrence in the U.S. population today.

- Renal disease can be asymptomatic until the late stages and may not be detected unless appropriate tests are performed.
- Because past or ongoing excessive lead exposure may also be a causative agent in kidney disease associated with essential hypertension [ATSDR 2010], primary care providers should closely follow the renal function of patients with hypertension and a history of lead exposure (See the "*Hypertension Effects"* section).

In patients with lead nephropathy, uric acid excretion is substantially lower than would be expected on the basis of their glomerular filtration rate (GFR). Studies have suggested enhanced reabsorption and reduced secretion of uric acid, explaining a high prevalence of gout [Kathuria et al. 2016]. In one study, more than 50% of

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| | patients suffering from lead nephropathy also suffered from gout [Bennett 1985 as cited in ATSDR 2010]. |
| **Hematological Effects** | Lead inhibits the body's ability to make hemoglobin by interfering with several enzymatic steps in the heme synthesis pathway.<br><br>• Specifically, lead decreases heme biosynthesis by inhibiting *d*-aminolevulinic acid dehydratase (ALAD) and ferrochelatase (FECH) activity.<br>• Ferrochelatase, which catalyzes the insertion of iron into protoporphyrin IX, is quite sensitive to lead.<br>• A decrease in the activity of this enzyme results in an increase of the substrate erythrocyte protoporphyrin (EP) in the red blood cells (also found in the form of ZPP—bound to zinc rather than to iron).<br>• Also associated with lead exposure is an increase in blood and plasma d-aminolevulinic acid (ALA) and free erythrocyte protoporphyrins (FEP) [EPA 1986, as cited in ATSDR 2010].<br><br>EPA estimated the threshold BLL for a decrease in hemoglobin to be 50 µg/dL for occupationally exposed adults and approximately 40 µg/dL for children, although other studies have indicated a lower threshold (*e.g.*, 25 µg/dL) for children [EPA 1986 as cited in ATSDR 2010]. Lead induced anemia in adults is not a common occurrence.<br><br>Recent data indicate that the EP level, which has been used in the past to screen for lead toxicity, is not sufficiently sensitive at lower levels of blood lead and is therefore not as useful as a screening test as previously thought (see "*Blood Lead Levels (BLLs)*" in the "*Clinical Assessment—Diagnostic Tests and Imaging"* section for further discussion of EP testing.).<br><br>Lead can induce 2 types of anemia, often accompanied by basophilic stippling of the erythrocytes [ATSDR 2010]. |

- Acute high-level lead exposure has been associated with hemolytic anemia.
- Frank anemia is not an early manifestation of lead exposure, and is evident only when the BLL is significantly elevated for prolonged periods.
- In chronic lead exposure, lead induces anemia by both interfering with heme biosynthesis and by diminishing red blood cell survival.
- The anemia of lead intoxication is hypochromic and normo - or microcytic with associated reticulocytosis.

The heme synthesis pathway, on which lead has an effect, is involved in many other processes in the body, including

- Endocrine,
- Hepatic,
- Neural, and
- Renal.

The impact of biochemical and enzyme changes (and their possible sequelae) that may exist at lower blood lead levels remains unclear.

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| **Endocrine Effects** | Studies of children with high lead exposure have found that a strong inverse correlation exists between BLLs and vitamin D levels.<br><br>• Lead impedes vitamin D conversion into its hormonal form, 1, 25-dihydroxyvitamin D, which is largely responsible for the maintenance of extra- and intra-cellular calcium homeostasis.<br>• Diminished 1, 25-dihydroxyvitamin D, in turn, may impair cell growth, maturation, and tooth and bone development.<br>• In general, these adverse effects seem to be restricted to children with chronically high BLLs (most striking in children with BLLs >62 µg/dL) and chronic nutritional deficiency, especially with regard to calcium, phosphorous, and vitamin D [Koo et al. 1991 as cited in ATSDR 2010].<br><br>Lead appears to have a minimal, if any, effect on thyroid function. |
| **Gastrointes-tinal Effects** | In severe cases of lead poisoning, children or adults may present with severe cramping abdominal pain (colic-like pain), which may be mistaken for an acute abdomen or appendicitis. Lead colic is a symptom of chronic lead poisoning and is associated with obstinate constipation. |

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| **Cardiovascular Effects** | A few population studies have shown a possible connection between lead exposure and other cardiovascular disorders including<br><br>• Ischemic coronary heart disease,<br>• Cerebrovascular accidents, and<br>• Peripheral vascular disease [Vaziri and Gonick, 2008].<br><br>Several epidemiological and clinical studies have found a link between chronic lead exposure and elevated blood pressure [Vaziri and Gonick, 2008].<br><br>Hypertension is a complex condition with many different causes and risk factors, including family history, age, weight, diet, and exercise habits.<br><br>• Lead exposure is one factor of many that may contribute to the onset and development of hypertension.<br>• Although low to moderate lead level exposures (BLLs <30 µg/dL) show only a low degree of association with hypertension, higher exposures (primarily seen in occupational settings) increase the risk for hypertensive heart disease and cerebrovascular disease as latent effects.<br>• One study found that adults who experienced lead poisoning as children had a significantly higher risk of hypertension 50 years later (relative to control adults without childhood lead exposure) [Hu 1991 as cited in ATSDR 2010]. The association has been shown in population-based studies with BLLs below 10 µg/dL. Data supports an association between lead exposure and elevations in blood pressure [Schwartz 1995 as cited in ATSDR 2010; Hu et al. 1996; Korrick et al. 1999; Victery et al. 1988]. |

**Reproductive Effects**

Reproductive effects examined in the literature include

- Sperm count,
- Fertility, and
- Pregnancy outcomes.

While several studies have implicated lead as contributing to reproductive and developmental effects, these effects have not been well-established at low exposure levels.

*Male Reproductive Effects*

Recent reproductive function studies in humans suggest that current occupational exposures may decrease sperm count totals and increase abnormal sperm frequencies [NTP 2012].

- In men, there is sufficient evidence that BLLs ≥15 µg/dL are associated with adverse effects on sperm or semen.
- It is unclear how long these effects may last in humans after lead exposure ceases.

*Fertility*

There is sufficient evidence that BLLs <10 µg/dL show adverse health effects on reproduction in adult women, and BLLs ≥20 µg/dL are associated with delayed conception time [NTP 2012].

*Pregnancy Outcomes*

Prenatal lead exposure has known influences on maternal health and infant birth and neurodevelopmental outcomes [CDC 2010].

Recent National Health and Nutrition Examination Survey (NHANES) estimates suggest that almost 1% of women of childbearing age (15-44 years) have BLLs greater than or equal to 5 µg/dL [CDC 2010]. As documented in the CDC guidelines for the identification and management of lead exposure in pregnant and lactating women

(https://www.cdc.gov/nceh/lead/publications/LeadandPregnancy2010.pdf), there is evidence that maternal lead exposure during pregnancy can cause fetal lead exposure and can adversely affect both maternal and child health across a wide range of maternal exposure levels.

There is consistent evidence that the risk for spontaneous abortion is increased by maternal exposure to high levels of lead (*e.g.,* occupational exposures) [Hertz-Picciotto 2000].

Borja-Aburto [1999] showed a statistically significant dose-response relationship between maternal BLLs and risk for spontaneous abortion at lower levels of exposure (0 to 30 µg/dL).

The previous lack of evidence for an association at these low-to-moderate BLLs may be due to methodologic deficiencies in these studies, such as small sample sizes, lack of control for confounding, problems in case ascertainment, and/or limitations in exposure assessment [Hertz-Piccioto 2000].

- The strongest evidence to date is a prospective study of pregnant women in Mexico City.
- This study addressed most of the deficiencies of the prior studies and demonstrated a statistically significant dose-response relationship between maternal BLLs (average 11.0 µg/dL) and risk for spontaneous abortion [Borja-Aburto et al. 1999].

There is also limited evidence that maternal BLLs <10 µg/dL are associated with preterm birth and spontaneous abortion [NTP 2012].

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| **Developmental Effects** | Developmental effects examined in the literature include pregnancy outcomes (*e.g.*, premature births and low birth weights), congenital abnormalities, and post-birth effects on growth or neurological development.<br><br>• Increasing evidence indicates that lead, which readily crosses the placenta, adversely affects fetal viability as well as fetal and early childhood development.<br>• Prenatal exposure to low lead levels (*e.g.*, maternal BLLs of 14 µg/dL) may increase the risk of reduced birth weight and premature birth [ATSDR 2010].<br>• Lead is an animal teratogen, but the available data are inadequate to establish the presence or absence of an association between maternal lead exposure and major congenital anomalies [CDC 2010].<br><br>In a retrospective study, a higher proportion of learning disabilities were found among school-aged children with biological parents who had lead poisoning as children 50 years previously [Hu 1991]. |

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| **Other Potential Effects** | *Lower Bone Mineral Density (BMD)*<br><br>Lead has been linked to problems with the development and health of bones. At high levels, lead can result in slowed growth in children.<br><br>There is a growing body of scientific literature that supports a role of lead exposure in the development of osteoporosis.<br><br>Rat studies have found that lead exposure is associated with decreased bone mineral density (BMD). However, human studies are limited. Lead-exposed animals had decreased bone mass that resulted in bones that were more susceptible to fracture. Lead decreased osteoblastic cell numbers leading to a depression of bone formation. Accompanying this, lead exposure elevated sclerostin protein levels in the skeleton, and correspondingly reduced levels of β-catenin and Runx2 in stromal precursor cells. Lead also increased skeletal expression of peroxisome proliferator-activated receptor-γ (PPAR-γ). These results indicate a shift in mesenchymal differentiation wherein lead promoted enhanced adipogenesis and decreased osteoblastogenesis. Substantial differences in bone marrow composition were observed, highlighted by an increase in adipocytes [Beier et al. 2013].<br><br>Human studies have shown both positive associations between BMD and blood lead levels in children (i.e., the higher the BMD, the higher the blood lead level) [Campbell et al. 2004] and negative [associations] in adults [Campbell and Auinger 2007; Nash et al. 2004], but these results have not allowed inferences about the likely causal direction of this relation [Theppeang et al. 2008].<br><br>Children with high lead exposure (mean, 23.6 µg/dL BLL), had a significantly higher BMD than did children with low lead exposure (mean, 6.5 µg/dL BLL). This may reflect a true phenomenon because lead exposure has been reported to accelerate bony maturation by inhibiting the effects of parathyroid hormone–related peptide. Accelerated maturation of bone may ultimately |

result in a lower peak BMD being achieved in young adulthood, thus predisposing to osteoporosis in later life.

Future studies need to investigate this proposed model [Campbell et al. 2004].

"There could be potential effect modification by BMD on the relations between blood and bone lead levels, an analysis directly relevant to hypotheses regarding BMD and release of lead from bone. A growing literature suggests that genetic polymorphisms may modify the toxicokinetics of lead in bone and blood" (i.e., VDR, APOE) [Theppeang et al. 2008].

Analysis of NHANES III data showed a significant inverse association between lead exposure and BMD, but because of NHANES's cross sectional design, caution should be taken in drawing conclusions from these findings alone.

*Dental Health*

Researchers are currently investigating the impacts of lead on dental health. One study found pre- and perinatal exposure to lead increased prevalence of caries in rat pups by almost 40% [Watson et al. 1997].

*Cancer*

EPA has classified elemental lead and inorganic lead compounds as Group 2B: probable human carcinogens, revised in 2011 [EPA 2013b]. This classification is based in part on animal studies, which have been criticized because the doses of lead administered were extremely high.

The NTP [2004] classified lead and lead compounds as "reasonably anticipated to be a carcinogen".

**Key Points**

- Adverse health effects may occur in children and adults at BLLs <5 µg/dL.
- In children, health effects generally occur at lower BLLs than in adults.

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| | | • There is no identified threshold or safe level of lead in blood.<br>• The nervous system is the most sensitive organ system for lead exposure in children.<br>• The developing nervous system of a child can be affected adversely at BLLs of ≤5 µg/dL. Subclinical effects may be present, but may not be detectable during clinical examination.<br>• There is a wide range of neurological effects associated with lead exposure, some of which may be irreversible.<br>• Lead exposure can lead to renal effects such as Fanconi-like syndromes, chronic nephropathy, and gout.<br>• Most lead-associated renal effects or diseases result from ongoing chronic exposure, present high acute exposure, or as latent effects from past chronic lead exposure.<br>• Lead inhibits several enzymes critical to the synthesis of heme, causing a decrease in blood hemoglobin.<br>• Lead interferes with a hormonal form of vitamin D which affects multiple processes in the body, including cell maturation and skeletal growth.<br>• Lead exposure may lead to increased risk for hypertension and its sequelae.<br>• Evidence suggests an association between lead exposure and certain reproductive and developmental outcomes.<br>• Maternal blood lead, from exogenous and endogenous sources, can cross the placenta and pose a risk to the fetus.<br>• Other potential health effects of lead are currently being studied. |
| **Progress Check** | 13. | How do lead's effects **DIFFER** between children and adults?<br><br>A. Effects in children are more likely to be reversible.<br>B. Adults suffer more neurological damage.<br>C. Children are less likely to become anemic. |

D. Children suffer neurological effects from lead at much lower blood lead levels than adults.

*To review relevant content, see "Children", "Adults" "Neurological Effects", "Hematological Effects" and "Other Potential Effects" in this section.*

14. Lead toxicity can affect

A. The kidneys.
B. IQ and neurological development in children.
C. Sperm count.
D. All of the above.

*To review relevant content, see "Neurological Effects," "Children," "Renal Effects," and "Reproductive Effects" in this section.*

15. What is the most sensitive organ system for lead exposure in children?

A. Skeletal system (Long bones and teeth).
B. Respiratory system.
C. Nervous system.
D. Renal system.

*To review relevant content, see "Introduction", "Children", "Adults" and "Neurological System" in this section.*

16. What is the identified threshold or safe level of lead in blood?

A. 15 µg/dL.
B. 10 µg/dL.
C. 5 µg/dL.
D. There is no identified threshold or safe level of lead in blood.

*To review relevant content, see "Introduction" and "Children" and "Neurological Effects" in this section.*

# Clinical Assessment – Exposure History

**Learning Objectives**

Upon completion of this section, you will be able to

- Describe how to take a screening exposure history for lead exposure, and
- Identify lead exposure-related questions to ask during a child visit.

**Introduction**

Most environmental and occupational diseases either manifest as common medical problems or have nonspecific symptoms. Unfortunately, hazardous exposures rarely enter into the clinician's differential diagnosis. As a result, clinicians may miss the opportunity to make correct diagnoses that might influence the course of disease. A correct diagnosis may help stop exposure and might prevent disease in others by avoiding exposure [ATSDR 2015].

What can a clinician do to improve recognition of disease related to current or past exposures?

- First, one must be suspicious and think about the possibility of environmental and occupational factors of disease.
- Next, one needs to incorporate an exposure history questionnaire into clinical practice.

*ATSDR Case Study in Environmental Medicine: Taking an Exposure History*

https://www.atsdr.cdc.gov/csem/csem.asp?csem=33&po=0

illustrates the principles and practices involved in the development of a differential diagnosis that includes possible hazardous exposure related etiologies.

Taking an exposure history may enable physicians to

- Make more accurate diagnoses,
- Influence the course of disease by stopping current exposure,

- Prevent disease in others by avoiding future exposure, and
- Prompt workplace evaluations and the protection of workers.

In the past, the Centers for Disease Control and Prevention (CDC) emphasized primary prevention, but also recommended screening blood lead levels (BLLs) in children to alert policymakers and others of potential lead contamination in communities.

Generally, sources of lead exposure were only identified and remediated after a child was identified with an elevated BLL, which is now a practice considered ineffective [ACCLPP 2012].

The strategy of identifying lead poisoning or elevated blood lead levels (BLLs) relied on detection in the child, relegating the child to the function of the proverbial 'canary in the coal mine' for

- Poor/contaminated housing,
- Contaminated water, and/or
- Tainted consumer products.

This strategy, which relies on identifying extant elevated BLLs, does not prevent the damage already incurred. Chelating agents can be used to treat overt lead poisoning, and possibly reduce the case fatality rate and other severe effects. However, chelating agents are not benign and can cause adverse health effects, especially when used by someone without expertise and experience treating lead poisoned patients. These agents have been demonstrated not to improve IQ or behavioral consequences of lead exposure [ACCLPP 2012]. Therefore, primary prevention is the most important and significant strategy [ACCLPP 2012].

The first step in evaluating a possibly lead-related health concern in a child is to take an environmental pediatric exposure history.

Screen all immigrant, refugee, and internationally-adopted children when they arrive in the United States,

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| | and for children <6 years old again 6 months after resettlement. |
| **Screening Questions** | The clinical setting allows little time for an extensive environmental pediatric exposure history. However, initial and subsequent well-child visits offer opportunities to provide parents and caregivers with educational materials on preventing exposures and actions to take if an exposure occurs. CDC [2012] recommends using screening questions.<br><br>Written checklists completed by parents may be used to facilitate obtaining an exposure history. Examples of these checklists are the National Environmental Education Foundation's [NEEF] Pediatric Environmental History (0-18 Years of Age). *The Screening Environmental History*, and *Additional Categories and Questions to Supplement The Screening Environmental History*, 2005. Also available in Spanish.<br><br>https://www.neefusa.org/resource/pediatric-environmental-history<br><br>*ATSDR Case Study in Environmental History: Taking a Pediatric Exposure History*<br><br>https://www.atsdr.cdc.gov/csem/csem.asp?csem=26&po=0<br><br>For a sick child whose illness might be environmentally related, the physician should consider an environmental agent as potentially related to the child's current illness, particularly when the illness does not follow a usual pattern or when more than one family member or a schoolmate is affected.<br><br>Physicians should take two environmental medicine actions for every well-child who presents to an office or a clinic.<br><br>1. A routine screening history for potential environmental exposures. |

2. Age-appropriate risk-based screening for lead poisoning, using the CDC's lead poisoning prevention guidelines [CDC 2012].

**Table 5. Screening Questions for Children's Lead Exposure History**
[modified from ATSDR 2013]

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| **Any Age - First Visit** | Where does your child live and spend most of his/her time?<br><br>• Home, day care, school, and,<br>• For working adolescents, the job setting may have unique environmental hazards.<br><br>What is the age and condition of your home?<br><br>• If the home was built prior to 1978, discuss risks of lead exposure from higher lead content paint.<br>• If parents are unsure of the age, they can test paint with an instant lead paint tester from a hardware store.<br><br>Are renovations planned or in progress?<br><br>• If a parent is planning renovation, advise how to avoid higher lead content paint exposure.<br>• If paint is old, peeling, or in poor repair, the parent should consider using a certified contractor.<br><br>Does anyone in the family smoke?<br><br>Is there exposure to second hand or third hand (residual tobacco) smoke (SHS & THS)?<br><br>What are the occupations and hobbies of adults in the household?<br><br>Is there an occupational exposure that could affect children's health?<br><br>Is there a chance of take-home contamination from work-related toxicants on |

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| | • Clothing,<br>• Hair,<br>• Skin, or<br>• Shoes?<br><br>Do you have concerns about environmental hazards in your home or in the surrounding neighborhood?<br><br>• Lead in drinking water (check source of drinking water).<br>• Lead in the ground or play areas.<br>• Exposure to hazardous waste sites.<br><br>Do you take herbal remedies or Ayurvedic (a system of health care native to the Indian subcontinent) medications? If so, which ones? Do you give any of these to your children?<br><br>Do you use skin creams that could contain paints, pigments, or heavy metals? Do you use any of these on your children? Some folk remedy creams or cosmetics may contain lead.<br><br>Other questions of interest:<br><br>• Condition of household pets.<br>• Past living conditions (international background is important).<br>• Siblings or playmates diagnosed with lead poisoning.<br>• Use of imported or glazed ceramics.<br><br>Assess the nutritional status, diet, and dietary behaviors of young children. |

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| **Well Baby Visits** | Are you breastfeeding?<br><br>• If no, are you using water to mix with the formula?<br>• If using water to mix with the formula, what water will you be using (tap water, bottled water, well water, etc.)?<br>• If tap water, is it from the municipal water system? What type of water service delivery and home plumbing pipes are used (galvanized, etc.)?<br><br>If well water, have you had it tested for the presence of contaminants, such as bacteria, lead, and nitrates? |
| **Well Toddler and Young School-age Child Visit** | Have there been any changes in your home surroundings or jobs?<br><br>Where does the child spend most of his/her time? |
| **Well Adolescent Visit** | Does the adolescent work?<br><br>If yes, what is the type of work?<br><br>Does the work expose the adolescent to toxic chemicals, fumes, or dust, or does it involve excessive musculoskeletal stress or work with slicing machines?<br><br>Is use of heavy or industrial machinery involved in the work?<br><br>Is the adolescent involved in hobbies that involve lead (leaded glass, fishing gear (weights), home reloading of shotgun cartridges)?<br><br>Does the adolescent consume illicit drugs or used them in the past? Examples: “huffing” (with intent to alter mood) of products that may contain or be contaminated with lead?<br><br>Alcohol use (ask about source and storage of alcohol).<br><br>Does the adolescent smoke or vape?<br><br>Is there exposure to second hand smoke (SHS)? |

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| **Sick Child Visit - Temporal Relationship** | In order to establish that lead exposure is the cause of an illness, it is necessary to ask if the exposure to the substance of concern occurred before the onset of the health condition.<br><br>Timing and duration of exposure can be important in determining whether a negative health effect may result. If the exposure is known, it is important to ask how long and how often the child was exposed to lead (daily, weekly, monthly, etc.). It is also important to ask about the amount or concentration (how much). |
| **Sick Child Visit - Are Others Affected?** | Others similarly affected can point to a possible lead exposure-related cause at home, at child care, at school, or the workplace. For public health reporting purposes, the appropriate authorities must be notified if an illness is found to be related to a lead environmental exposure. |
| **Sick Child Visit - Linking Exposure to Illness** | After completing the screening exposure history and asking more specific exposure-related questions, the physician should then answer these questions to determine whether the illness might be lead exposure-related.<br><br>• What is the child's specific health condition?<br>• Is lead known to cause this type of health problem?<br>• If so, what is the weight of scientific evidence linking that health condition to lead?<br>• Did any other exposures occur that might be related to the identified signs and symptoms?<br><br>If the answers to these questions, previous questions and the physical and laboratory findings point to a link between an illness and an exposure, the physician can consult with a specialist in pediatric environmental medicine as needed (see http://www.pehsu.net/). |
| **Key Points** | • Clinicians must be suspicious and think about the possibility of environmental and occupational factors of disease.<br>• Clinicians need to incorporate an exposure history questionnaire into clinical practice.<br>• The initial well-child visit presents an excellent opportunity to ask basic screening questions about |

common environmental hazards, including lead exposure.

- For a sick child, the physician should consider an environmental agent as potentially related to the child's current illness, particularly when the illness does not follow a usual pattern or when more than one family member or a schoolmate is affected.
- It is important to incorporate age-appropriate questions about lead hazards during other routine office visits.
- Screen all immigrant, refugee, and internationally-adopted children when they arrive in the United States, and for children <6 years old again 6 months after resettlement.
- Assess the nutritional status, diet, and dietary behaviors of young children.

**Progress Check**

17. Which of the following statement(s) about taking screening exposure histories for children is/are true?

    A. It is necessary to ask all the screening questions at every visit.
    B. The physician should perform age-appropriate risk-based screening for lead poisoning during an initial well-child visit.
    C. There is no need to ask age-specific screening questions because all children are exposed equally.
    D. All of the above.

    *To review relevant content, see "Introduction", "Screening Questions", "Sick Child Visit-Temporal Relationship", "Sick Child Visit-Are Others Affected?" and "Sick Child Visit-Linking Exposure to Illness" in this section.*

18. As part of the exposure history, you should explore

    A. Possible lead exposure at parent's work.
    B. Household members' hobbies that might involve lead.
    C. Household use of imported home remedies and cosmetics.

D. All of the above.

*To review relevant content, see "Introduction", "Screening Questions", "Sick Child Visit-Temporal Relationship", "Sick Child Visit-Are Others Affected?" and "Sick Child Visit-Linking Exposure to Illness" in this section.*

## Clinical Assessment - Signs and Symptoms

**Learning Objectives**

Upon completion of this section, you will be able to

- Name typical signs and symptoms consistent with lead toxicity,
- Describe how lead exposure dose and symptoms can vary, and
- Describe key features of the physical examination for patients exposed to lead.

**Introduction**

The patient assessment should include a review of systems for symptoms and signs as well as a complete physical examination of patients with potential exposure to lead, in addition to the environmental exposure history.

Primary health care providers can use the history, review of systems, and physical examination to establish a problem list. Then initial laboratory tests/imaging can be requested to systematically work through the differential diagnoses to come up with a diagnosis. This will be discussed in more detail in the next section.

Because children may have adverse health effects that may be subclinical or without overt clinical symptoms, as may occur with low blood lead levels, it is vital that primary care providers adopt a preventive approach to determine which of their patients may be at risk.

For the child with a history of a known lead exposure, with or without symptoms, concerned parents may visit their child's pediatrician or physician with worries that their child may become sick in the future. The parents

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| | may inquire about signs and symptoms associated with exposures. |
| **Continuum of Signs and Symptoms** | Typically, a sign is something the health care provider "sees" or "finds" during a physical exam. A symptom is experienced and reported by the patient.<br><br>A review of systems is an inventory of specific body systems performed by the health care provider during the process of taking a medical history from the patient. It is designed to bring out clinical symptoms the patient may have overlooked, forgotten, or may not have realized were important enough to mention to the physician, but may, in fact, be key toward making an accurate diagnosis.<br><br>Many patients who suffer from lead poisoning may be asymptomatic, hence the importance of exposure assessment and screening.<br><br>A *continuum of signs and symptoms* can be seen depending on level (amount), frequency, and duration of lead exposure. However, this is not a clear-cut picture of how the cases present, but a guide to understanding how the different levels of exposure reflect in the presentation. Keep in mind that categorizing the signs and symptoms by exposure dose from "lowest to high" is somewhat artificial — the signs and symptoms generally become more noticeable as BLLs increase, and no specific BLL numbers can be assigned to exposure levels in the continuum, as symptoms may vary by individual.<br><br>**Table 6. Continuum of Signs and Symptoms of Ongoing Lead Exposure** [ATSDR 2010] |

*Lowest Exposure Dose Signs and Symptoms: Impaired Cognitive Abilities/Subclinical Neuro/Psychoneuro/Neurobehavioral Findings* (patient may appear asymptomatic)

- Decreased learning and memory
- Decreased verbal ability
- Early signs of hyperactivity or ADHD
- Impaired speech and hearing functions
- Lowered IQ

*Low Exposure Dose Signs and Symptoms*

- Irritability
- Lethargy
- Mild fatigue
- Myalgia or paresthesia
- Occasional abdominal discomfort

*Moderate Exposure Dose Signs and Symptoms*

- Arthralgia
- Constipation
- Difficulty concentrating/Muscular exhaustibility
- Diffuse abdominal pain
- General fatigue
- Headache
- Tremor
- Vomiting
- Weight loss

*High Exposure Dose Signs and Symptoms*

- Colic (intermittent, severe abdominal cramps)
- Encephalopathy—may abruptly lead to seizure, change in consciousness, coma, and death
- Paresis or paralysis

In interpreting this table, it is important to remember that some of the hematological abnormalities of lead poisoning are similar to those of other diseases or conditions.

- For example, in the differential diagnosis of microcytic anemia, lead poisoning can usually be ruled out by obtaining a venous blood lead

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| | concentration; if the BLL is less than 25 micrograms per deciliter (µg/dL), the anemia usually reflects iron deficiency or hemoglobinopathy [Hegazy et al. 2010].<br>• Other examples are the two rare diseases, acute intermittent porphyria and coproporphyria, that result in hematological abnormalities similar to those of lead poisoning.<br><br>Children may appear to be asymptomatic at a low level lead exposure dose, but these levels may still impact the health of children and adults. With increasing exposure dose, the likelihood and severity of symptoms can be expected to increase.<br><br>• Because of differences in individual susceptibility, symptoms of lead exposure and their onset may vary.<br>• Impaired abilities may occur at BLLs ranging from 10 to 25 µg/dL and no threshold for these effects has been identified, whereas in symptomatic lead intoxication, BLLs generally range from 35 to 50 µg/dL in children and 40 to 60 µg/dL in adults [ATSDR 2010].<br>• Severe toxicity (high exposure dose) is frequently found in association with BLLs of 70 µg/dL or more in children and 100 µg/dL or more in adults.<br><br>The importance for the clinician is to recognize ongoing lead exposure, interrupt that exposure, and treat the patient as appropriate. Only through an increased suspicion of lead exposure as the etiology of many nonspecific signs, symptoms, and common health conditions, can a diagnosis be made early so that preventive actions can take place. |
| **Delayed or Misdiagnosis** | It is important to keep in mind, that even a complete physical examination may not identify subtle neurological effects that may be associated with low-level lead exposure in children.<br><br>The first signs of lead poisoning in children are often subtle neurobehavioral problems that adversely affect classroom behavior and social interaction. |

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| | Failing to identify signs and symptoms of lead toxicity has led to misguided medical treatments.<br><br>• Patients exhibiting neurological signs due to lead exposure may have been treated only for peripheral neuropathy or carpal tunnel syndrome, further delaying treatment for lead intoxication.<br>• Failure to correctly diagnose lead-induced gastrointestinal distress has led to inappropriate abdominal surgery.<br>• Current health effects (*e.g.,* neurological/developmental) resulting from past exposure, even without current exposure, may also need intervention (*e.g.* special education may be needed, finding and mitigating sources of exposure for the patient and others at risk for exposure may still be needed, etc.). |
| **Physical Examination** | The physical examination should include special attention to the following systems:<br><br>• Cardiovascular,<br>• Gastrointestinal,<br>• Hematological,<br>• Neurological, and<br>• Renal systems.<br><br>Health care providers should remember to<br><br>• Carefully evaluate the nervous system, including behavioral changes,<br>• Check blood pressure to evaluate whether the patient is hypertensive, and pay special attention to the renal system in those who are positive for hypertension, and<br>• Check for a purplish line on the gums (lead line). This is rarely seen today, but if present, usually indicates severe and prolonged lead poisoning. |

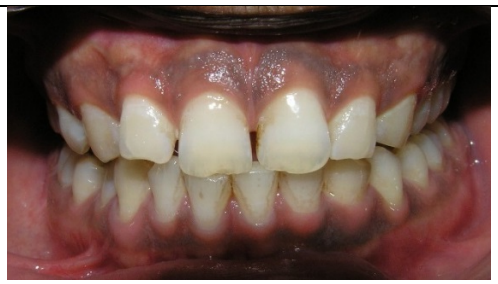

**Figure 4. Lead lines on gingiva** (Public domain)

With regard to children potentially exposed to lead, health care providers should be mindful that

- Hearing, speech, and other developmental milestones should be carefully evaluated and documented, and
- Nutritional status, diet, and dietary behaviors of young children should be assessed, since iron and calcium deficiencies are known to enhance the absorption of lead and to aggravate pica behavior.

**Establish a Problem List**

The problem list details the patient's most important medical information, which includes diagnoses, family history, and past tests and procedures. It will assist in the identification of an environmentally related condition. In other situations, the initial problem list may include only

- Signs,
- Symptoms, and
- Laboratory test results.

The physician who has experience with environmental toxicants may quickly suspect that a disease or syndrome (e.g. acute lead toxicity) is associated with a hazardous environmental exposure. The problem list should still be used, however, to keep the differential diagnosis broad in the beginning. Any and all specific exposures identified by the child's parents or caregiver(s) or suspected by a pediatrician should be listed.

**Key Points**

- Patients who suffer from lead poisoning may appear to be asymptomatic.

- Symptoms of lead toxicity and their onset may vary due to differences in individual susceptibility
- The first signs of lead poisoning in children are often subtle neurobehavioral problems that adversely affect classroom behavior and social interaction. Hearing, speech, and other developmental milestones should be carefully evaluated and documented.
- The physical examination alone will not always reveal when a patient is at risk for adverse health effects from elevated lead exposure
- A *continuum of signs and symptoms* can be seen depending on the level (amount), duration and frequency of lead exposure.
- Carefully evaluate the nervous system for subtle changes, including behavioral changes.
- Check blood pressure to evaluate whether the patient is hypertensive and pay special attention to the renal system in those who are hypertensive.
- Some of the health effects of lead exposure on the various organ systems are permanent and/or latent, and may appear after exposure has ceased.

**Progress Check**

19. Which of the following is not a typical sign or symptom of lead toxicity?

    A. Impaired speech and hearing functions.
    B. Decreased verbal ability.
    C. Respiratory distress.
    D. Decreased learning and memory.

    *To review relevant content, see "Continuum of Signs and Symptoms" in this section.*

20. Which of the following statements is true regarding the signs and symptoms of lead toxicity?

    A. Signs and symptoms will always be more noticeable with increasing BLLs.
    B. All children with low dose level exposure, will be asymptomatic.
    C. Categorizing the signs and symptoms by BLL from lowest to highest is very accurate.
    D. Symptoms of lead exposure and their onset may vary.

    *To review relevant content, see "Introduction" in this section.*

21. Which of the following statements regarding the physical examination and review of systems is true?

    A. Carefully evaluate the nervous system for subtle changes, including behavioral changes.
    B. Check blood pressure to evaluate whether the patient is hypertensive and pay special attention to the renal system in those who are hypertensive.
    C. Hearing, speech, and other developmental milestones must be carefully evaluated and documented.
    D. All of the above.

    *To review relevant content, see "Physical Examination" in this section*.

# Clinical Assessment – Diagnostic Tests and Imaging

**Learning Objectives**

Upon completion of this section, you will be able to

- Describe guidelines for blood lead screening and confirmatory diagnostic testing on patients at risk of recent or ongoing lead exposure, and
- Describe imaging and other clinical modalities that may assist in the diagnosis of current or past lead exposed patients.

**Introduction**

If lead exposure is suspected, a blood lead level (BLL) test should be performed.

Oftentimes, recognition of lead exposure doesn't occur until the initial reporting of high blood lead levels (BLLs) by primary care providers.

In 1991, CDC recommended universal blood lead level (BLL) testing for all children, in the absence of a statewide or local plan.

Over the past 40 years, there has been a dramatic decline in the United States in BLLs. Findings from the most recent National Health and Nutrition Examination Survey (NHANES), 2007 – 2010, indicate that BLLs are continuing to decrease across all age and racial/ethnic groups in the United States. Despite progress in reducing BLLs among children overall, differences between the geometric mean (GM) BLLs of different racial/ethnic and income groups still persist.

Based on the prevalence of elevated BLLs, local health departments or other relevant agencies may implement different testing guidelines, such as screening more frequently or at different ages.

The Advisory Committee On Childhood Lead Poisoning Prevention [ACCLPP 2012] recommends that health care providers:

- Follow local and state lead screening guidelines,
- Screen children coming from other countries when they arrive in the United States, and

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| | • Screen neonates and infants born to women with lead exposure during pregnancy and lactation per earlier CDC guidance.<br><br>Some communities may provide screening outside of the child's medical home (such as through the Women, Infants, and Children (WIC) program). It is not necessary for the clinician to duplicate those efforts, but he/she should verify that the screening was performed elsewhere before testing is deferred during the office visit.<br><br>Evidence continues to accrue that commonly encountered blood lead concentrations, even those below 5 µg/dL (50 ppb), impair cognition [AAP 2016]. There is no identified threshold or safe level of lead in blood [AAP 2016, ACCLPP 2012].<br><br>Over the past several decades there has been a remarkable reduction in environmental sources of lead, improved protection from occupational lead exposure, and an overall decreasing trend in the prevalence of elevated BLLs in U.S. adults. As a result, the U.S. national BLL geometric mean among adults was 1.2 µg/dL during 2009-2010 [CDC 2013i]. The OSHA lead standard allows blood lead levels higher than what is currently recommended by CDC/NIOSH. Therefore, some workers may continue to experience elevated blood lead levels. |
| **Blood Lead Screening for children** | A 2005 guidance statement from the American Academy of Pediatrics [AAP 2005] summarized the history of lead screening and suggested that pediatricians screen according to local and state guidelines where they apply. Additionally, pediatricians should screen:<br><br>• All non-Medicaid children in the absence of local and state guidelines, and<br>• All immigrant, refugee, and internationally-adopted children when they arrive in the United States (regardless of age), due to their increased risk, as they may have been exposed to lead in their country of origin. |

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| | In 2009 the Centers for Medicare and Medicaid Services (CMS) and the CDC recommended that local officials have the flexibility to develop lead screening strategies that reflect local risk for high blood lead levels. In 2013 CMS published guidelines for states interested in transitioning to targeted blood lead screening for Medicare/Medicaid eligible children.<br><br>In addition to a national surveillance program, clinical testing for lead exposure must continue for the foreseeable future in order to identify those children for whom primary prevention measures have failed [ACCLPP 2012].<br><br>• BLL testing is currently required at 12 and 24 months for all Medicaid-enrolled children, unless the state has a Centers for Disease Control and Prevention and the Centers for Medicare and Medicaid Services (CDC/CMS) waiver indicating that children enrolled in Medicaid are not at higher risk for high BLLs than other children.<br>• Testing will often occur during routine well-child care as recommended by the American Academy of Family Physicians (AAFP) and the American Academy of Pediatricians (AAP).<br>• Children ≤72 months that missed recommended screening at a younger age should be screened at presentation.<br>• Screening at 12 and 24 months satisfies the Healthcare Effectiveness Data and Information Set (HEDIS) measures.<br><br>The CDC [2010] also recommends initial and follow-up screening of pregnant and lactating women, as well as for neonates and infants of women with BLLs ≥5 micrograms per deciliter (µg/dL). |
| **Blood Lead Levels (BLLs)** | Different tests have been used in the past to evaluate lead exposure and/or to gauge the effects of lead exposure.<br><br>• Venous BLL testing is the most useful screening and diagnostic test for recent or ongoing lead exposure [ACCLPP 2012], and requires a phlebotomist trained in the specific methods and |

techniques involved with proper collection and processing of a specimen for blood lead level testing (to avoid lead contamination of the puncture site or the sample).

- Direct measurement of lead in capillary blood samples are easier to collect, but have a high potential for lead contamination [CDC 1997a]. For this reason, this method is not recommended unless the collection method used, close attention to hand washing, and other strategies to reduce lead contamination are strictly followed. Confirmatory testing using a venous blood lead sample for all capillary and venous BLL results greater than or equal to the reference value should be performed [ACCLPP 2012].
- BLLs respond relatively rapidly to abrupt or intermittent changes in lead intake (for example, ingestion of higher lead content paint chips by children) and, for relatively short exposure periods, bear a linear relationship to those intake levels.
- For individuals with high or chronic past exposure, however, BLLs often under-represent the total body burden because most lead is stored in the bone. Individuals can therefore have high body burden of lead with “normal” levels in the blood.
- One exception is patients with a high body burden under physiological stressful circumstances whose BLLs may be elevated from the release of lead stored in bones.
- Erythrocyte protoporphyrin (EP), commonly assayed as zinc protoporphyrin (ZPP), was previously considered the best test for screening asymptomatic children for lead exposure. However, it is not sufficiently sensitive at lower BLLs and therefore not as useful for screening as previously believed.
- Hemoglobin (Hgb) screening was recommended in the past; however, if performed alone it is only sufficient to diagnose anemia (by definition), and does not specifically rule out iron deficiency

BLLs are continuing to decrease across all age and racial/ethnic groups in the United States.

- The average BLL for children 1-5 years of age was 1.9 µg/dL in 2002, down from 15.0 µg/dL in 1976-1980 (before leaded gasoline was banned for use in “on road” vehicles) [CDC 2005].
- The average BLL for adults 18-74 years of age was 14.2 µg/dL from 1976-80; in 1988-1991, the average BLL for adults was 3.0 µg/dL [CDC 1997b]; and the BLL geometric mean among adults was 1.2 µg/dL during 2009-2010 [CDC 2014].
- The difference between the geometric mean (GM) BLL of non-Hispanic black children (1.8 µg/dL) remains significant ($p<0.01$) compared with either non-Hispanic white (1.3 µg/dL) or Mexican American (1.3 µg/dL) children [CDC 2013h].
- Children belonging to families with a poverty income ratio (PIR) <1.3 have a significant GM BLL difference (1.6 µg/dL versus 1.2 µg/dL [$p<0.01$]), compared to families with a PIR ≥1.3. This also applies to those enrolled in Medicaid [CDC 2013h].

Current research continues to find that BLLs previously considered harmless can have harmful effects in adults, such as decreased renal function and increased risk for hypertension and essential tremor at BLLs <10 µg/dL.

In 2015, NIOSH designated 5 µg/dL (five micrograms per deciliter) of whole blood, in a venous blood sample, as the reference blood lead level for adults [CDC 2013h]. An elevated BLL is defined as a BLL ≥5 µg/dL. This case definition is used by the CDC's Adult Blood Lead Epidemiology and Surveillance program (ABLES tracks elevated BLLs among adults in the United States), the Council of State and Territorial Epidemiologists (CSTE), and CDC’s National Notifiable Diseases Surveillance System (NNDSS). Previously (i.e., from 2009 until November 2015), the case definition for an elevated BLL was a BLL ≥10 µg/dL. The U.S. Department of Health and Human Services recommends that BLLs among all adults be reduced to <10 µg/dL.

| | |
|---|---|
| | During 2002-2011, ABLES identified 11,536 adults with very high BLLs (≥40 µg/dL). A very high BLL measured in >1 calendar year was defined as a persistent very high BLL. Among these adults, 2,210 (19%) had persistent very high BLLs, 1,487 (13%) had BLLs ≥60 µg/dL, and 96 had BLLs ≥60 µg/dL in >1 calendar year. Occupational exposures accounted for 7,076 adults with very high BLLs (91% of adults with known exposure source) and 1,496 adults with persistent very high BLLs [CDC 2013h].<br><br>In contrast to the CDC reference level, prevailing Occupational Safety and Health Administration (OSHA) lead standards allow workers removed from lead exposure to return to lead work when their BLL falls below 40 µg/dL. However, NIOSH recommends that the most current guidelines for management of lead exposed adults be implemented by the medical community at the current CDC/NIOSH reference BLL of 5 µg/dL [CDC 2013h].<br><br>The finding that many workers may have harmful BLLs, some that are present for >1 calendar year, is of grave concern. Adverse health effects associated with very high BLLs underscore the need for increased efforts to prevent lead exposure at workplaces and in communities [CDC 2013i]. An attempt should be made to identify and minimize lead exposures when BLLs indicate that they are occurring at any blood lead level above background population levels.<br><br>If an adult has a BLL of 20 µg/dL, e.g., an unusual exposure is likely occurring and should be interrupted, if possible. This is especially important for fertile and pregnant females. |
| **Confirmatory Testing of Children with BLLs Above the Reference Value** | Given the uncertainty of individual blood lead test results, it is important to do confirmatory testing, especially for capillary blood samples that might be elevated due to residual lead on the skin at the puncture site. Collection tubes need to be confirmed “lead free”. The recommended schedule for confirmatory testing is summarized in Table 7 and includes |

- All capillary and venous BLL results greater than or equal to the reference value must be confirmed within 1-3 months, and
- Children with BLLs ≥45 µg/dL or with symptoms of lead poisoning should have an immediate (within 48 hours) confirmatory test.

**Table 7. Recommended Schedule for Obtaining a Confirmatory Venous Sample**

| Blood Lead µg/dL | Time to Confirmation Testing |
|---|---|
| ≤ Reference value of 5* | 1-3 months |
| 6-44** | 1 week–1 month |
| 45-59 | 48 hours |
| 60-69 | 24 hours |
| ≥70 | Urgently as emergency test |

* ACCLPP 2012
** The higher the BLL on the screening test, the more urgent the need for confirmatory testing.

Adapted and updated from: *Screening Young Children for Lead Poisoning: Guidance for State and Local Public Health Officials* [CDC 1997a].

Response actions should be initiated only after elevated BLLs are confirmed.

**Imaging and Other Clinical Modalities**

There are different clinical modalities available to further evaluate patients with elevated BLLs.

- Complete blood count (CBC) may be useful for patients with extensive lead exposure. In lead-exposed patients, the hematocrit and hemoglobin values may be slightly to moderately low in the CBC, and the peripheral smear may be either normochromic and normocytic or hypochromic and microcytic.

- There may be **basophilic stippling** in patients who have been significantly poisoned for a prolonged period.
- However, because these results are not specific to lead exposure, the CBC test is not as valuable for detecting lead exposure as the BLL and EP assays.

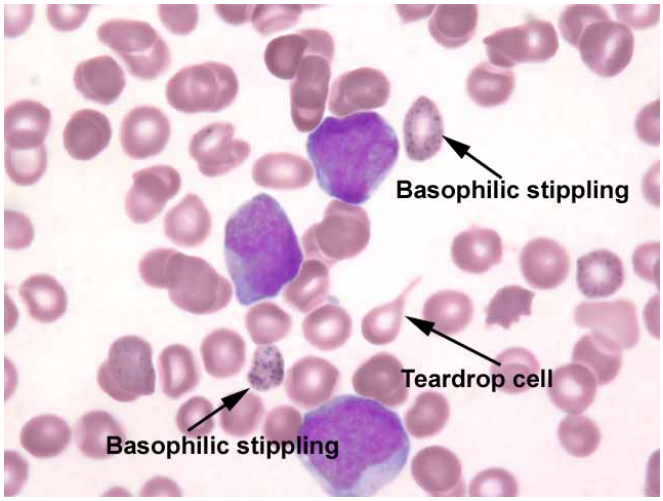
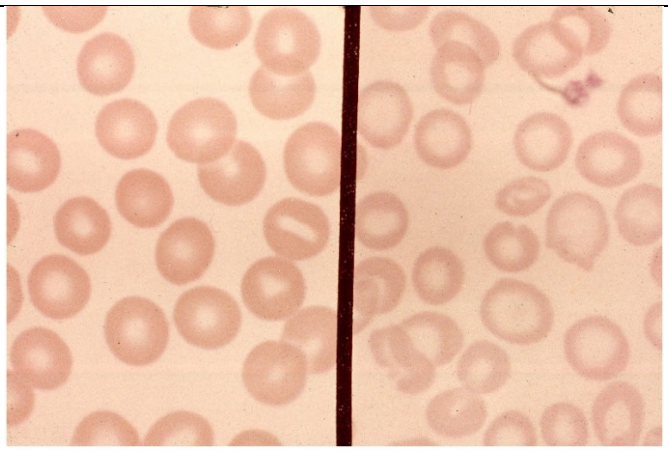



**Figure 5. Basophilic stippling** -Venous blood smear with basophilic stippling (Provided courtesy of ©Wadsworth Center, New York State Department of Health)

- A hypochromic, microcytic anemia should be appropriately differentiated from other causes, especially iron-deficiency anemia by the use of testing for iron, iron binding capacity, and ferritin.



Normal red blood cells Microcytic anemia

**Figure 6. Microcytic hypochromic anemia can be associated with lead poisoning** (Public domain)

- Abdominal radiographs may show the presence of radiodense lead foreign bodies in the gastrointestinal tract. These are helpful in cases of acute ingestion (e.g., of lead sinkers, curtain weights, jewelry, or paint chips) or unusual persistence of high blood lead values. Shrapnel or bullet fragments within tissues can also be observed.
- Long bone radiographs can show “lead lines”. These are lines of increased density on the metaphysis (growth plate) of the bone, showing radiological growth retardation. This is not a routine procedure to identify lead poisoning, but a radiological finding of chronic exposure. See Figure 6 and Figure 7.
- Long bone radiographs are not recommended for diagnosing lead exposure [CDC 2002], however, they are useful to determine growth retardation.
- Because hair and fingernails are subject to external environmental contamination, assaying their lead content is an uncertain estimate of body burden and is not recommended [AAP 1993; CDC 2002].
- Second tier tests (such as neurobehavioral/psychological evaluation for children with indicative findings on exam) should be considered, as appropriate.

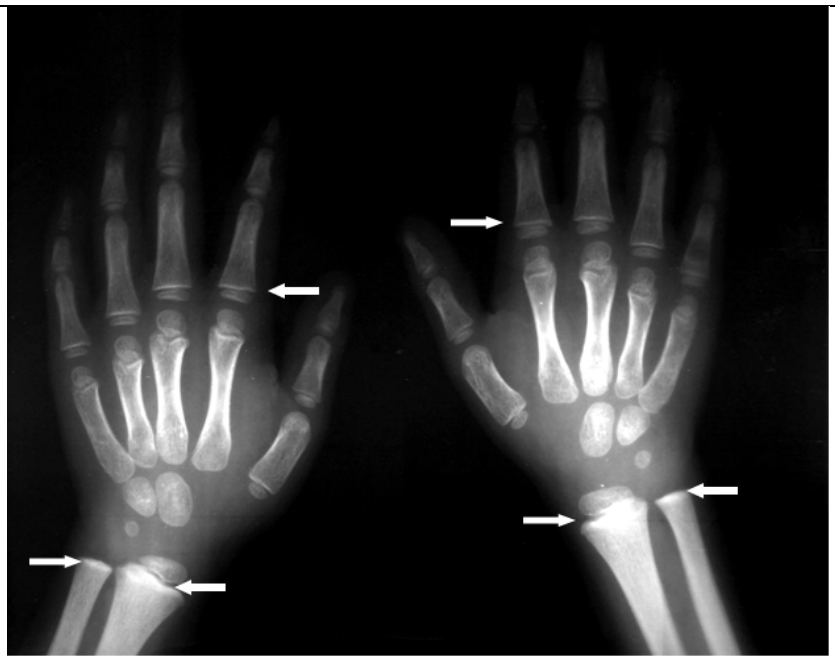


**Figure 7**. **Long Bone Radiograph of Hands** — "lead lines" shown as increased density on the metaphysis (growth plate) of the proximal segments of phalanges and distal segments of ulna and radius in a 5-year-old male with radiological growth retardation and BLL of 37.7 µg/dL (Photo courtesy of Dr. Celsa López, Clinical Epidemiologic Research Unit, IMSS, Torreón, México).

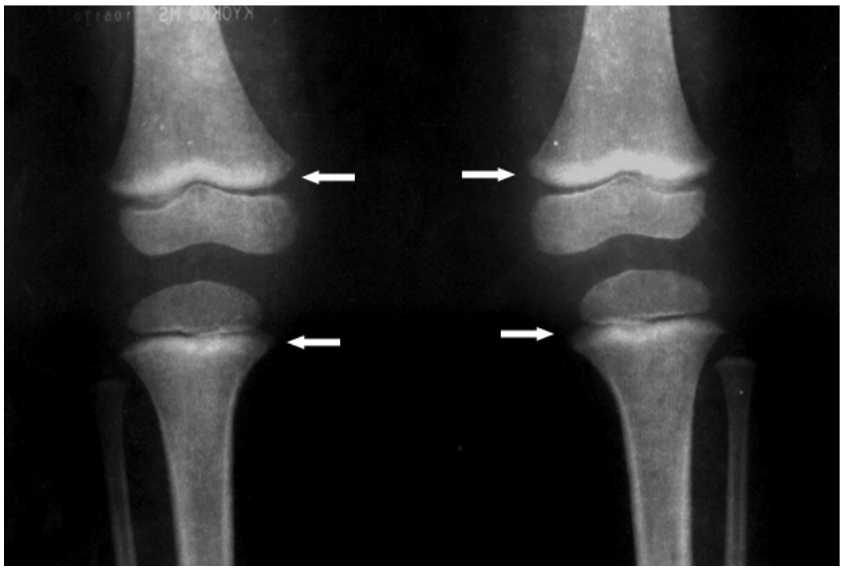


**Figure 8**. **Long Bone Radiograph of Knees** - "lead lines" in three-year old girl with BLL of 0.6 µg/dL. Notice the increased density on the metaphysis growth plate of

| | |
|---|---|
| | the knee, especially in the femur (Photo courtesy of Dr. Celsa López, Clinical Epidemiologic Research Unit, IMSS, Torreón, México). |
| **Key Points** | • The best screening and confirmatory diagnostic tool for evaluating recent or ongoing lead exposure is the venous BLL test.<br>• Pediatricians should screen for lead in all non-Medicaid children in the absence of local and state guidelines.<br>• All immigrant, refugee, and internationally-adopted children should be screened for lead when they arrive in the United States.<br>• Pregnant and lactating women should be screened for lead.<br>• The CDC (2012) has updated the blood lead reference value to 5 µg/dL.<br>• Using an EP or ZPP assay to screen children for lead exposure is not as useful as once believed, and not recommended.<br>• Other tests may be appropriate for specific situations, such as abdominal radiographs to detect swallowed objects.<br>• Secondary testing/imaging for signs of other health effects may also be useful. |

**Progress Check**

22. What is the best screening and confirmatory diagnostic tool for evaluating recent or ongoing lead exposure in a child?

    A. EP/ZPP.
    B. Capillary BLL (finger stick).
    C. Venous BLL.
    D. Abdominal radiograph.

    *To review relevant content, see "Blood Lead Levels" in this section.*

23. In addition to screening according to local and state guidelines where they apply, pediatricians/primary health care providers should also screen which of the following populations?

    A. All non-Medicaid children in the absence of local and state guidelines.
    B. All immigrant, refugee, and internationally-adopted children when they arrive in the United States.
    C. Pregnant and lactating women.
    D. All of the above.

    *To review relevant content, see "Blood Lead Screening" in this section.*

24. What imaging and other clinical modalities may assist in the diagnosis of current or past lead exposed patients?

    A. Abdominal radiographs.
    B. Long bone radiographs.
    C. Hair assay.
    D. All of the above.
    E. None of the above.

    *To review relevant content, see "Imaging and Other Clinical Modalities" in this section.*

# How Should Patients Exposed to Lead Be Treated and Managed?

**Learning Objectives**

Upon completion of this section, you will be able to

- Describe a management strategy for children whose blood lead levels are equal to or greater-than the current CDC reference value of 5µg/dL.

**Introduction**

"Preconception and prenatal counseling sessions present opportunities to prevent lead exposures that could lead to possibly devastating and lifelong effects."

Office of Surgeon General 2008

With the move away from a designated "level of concern," a new algorithm is needed to provide clinicians with guidance on responding appropriately to the lower range of BLLs. No blood lead threshold for adverse health effects has been identified in children.

Treatment and management strategies for children whose blood levels are equal to or greater than the reference value include nutritional education and intervention (as indicated), lead educational intervention, ongoing monitoring, and coordination with other organizations.

Chelation therapy is considered a mainstay in the medical management of children with BLLs > 45 µg/dL, but should be used with caution. Consultation with a physician with expertise and experience in treating children with lead toxicity is recommended.

Therefore, prior to suggesting or prescribing chelation agents, it would be prudent to consult with a

- Local or state lead poisoning prevention program, a
- Local poison control center, and/or a
- Regional Pediatric Environmental Health Specialty Unit (PEHSU).

**Evaluation and Intervention Strategies for Children with BLLs at or Above the Reference Value**

When the neurological exam, milestones, or behavior suggest it, further neurobehavioral testing or evaluation for Attention Deficit Hyperactivity Disorder (ADHD) may be indicated.

Table 8 shows ACCLPP Recommended Actions Based on BLLs. It is important to mention the increased urgency of these interventions as BLLs increase to reduce the damage to the persons exposed, especially children.

A BLL of ≥45 µg/dL is not a threshold for chelation, but a guideline. Professional judgment should guide the decision to chelate a child or adult, based on their individual clinical considerations. In some instances, a patient may need to be chelated at somewhat lower BLLs.

**Table 8: ACCLPP Recommended Actions Based on BLL** [ACCLPP 2012]

| **<Reference Value** | **≥Reference Value of 5-≤45 µg/dL** | **≥45 - ≤69 µg/dL** |
|---|---|---|
| Lead education<br><br>-Dietary<br><br>-Environmental<br><br>Environmental assessment* for pre-1978 housing | Lead education<br><br>-Dietary<br><br>-Environmental<br><br>Follow-up blood lead monitoring<br><br>Complete history and physical exam<br><br>Lab work:<br>- Iron status<br><br>Consider Hemoglobin or hematocrit | Lead education<br><br>-Dietary<br><br>-Environmental<br><br>Follow-up blood lead monitoring<br><br>Complete history and physical exam<br><br>Lab work:<br>- Iron status<br><br>- Free erythrocyte protoporphyrin<br><br>Environmental investigation |

| | | | |
|---|---|---|---|
| | Environmental investigation<br><br>Lead hazard reduction<br><br>Neurodevelopmen-tal monitoring<br><br>- Abdominal X-ray (if particulate lead ingestion is suspected) with bowel decontamination if indicated | Lead hazard reduction<br><br>Neurodevelopmental monitoring<br><br>Abdominal X-ray with bowel decontamination if indicated<br><br>Oral chelation therapy<br><br>Consider hospitalization if lead-safe environment cannot be assured | actions fo<br>µg/dL |

*The scope of an "environmental assessment" will vary based on local resources and site conditions. However, at a minimum this would include a visual assessment of paint and housing conditions, but may also include testing of paint, soil, dust, and water and other lead sources [Levin et al. 2008]. This may also include looking for exposure from imported cosmetics, folk remedies, pottery, food, toys, etc. which may be more important in low-level lead exposure [ACCLPP 2012].

Coordination of care with local authorities and organizations, including local Childhood Lead Poisoning Prevention programs, is essential to

- Initiate prompt investigation for the source of lead exposure, and
- Plan a response strategy.

Although these services are typically outside of the clinician's role, medical and environmental interventions

should be implemented simultaneously to best protect the child.

In addition, families with children whose BLLs are above the reference value should be given access to services that provide education about:

- Existing codes or ordinances,
- Lead-safe housing rules,
- Disclosure requirements,
- Landlord responsibilities,
- Risk factors for lead exposure in the home and at work, and
- Steps for maintaining a lead safe home (lead hazard identification and repair, lead dust testing, EPA and state Renovation, Repair and Painting (RRP) requirements, and do-it-yourself precautions).

Home visits by CLPPP staff, community health workers, Maternal and Child Health home visiting programs, and other systems to assess the home should:

- Advise occupants of lead hazards,
- Make referrals in response to identified lead hazards, and
- Report observations and lead test results.

Assistance and guidance is available regarding:

- Housing codes, including legal services for egregious situations like evictions and serial offender property owners and referrals to code enforcement,
- Landlord violations of RRP, and
- Other lead rules.

*"Low health literacy is a threat to the health and wellbeing of Americans. And low health literacy crosses all sectors of our society. All ages, races, incomes, and education levels are challenged by low health literacy."*

Rear Admiral Kenneth P. Moritsugu, MD, MPH
Acting United States Surgeon General, December 2006

Health Literacy is the capacity to obtain, process and understand basic health information and services needed to make appropriate health decisions.

Approximately one-half of the adult population may lack the needed health literacy skills to best utilize the U.S. healthcare system. Low health literacy has been linked to poor health outcomes such as higher rates of hospitalization and less frequent use of preventive services [CDC 2013f].

CDC Healthy Homes and Lead Poisoning Prevention Program addresses health literacy. It created several resources to help communicate about childhood lead poisoning.
https://www.cdc.gov/nceh/lead/tools/LeadLiteracy.htm

**Recommendations on Medical Management of Childhood Lead Exposure and Poisoning**

No level of lead in the blood is safe. In 2012, the CDC established a new "reference range upper value" for BLLs (5 µg/dL), thereby lowering the level at which evaluation and intervention are recommended.

Effective screening policies and practices should ensure that the children of high-risk families (e.g., families on Medicaid) are screened, and that lead-exposed children or children with elevated BLLs receive key environmental interventions and case management services [ACCLPP 2012].

**Table 9. Clinical Recommendations Based on Blood Lead Levels (BLLs)** [PEHSU 2013]

| Blood Lead Level | Recommendation |
|---|---|
| <5 µg/dL | 1. Review lab results with family. For reference, the geometric mean BLL for children 1-5 years old is less than 2 µg/dL. |

| | | |
|---|---|---|
| | | 2. Repeat the BLL test in 6-12 months if the child is at high risk or risk changes during the timeframe. Ensure levels are done at 1 and 2 years of age.<br>3. For children screened at age <12 months, consider retesting in 3-6 months, as lead exposure may increase as mobility increases.<br>4. Perform routine health maintenance, including assessment of nutrition, physical and mental development, and iron deficiency risk factors.<br>5. Provide anticipatory guidance on common sources of environmental lead exposure: paint in homes built prior to 1978, soil near roadways or other sources of lead, take-home exposures related to adult occupations, imported products such as spices, cosmetics, home remedies, and cookware. |
| | 5-14 µg/dL | 1. Perform steps as described above for levels <5 µg/dL.<br>2. Re-test venous BLL within 1 month to ensure the lead level is not rising. If it is stable or decreasing, retest the BLL in 3 months. Refer patient to local health authorities if such resources are available. Most states require elevated BLLs be reported to the state health department. Contact the CDC at 800-CDC-INFO (800-232-4636) or the National Lead Information Center at 800-424-LEAD (800-424-5323) for resources regarding lead poisoning prevention and local childhood lead poisoning prevention programs.<br>3. Take a careful environmental history to identify potential sources of exposures (see #5 above) and provide preliminary advice about reducing/eliminating exposures. Take care to consider other children who may be exposed. |

| | | |
|---|---|---|
| | | 4. Provide nutritional counseling related to calcium and iron. In addition, recommend the child eat a fruit or vegetable high in vitamin C (e.g., citrus fruits and leafy greens) at every meal, as iron absorption quadruples when taken with vitamin C-containing foods. Encourage the consumption of iron-enriched foods (e.g., cereals, meats). Some children may be eligible for Special Supplemental Nutrition Program for Women, Infants and Child (WIC) or other nutritional counseling.<br>5. Ensure iron sufficiency with adequate laboratory testing (CBC, Ferritin, CRP) and treatment per AAP guidelines. Consider starting a multivitamin with iron.<br>6. Perform structured developmental screening evaluations at child health maintenance visits, as the effect of lead on development may manifest over years. |
| | 15-44 µg/dL | 1. Perform steps as described above for levels 5-14 µg/dL.<br>2. Confirm the BLL with repeat venous sample within 1 to 4 weeks.<br>3. Additional, specific evaluations of the child, such as an abdominal x-ray should be considered based on the environmental investigation and history (e.g., pica for paint chips, mouthing behaviors). Gut decontamination may be considered if leaded foreign bodies are visualized on x-ray. Any treatment for BLLs in this range should be done in consultation with an expert. Contact local PEHSU or PCC for guidance; see “Sources of Additional Information” section for contact information. |

| | | |
|---|---|---|
| | >44 µg/dL | 1. Follow guidance for BLL 15-44 µg/dL as listed above.<br>2. Confirm the BLL with repeat venous sample within 48 hours.<br>3. Consider hospitalization and/or chelation therapy (managed with the assistance of an experienced provider). Safety of the home with respect to lead hazards, isolation of the lead source, family social situation, and chronicity of the exposure are factors that may influence management. Contact your regional PEHSU or PCC for assistance. |

Given the challenges involved in measuring BLLs as low as 5 µg/dL, quality assurance practices will need to be updated with the goal of improving accuracy and repeatability of BLL testing results.

**Management of Children with BLLs Above 45 µg/dL**

Chelation therapy is considered a mainstay in the medical management of children with BLLs > 45 µg/dL. However, this level is a guideline, not a threshold for hospitalization and/or chelation, and should be used with caution. Professional judgment should drive determinations of when to chelate. In some instances, a patient may need to be chelated at somewhat lower BLLs. Therefore, prior to suggesting or prescribing chelation agents, primary care providers should consult with their local or state lead poisoning prevention program, local poison control center, or regional Pediatric Environmental Health Specialty Unit (PEHSU) for the names of accessible physicians that have both expertise and experience with chelation for lead toxicity.

A child with an elevated BLL and signs or symptoms consistent with encephalopathy should be chelated in a center capable of providing appropriate intensive care services [ACCLPP 2012].

Physicians who suspect an unusual environmental cause for an illness will often find it useful to contact an expert in pediatric environmental medicine.

- The Pediatric Environmental Health Specialty Units (PEHSU), located in the ten Federal Regions of the United States and in Canada, can provide information, assistance, and referral for clinical evaluation and treatment if environmental exposures are verified (for additional information regarding the PEHSU, visit: http://www.pehsu.net/
- Regional poison control contact information is available at: http://npic.orst.edu/health/poison.htm.
- CDC's Lead Poisoning Branch is an information resource available to clinicians at: https://www.cdc.gov/nceh/lead/about/program.htm

Because there are potential side effects associated with each chelating drug, and because treatment protocols differ for each, it is vital that physicians with experience in chelation therapy be consulted before any chelation therapy is begun [AAP 1995].

An accredited regional poison control center, a university medical center, or a state or local health department can help identify an experienced physician.

Note also that the $CaNa_2EDTA$ (i.e., edetate calcium disodium, Calcium EDTA) mobilization (challenge) test is no longer recommended because of its difficulty, expense, and potential for increasing lead toxicity [ACMT 2013; AAP 1995].

The utility of provoked urine tests for the diagnosis of metal poisoning has been addressed previously by the American College of Medical Toxicology [ACMT 2010]. It published a position statement recommending against the use of this test. Similarly, authors from the ATSDR and CDC have detailed the problems with provoked urine tests and have concluded that they should not be used as diagnostic tools [Risher and Amler 2005]. Yet despite these recommendations against the use of provoked

urine testing by respected organizations, the test is still commonly used and recommended by some practitioners [Ruha 2014].

**Potential Medical Error**

There are several commercial drugs with the active ingredient EDTA. Only $CaNa_2EDTA$ (also known as calcium disodium versenate or edetate calcium disodium) is appropriate for chelation. **$Na_2EDTA$** (disodium ethylenediaminetetraacetic acid) **is not appropriate for chelation.**

Please write your script carefully and legibly to avoid mistakes with chelating agents.

**Ongoing Monitoring For Lead-Exposed Children**

For the child identified with BLL results greater than or equal to the reference value, ongoing monitoring of BLL is indicated during and after appropriate medical, educational, and environmental interventions (See Table 9).

BLLs that increase may be indicative of

- An unrecognized source of exposure,
- Inappropriate abatement activities,
- Failure to mitigate the identified hazard, or
- The redistribution of lead stores within the child's body.

For the child with an increasing BLL, additional medical and environmental evaluation and interventions may be necessary, along with ongoing coordination of care with the local Childhood Lead Poisoning Prevention Program (CLPPP).

This monitoring is essential to identify a given source of lead, help determine if there is any ongoing exposure, and to verify the decline in BLL after lead sources have been reduced or eliminated. Ongoing monitoring is also essential for children undergoing chelation [AAP 1995, CDC 2002].

**Table 10. Ongoing Monitoring for Lead-Exposed Children[a]**

| **Venous BLL µg/dL** | **Early Follow-up Testing** (2-4 Tests after Identification) | **Later Follow-up Testing After BLL Decline** (5 µg/dL) |
|---|---|---|
| ≥Reference value 5-9 | 3 months* | 6-9 months |
| 10-19 | 1-3 months* | 3-6 months |
| 20-24 | 1-3 months* | 1-3 months |
| 25-44 | 2 weeks-1 month | 1 month |
| ≥45 | As soon as possible | As soon as possible |

[a]Seasonal variation of BLLs exist and may be more apparent in colder climate areas. Greater exposure in the summer months may necessitate more frequent follow-up.

*Some case managers or PCPs may choose to repeat blood lead tests on all new patients within one month to ensure that their BLL is not increasing more quickly than anticipated [ACCLPP 2012].

**Key Points**

- Management strategies for children whose BLLs are equal to or greater than the reference value include ongoing monitoring during and after appropriate medical, nutritional, educational, and environmental interventions, and coordination with other organizations.
- BLLs that increase may indicate an unrecognized source of exposure, inappropriate abatement activities, failure to mitigate the identified hazard, or the redistribution of lead stores within the child's body.
- Consultation and/or referral to a health care provider with expertise and experience in treating and managing patients with lead toxicity is highly recommended, especially for children with BLLs ≥

45 µg/dL or other appropriate individual children at somewhat lower BLLs.

- Chelation challenge to detect or monitor for lead toxicity is not recommended and may be harmful to the patient.
- Chelation is not risk free. The possible complications need to be considered and weighed against with the possible benefits.

**Progress Check**

25. Treatment and management strategies for children whose BLLs are equal to or greater than the CDC reference value include which of the following?

    A. Nutritional education and intervention.
    B. Educational intervention and ongoing monitoring.
    C. Coordination with other organizations.
    D. Chelation.
    E. All of the above.

    *To review relevant content, see "Evaluation and Intervention Strategies for Children with BLLs Above the Reference Value" in this section.*

26. When is ongoing monitoring of BLLs indicated?

    A. When a child is identified with BLL results greater than or equal to the CDC reference value (≥5 µg/dl).
    B. When a child has a venous BLL <5 µg/dl.
    C. When any child presents with hypertension and neurological symptoms.
    D. When there is more than one child living in a pre-1978 home.

    *To review relevant content, see "Ongoing Monitoring For Lead-Exposed Children" in this section.*

27. BLLs that increase may indicate which of the following?

    A. An unrecognized source of exposure.

B. Inappropriate abatement activities and failure to mitigate the identified hazard.
C. The redistribution of lead stores within the child's body post-chelation.
D. All of the above.

*To review relevant content, see "Ongoing Monitoring For Lead-Exposed Children" in this section.*

## What Instructions Should Be Given to Patients?

**Learning Objectives**

Upon completion of this section, you will be able to

- Describe instructions to parents and patients to prevent or reduce lead exposure,
- Describe instructions for patients exposed to lead, and
- Describe communication strategies that health care providers can use to best deliver clinical information to their lead exposed or potentially exposed patients.

**Introduction**

"Clinicians should be a consistent and reliable source of information, and take a primary role in educating families about the risks of lead-exposure. If appropriately educated, all families will be better equipped to make sound housing decisions based on an understanding of the risks associated with lead hazards" [ACCLPP 2012].

The primary instruction to patients and parents of children exposed to lead should be to eliminate or control sources of all lead exposure. These recommendations will depend on lead exposure source type and setting (e.g., home or workplace).

Guidance for parents should cover a number of lead risk topics, including

- In-home exposures,
- Potential lead-exposures associated with parental occupations and hobbies, and

- Unsafe renovation practices.

This section focuses on instructions the health care provider can give to parents and patients regarding steps they can take to prevent, reduce, or mitigate lead exposure from the home, workplace, and environment.

Also discussed are risk communication and education strategies that health care providers can use to best explain lab results, deliver instructions on clinical follow-up, and impart preventive messages to their lead exposed or potentially exposed patients.

| | |
|---|---|
| **Communication with Parents and At Risk Populations** | Parents should be provided with information on identifying lead hazards and safe/reliable methods to minimize exposures, as well as contact information for additional local lead-related resources. This information should be provided in appropriate cultural formats and reading level for the target audience.<br><br>In addition, the clinician has a role in recognizing risks for potential lead exposures specific to<br><br>• Immigrant communities,<br>• Refugees, and<br>• Children adopted from foreign countries,<br><br>whose previous and/or ongoing lead exposure may include<br><br>• Ceramic ware,<br>• Cosmetics,<br>• Folk /home remedies,<br>• Food,<br>• Medications,<br>• Toys, and<br>• Other less common items (like automobile batteries).<br><br>The health care provider should ensure there is time available to carefully listen to expressed concerns and questions and provide empathetic responses with voiced understanding by the parent or patient. Information may need to be repeated. This is especially important during high risk/emotionally charged situations when the ability to receive and process information may be decreased. |
| **Blood Lead Level Risk Communication and Education Strategies** | Effective screening policies and practices should ensure that the children of high-risk families (e.g., families on Medicaid) are screened, and that lead-exposed children or children with elevated BLLs receive key environmental interventions and case management services [ACCLPP 2012].<br><br>• Interactions with affected families must be performed in a culturally-sensitive, same-language, |

| | |
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| | and streamlined manner (see Lead Health Literacy Initiative at: https://www.cdc.gov/nceh/lead/tools/LeadLiteracy.html.<br>• The medical home, laboratory, and other providers should offer simple information about the meaning of elevated BLL test results, and relevant, culturally-sensitive messages about their impact should be conveyed.<br>• Specialized terms such as “detectable level” or “elevated BLL” should be defined.<br>• Pediatricians and other providers shall integrate BLL test results into the “basic” report of indicators like weight, height, and developmental percentiles.<br>• Pediatricians commonly present data in the form of percentiles, and a similar convention could help physicians explain elevated BLLs to parents (see [CDC 2011b] for patient handouts).<br>• Test results should not be difficult to obtain; parents should have continuous access to BLL test results via internet and telephone retrieval systems until the child reaches the age of twelve.<br>• Physicians should explain the uncertainty of all quantitative medical tests and BLL testing. |
| **Communicating Instructions to Prevent, Lower, or Mitigate Domestic Lead Exposure** | For children (and adults) with domestic exposures, there may be multiple sources. Therefore, it is important to identify and encourage patients and parents to address all potential sources of lead and to continue blood lead monitoring to help confirm that the source(s) has(have) been effectively eliminated.<br><br>It would be important to explain to parents and patients that domestic exposure to lead can come from a variety of sources, including<br><br>• Deteriorated paint,<br>• Contaminated soil,<br>• Water (i.e., lead solder in pipes), or<br>• Other products.<br><br>Patients or parents should be advised to<br><br>• Eliminate source(s) of lead exposure, |

- Flush standing water from the lines and faucet for several minutes before use, and use cold water for drinking (if they have older homes with galvanized lead or lead soldered pipes and/or lead service lines),
- Maintain a low-fat diet high in calcium, zinc, vitamin C and iron, and
- Continue to monitor BLLs (if applicable).

It may be difficult for low-income patients and their families to permanently address all lead hazards in their homes, due in part to costs and/or landlord accountability (if they rent).

Patients or parents should be informed of the following:

- There are federal disclosure laws for potential renters/buyers that require landlords and sellers to disclose any known lead hazard.
- State and/or local ordinances require property owners to address higher lead content paint hazards, and in many communities, grants are available to help with lead hazard control.
- Additionally, there are many low-cost ways to temporarily reduce lead hazards in homes. The *"Sources of Additional Information"* section provides several helpful resources.

Since lead poisoning from old or peeling paint continues to be a serious health risk to American children, the U.S. Environmental Protection Agency (EPA) wants to remind parents and contractors and increase the awareness of health care workers of the importance of lead-safe practices during renovation of homes built before 1978. See: https://www3.epa.gov/region9/lead/index.html

Covering bare soil contaminated with lead in the yard with grass or other type of covering may reduce exposures. Guidelines are available from governmental and nongovernmental organizations to help health care providers instruct their patients in reducing home lead hazards [ACCLPP 2012]. It is also important that residents mop the floors and use a wet rag for cleaning the window sills regularly, as children's BLLs have been

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| | found to be directly correlated with levels of lead in dust in their homes [Lanphear et al. 1998]. |
| **OSHA's Lead and Hazard Communica-tion Standards** | Health care providers need to be aware of OSHA regulations for workplace lead exposure prevention and surveillance. They should also be aware of the OSHA Hazardous Communication standard.<br><br>Inform workers that they have a right to a safe workplace. The Occupational Safety and Health Act of 1970 (OSH Act) was passed to prevent workers from being killed or seriously harmed at work. The Act created the Occupational Safety and Health Administration (OSHA), which sets and enforces protective workplace safety and health standards. The law requires employers to provide their employees with working conditions that are free of known dangers [OSHA 2014]. It is important that workers understand what these regulations and controls mean and the proper use of personal protective equipment to avoid exposures.<br><br>OSHA requires employers to establish hazard communication programs to transmit information on the hazards of chemicals to their employees by means of labels on containers, material safety data sheets, and training programs. Implementation of these hazard communication programs will ensure all employees have the "right-to-know" about the hazards and identities of the chemicals they work with, and will reduce the incidence of chemically - related occupational illnesses and injuries [OSHA 2014b].<br><br>Communicate with workers that as part of OSHA's lead standard, BLLs are monitored. If workers have elevated BLLs, they need to understand and comply with work site controls to lower these levels and their responsibilities to prevent future exposures.<br><br>Inform workers in environments with lead that they can take lead home on their skin, hair, shoes, tools, and clothing. That is why it is important to change clothing and shower after work before going home to avoid taking lead home. Clothing contaminated with lead can |

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| | be placed in a plastic bag and washed separately from other clothing to avoid contamination. Some workplaces provide work clothing and/or laundering service for their employees.<br><br>Advise workers that it is a violation of the Act for an employer to fire, demote, transfer or discriminate in any way against a worker for filing a complaint or using other OSHA rights.<br><br>OSHA can help answer questions or concerns from employers and workers. To reach a regional or area OSHA office, go to OSHA's Regional & Area Offices webpage or call 1-800-321-OSHA (6742).<br><br>Employee rights under OSHA [OSHA 2014b]: https://www.osha.gov/Publications/osha3021.pdf. |
| **Clinical Follow Up Instructions to Patients** | Patients need to understand when and why they should call their physician for further medical attention. This will depend on several factors including their blood lead level results, signs and symptoms, exposure risk and exposure status, comorbid health conditions, and past and current health status. In particular, they should know that they may need their blood lead monitored on an ongoing basis to confirm removal from the source of exposure and/or response to clinical modalities including chelation therapy.<br><br>ATSDR's Lead Toxicity Patient Education Sheet https://www.atsdr.cdc.gov/csem/csem.asp?csem=7&po=19 provides a job aid to facilitate patient education and clinical care follow-up instructions. |
| **Key Points** | • Health care providers should communicate and share accurate, up to date, relevant information and resources with parents and patients exposed or potentially exposed to lead from the workplace, home, and the environment.<br>• The primary instruction to patients and parents of children exposed to lead should be to eliminate or control sources of all lead exposure.<br>• Health care providers should be aware of relevant OSHA and CDC guidelines that govern screening |

and clinical management of lead exposed or potentially exposed patients.

- Health care providers should use effective communication strategies when explaining how their patients can take steps to reduce exposure to lead in the workplace, home, and environment.

**Progress Check**

28. Examples of instructions that health care providers can communicate to patients who have been exposed to lead in their pre-1978 home include which of the following?

    A. Make sure all paint is in good condition.
    B. Mop and dust regularly.
    C. Follow lead safe work practices for remodeling.
    D. Cover bare soil in the yard.
    E. All of the above.

    *To review relevant content, see "Identifying Domestic Exposures to Lead" in this section.*

29. Communication strategies that health care providers can use to best deliver clinical information to their lead exposed or potentially exposed patients include all of the following, **EXCEPT**:

    A. Interactions with affected families performed in a culturally-sensitive, same-language, and streamlined manner.
    B. Providing simple information about the meaning of elevated BLL test results, and relevant, culturally-sensitive messages about their impact.
    C. Physicians explain the uncertainty of all quantitative medical tests and BLL testing.
    D. Speak using scientific language and statistics to increase the credibility of information to the patient.

    *To review relevant content, see "Blood lead level risk communication and education strategies" in this section.*

30. When explaining patients or parents that domestic exposure to lead can come from a variety of sources, it is important to advise to:

A. Eliminate source(s) of lead exposure.
B. Flush standing water from the lines and faucet for several minutes before use, and use cold water for drinking (if they have older homes with galvanized lead or lead soldered pipes and/or lead service lines).
C. Maintain a low-fat diet high in calcium, zinc, vitamin C and iron.
D. Continue to monitor BLLs (if applicable).
E. All of the above.

*To review relevant content, see "Communicating Instructions to Prevent, Lower, or Mitigate Domestic Lead Exposure" in this section.*

## Sources of Additional Information

**Lead-Specific Information**

Please refer to the following online resources for more information on the adverse effects of lead, the treatment of lead-associated diseases, and management of persons exposed to lead.

- Agency for Toxic Substances and Disease Registry (ATSDR): https://www.atsdr.cdc.gov
  - For chemical, emergency situations:
    - CDC Emergency Response: 770-488-7100 and request the ATSDR Duty Officer.
  - For chemical, non-emergency situations:
    - CDC-INFO https://www.cdc.gov/cdc-info/
    - 800-CDC-INFO (800-232-4636) TTY 888-232-6348 – 24 Hours/Day
    - E-mail: cdcinfo@cdc.gov

PLEASE NOTE: ATSDR cannot respond to questions about individual medical cases, provide second opinions or make specific recommendations regarding therapy.

- Toxicological Profile for Lead: https://www.atsdr.cdc.gov/toxprofiles/TP.asp?id=96&tid=22
- ATSDR's ToxFAQs and ToxFAQs-Chemical Agent Briefing Sheet (ToxFAQs-CABS) answer the most frequently asked health questions about lead: https://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=93&tid=22
- TOXFAQs – Plomo (Lead in Spanish): https://www.atsdr.cdc.gov/es/toxfaqs/es_tfacts13.html

- Centers for Disease Control and Prevention (CDC)

  - CDC Lead portal: https://www.cdc.gov/nceh/lead/
  - CDC Childhood Lead Poisoning Prevention Program https://www.cdc.gov/nceh/lead/about/program.htm?
  - National Institute of Safety and Health (NIOSH) Workplace Safety and Health Topics – Lead: https://www.cdc.gov/niosh/topics/lead/

- U.S. Environmental Protection Agency

  - EPA Lead Home at: https://www2.epa.gov/lead
  - Lead Awareness Program provides information about lead in paint, dust, and soil and how to protect children from lead poisoning at: https://www.epa.gov/lead/
  - EPA's Water on Tap, what you need to know. https://water.epa.gov/drink/guide/upload/book_waterontap_full.pdf
  - Learn About Lead, Protect Your Family, and Renovate Right https://www.epa.gov/lead/pubs/renovation.htm

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| | o Protect Your Family From Lead In Your Home https://www2.epa.gov/lead/protect-your-family-lead-your-home<br>o Let's Wipe Out Lead Poisoning: Renovate Right https://www2.epa.gov/lead/lead-safe-certified-guide-renovate-right<br>o Safe Water Drinking Act. https://water.epa.gov/lawsregs/rulesregs/sdwa/index.cfm<br>o Safe Drinking Water Hotline 1-800-426-4791.<br><br>• The National Lead Information Center (NLIC), funded by EPA, the CDC and the Department of Housing and Urban Development (HUD), provides the general public and professionals with information about lead hazards and their prevention: http://www2.epa.gov/lead/forms/lead-hotline-national-lead-information-center, or call 800-424-LEAD (800-424-5323) Information is available in Spanish with the use of a translator.<br><br>• Occupational Safety and Health Administration (OSHA) Safety and Health Topics – Lead: https://www.osha.gov/SLTC/lead/<br><br>• U.S. Department of Housing and Urban Development. The Renovation, Repair and Painting Rule. Renovation Training and resources https://portal.hud.gov/hudportal/HUD?src=/program_offices/healthy_homes/training/rrp/rrp<br><br>• National Poison Control Center 1-800-222-1222<br><br>• Health departments and other agencies may have additional materials that may be useful to patients with environmental lead exposures. |
| **General Environmental Health Information** | Please refer to the following online resources for general information on environmental health.<br><br>• Agency for Toxic Substances and Disease Registry: https://www.atsdr.cdc.gov |

- Case Studies in Environmental Medicine (CSEM) – Taking a Pediatric Exposure History: https://www.atsdr.cdc.gov/csem/csem.asp?csem=26&po=0
- Case Studies in Environmental Medicine (CSEM) – Taking an Exposure History: https://www.atsdr.cdc.gov/csem/csem.asp?csem=33&po=0
- Complete library of CSEMs: https://www.atsdr.cdc.gov/csem/csem.html
- Exposure History Worksheet [Adult] (pdf): https://www.atsdr.cdc.gov/csem/exphistory/docs/CSEMExposHist-26-29.pdf
- ATSDR Division of Regional Operations:
  - Through the working relationships they have established with EPA, other federal and state agencies, individual citizens, and community groups, regional representatives are able to maintain current and historic knowledge of the sites and issues in their regions.
    - ATSDR's Regional Offices, the states and territories they cover, and corresponding contact information can be found at: https://www.atsdr.cdc.gov/dro/index.html
- ATSDR State Cooperative Agreement Program: https://www.atsdr.cdc.gov/states/index.html
  - The Cooperative Agreement Program provides essential support in communities nationwide to fulfill the mission of ATSDR.
  - The program funds 30 states and one tribal government to develop and strengthen their abilities to evaluate and respond to environmental public health issues.

- Centers for Disease Control and Prevention (CDC): https://www.cdc.gov/
  - The CDC works to protect public health and safety by providing information to enhance health decisions, and promotes health through

partnerships with state health departments and other organizations.
    - The CDC focuses national attention on developing and applying disease prevention and control (especially infectious diseases), environmental health, occupational safety and health, health promotion, prevention, and education activities designed to improve the health of the people of the United States.

- National Center for Environmental Health (NCEH): https://www.cdc.gov/nceh/

    - NCEH works to prevent illness, disability, and death from interactions between people and the environment. It is especially committed to safeguarding the health of populations that are particularly vulnerable to certain environmental hazards — children, the elderly, and people with disabilities.
    - NCEH seeks to achieve its mission through science, service, and leadership.

- Environmental Protection Agency (EPA): https://www.epa.gov/

    - EPA is a government agency concerned with the American environment and its impact on human health.

- National Institutes of Health (NIH): https://www.nih.gov/

    - Part of the U.S. Department of Health and Human Services (HHS), NIH is the primary federal agency that conducts and supports medical research.

- National Institute of Occupational Safety and Health (NIOSH): https://www.cdc.gov/niosh/

    - Part of HHS, NIOSH helps to assure safe and healthy working conditions for working men and women by providing research, information,

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| | education, and training in occupational safety and health.<br><br>• Children's Environmental Health Network. Training Manual on Pediatric Environmental Health: Putting it into Practice (CEHN) http://www.nchh.org/Portals/0/Contents/Training_manual_lead.pdf<br><br>• The U.S. National Library of Medicine's Toxicology and Environmental Health Information Program (TEHIP): https://sis.nlm.nih.gov/enviro.html<br><br>o TEHIP maintains a comprehensive toxicology and environmental health web site that includes access to resources produced by TEHIP and by other government agencies and organizations.<br>o This web site includes links to databases, bibliographies, tutorials, and other scientific and consumer-oriented resources.<br>o TEHIP also is responsible for the Toxicology Data Network (TOXNET®), an integrated system of free toxicology and environmental health available at: https://toxnet.nlm.nih.gov/ |
| **Clinical Resources (Publically Available)** | Please refer to the following online resources for more information on the clinical treatment of lead-associated diseases, and management of persons exposed to lead.<br><br>• American Association of Poison Control Centers (AAPCC): http://www.aapcc.org or 800-222-1222<br><br>o The AAPCC can be contacted for questions about poisons and poisonings. The web site provides information about poison centers and poison prevention.<br>o The AAPCC does not provide information about treatment or diagnosis of poisoning or research information for student papers.<br><br>• American College of Medical Toxicologists (ACMT): http://www.acmt.net |

- ACMT is a professional, nonprofit association of physicians with recognized expertise in medical toxicology.
- ACMT is dedicated to advancing the science and practice of medical toxicology through a variety of activities.

- American College of Occupational and Environmental Medicine (ACOEM) http://www.acoem.org/

  - ACOEM is the nation's largest medical society dedicated to promoting the health of workers through preventive medicine, clinical care, research, and education.
  - Its members are a dynamic group of physicians encompassing specialists in a variety of medical practices who develop positions and policies on vital issues relevant to the practice of preventive medicine, both within and outside of the workplace.

- American College of Preventive Medicine (ACPM) http://www.acpm.org

  - ACPM is the national professional society for physicians committed to disease prevention and health promotion.
  - ACPM's 2,000 members are engaged in preventive medicine practice, teaching, and research.

- Association of Occupational and Environmental Clinics (AOEC): http://aoec.org

  - AOEC is a network of more than 60 clinics and more than 250 individuals committed to improving the practice of occupational and environmental medicine through information sharing and collaborative research.
  - Medical Management Guidelines for Lead-Exposed Adults. Revised 04/24/2007. CSTE Medical Management Guidelines Added October 2013 See Pages 16-17.

http://www.aoec.org/documents/positions/mmg_revision_with_cste_2013.pdf

- Pediatric Environmental Health Specialty Units (PEHSUs): http://www.PEHSU.net

  - Based at an academic center, each PEHSU is a collaboration between the pediatric clinic and the occupational and environmental clinic at each site.
  - The PEHSUs were developed to provide education and consultation for health care providers, public health professionals, and others about the topic of children's environmental health.
  - The PEHSU staff is available for consultation about potential pediatric environmental health concerns affecting both the child and the family. Health care professionals may contact their regional PEHSU site for clinical advice

## Posttest

**Posttest** *Please select the one best answer choice.*

1. Lead is a

   A. Soft, heavy, blue-gray metal
   B. Naturally occurring substance
   C. Commercially used substance
   D. All of the above.

2. Which of the following is true about organic lead in the United States?

   A. It is more commonly found in home environments today than is inorganic lead.
   B. It is the most available source of exposure through natural processes.
   C. It was a common source of lead exposure in the United States when leaded gasoline was used in “on road” vehicles.

D. Cannot enter the body through dermal exposure.

3. In the U.S., the majority of children exposed to lead are exposed from

   A. Contaminated drinking water.
   B. Lead-contaminated dust, soil, and deteriorated lead-based paint.
   C. Imported food, home remedies, and cosmetics.
   D. Commercial products containing lead.

4. Which of the following is **NOT** considered a potential source of lead exposure?

   A. Jewelry.
   B. Unfinished treated lumber.
   C. Imported cosmetics and home remedies.
   D. Glazed ceramics.

5. Which of the following statements about sources of lead in the environment is true?

   A. Lead dust exposure can raise children's BLLs above the reference value.
   B. Lead is heavy, so it does not travel far in the air from smelters or industries.
   C. Lead is only a problem in urban areas with pre-1978 housing.
   D. Children who eat paint chips make up the majority of those with BLLs above 5 µg/dL.

6. The most common route of exposure to lead in U.S. children is?

   A. Ingestion.
   B. Inhalation.
   C. Dermal contact.
   D. All are equally common.

7. Which is the U.S. population most susceptible to adverse health effects from lead exposure? Of the following, the U.S. population most at risk for exposure to lead today is

A. People who work in lead mining and smelting.
B. Adult household contacts of workers engaged in the manufacture of lead-containing products who remove contaminated clothing and take showers before going home.
C. Children living in pre-1978 buildings with deteriorated paint.
D. Construction workers.

8. CDC's upper reference level value of 97.5% based on 2012-2015 population distributions of children's blood lead is which of the following?

A. 3 µg/dL.
B. 5 µg/dL.
C. 10 µg/dL.
D. 25 µg/dL.

9. What does the CDC's reference value for children's blood lead indicate?

A. The BLL below which no effects have been found.
B. The level OSHA uses as a level of concern in workers.
C. An advisory level for environmental and educational intervention.
D. A regulatory level at which children must be immediately removed from any pre-1978 residences.

10. What are the OSHA standards for Lead Levels?

A. Permissible exposure limit (PEL) of lead in the workplace.
B. The frequency and extent of medical monitoring triggered by the action level.
C. Other responsibilities of the employer.
D. All of the above.

11. What is the U.S. EPA drinking water action level for lead?

A. 15 ppb in more than 10% of customer taps sampled.
B. The frequency and extent of medical monitoring for a BLL of 10 µg/dL.
C. 5 ppm in tap water.
D. All of the above.

12. What is the CPSC regulatory limit value for lead in paint?

A. 5 ppb.
B. 5 µg/L.
C. 10 µg/L.
D. 15 µg/L.
E. 90 ppm (0.009%).

13. What is the percentage of ingested inorganic lead a child will absorb after a meal and on an empty stomach

A. 10 and 40%.
B. 25 and 60%.
C. 40 and 80%.
D. 50 and 100%.

14. Which of the following answer choices best describes where lead is distributed once it enters the body?

A. Blood, sweat and tears.
B. Stomach, liver and bones.
C. Blood, mineralizing tissues and soft tissue.
D. Blood, cerebrospinal fluid and brain.

15. What is the approximate half-life of lead in the blood of an adult?

A. Seven days.
B. Twenty-eight days.
C. Three to six months.
D. One year.

16. Why would a patient's BLL drop only gradually, even with complete removal from the source of exposure?

    A. Lead's half-life in the blood is almost one year.
    B. Everyone is exposed to high background levels of lead.
    C. Lead stored in the bones and soft tissues may be released over time.
    D. None of the above.

17. The most commonly reported adverse health effects in children at BLLs <5µg/dL include all of the following **EXCEPT**

    A. Endocrine effects.
    B. Attention-related behavioral problems.
    C. Decreased IQ and cognitive performance.
    D. Greater incidence of problem behaviors.

18. Some researchers have suggested that lead exposure in the U.S. continues to contribute significantly to

    A. Socio-behavioral problems such as juvenile delinquency and violent crime.
    B. Kidney disease.
    C. Decreased IQ and cognitive performance.
    D. All of the above.

19. What is the most sensitive organ system for lead exposure in children?

    A. Endocrine system.
    B. Nervous system.
    C. Immunologic system.
    D. Renal system.

20. What is the identified threshold or safe level of lead in blood for children?

    A. 5 µg/dL.
    B. 10 µg/dL
    C. 15 µg/dL.

D. There is no identified threshold or safe level of lead in blood.

21. Which of the following statement(s) about taking screening exposure histories for children is/are true?

A. It is necessary to ask all the screening questions at every visit.
B. The physician should perform age-appropriate risk-based screening for lead poisoning during an initial well-child visit.
C. There is no need to ask age-specific screening questions because all children are exposed equally.
D. All of the above.

22. As part of the exposure history, you should explore

A. Possible lead exposure at parent's work.
B. Household members' hobbies that might involve lead.
C. Household use of imported home remedies and cosmetics.
D. All of the above.

23. Which of the following statements regarding the clinical assessment of a lead exposed patient is/are true?

A. Carefully evaluate the nervous system for subtle changes, including behavioral changes.
B. Check blood pressure to evaluate whether the patient is hypertensive and pay special attention to the renal system in those who are hypertensive.
C. Hearing, speech, and other developmental milestones must be carefully evaluated and documented.
D. Assess the nutritional status, diet, and dietary behaviors of young children.

E. All of the above.

24. Which of the following statements is true regarding the signs and symptoms of lead toxicity?

A. Signs and symptoms will always be more noticeable with increasing BLLs.
B. All children with low dose level exposure, will be asymptomatic.
C. Symptoms of lead exposure and their onset may vary.
D. Categorizing the signs and symptoms by BLL from lowest to highest is very accurate.

25. What is the best screening and confirmatory diagnostic test for evaluating recent or ongoing lead exposure in a child?

A. EP/ZPP.
B. Capillary BLL (fingerstick).
C. Venous BLL.
D. Abdominal radiograph.

26. Blood lead level (BLL) testing is recommended for all of the following at risk groups **EXCEPT**

A. Neonates and infants of women with BLLs ≥5μg/dL.
B. Children ≤72 months that missed recommended screening at a younger age.
C. All immigrant, refugee, and internationally-adopted children when they arrive in the U.S.
D. All children when they start school.

27. What imaging and other clinical modalities may assist in the diagnosis of current or past lead exposed patients?

A. Abdominal radiographs.
B. Long bone radiographs.
C. Hair assay.
D. All of the above.
E. None of the above.

28. Management strategies for children whose blood levels are equal to or greater than the reference value include of the following:

    A. Nutritional education and intervention.
    B. Educational intervention and ongoing monitoring.
    C. Coordination with other organizations.
    D. All of the above.

29. When is ongoing monitoring of BLLs indicated?

    A. When a child is identified with BLL results greater than or equal to the CDC reference value (≥5 µg/dL).
    B. When a child has a venous BLL <5 µg/dL.
    C. When any child presents with hypertension and neurological symptoms.
    D. When there is more than one child living in a pre-1978 home.

30. BLLs that increase after interventions to mitigate lead exposure may indicate which of the following?

    A. An unrecognized source of exposure.
    B. Inappropriate abatement activities and failure to mitigate the identified hazard.
    C. The redistribution of lead stores within the child's body post-chelation.
    D. All of the above.

31. What should you tell patients who are concerned about lead in their drinking water, but there is no confirmation of lead contamination from the Department of Health?
    A. As long as they don't have well water, their water is safe.
    B. Until they can get their water tested, boil their drinking water.
    C. Drinking water is non-acidic and will not leach lead out of old pipes, fixtures, or solder.
    D. Until they can get their water tested, they can drink bottled water, or run cold water for 1 to 2 minutes before use. They can contact their

water provider for recent lead level test results (large water suppliers).

32. When explaining patients or parents that domestic exposure to lead can come from a variety of sources, it is important to advise to:

    A. Eliminate source(s) of lead exposure.
    B. Flush standing water from the lines and faucet for several minutes before use, and use cold water for drinking (if they have older homes with galvanized lead or lead soldered pipes and/or lead service lines).
    C. Maintain a low-fat diet high in calcium, zinc, vitamin C and iron.
    D. Continue to monitor BLLs (if applicable).
    E. All of the above.

33. What effective doctor/patient communication strategies can you use?

    A. Offer simple information about the meaning of elevated BLL test results, and relevant, culturally-sensitive messages about their impact.
    B. Allow interactions with affected families performed in a culturally-sensitive, same-language, and streamlined manner.
    C. Define specialized terms such as “detectable level” or “elevated BLL”.
    D. All of the above.

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## Relevant Content

| Question | Location of Relevant Content |
|---|---|
| 1. | What Is Lead?<br>• Explain what lead is. |
| 2. | Where is Lead Found? |

- Describe potential sources of lead exposure in the United States today.

**3.** Where Is Lead Found?

- Describe potential sources of lead exposure in the United States today.

**5.** Where Is Lead Found?

- Describe potential sources of lead exposure in the United States today.

**6.** Where Is Lead Found?

- Identify the most common routes of exposure to lead in the United States today.

**7.** Who Is At Risk of Lead Exposure?

- Identify the populations most heavily exposed to lead.

**8.** What Are U.S. Standards for Lead Levels?

- Describe the Centers for Disease Control and Prevention's (CDC) reference value for lead in children's blood.

**9.** What Are U.S. Standards for Lead Levels?

- Describe the Centers for Disease Control and Prevention's (CDC) reference value for lead in children's blood.

**10.** What Are the U.S. Standards for Lead Levels?

- Describe the U.S. Occupational Safety and Health Administration's (OSHA) Permissible Exposure Limit (PEL) for lead in workplace air.

**11.** What Are U.S. Standards for Lead Levels?

- Describe the U.S. Environmental Protection Agency's (EPA) drinking water regulation for lead.

**12.** What Are U.S. Standards for Lead Levels?

- Describe the Consumer Product Safety Commission's (CPSC) regulatory limit value for lead in paint.

**13.** What Is the Biological Fate of Lead in the Body?

- Describe how lead is absorbed.

**14.** What Is the Biological Fate of Lead in the Body?

- Describe how lead is distributed in the body.

**15.** What Is the Biological Fate of Lead in the Body?

- Identify the half-life of lead in the blood.

**16.** What Is the Biological Fate of Lead in the Body?

- Describe how lead is distributed in the body.

**17.** What are Possible Health Effects from Lead Exposure?

- Describe how lead affects adults and children.

**18.** What are Possible Health Effects from Lead Exposure?

- Describe how lead affects adults and children.

**19.** What Are Possible Health Effects from Lead Exposure?

- Describe what is the most sensitive organ system for lead exposure in children.

**20.** What Are Possible Health Effects from Lead Exposure?

- Specify that there is no identified threshold or safe level of lead in blood.

**21.** Clinical Assessment –Exposure History

- Describe how to take a screening exposure history for lead exposure.

**22.** Clinical Assessment –Exposure History

- Identify lead exposure-related questions to ask during a child visit.

**23.** Clinical Assessment – Signs and Symptoms

- Name typical signs and symptoms consistent with lead toxicity.

**24.** Clinical Assessment – Signs and Symptoms

- Describe key features of the physical examination for patients exposed to lead.

**25.** Clinical Assessment – Diagnostic Tests and Imaging

- Describe guidelines for blood lead screening and confirmatory diagnostic testing on patients at risk of recent or ongoing lead exposure.

**26.** Clinical Assessment – Diagnostic Tests and Imaging

- Describe guidelines for blood lead screening and confirmatory diagnostic testing on patients at risk of recent or ongoing lead exposure.

**27.** Clinical Assessment – Diagnostic Tests and Imaging

- Describe imaging and other clinical modalities that may assist in the diagnosis of current or past lead exposed patients.

**28.** How Should Patients Exposed to Lead be Treated and Managed?

- Describe a management strategy for children whose blood lead levels are equal to or greater than the current CDC reference value of 5 µg/dL.

**29.** How Should Patients Exposed to Lead be Treated and Managed?

- Describe a management strategy for children whose blood lead levels are equal to or greater than the current CDC reference value of 5 µg/dL.

**30.** How Should Patients Exposed to Lead be Treated and Managed?

- Describe a management strategy for children whose blood lead levels are equal to or greater than the current CDC reference value of 5 µg/dL.

**31.** What Instructions Should be Given to Patients?

- Describe instructions to parents and patients to prevent or reduce lead exposure.

**32.** What Instructions Should be Given to Patients?

- Describe instructions for patients exposed to lead

**33.** What Instructions Should be Given to Patients?

- Describe communication strategies that health care providers can use to best deliver clinical information to their lead exposed or potentially exposed patients.

# Table of Tables and Figures

**Table of Figures**



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